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Silvicultural characteristics and natural regeneration of *Pinus brutia* Ten. – a review

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Abstract

Pinus brutia Ten. is a characteristic species of the eastern Mediterranean. *P. brutia* and *P. halepensis* Mill. are distinct species; but *P. eldarica*, *P. stankewiczii* and *P. pityusa* are subspecies of *P. brutia*. Fire is the major disturbance in *P. brutia* forests, and several adaptations generally contribute to post-fire regeneration of *P. brutia;* however, *P. brutia* can also naturally regenerate without fire. Flowering occurs between March and May. Seed distribution occurs throughout the year, with maximum dispersal in August and the great majority of seeds dispersing within the period July-December.*P. brutia* retains some closed cones and so establishes a natural canopy seed bank. Seed germination occurs in the rainy season with two frequency peaks: the major one in spring and a minor one in autumn. *P. brutia* seedlings develop rapidly-growing tap roots. Shelterwood, clearcutting and strip clearcut methods can successfully be applied to *P. brutia* forests, depending on local conditions. Density of *P. brutia* seedlings was greater and seedlings were more vigorous when the natural regeneration methods were combined with prescribed fire. Clearcutting methods combined with laying cone bearing branches on the surface of the soil and additional seeding increases regeneration success. Ground litter of 2–4 cm creates a medium that reduces evapotranspiration, delays growth of competing vegetation, and increases seedling survival. Successful regeneration must be established by the end of first vegetation period.

Introduction

P. brutia is commonly found in fire-related ecosystems of the eastern Mediterranean region. It usually grows in pure stands and is valuable for its timber products as well as for soil stabilization and wildlife habitats. This paper describes the taxonomy and seeding and regeneration characteristics of the species, with special emphasis to studies in Asia Minor, Turkey. The paper then describes general silvicultural methods for naturally regenerating *P. brutia* stands.

In Turkey, *P. brutia* forms extensive forests, especially in regions where the Mediterranean climate prevails. Ecologically and economically, it is one of the most important forest tree species of the country. *P. brutia* accounts for 20.18% of Turkey's total forest area, where it covers 3.69 million hectares (Anon. 2001). Of this, 2.15 million hectares are productive while 1.54 million hectares are degraded. The elevation range of *P. brutia* varies according to the region: in the Mediterranean region, 0–1500 m; Aegean region, 0–1000 m; and Black Sea region, 0–600 m (Saatçioğlu 1976, Atalay et al. 1998). It is also found in Thrace, the European part of Turkey.

It is a fast growing tree species; and its mean annual increment in plantations can be over 10 m^3 / hectare (at a spacing of 4.5 square metres; 2,222 trees per hectare, site class I, site index 20 m) between the ages of 25 and 35 years (Usta 1993).

Taxonomy

P. brutia is a characteristic species of the eastern Mediterranean, while *P. halepensis* generally occupies the western and middle Mediterranean except for local occurrences in the southern parts of the eastern basin (Critchfield and Little 1966, Saatçioğlu 1976, Kayacık

1980, Alptekin 1990, Quézel 2000). *P. brutia* and *P. halepensis* were historically considered two varieties of *P. halepensis* (Duffield 1952); however, morphological and biochemical analyses have confirmed that they are two distinct species (Selik 1963, Mirov 1967, Nahal 1986, Schiller 2000). Natural hybrids of *P. brutia* × *P. halepensis* have been found in many places (Mirov 1967, Nahal 1983, Panetsos 1986, Yaltırık and Boydak 1989).

P. brutia consists of four subspecies; *brutia*, *pityusa*, *stankewiczii* and *eldarica*. They had formerly been considered distinct species based on morphological characteristics (*P. brutia* Ten., *P. eldarica* Medw., *P. pityusa* Stevenson, *P. stankewiczii* Sukaczew; in Selik 1963, Schiller 2000). Recent studies have revealed that enzyme allel frequencies of the other subspecies closely resemble those of subspecies *brutia* (Schiller 2000); and they have been classified as subspecies by several studies (Selik 1963, Kayacık 1980, Nahal 1986, Schiller 1994; 2000 [after Goncharenco et al.]). There are four known varieties of *P. brutia* subsp. *brutia* (Papajoannou 1936, Selik 1961/1962, Yaltırık and Boydak 1989, 2000, Frankis 1993, Schiller 2000):

- *P. brutia* Ten. var. *agrophiotii* Papaj.,
- *P. brutia* Ten. var. *pyramidalis* Selik,
- *P. brutia* Ten. var. *densifolia* Yalt. and Boydak,
- *P. brutia* Ten. var. *pendulifolia* Frankis.

