Seed Production of *Pinus greggii* Engelm. in Natural Stands in Mexico

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Five cones of Pinus greggii *Engelm. were collected from each of 117 trees at 12 widely separated sites in Mexico to examine their seed potential and efficiency. Seed efficiency of* P. greggii *in natural stands was 63% rangewide. Differences were found in seed-yield traits related to geographical location. Trees in southern stands in the states of Hidalgo and Queretaro had greater seed potential (117 versus 91 seeds/cone) and produced more filled seeds per cone (74 versus 46) than trees in northern stands in Coahuila and Nuevo Leon. Trees in northern stands had more first-year aborted seeds per cone (42 versus 32) and three times more insect-damaged seeds than trees in southern stands in 1993.* Tree Planters' Notes 46(3):86-92; 1995.

Pinus greggii Engelm. is a closed-cone pine that grows in two disjunct regions of the Sierra Madre Oriental in Mexico (figure 1). The species' northern region includes the states of Coahuila and Nuevo León, while the southern region consists of San Luis Potosi, Queretaro, Hidalgo, Puebla, and Veracruz (figures 2 and 3). The northern and southern locations have distinct environments. Northern *P. greggii* sites are usually at higher elevations (2,300 to 2,800 m versus 1,200 to 2,300 m) and have lower rainfall (650 mm versus 800 to 1,600 mm) than most southern sites, and have near neutral or slightly alkaline topsoils (Donahue 1993). Soil pH at southern *P. greggii* sites tends to be more acidic. Environmental details are listed in table 1.

Many stands of *P. greggii* have been disturbed by selective cutting and burning, particularly in northern stands. The largest, least disturbed stands are in the state of Queretaro, in the southern region, where the trees grow faster and appear to have less disease and insect problems than at northern sites.

Pinus greggii is a precocious species. It produces seed cones in natural stands at 3 to 5 years of age (Lopez -Upton 1986) and in exotic field trials after the first year (Dvorak and Donahue 1992). It is quite prolific when mature, producing large cone crops on a regular basis (figure 4). Cone buds mature and pollination occurs in April-May in the southern stands, and May-June in northern stands. Seed cones begin to mature in December of the following year, with seed dispersal delayed primarily until the hotter months of April and May, varying among stands and trees. The slow opening of *P. greggii* "closed-cones" allows for an extended seed collection period beginning in January, and continuing through March or April.

The objective of this study was to determine the species' variation in seed potential and production in natural conditions, over the range of environments where it grows. The study was done in conjunction with a rangewide survey of *P. greggii* to study the morphological variation and terpene chemistry of the species.

Materials and Methods

In 1993, a project was initiated between the Colegio de Postgraduados, Montecillo, Mexico, and the Central America and Mexico Coniferous Resources (CAMCORE) Cooperative, North Carolina State University, USA, to study geographic variation in cone, leaf, and seed morphology of *Pinus greggii.* A rangewide sample was collected from 12 sites (figure 1), from a total of 177 trees. Cones from 15 trees were obtained at most sites (table 1), with the sample covering the majority of the targeted stand.

Cones were collected from healthy dominant and codominant trees, spaced at a minimum of 100 m. A cone was collected from five distinct locations in the upper third of the crown of each tree (5 cones/tree). The cones were ovendried for approximately 48 hours at 50 ºC to facilitate opening, and the seeds were counted and classified (by dissection) as filled, empty, first-year aborted, second-year aborted, or insect-damaged following the methodology described by Bramlett and others (1977). The number of fertile cone scales was counted to calculate seed potential and determine seed efficiency. Seed potential is the number of cone scales multiplied by two. Seed efficiency is the total number of filled seeds divided by the seed potential.

