Fertility Variation and Effective Number in the Seed Production Areas of *Pinus radiata* and *Pinus pinaster*

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Abstract

Maritime (*Pinus pinaster* Ait.) and radiata (*Pinus radiata* D. Don.) pines are exotic species for Turkey. The afforestations of these species have been continued since late 1960s. There are approximately 54,000 and 1,700 hectares of industrial plantations, 333 and 81 hectares of seed stands of *P. pinaster* and *P. radiata* pines according to 1997's data from the forest inventory in Turkey, respectively. Production of female and male strobili was surveyed for two consecutive years in a seed stand of *P. radiata,* and a plantation of *P. pinaster* in northern Turkey. There were positive and significant correlations (r = 0.406 and 0.709 in *P. radiata,* 0.596 and 0.853 in *P. pinaster* for consecutive two years) between female and male strobilus production. The effective numbers of parents were calculated as percentages of census number to 76% and 70% in the *P. radiata* seed stand, and 83% and 78% in the *P. pinaster* plantation for 2001 and 2002, respectively. Male fertility variation was larger than female fertility variation in *P. radiata* for both years, but the variation of female fertility was larger than that of male fertility in *P. pinaster.* Management of the stands and procedure of seed collection were discussed.

Key words: seed stand, fertility variation, effective number, gene diversity, *Pinus radiata, Pinus pinaster.*

Introduction

Large differences in fertility among trees were reported in natural populations (BILA and LINDGREN, 1998), in plantations (BILA *et al.,* 1999) and in seed orchards (KANG, 2001). In general, only a fraction of individuals in a population contributes to much of the gamete gene pool and transmits their genes to the progeny generation (ERIKSSON *et al.,* 1973; EL-KASSABY, 1995; BILA, 2000). Such fertility variation will contribute to rapid accumulation of relatedness and subsequent inbreeding in the following generations (BILA, 2000; KANG, 2001).

It is practical to have a unique term for effective number based solely on fertility variation among trees, where the pedigree of population or relatedness among trees is not known. A sibling coefficient and an effective number of parents have been suggested as such a tool (KANG and LINDGREN, 1999). The relationship between the effective number of parents, status number and effective number in the variance sense was well documented in KANG and LINDGREN (1998; 1999) and BILA (2000).

Seed stands (or seed production areas) are artificial plantations or natural stands where a group of trees seems to be phenotypically superior and thus somewhat improved seeds are collected. There are options to thin the stand and thus improve the pollen and seed quality or to select trees for cone harvesting. Those are low-cost and low-tech options.

The demands for forest products have been increasing in Turkey. Annual wood product from natural forests was 15 million m^3, and 33 million m^3 wood product was used in Turkey in 1993. The demand for forest products in Turkey is estimated to reach 50 million m^3 and 61 million m^3 in 2010 and 2020, respectively (BIRLER, 1998). Industrial plantations of fast-growing exotic tree species such as *Pinus radiata* D. Don., *Pinus pinaster* Ait. and *Pseudotsuga menziesii* (Mirb.) Franco will play a very important role in supplying the future wood demand of Turkey. The afforestations with *P. pinaster* and *P. radiata* pines were continued intensively until end of 1970's. But, the afforestation with *P. pinaster* has been decreased because of the snow damage (TOPLU and BOZKUS, 1988), and the afforestation with *P. radiata* was stopped because of the insect damage (TOPLU *et al.,* 1987). Even with these damages, *P. pinaster* and *P. radiata* pines grow better than commercial native species (TUNCTANER and TULUKCU, 1991; 1993). According to 1997's data, plantation areas of *P. radiata* and *P. pinaster* in Turkey are 1,642 ha and 54,000 ha, respectively (CALISKAN, 1998). Some of the plantation areas are designated as seed stands that may be used as seed sources in Turkey in the near future.

The objective of the present study is to evaluate fertility variation among trees in seed stands and its effect on the gene diversity of seed (i.e., effective number of parent), and to monitor if the plantation areas are good enough for seed sources or gene conservation in Turkey. Some management alternatives in seed sources are also discussed.