Dimorphic crown (witch broom) trees of *P. brutia* have also been found within its range (Papajoannou 1936, Selik 1963, Yaltırık and Boydak 1989).

The range of subsp. *brutia* extends from Athos-Greece, the Aegean Islands, Crete, and Cyprus through Turkey to Syria, Lebanon and Iraq (Critchfield and Little 1966, Saatçioğlu 1976, Quézel 2000). Subsp. *pityusa* is found on the Black Sea coast of the Caucasus range and *stankewiczii* is found in the Crimea. The natural distribution of subsp. *eldarica* covers a very small area in the Caucasus; land races probably extend to parts of Iran and possibly Afghanistan (Schiller 2000).

Ecological characteristics of *P. brutia*

Climate

P. brutia generally occurs in the Mediterranean-type climate of hot and dry summers and mild and rainy winters. *P. brutia* and *P. halepensis* occur most abundantly in the semi-arid and sub-humid zones (Quézel 2000). *P. brutia* has stricter rainfall requirements than *P. halepensis*, being absent from the arid bioclimatic zone and rare in the lower semi-arid zone, but widespread in the humid zone (Quézel and Barbero 1992). *P. brutia* occurs where mean annual temperatures are between 12 °C (Marmara region) and 20 °C (Mediterranean region) and mean annual precipitation is between 400 mm (e.g., Mut 418 mm, Burdur 424 mm) and 2000 mm (e.g., Beşkonak 1800 mm, Aydınkent 2170 mm; Atalay et al. 1998). *P. brutia* is well adapted to the Mediterranean-type climate in several physiological and morphological characteristics and is a drought resistant species (Falusi and Calamassi 1982, Abido 1983, Thanos and Scordilis 1987, Grunwald and Schiller 1988, Dirik 1994, Boydak et al. 2002). The adaptabilities of its provenances to drought vary (Dirik 2000), but *P. brutia* generally achieves its optimum growth in rainy regions of more than 900–1000 mm mean annual precipitation.

Parent material and soil

P. brutia stands are found on cracked limestone, colluvial, marly and flysch deposits with alternating sandy, silt and limey layers in Turkey (Atalay et al. 1998). The species also establishes vigorous populations on marl limestone and cracked parent material in Crete, Syria, and Lebanon (Quézel 2000). Unweathered serpentine-peridotite parent materials provide poor quality sites, but well weathered ultrabasic and clayey schists produce good quality sites. Volcanic tuffs and siliceous materials mostly represent poor quality sites (Atalay et al. 1998). *P. brutia* is also found on sandstone, schists and mica schists (Quézel 2000), as well as on limestone, metamorphic schists, volcanic tuffs and basaltic volcanic areas (Atalay et al. 1998) in Aegean Asia Minor.

P. brutia grows on many soil types, but primarily on rendzina soils on soft limestones and marl deposits. Red Mediterranean soils are common in karstic areas and on flat lands that generally have a neutral reaction and are clayey in texture (Atalay et al. 1998). Red-brown Mediterranean soils (Neyişçi 1986) and brown forest soils (Eron and Gürbüzer 1988, Atalay et al. 1998) are also found in *P. brutia* forests. *P. brutia* does not tolerate poorly drained soils (Quézel 2000).

Vegetation

The ecological position of *P. brutia* can be described from both the “climax” and “dynamic” perspectives. From the climax perspective, *P. brutia* forms stable, pure forests as climax communities in large areas in

Asia Minor (Saatçioğlu 1976; Akman et al. 1978, 1979a, 1979b; Mayer and Aksoy 1986). Although debates have continued over whether *P. brutia* and *P. halepensis* are paraclimax during succession towards a climax dominated by *Quercus* (usually a sclerophyllous species; Quézel 2000), research has confirmed that *P. brutia* and *P. halepensis* are capable of forming a true climax (Quézel 2000 after Nahal).