Site and individual tree means and coefficients of variation were computed for each seed-yield trait. An analy-

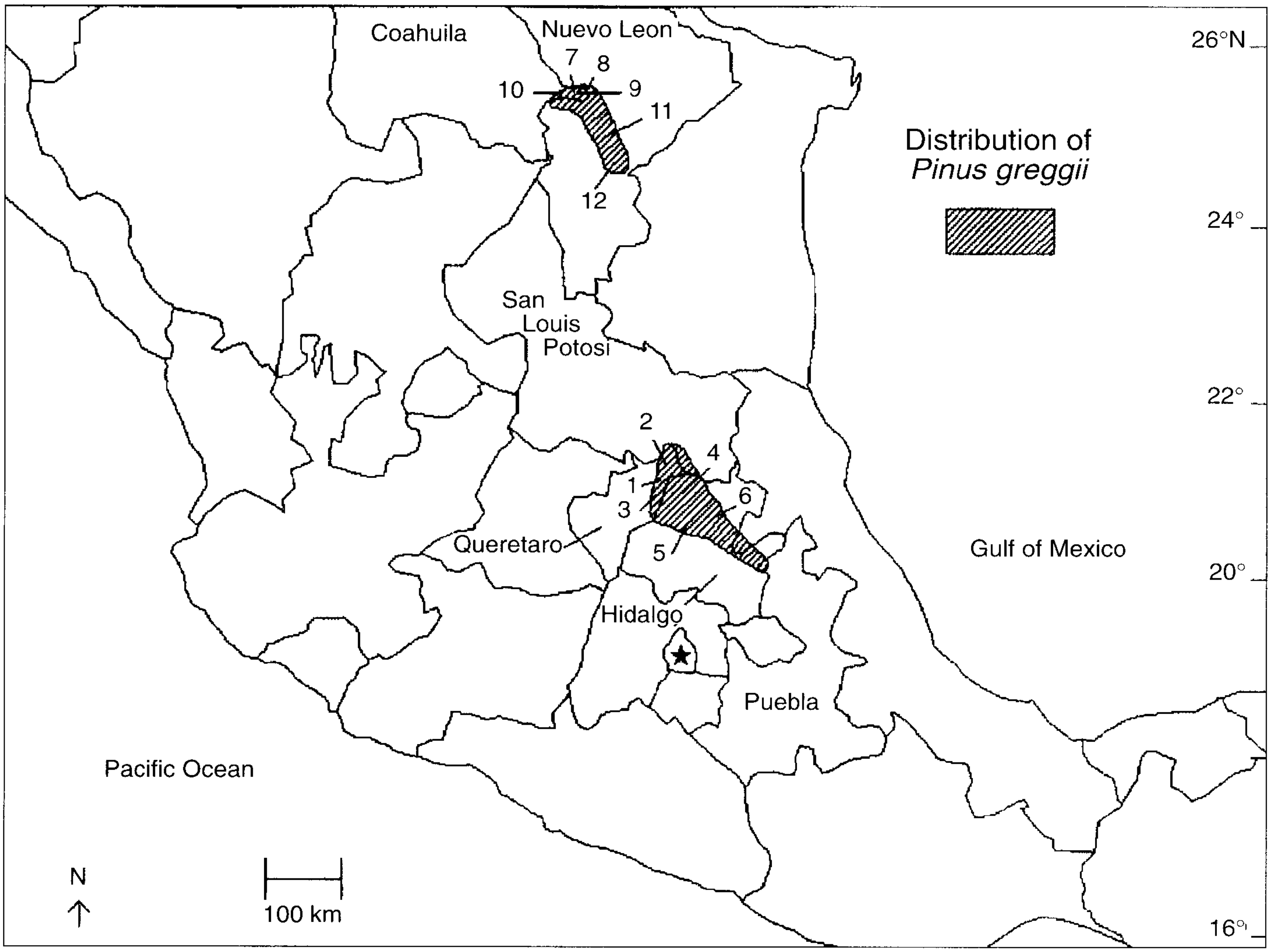

Figure 1—*Location of the seed production study sites in Mexico.*

sis of variance was conducted on the individual tree means using the GLM procedure of the Statistical Analysis System Institute (SAS 1989), with a nested model; trees, sites, and sites within region (north and south regions). Waller-Duncan comparisons were done on site means to detect differences among sites, and to look for trends across regions.