Material and Methods

Stand description and data collection

A seed stand of *P. radiata* and a plantation of *P. pinaster* were established at the end of 1960's in Adapazari, northern part of Turkey (latitude 41°07' N, longitude 30°22' E and altitude 50 m). There are 81 ha of *P. radiata* and 333 ha of *P. pinaster* seed stands in Turkey (ANONYMOUS, 2001). Seedlings were planted at 6 m x 6 m in the *P. radiata* seed stand, and 3 m x 3 m in the *P. pinaster* plantation. The survey of strobilus production was done in core areas, two hectares of seed stand and plantation, respectively. The core areas mean that seeds are mainly collected from those areas. Data on the production of female and male strobili were collected from 118 trees of *P. radiata* stand and 50 trees of *P. pinaster* plantation, chosen randomly, in the beginning of April 2001 and in the end of April 2002. The average number of trees per hectare is about 300 in *P. radiata* (total 600 trees in the core area). The average number of trees per hectare is about 1,100 in *P. pinaster.*

Effective number of parent

Effective number of parent (N_p) can be defined as the number of genotypes divided by the sibling coefficient (Ψ) (see KANG and LINDGREN, 1999). The effective number of parent is divided into the effective number of female parent ($N_{p(f)} = CV_f^2 + 1$) and that of male parent ($N_{p(m)} = CV_m^2 + 1$). In this study, we applied their approaches into the seed stands. Considering correlation

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between female and male fertility, Np was calculated (KANG and EL-KASSABY, 2002) as

$$N_p = \frac{N}{\Psi} = \frac{4N}{CV_f^2 + CV_m^2 + 2rCV_fCV_m + 4} \quad [1]$$

where CV_f and CV_m are the coefficients of variation in female and male fertility, r is the correlation coefficient between female and male fertility and N is the number of individuals. Here, fertility is estimated based on the flowering assessment. The sibling coefficient (Ψ) can be interpreted as the likelihood of two random gametes being identical by descent in a set of gametes from the same group, considering fertility variation (KANG, 2001). Thus, Ψ=1 means that there is an equal contribution of individual to gamete gene pool in the population.

When an equal amount of seed is collected from each tree, the female fertility is constant and thus $CV_f = 0$ (i.e., equal contribution among seed parents). Under equal seed harvesting, the effective number of parent of equation [1] can be simplified (KANG and EL-KASSABY, 2002) as

$$N_p = \frac{4N}{CV_m^2 + 4} \quad [2]$$

Results and Discussion

Female and male strobilus production

The average, coefficient of variation (*CV*), range of female and male strobili and phenotypic correlation coefficients between female and male strobili for the studied years are presented in *Table 1.*

Table 1. – Average, coefficient of variation (*CV*), range and correlation (*r*) of female and male strobilus production in the studied seed stand and plantation.

	Pinus radiata				*Pinus pinaster*			
	2001		2002		2001		2002	
	female	male	female	male	female	male	female	male
Average	87.3	434.6	83.7	362.4	72.8	241.2	94.2	220.8
CV	0.505	0.811	0.549	0.858	0.659	0.337	0.623	0.496
Range	16-242	0-2380	0-220	0-1820	9-182	84-378	20-231	56-495
r [a)]	0.406**		0.709**		0.596**		0.853**	

[a)] phenotypic correlation coefficient between female and male strobilus production.
**: statistically significant at 0.01 probability level.

All seed trees in *P. pinaster* produced strobili, but some trees in *P. radiata* did not produce female or male strobili at all. The male fertility variation (*CV*) was larger than female fertility variation in *P. radiata* while female fertility variation was larger than male fertility variation in *P. pinaster* for both years. Significant positive correlations ($P<0.01$) between female and male strobilus production in both species and years were found (*Table 1*).

Fertility variation and effective number

Female and male fertility variation (Ψ_f and Ψ_m), effective number of parent ($N_{p(f)}$ and $N_{p(m)}$) and relative effective number of parent ($N_{r(f)}$ and $N_{r(m)}$) according to years are given in *Table 2*. The larger fertility variation was among trees, the smaller effective number of parent was found. $N_{p(f)}$ were higher than $N_{p(m)}$ in *P. radiata*, but it was found as an opposite situation in *P. pinaster* for both years (*Table 2*).

Table 2. – Fertility variation (Ψ_f & and Ψ_m), effective number of parent ($N_{p(f)}$ and $N_{p(m)}$) and relative effective number of parent ($N_{r(f)}$ and $N_{r(m)}$) in the female and male gametic gene pool of studied populations for two years.

	Pinus radiata (118) [a)]				*Pinus pinaster* (50)			
	2001		2002		2001		2002	
	female	male	female	male	female	male	female	male
Ψ_f & Ψ_m [b)]	1.26	1.66	1.30	1.74	1.43	1.11	1.39	1.25
$N_{p(f)}$ & $N_{p(m)}$	94.0	71.2	90.7	68.0	34.9	44.9	36.0	40.1
$N_{r(f)}$ & $N_{r(m)}$	0.80	0.60	0.77	0.58	0.70	0.90	0.72	0.80

[a)] census number (*N*) in parentheses.
[b)] *f* and *m* represent female and male, respectively.