From the dynamic perspective that views forests as always changing and never reaching a single "end point" (Oliver and Larson 1996), *P. brutia* forests are altered by forest fires and human impacts which lead to new *P. brutia* regeneration, to mixed *P. brutia* maquis forests, to maquis, or to arable lands depending on the spatial and temporal behaviour of the disturbances. The Mediterranean is considered to be the ecoregion in the world most impacted by people (Zohary 1969, Aschmann 1973, Naveh and Dan 1973, Boydak and Doğru 1997).

P. brutia is typically found in thermo-Mediterranean and meso-Mediterranean belts but it can extend into the supra-Mediterranean belt and even have contact with the mountain-Mediterranean belt under some conditions (Mayer and Aksoy 1986, Quézel 2000). The thermo-Mediterranean belt is included in the *Oleo-Ceratonion* vegetation type and is distinguished by containing the following species: *Ceratonia siliqua, Pistacia lenticus, Mytrus communis, Rhus tripartita, Euphorbia dendroides, Clematis cirrhosa, Prasium majus, Capparis spinosa, Ephedra campylopoda, Rubia tinctoria, Rubia olivieri, Asparagus aphyllus* subsp. *orientalis, Oryzopsis coerulescens, Phagnalon rupestre* and *Teucrium creticum* (Akman et al.1978). Besides *P. brutia*, several *Quercus* species, particularly sclerophyllous ones, are dominant in the meso-Mediterranean belt (Quézel 2000). *P. brutia* and *Quercus coccifera* also occur in *Lonicero-Cedrion* forests in the supra-Mediterranean belt up to 1700 m elevation, with shrubby forms in the Tahtalı and Teke mountains of the western Taurus Mountain Range (Aksoy and Özalp 1990). Studies of post-fire regeneration of *P. brutia* have greatly added to the knowledge of the dynamics of Mediterranean vegetation (Thanos et al. 1989, Thanos and Marcou 1991, Thanos and Doussi 2000).

Silvicultural characteristics of *P. brutia*

Light requirements and growth characteristics

P. brutia can grow to rather old ages. One population includes trees of 250 to 305 years old at Muğla-Fethiye-Üzümlü (Boydak 1988). The maximum height and diameter (dbh) measured in this stand were 45 m and 133 cm, respectively. *P. brutia* is a light demanding and fast-growing tree species.

Seedlings degenerate and mortality increases when the light intensity falls below 55–60% (Pamay 1966) or 65–70% (Özdemir 1977). Thanos and Doussi (2000) also indicated that the heliophilous nature of this species confines germination and establishment primarily to open, well illuminated places.

Growth of natural populations of *P. brutia* was found to be better on shady exposures than on sunny exposures in the Antalya region (Zech and Çepel 1972). Topographically, only the distance of sample stands from the main ridge appeared to be important for growth. A high correlation was found between height growth and the available water holding capacity of the A and AB soil horizons (Zech and Çepel 1972).

New stands of *P. brutia* generally begin after fires, although it can also naturally regenerate without fire (Özdemir 1977, Saatçioğlu 1976, Odabaşı 1983, Boydak 1993, 2000). Several adaptations greatly contribute to its post-fire regeneration (Thanos et al. 1989, Boydak 1993). Seedlings develop rapidly-growing tap roots while the stems grow comparatively slowly in height, so that seedlings can have 65 cm tap roots within five to six months after germination (Saatçioğlu 1976, Boydak 1993). Early stem growth is greater at higher elevations, while average root growth is the opposite (Özdemir 1977). The early rapid growth of *P. brutia* continues during the following years; and mean annual increment can be over 10 m^3/ha in appropriately spaced plantations between the ages of 25 and 35 years, as described earlier (site class I, site index 20 m; Usta 1993).

Flowering and seed maturity

P. brutia has a remarkably short juvenile phase (Selik 1963, Thanos and Daskalakou 2000). Flowering can begin in the second year. Normal cone development has been observed in four year old seedlings (Selik 1963) and in seven year old trees (Thanos and Marcou 1991). Flowering takes place between March and May depending on elevation and temperature (Alpacar 1981, Boydak 1993). The following year, conelets begin to elongate between late February (300 m) and early March (600 m and 800 m) and cones reach their normal size in early July (Alpacar 1981). Research has revealed that anatomical ripeness of *P. brutia* seeds occurs in September (Eler and Şenergin 1992), in November (Shafig 1978), in December (Beşkök 1970), or in January (Şefik 1965, Alpacar 1981) of the second year while the cones are still green in colour. Physiological ripeness takes place during the following season by the end of spring, when cone colour turns brown. Seed dispersal starts in June or July, depending on elevation (Ürgenç 1977, Ürgenç et. al. 1989); however, some of the cones remain closed (Selik 1963, Şefik 1965, Thanos et al. 1989, Daskalakou and Thanos 1996). Closed cones can remain on the tree or eventually drop to the ground. They are stimulated to open and disperse the seeds by fire or heat.