Results and Discussion

Table 2 gives the results of the analysis of variation of the data in which the sources of variation were sites and individual trees within sites. Highly significant statistical differences were found for both sources of variation for all traits analyzed (table 2). In general, there was considerable tree-to-tree variation among traits, as indicated by the high coefficients of variation. The extreme coefficient of variation for second-year abortions coincides with a highly extreme CV for insect-damaged seeds, indicating insect damage as the principal cause for the high number of second-year abortions. In the southeastern United States, second-year abortions are caused primarily by *Leptoglossus corculus* Say, the leaf-footed pine seedbug (Bramlett and others 1977). *Leptoglossus occidentalis* Heidemann has been reported to attack *P. greggii* in native stands and is considered one of the most important pine cone and seed pests in Mexico (CibrianTovar and others 1995). There were no significant statistical differences between northern and southern groups of sites for any traits. There are some apparent north-south trends in the data for number of fertile cone scales, number of insect-damaged seeds, and firstand second-year aborted seeds,

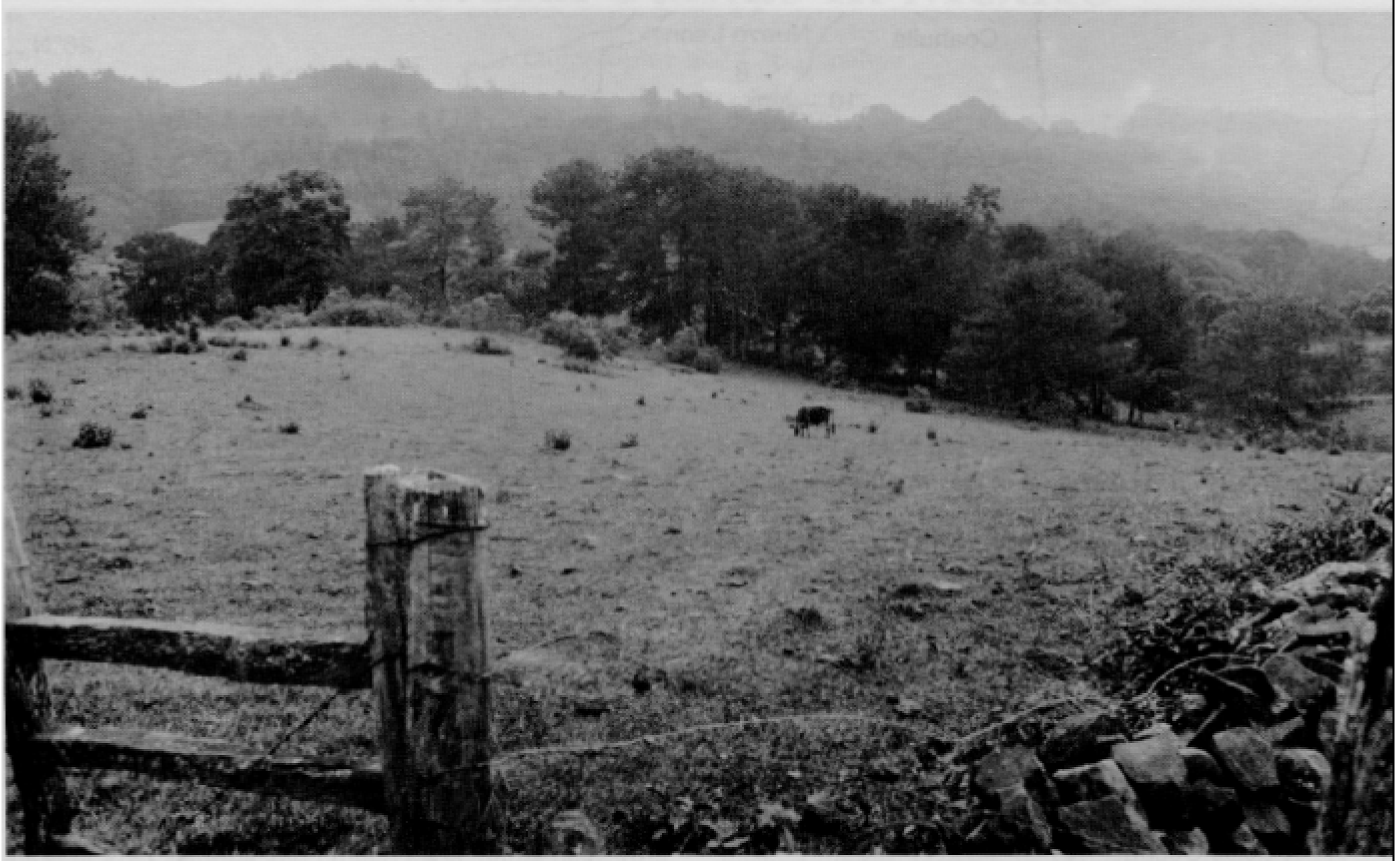

Figure 2—Pinus greggii *in a typical stand of small groups of trees scattered about pasturelands (Laguna Atezca, in Hidalgo, Mexico).*

where 4 of 6 sites in a region cluster together (table 3). Because the cones were collected for a morphology study, those that were obviously deformed were rejected. These results are for seed-yield traits of normal cones.