When fertility varied among trees and equal seed harvest was imposed, fertility variation (Ψ), effective number of parent (N_p) and relative effective number of parent (N_r) for total fertility are shown in *Table 3*. Ψ in *P. radiata* was higher than *P. pinaster.* N_p and N_r for the total fertility was high in the studied species (*Table 3*). This result confirms that fertility variation in stands causes a deviation of equal contribution from the idealized situation, and thus decreases the effective number of parent; i.e., gene diversity (KANG and EL-KASSABY, 2002).

Based on a literature review, KANG (2001) suggested that the sibling coefficient of stands as a heuristic rule of thumb could be set to three (Ψ = 3) and that of seed orchards could be set to two (Ψ = 2), when data on fertility were not available. The sibling coefficients in the studied populations were lower, implying that the studied populations have rather equal reproductive success among trees. It should note that the sampling might give a biased estimation of fertility variation at the population level because some of zero-fertility individuals were missing in the observations.

Table 3. – Fertility variation (Ψ), effective number of parent (N_p) and relative effective number of parent (N_r) in the total gene pool under where fertility varied and under equal seed harvest in the studied populations for consecutive two years.

	2001						2002					
	fertility varied			equal seed harvest			fertility varied			equal seed harvest		
	Ψ	N_p	N_r	Ψ	N_p	N_r	Ψ	N_p	N_r	Ψ	N_p	N_r
P. radiata (118) [a)]	1.31	90.0	0.76	1.16	101.4	0.84	1.43	82.7	0.70	1.18	99.7	0.82
P. pinaster (50)	1.20	41.6	0.83	1.03	48.6	0.97	1.29	38.8	0.78	1.06	47.1	0.94

[a)] census number (*N*) in parentheses.

Using equal seed harvest among trees, Ψ could be somewhat improved (*Table 3*). However, this effect is rather week and the same result on the effective number of mother trees for the seed harvest would be obtained by increasing the number of harvested trees by some 10–20%. Equal seed harvest results in much trouble; high cost for the seed harvest and in some situations too few seed collection. Equal seed harvest is not possible to execute if some trees have little or no seed. So, there must be a lower bound (KANG *et al.,* 2002).

As long as hundreds of trees are harvested in seed stands, loss of gene diversity cannot be considered to be serious. Thus we do not recommend to practice the control of seed harvest per tree in the studied objects. It could be recommended to harvest seeds from several hundred trees when seed collections are performed. An instruction could be issued to avoid harvest seeds from trees that have abundant male flowering in *P. radiata* stands, because high male fertility trees will spread their genes as fathers and may cause more selfing. It could also be considered not to collect all cones from a few trees with abundant seed set in *P. pinaster*, because controlling of maternal contribution on most fertile trees will increase the effective number and give an acceptable amount of seed collection (KANG *et al.,* 2002).

The seed stands of *P. radiata* and *P. pinaster* included many superior trees, thus the seed stand will be used as the main seed sources in Turkey, after thinning. When silvicultural thinning is carried out, inferior trees will be removed to increase timber production. Seeds from the thinned stands would thus be genetically somewhat improved. It is reported that fertility variation is higher in stands than seed orchards (KANG, 2001). From the gain and diversity points of view, seed orchards of the studied species should be established in the near future for seed supply.

The studied species are exotic species in Turkey. Our results supported that both stands could be used for *ex situ* gene conservation areas. Adaptation is a problem to be considered for an exotic species. Reproductive success can be regarded as a sign of adaptation by definition (ZOBEL and TALBERT, 1984). Trees, which get offspring, are probably better adapted for the local environment than those, which do not. Thus, removing infertile trees may increase the genetic adaptation.

Although the studied seed stands were established as a commercial plantation at the beginning, parts of the plantations were separated as seed collection areas due to resistance against insect damage. Snow damage at the studied plantation of *P. pinaster* is not observed during the survey years or reported by other researchers. When these advantages and roles in supplying the future wood demand of these species for Turkey are taken into consideration, these studied areas may be considered as seed sources. To convert a stand into a seed stand means to make actions and investments, which benefits seed production on the cost of other values. This may include more intensive thinning and focus mainly on inferior trees. Industrial plantations of these species should be increased to supply the forest products of Turkey in the near future (AKCIDEM, 1991; BILIR and ISBILIR, 2002). Forest productivity would be improved if seeds are collected and used from the seed stand and the plantation.

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