Seed dispersal, quantity and quality of seed crop

Research from 1971 to 1974 (Ürgenç 1977) and 1979 to 1987 (Ürgenç et al. 1989) in the Antalya region of Asia Minor revealed considerable differences among the seed crops of different years, elevations, age classes, and even populations of the same age and site classes. Seed crops were analyzed by "lower" and "higher" elevation zones in both studies, however, in retrospect a better approach would have been to consider three elevation zones:

- "lower elevation" zone (Antalya-Düzlerçamı; 290–330 m);
- "middle elevation" zone (Antalya-Bucak; 800–850 m); and
- "higher elevation" zone (Antalya-Hacıbekar; 1070–1200 m).

In sample plots of the middle zone (Antalya-Bucak), considerably higher seed crops were generally recorded during the measurement years. These populations represented 60-year-old trees on good site classes (Table 1; Ürgenç et al. 1989). Similarly, higher seed crops were also recorded in the middle zone (Bucak; 800 m) than in the lower zone (Düzlerçamı; 240–250 m) in the Antalya region (Urgenç 1977). During this investigation 37 (1971), 70 (1972), 99 (1973) and 43 (1974) seeds per square metre were recorded in the middle zone while 13 (1971), 23 (1972), 43 (1973), and 103 (1974) seeds per square metre were obtained at the lower zone as average of the sample plots. Beside inherent factors, these results could be attributed to the positive effect of better site classes on seed crops together with the elevations of the populations. The middle zone elevation of 800–850 m represents the optimum occurrence of *P. brutia*. On the other hand, average seed crops in good site classes of the lower zone populations (290–330 m) were more than the averages of medium site classes of higher zone populations (1070–1200 m; Urgenç et al. 1989). If 60 or more seeds per square metre is the criterion for a good seed year, good seed years occurred every two or three years in the optimum range of the *P. brutia* (middle zone), but occurred every four years in the lower zone. Higher elevation zone populations (Antalya-Hacıbekar) did not produce enough seeds for any year between 1979 and 1987 to be accepted as a good seed year. Besides inherent factors, poor seed crops at the higher elevations could be attributed to past inappropriate silvicultural treatments, poor crown development, and medium site class conditions there. Either good seed years or medium seed years (40–60 seeds per square metre) generally occurred every year, every three years and every four years at medium, lower, and higher zones, respectively. Thanos and Daskalakou (2000, after Panetsos) also reported that higher than average seed crops were produced every 3 years in *P. brutia*; this result corresponds to results of lower elevation zone seed crops obtained from the above-mentioned research.

Because seeds from some of the closed cones drop after several years, the annually dispersed seeds of *P. brutia* may include seeds produced in different years. Some closed cones are set each year (Selik 1963, Şefik 1965, Thanos 2000, Thanos and Daskalakou 2000); therefore, seed dispersal of any year does not include all of the seeds from the same flowering period. Instead, it also consists of seeds of some closed or half-opened cones of previous years. Research revealed that the age of cones did not affect the germination considerably; 89.9%, 84.4%, 83.0%, 94.0% and 73.3% germination percentages were obtained from cones of 4, 5, 6, 7 and 9 years old, respectively (Şefik 1965). Post-fire regeneration of *P. brutia* depends exclusively upon the canopy seed bank of closed cones (Thanos 2000).

Seed distribution occurs throughout the year, with maximum dispersal in August and the great majority of seeds dispersing between July and December (Table 2; Urgenç et al.1989).

Germination percentages from seeds collected from trees in sample plots in the years 1982 and 1983 varied between 68% and 93% at the lower zone and 65% and 90% at the higher zone. The total average

Table 1. Seed yields per square metre by age classes of *Pinus brutia* in different years as an average of the control and silviculturally treated sample plots (Ürgenç et al. 1989).