The average number of fertile cone scales across all sites was 52, giving an average seed potential of 104 seeds/cone for the species. Based on the number of fertile cone scales, seed potential at southern region sites was 28% higher than northern region sites; 117 seeds per cone versus 91 seeds/cone (table 3). Although not statistically significant at the region level, southern sites tended to have higher numbers of fertile cone scales, except for Laguna Atezca. This site had the lowest average, and also had the lowest number of filled seeds. Laguna Atezca is the study site located nearest to a *Pinus patula* stand (Jalamelco, at 3 km distance). Introgression may have occurred between the two species in the past, resulting in altered cone and seed development. Trees from this site are statistically distinct from trees of other southern stands in cone and seed morphology, and resemble trees of *Pinus patula* from Zacualtipan, Hidalgo in some traits (Donahue and Upton 1995). The Laguna Atezca stand is also one of the more fragmented; most of the trees are growing in small groups, scattered about pasture land (figure 2). Trees from El Madrono had the highest number of fertile cone scales. This site has the largest, least disturbed area of *P. greggii* in the southern region, encompassing nearly 10,000 ha.

Information on "per-cone" seed production in natural stands is not readily available for Mexican pines. Bello-Gonzalez (1983) reported on two other closed-cone pines, *Pinus pringlei* Shaw, and *P. oocarpa* Schiede, in a survey conducted in the state of Michoacan in 1981. The sample was comprised of 5-tree bulks from one site for each species. His results showed a seed potential of 36 seeds/cone for *P. pringlei* and 60 seeds/cone for *P. oocarpa.* Seed viability per cone was 26 and 55%, respectively, for the 2 species. Dvorak and Lambeth (1993) reported a seed potential for *Pinus tecunumanii* (Schw.) Enguiluz et Perry in Guatemala and Chiapas, Mexico of 90 seeds/cone. Narvaez-Flores (1993) found a seed potential for *Pinus arizonica* Engelm. in Chihuahua of 88 seeds/cone.

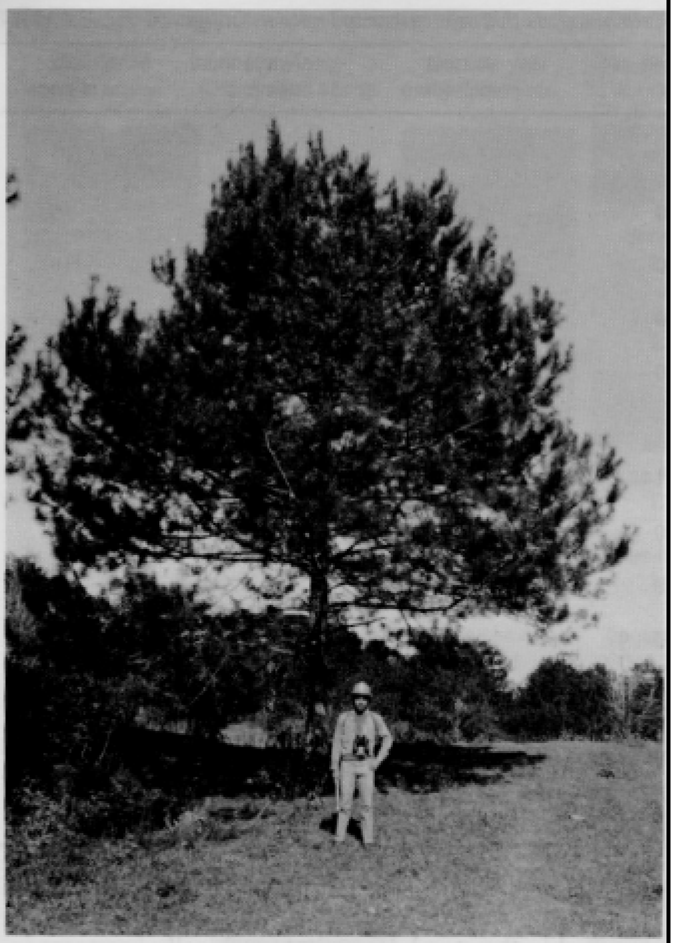

Figure 3—Pinus greggii *showing the high stem diameter to tree height ratio common on many sites (Laguna Atezca, in Hidalgo, Mexico).*

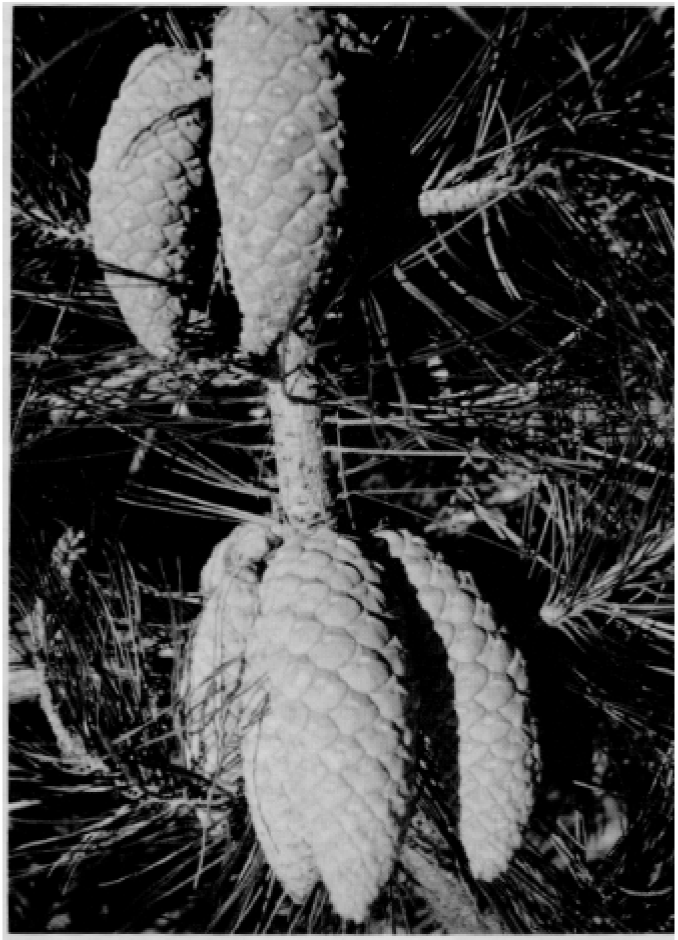

Figure 4—*Closed mature (bottom) and immature (top) cones of* Pinus greggii *(Las Placetas, Nuevo Leon, Mexico). Cones may be produced in clusters of up to 10 to 12 and multiple flushes do occur in one year.*