Zone, Locality and Elevation	Age Class[1]	Years 1979	1980	1981	1982	1983	1984	1985	1986	1987
Lower elevation	20	24	18	51	58	27	30	–	–	–
Antalya-Düzlerçamı	40	27	17	116	78	31	33	16	25	11
(290–330 m)	60	7	4	26	44	18	26	19	17	10
	Average	**19**	**13**	**64**	**60**	**25**	**30**	**17**	**21**	**10**
Higher elevation	20	1	1	2	6	4	3	–	–	–
Antalya-Hacıbekar	40	6	2	7	20	5	12	14	46	21
(1070–1200 m)	60	6	2	7	12	3	12	11	29	22
	Average	**4**	**2**	**5**	**13**	**4**	**9**	**12**	**37**	**21**
Middle elevation Antalya-Bucak (800–850 m)	60							83	44	22

[1] Each age class includes three populations

germination percentages at the lower zone were 85% and 88% and 82% and 82% at the higher zone in 1982 and 1983. Between 1982 and 1987, empty seed percentages recorded by means of seed traps in sample plots varied from 1% to 26% in the lower zone and from 0 to 27% in the higher zone. During those years, the total average minimum and maximum empty seed percentages were 5% and 14% at lower zones, and 8% and 17% at higher zones. At the medium zone between the years of 1985 and 1987, empty seed percentages in sample plots varied from 7 to 13%, while the total average minimum and maximum values were 9% and 12% (Ürgenç et al. 1989).

Five year research results revealed that average annual litter fall of *P. brutia* ranged from 1242.5 kg $\cdot$ ha$^{-1}\cdot$ year^{-1} to 2341.8 kg $\cdot$ ha$^{-1}\cdot$ year^{-1} at the lower zone and from 744.5 kg $\cdot$ ha$^{-1}\cdot$ year^{-1} to 1293.6 kg $\cdot$ ha$^{-1}\cdot$ year^{-1} at the higher zone (Çepel et al. 1988) in the same sample plots in which seed crop research was carried out (Ürgenç et al. 1989). More than 84% of the litter fall occurred between July and October, which in general coincides with the maximum seed dispersal period and also the season of greatest forest fire probability of*P. brutia* forests (however, 28% and 17% of the seeds were dispersed, at lower and upper zones, respectively, in the November-April period, which is outside the season of greatest forest fire probability). An average of 6.57–4.23 kg $\cdot$ ha^{-1} of nitrogen, 2.53–3.00 kg/ha of potassium, and 0.98–1.67 kg $\cdot$ ha^{-1} of phosphorus is transferred to the forest soil by litter fall each year (Çepel et al. 1998).

Seed germination in the field

If temperatures are suitable, seeds of *P. brutia* germinate throughout the rainy season, especially at lower elevations (Ayhan 1983,Thanos et al. 1989, Odabaşı 1983, Boydak 1993, Keskin et al. 2001). Özdemir (1977) found that germination starts in the Antalya region of Asia Minor in January and March at the lower and higher zones, respectively. A post-fire study in the same region revealed that over 75% of the germination was obtained during the October-December period in the lower zone (between 75–170 m; Keskin et al. 2001), indicating the importance of fire and precipitation for inducing germination.

Although rare autumn germination does occur at higher elevations, severe winter conditions shift much of the germination to early or middle spring (Özdemir 1977, Thanos et al. 1989). Similar results were also obtained from three latitudinally distributed provenances of *P. brutia.* Based on the laboratory germination behaviour, Skordilis and Thanos (1995) postulated that inherent seed dormancy completely prohibits autumn germination in seeds from Soufli, Thrace (the northernmost provenance). This behaviour was attributed to an evolutionary selection response to a long, severe winter that prevented young seedlings from being damaged by freezing temperatures. Depending on the climatic conditions and locality, time of germination at middle elevations is intermediate between the times at lower and higher elevations (Eron 1987). Moreover, seed germination of *P. brutia* is very heterogeneous, indicating changing degrees of

Table 2. Average annual periodic seed dispersal (amounts and percentages) in *Pinus brutia* populations by elevation zone and age class between 1982 and 1984 (summarized from Table 16, Ürgenç et al. 1989).

Zone, Locality and Elevation	Age Class	Amount of Seeds	Months 1–2	3–4	5	6	7	8	9	10	11–12	Total
Lower elevation	20	Seeds · m^{-2}	4.5	0.5	0.8	1.3	1.5	9.5	6.8	7.1	7	38.8
Antalya-Düzlerçamı		(%)	12	1	2	3	3	24	18	19	18	100
(290–330 m)	40	Seeds · m^{-2}	6.3	0.2	0.8	1.8	2.2	13.3	9.2	6.2	6	46
		(%)	14	–	2	4	5	29	20	13	13	100
	60	Seeds · m^{-2}	1.7	–	0.3	0.5	0.8	9.2	6	5.2	5.2	28.8
		(%)	6	–	1	1	3	32	21	18	18	100
	Total	Seeds · m^{-2}	12.5	0.7	1.9	3.6	4.5	32	22	18.5	18.2	113.6
		(%)	**11**	**1**	**2**	**3**	**4**	**28**	**19**	**16**	**16**	**100**
Higher elevation	20	Seeds · m^{-2}	–	–	0.3	–	0.7	1.8	0.5	0.8	0.3	4.5
Antalya-Hacıbekar		(%)	–	–	7	–	15	41	11	19	7	100
(1070–1200 m)	40	Seeds · m^{-2}	0.7	–	0.2	–	1.3	3.5	2.2	2.2	1	11
		(%)	6	–	1	–	12	32	20	20	9	100
	60	Seeds · m^{-2}	–	0.2	–	–	0.3	2	1.7	1.3	1.5	7
		(%)	–	2	–	–	5	29	24	19	21	100
	Total	Seeds · m^{-2}	0.7	0.2	0.5	–	2.3	7.3	4.4	4.3	2.8	22.5
		(%)	**3**	**1**	**2**	–	**10**	**33**	**19**	**19**	**13**	**100**

dormancy among seeds of the same population (Ürgenç et al. 1989) and different populations (Işık 1986, Ürgenç et. al. 1989, Skordilis and Thanos 1995). This heterogeneity may be considered an adaptive mechanism for seedling survival in which germination of some seeds is delayed until well into the wet season (Boydak 1993, Thanos 2000). To summarize, germination of *P. brutia* seeds occurs throughout the rainy season if temperatures are suitable, with two frequency peaks: the major one in the spring and the minor one in the autumn (Boydak 1993, Thanos et al. 1989, Thanos and Doussi 2000). Depending on elevation, latitude and climatic conditions, however, the amount of seeds germinating in autumn may exceed the amount germinating in spring, especially at lower elevations and/or southernmost distributions; or autumn germination may shift to December.

P. brutia is a fire-adaptive species (Neyişçi 1986, Thanos et al. 1989, Thanos and Marcou 1991, Boydak 1993, Thanos 2000, Thanos and Daskalakou 2000, Thanos and Doussi 2000). Its post-fire regeneration depends exclusively upon the canopy seed bank of closed cones (Thanos at al. 1989, Thanos 2000, Thanos and Daskalakou 2000). Following the high temperatures developed by the fire, the cones burst open and massive seed dissemination occurs (Neyişçi 1987, Thanos at al. 1989, Thanos and Doussi 2000). The average bark thickness of *P. brutia* when harvested is 7.8 cm (4–14 cm) and the bark volume is 15% of the stem volume with bark. The thickest bark is between the root collar and 2 m up the stem (Yiğitoğlu 1940). Thus, *P. brutia* has developed a thick bark that allows it to survive ground fires that do not develop high enough temperatures to cause the cones to open.

Seeds of *P. brutia* can remain viable when cones are heated to 125 °C. Moreover, when seeds were exposed to 150 °C for 5 and 10 minutes in an oven, some seeds maintained their germination ability (Neyişçi and Cengiz 1985, Cengiz 1993). In another case, germination percentages of naked seeds decreased significantly when they were exposed to 70-90 °C for 5 minutes, but about 35% germination percentages were obtained even at 110 °C (Neyişçi 1988).

Natural regeneration methods

Decision criteria and basic application rules

Management objectives such as production, protection, and conservation should be established by considering the major site-specific conditions as well as overall sustainability for different *P. brutia* forests. The dynamics of *P. brutia* forests, together with silvicultural characteristics, generally necessitate even-aged management methods (Boydak 1993, Köse and Yavuz 1993). In production forests of *P. brutia,* clearcutting, shelterwood and strip clearcut methods can be applied. The decision of an appropriate regeneration method should be made after studying the site adequately.