Seed efficiency, the number of filled seeds as a ratio to the seed potential, averaged 63% for all sites. This compares favorably to seed orchards in the southeastern United States, where a seed efficiency of 55% is considered good (Bramlett and others 1977). Trees at El Madroño had the highest seed efficiency, and those at La Tapona, a northern stand, the second highest. Like the stand at El Madroño, the stand at La Tapona is the least disturbed in its region and covers an area of approximately 220 ha. The stand at San Joaquin had the lowest seed efficiency of all sites. This stand is at the highest elevation reported for *P. greggii* in the southern region and also is among the most affected by human activities. Stand density is very low, and the trees are scattered about in small groups, interspersed among pasture areas over an area of approximately 150 ha. Inadequate pollination may be the cause for low seed efficiency at San Joaquin, as indicated by its having the highest number of first-year aborted seeds (table 3). The stand at Valle Verde, in the south, also ranked low in filled seeds. This is interesting due to the fact that like the stand at El Madroño, it covers a large area (nearly 10,000 ha) but stand density is very variable, ranging from dense to widely dispersed. This site is located approximately 10 km north of El Madroño, at the lowest elevation reported for the species (1,150 m). The stands appeared to be in general poor condition based on the large number of trees observed with shoot borer attacks and cone pests. Based on casual observation, no other southern stand had this amount of insect problems. Seed efficiency in *P. greggii* was much higher than *Pinus arizonica* Engelm. in Chihuahua. Narváez-Flores (1993) reported an efficiency of only 19%, and first- and second-year abortions together averaged 44%.

The number of filled seeds per cone averaged 28% more in southern stands of *P. greggii* than northern stands (73.5 versus 57.2). Both the highest and lowest amounts of filled

Table 1- *Summary of the **Pinus greggii** sites included in the study, with site numbers that reference map locations in figure 1*

Site	Latitude & longitude	Elevation (m)	Annual precip. (mm)	Ave. annual temp. (ºC)	No. of trees
Southern region					
1. El Madroño, Queretaro	21/ 16' N 99/ 10' W	1,650-1,730	1,200	17	15
2. Valle Verde, Queretaro	21/ 29' N 99/ 12' W	1,150-1,250	1,400	17	15
3. San Joaquin, Queretaro	20/ 56' N 99/ 34' W	2,310-2,380	1,100	16	15
4. Laguna Seca, Hidalgo	21/ 02' N 99/ 10' W	1,670-1,830	820	18	12
5. Cerro Perico, Hidalgo	20/ 44' N 99/ 02' W	1,830-1,970	800	17	15
6. Laguna Atezca, Hidalgo	20/ 49' N 98/ 46'W	1,250-1,420	1,642	19	15
Northern region 7. Santa Anita, Coahuila	25/ 27' N 10/ 34'W	2,515-2,620	650	13	15
8. Mesa del Rosario*, Coahuila	25/ 26' N 100/ 28'W	1,920-2,325	650	13	15
9. Cañon Los Lirios, Coahuila	25/ 22' N 100/ 29'W	2,260-2,460	650	12	15
10. Loma El Oregano, Coahuila	25/ 22' N 100/ 55'W	2,310-2,350	600	13	15
11. Las Placetas, Nuevo Leon	24/ 55' N 100/ 11'W	2,370-2,520	750	16	15
12. La Tapona, Nuevo Leon	24/ 43' N 100/ 10'W	2,090-2,350	650	15	15

Source: INEGI (1980).
*This includes the dispersed stands that occur between Agua Fria (25/ 24'N, 100/ 25'W) and El Tarrillal (25/ 27'N, 100/ 31'W).

Table 2- *Means and variances for cone and seed-yield traits across all sites*

Trait	Mean	Min.	Max.	CV
No. of fertile cone scales	52.0***	9	111	34.4
No. of filled seeds	64.8***	0	221	62.1
No. of empty seeds	10.1***	0	73	94.7
No. of insect damaged seeds	0.5***	0	9	281.4
No. of aborted seeds-1st year	37.1 ***	0	132	57.0
No. of aborted seeds-2nd year	1.7***	0	24	140.2
Seed efficiency	62.6***	0	100	59.3