Research results reveal that survival and growth of natural *P. brutia* seedlings on clearcut sample plots were better than those on shelterwood sample plots. Clearcutting positively affected the water balance of soils during the drought period and led to better seedling survival and growth (Eler et al. 1992). Similarly, in comparisons of different widths of clearcut strips and the shelterwood method, the best seedling survival and growth were achieved in the widest clearcut strips (40 m width; Özdemir 1977). The above-mentioned results and the light demanding character of *P. brutia* have given priority to the clearcutting method for naturally regenerating this species in Turkey.

Any harvest method, combined with laying cone-bearing branches on the soil surface, together with additional seeding, increases the regeneration success (Ayhan 1983, Odabaşı 1983, Boydak 1993, Yaka 1993, Çepel et al. 1995). Observations suggest that additional seeding at a rate of 8–15 kg $\cdot$ ha^{-1} could be satisfactory, depending on the stand and site conditions (Boydak 1993, Çepel et al.1995). Since the genetic quality of many populations has been lowered by past inappropriate silvicultural treatments, a high genetic quality of local seeds must be used, taking into account elevational seed transfer limits ($\pm$200 m). Ground litter 2–4 cm thick does not prevent seeds from reaching the mineral soil and germinating. Such ground litter creates a medium that reduces evapotranspiration, delays growth of competing vegetation, and increases seedling survival (Özdemir 1977, Ayhan 1983, Boydak 1993, Yaka 1993, Çepel et al. 1995). At lower elevations, ground litter of 2–6 cm thickness is essential for regeneration success (Cengiz 1996). Regeneration success must be achieved at the end of first vegetation period; otherwise, competing vegetation occupies the growing space and any further attempts at natural regeneration will probably fail. This failure necessitates repeated site preparations, but success still cannot be guaranteed on every site.

Prescribed fire is a very efficient and reliable silvicultural tool in the regeneration of *P. brutia.* Fire provides a favourable seed bed for germination and vigorous growth; consequently, it enables higher survival, especially on hot and dry sites (Eron and Gürbüzer 1988, Neyişçi 1989, Thanos et al. 1989, Thanos and Marcou 1991). Moreover, cation exchange capacity, soil pH reaction, and mineral plant nutrients – available phosphorus, available nitrogen, exchangeable potassium – increase after fire (Eron and Gürbüzer 1988, Neyişçi 1989); therefore, post-fire seedlings of *P. brutia* are more vigorous and healthy. Since regeneration success is achieved by clearcutting or other methods, inclusion of prescribed fire in the regeneration activities is not a usual practice unless there is a specific reason for it; e.g. if there is excessive competing vegetation because of past inappropriate silvicultural treatments.

In regenerating *P. brutia,* the criteria for success is suggested as at least 20,000–30,000 (Odabaşı 1983) or 10,000–20,000 (Boydak 1993) biologically independent seedlings per hectare distributed homogeneously in the regeneration area; however, 3,000–10,000 seedlings per hectare could also be accepted as successful regeneration in certain parent materials and poor soil conditions. Interplanting of non-stocked places in an area to be regenerated must be done using high quality seedlings (containerized seedlings preferably) after the first or second vegetation period. Some small opening (e.g., 10–15 square metres) may be ignored during the interplanting. Thinning of dense seedlings should be carried out after the third or fourth vegetation period (Boydak 1993).

Clearcutting method

Clearcutting is the most successful regeneration method for *P. brutia* forests, providing ecological conditions are suitable. It should not be applied in areas of steep slopes; and the size of the regeneration area should not be more than 25 hectares even in the most suitable, flat areas. The area must not exceed 1–5 hectares when the slope is high. In calcareous areas where the cracks between rocks are not adequate, on shallow peridotite-serpentine parent material, and on unstable soils, the shelterwood method could be preferable or the size of the regeneration area should be reduced to a minimum if the clearcutting method is to be applied. Felling, extracting, reducing the thickness of ground litter to 3–4 cm, additional seeding, and laying of cone-bearing branches on the ground must be completed 2–3 weeks before germination, and so should consider altitude and local climatic conditions (Boydak 1993, Çepel et al 1995) as well as the variations in germination described earlier in this paper. At lower elevations where autumn germination is expected, the site preparation should generally be completed before the end of September or middle of October, and at higher elevations probably before the end of February or March, with close attention paid to climatic conditions (Odabaşı 1983, Boydak 1993, Yaka 1993).