*** Differences among sites and trees within site significant at P#.001.

Laguna Atezca, respectively. Again, there could be a seed development problem at Laguna Atezca due to the reasons mentioned previously. The low number of fertile cone scales and number of first-year aborted seeds appear to be the dominant factors affecting the number of filled seeds at Laguna Atezca. Las Placetas, possibly the largest stand in northern Mexico (approximately 400 ha), had the second lowest number of filled seeds. This site had the highest incidence of insect attacks, both shoot borers and cone pests, of all sites inspected in 1993. The trees appeared to be under stress— top dieback and bark beetle attacks were frequently observed in the stand. Precipitation usually increases in May in this zone. In 1993 rains were delayed until midJune, indicating that the region perhaps was in a prolonged dry-season cycle, putting the trees under moisture stress, leading to pest problems and reduced seed yields.

Upton and others (1993) got similar results for *P. greggii* from a collection done in 1990, when they sampled a total of 11 populations; 5 in southern region stands and 6 in northern region stands. Trees in southern stands had 17% more filled seeds than trees in northern stands. His results showed 75 and 46 filled seeds/cone for El Madroño and Molango (same site as Laguna Atezca), respectively. Trees at Las Placetas, in northern Mexico also had 46 filled seeds/cone. Plancarte (1988) sampled the stand at Molango in 1988 and got 97 filled seeds/cone. His results were based on bulked multipletree samples. Dvorak and Lambeth (1993) reported 6 filled seeds/cone for *P. tecunumanii* in Guatemala, and 30 filled seeds/cone in Nicaragua. Comparative data are unavailable for other species, but Flores (1969) reports 60 to 80 "viable" seeds per cone for *Pinus arizonica, P. durangensis* Mart. and *P. engelmannii* Carr in the northern

Table 3— *Site means and Waller-Duncan groups for seed-yield traits of* Pinus greggii *in natural stands.*

No. fertile cone scales	No. insect-damaged seeds	No. first-year aborted seeds	No. second-year aborted seeds	No. empty seeds	No. filled seeds	(%) Seed efficiency
El Madroño **74.7 a**	Santa Anita **2.27 a**	San Joaquin **64.0 a**	Valle Verde **4.31 a**	Cerro Perico **15.2 a**	El Madroño **122.6 a**	El Madroño **82.1 a**
Cerro Perico **68.3 b**	Mesa Rosario **1.10 b**	Laguna Seca **44.5 b**	Santa Anita **2.37 b**	San Joaquin **14.6 a**	Cerro Perico **95.1 b**	La Tapona **73.1 b**
Laguna Seca **65.5 c**	La Tapona **0.55 c**	Valle Verde **44.1 bc**	Los Lirios **2.11 c**	Los Lirios **13.6 b**	Laguna Seca **85.4 c**	Cerro Perico **69.5 b**
San Joaquin **56.6 d**	Laguna Atezca **0.53 c**	Cerro Perico **39.6 cd**	Cerro Perico **1.88 d**	Laguna Seca **12.4 c**	La Tapona **77.6 d**	Laguna Seca **65.0 bc**
La Tapona **52.5 e**	Loma Oregano **0.36 d**	Santa Anita **38.7 de**	Las Placetas **1.73 d**	Las Placetas **10.3 d**	Santa Anita **59.6 e**	Loma Oregano **63.0 cd**
Santa Anita **50.9 f**	Las Placetas **0.21 e**	Las Placetas **35.6 def**	Mesa Rosario **1.38 e**	Santa Anita **10.1 de**	Mesa Rosario **56.2 f**	Santa Anita **61.9 cde**
Valle Verde **48.6 g**	Los Lirios **0.21 e**	Los Lirios **34.1 ef**	Loma Oregano **1.29 ef**	Loma Oregano **9.4 e**	Los Lirios **52.5 g**	Los Lirios **59.0 de**
Mesa Rosario **44.7 h**	Cerro Perico **0.19 e**	Laguna Atezca **31.6 fg**	El Madroño **1.29 ef**	La Tapona **7.9 f**	Loma Oregano **51.5 g**	Mesa Rosario **57.6 ef**
Los Lirios **44.4 h**	Valle Verde **0.19 e**	Mesa Rosario **31.6 fg**	Laguna Seca **1.27 ef**	Valle Verde **7.4 fg**	Valle Verde **48.6 h**	Laguna Atezca **55.2 ef**
Las Placetas **41.4 i**	Laguna Seca **0.18 e**	Loma Oregano **28.6 gh**	San Joaquin **1.16 f**	Mesa Rosario **7.0 gh**	San Joaquin **47.9 hi**	Las Placetas **54.7 ef**
Loma Oregano **40.9 i**	San Joaquin **0.13 e**	La Tapona **27.5 gh**	Laguna Atezca **1.11 f**	Laguna Atezca **6.8 gh**	Las Placetas **45.9 i**	Valle Verde **50.0 fg**
Laguna Atezca **37.2 j**	El Madroño **0.09 e**	El Madroño **25.5 h**	La Tapona **0.47 g**	El Madroño **6.3 h**	Laguna Atezca **41.3 j**	San Joaquin **42.3 g**

The values shown represent average per cone. Shaded blocks are sites from the southern region, all others are northern region. Means in a column with the same letter are not significantly different at the 0.05 level.

Mexico states of Chihuahua and Sonora. The lower and upper values correspond to typical and abundant seed years respectively.

Northern stands of *P. greggii* had almost triple the amount of insect-damaged seeds per cone as southern stands— 0.62 versus 0.22. The highest incidence of insect damage was at Santa Anita, which had double the amount found at the second highest ranked site, Mesa del Rosario. Except for the one outlier southern site, Laguna Atezca, the results show a geographical trend; northern sites had more insect-damaged seed than southern sites. This could be attributed to moisture stress on the drier northern Mexico sites. Averaged across sites, *P. greggii* had only 0.4% insect-damaged seed. This compares favorably to the *P. arizonica* study done by Narváez-Flores (1993), which showed 8% insect damage due to seed chalcids *(Megastigmus* sp.*)*.

A slight geographical trend also appears in the first-year data on aborted seeds. On average, southern stands of P. *greggii* had 28% more first-year aborted seeds than northern stands (41.5% versus 32.3%). This trait was the dominant loss effect on seed efficiency. San Joaquin had the highest average of first-year abortions, possibly due to inadequate pollination, while El Madroño, the apparently healthiest stand, had the lowest average. It appears that the southern stands may have a general problem of inadequate pollination. Usually, first-year seed abortions are attributed either to a lack of pollination or to insect attack. In this study, the southern stands had fewer insect-damaged seeds on average, thus indicating inadequate pollination as the major cause of first-year aborted seeds. The study reported by Lopez-Upton and others (1993) showed 40% more aborted seeds (1st- and 2nd-year combined) in southern stands of *P. greggii* than in northern stands.

The stand at Valle Verde stands out as having the highest number of second-year aborted seeds. It also ranked high in first-year abortions, and subsequently low in seed efficiency. It is possible that the seeds are having developmental problems related to the apparent stress that the trees were suffering. As mentioned, a high incidence of shoot borer and cone pest attacks was observed in the field, but the site ranked low in the number of insect-damaged seeds. As such, the cause of this stress is unclear.

Conclusions

Seed efficiency for *Pinus greggii* in natural stands appears to be high in comparison to other pine species, and appears to have fewer and less severe seed insect problems. Adequate seed production in orchards located in the species' natural range should not be a problem. Sound seed production and seed efficiency is higher in southern stands than in northern stands. This may be due to genetic differences in numbers of fertile cone scales among populations, to the better soils and higher rainfall found at southern sites, or fewer pest problems than at northern sites. Further research is required to determine the actual cause of first-year seed abortions, which was the primary seed loss factor in this study. These results indicate a potential for insect problems in seed orchards of *Pinus greggii.* Close monitoring and control programs should be included in seed orchard management for this species.

Stands that were least disturbed by human activities, and growing under optimum conditions, had higher amounts of filled seeds. El Madroño (a southern site) and La Tapona (a northern site) had the highest seed efficiencies. Both stand out as large, homogeneous stands in their respective regions. Stands at elevational and precipitation extremes produced fewer sound seeds.

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