Shelterwood method

When applying the shelterwood method, preparatory cutting is generally not necessary except in stands which have about 80%–100% crown coverage; therefore, only a seeding cutting and final cutting are usually applied in *P. brutia* stands. Seeding cutting, extraction, and other necessary treatments to affect the litter thickness, as well as additional seeding and laying cone bearing branches on the ground, must also be applied and completed 2–3 weeks before germination. The suggested number of seed trees to be left in the regeneration area after the seeding cutting is between 25–60 trees per hectare, depending on the diameters of their crowns (Pamay 1966, Özdemir 1977, Saatçioğlu 1979, Boydak 1993). The light intensity must be over 55–60% (Pamay 1966) or 65–70% (Özdemir 1977) after seeding cutting. Otherwise, the seedlings degenerate and mortality increases. From the practical point of view, 20% crown coverage may meet the light needs (Yaka 1993). Final cutting (overstory removal) should be applied at the end of the first or second vegetation period, after regeneration success has been achieved (Özdemir 1977, Ayhan 1983, Odabaşı 1983, Boydak 1993, Yaka 1993).

Strip clearcut method

The strip clearcut method is also a successful regeneration method for natural regeneration of *P. brutia*. Width of the first strip can be 40 m (Özdemir 1977), and the following strips 20 to 25 metres. Subsequent strips can be opened after the second or third years. Preparatory activities of regeneration operations such as felling, extracting, modifying the thickness of the ground litter, and laying of cone-bearing branches on the soil, must be applied as explained earlier. This method should not be carried out on steeper slopes (Boydak 1993).

Conclusions

Mediterranean foresters need to plan every silvicultural activity in anticipation of several consecutive dry years and establish protection measures accordingly. Regeneration success of *P. brutia* must be achieved at the end of the first vegetation period. Otherwise, the site's growing space is occupied by competing vegetation, necessitating further expensive activities such as repeated site preparation and planting; even then, success cannot be guaranteed on every site. Fire is a major disturbance in *P. brutia* forests. It is a fire adapted tree species and a number of adaptations generally contribute to the post-fire regeneration. The dynamics of its forests, together with its silvicultural characteristics, generally necessitate application of even-aged management methods. Clearcutting, shelterwood, and strip clearcutting methods can be applied to *P. brutia* forests. In most cases clearcutting and strip clear cut methods are more successful than shelterwood. The decision of natural regeneration methods must be based on site-specific examinations. Regeneration of *P. brutia* largely depends on the canopy seed bank. The success of any regeneration method is guaranteed by laying cone bearing branches homogenously on the soil surface in combination with additional seeding. In natural regeneration activities, every preparatory activity must be completed at least 2–3 weeks before seed germination. Ground litter of 2–4 cm creates a medium that reduces evapotranspiration, delays growth of competing vegetation and increases the percent of seedling survival, especially at lower elevations. *P. brutia* seedlings were more numerous and more vigorous when natural regeneration methods were combined with prescribed fire; however, since regeneration success is achieved by clearcutting or other methods, inclusion of prescribed fire with other regeneration activities is not a usual practice.

In *P. brutia* forests there are suitable sites where intensive cultural methods can be applied. In these sites, planting seedlings obtained from improved, higher genetic quality seeds may be preferred to natural regeneration (Çepel et al. 1995). In this way, the rotation period can be shortened and profits can be maximized. Although some applicable preliminary results were obtained from a continuing comprehensive breeding programme of *P. brutia*, Turkey's forest management system is not yet ready for the application of intensive culture in normal *P. brutia* populations; therefore, natural regeneration methods must be continued to maintain the genetic diversity until forest management conditions reach the appropriate technical, biological and administrative levels. Presently intensive culture could be applied in suitable degraded *P. brutia* stands or in other convenient bare lands.

Sustainable forest management is an important element of sustainable development, especially in fragile Mediterranean ecosystems; therefore, effective cooperation, research and exchange of knowledge among the Mediterranean countries should be continued.

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