

Short Note: An Index of Phenological Overlap in Flowering for Clonal Conifer Seed Orchards

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Abstract

An index for measuring phenological overlap is developed and described relative to clonal conifer seed orchards. This index provides orchard managers with a method of quantifying the degree of reproductive synchronization between all mating pairs of clones. It can facilitate management decisions involved with activities such as roguing and supplemental mass pollination. An example of the index's utility is provided for a first-generation loblolly pine seed orchard where asynchronous flowering exists between some pollen and seed parents. The index may provide a tool for tracking the development of young orchards and monitoring the stability of established orchards.

Key words: Loblolly pine, flowering, supplemental mass pollination, seed orchard management, *Pinus taeda* L.

Introduction

Evaluating the effectiveness of female and male strobili function in a wind-pollinated clonal seed orchard requires a standard measure of the relative probabilities of cross-pollination between all possible pairs of parents. Female or male reproductive phenologies can be quantified by recording the proportion of sampled strobili that are receptive or shedding pollen on a given census date. MAHALL and BORMANN (1978) presented observations of vegetative phenology as "phenograms" in which the duration of phenological stages were represented by bands on a time line. The band widths represented the proportion of plant organs in a given phenological stage at a given time. This technique is readily adaptable to displaying clonal patterns of female and male reproductive phenology in conifer seed orchards (e.g. ASKEW, 1986). However, these phenograms are difficult to interpret for some types of information. For example, identifying a pollen parent that is optimally synchronized with a given female parent requires a visual rating of the degree of overlap between all possible pollen parents and the female parent in question. This is impractical for orchards with a large number of clones and the results of such an empirical technique are difficult to quantify and express.

Rating an entire orchard for its relative degree of flowering synchronization is difficult without a quantitative index. Quantification is essential for tracking changes in flowering patterns throughout the life of an orchard, evaluating the degree of panmixia within an orchard, or for contrasting several orchards. PRIMACK (1980) suggested an index for quantifying the degree of overlap for "strongly" flowering plants with dimorphic flowers. This index did not allow for differentiation of separate sexes and did not accommodate measurements of the proportion of strobilus activity on a given census

day. Separate strobilus maturation rates for each sex in pine species requires an index that will accommodate each strobilus type as an independent variable. An index by ASKEW (1985) provided a method for quantifying the overall uniformity of gamete contributions in a seed orchard system but did not directly address flowering synchronization.

We describe an index of overlapping phenologies (PO) that quantifies the similarity of any pair of male and female phenograms in terms of symmetry in gamete contribution proportions. The index was developed subject to several criteria. First, the phenograms must illustrate the reproductive phenologies of both the male and female strobili from a plant species with monomorphic flowers, pines in our case. Second, the index must account for all days of flowering overlap and accommodate intensity of pollen dispersal and the proportion of receptive female strobili for the clones being evaluated.

Index Development

Five specific criteria were established for the index so that it would reflect similarities in both shape and temporal position of the male and female orchard phenograms:

- 1) the index must reach its maximum value of 1.0 if the phenograms are identical in shape and position;
- 2) the index must reach its minimum value of 0 if the phenograms share no common flowering times;
- 3) when the male and female phenograms have partial overlap, the index value must lie between 0 and 1.0;
- 4) the proportion of shedding male and receptive female flowers can range from 0 to 1.0 on any day;
- 5) the pollination period begins on the first day of pollen flight or female strobili receptivity of the two parents being compared and continues until pollen dispersal is complete and strobili receptivity has ended.

Mathematical Development

- 1) Let p_{ij} represent the proportion of monitored male strobili from clone j that are shedding pollen on day i , such that $0 \leq p_{ij} \leq 1$.
 - 2) Let m_{ik} represent the proportion of monitored female strobili from clone k that are receptive on day i , such that $0 \leq m_{ik} \leq 1$.
 - 3) Let s_{ijk} represent the larger of m_{ik} and p_{ij} .
- Then:

$$\Delta_{ijk} = |m_{ik} - p_{ij}| \quad (1)$$

which is the absolute value of the difference between m_{ik} and p_{ij} and

$$PO_{jk} = \frac{\sum_{i=1}^n (s_{ijk} - \Delta_{ijk})}{\sum_{i=1}^n s_{ijk}} \quad (2)$$

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In effect, for each of the "n" pollination days, we determine the largest area delineated by the phenograms of the two comparison clones, j and k. This area, s_{ijk} is determined by the largest of m_{jk} and p_{ij} . We then determine the difference in area between the two phenograms. The index, PO_{jk} , for the two comparison trees is the ratio of the common area to the maximum area summed across all days. The index is a quantitative measure of the proportional symmetry of the two phenograms.

For an orchard with t clones, the overall PO index for all outcross (non-self) mating combinations is:

$$PO_o = \frac{\sum_{j=1}^t \sum_{k=1}^t PO_{jk}}{t(t-1)} \quad j \neq k \quad (3)$$

Maximum $PO_o = 1.0$ when all clones have exactly the same flowering phenology and minimum $PO_o = 0$ when no pair of clones have any common mating days.

Mean PO of a given female clone k for all outcross seed orchard pollen parents is calculated as:

$$\overline{PO}_k = \frac{1}{t-1} \sum_{j=1}^t PO_{jk} \quad j \neq k \quad (4)$$

and the mean PO of a given male clone j for all outcross seed orchard seed parents is calculated as:

$$\overline{PO}_j = \frac{1}{t-1} \sum_{k=1}^t PO_{jk} \quad j \neq k \quad (5)$$

These mean PO values are indicators of a clone's female or male synchronization with the remaining orchard clones.

Example

Female and male reproductive phenology was monitored on the 15 clones in a mature first-generation coastal loblolly pine (*Pinus taeda* L.) seed orchard near Charleston, South Carolina in 1986. Twenty clusters of female strobili and thirty clusters of male strobili were observed approximately every other day on each of two ramets per clone. Observation branches were located on the north and south sides of crowns and stratified among lower, middle and upper crown levels in proportion to each ramet's strobilus production. Female strobilus activity on a given observation branch was scored as positive if any of the strobili were between stages 4-late and 5-late on the development scale of BRAMLETT and O'GWYNN (1980) on the census day. Male strobili were scored as positive on a given observation branch if pollen was being shed by any of the strobili on the census day.

Phenograms of the female and male reproductive phenologies (Figures 1 and 2) revealed diversity in patterns among clones for a given sex and between sexes for a given clone. The majority of flowering activity for clone #10 occurred prior to the onset of either the female or male strobilus activity of most of the other clones. Of the male strobilus phenograms, clone #10 and clone #5 had strikingly different patterns. Pollen shedding for clone #10 began much earlier than all of the other clones and ended abruptly after only a few days. Pollen shedding for clone #5 began much later than the rest of the clones and lasted for only a short period. Of the female phenograms, clone #10 and clone #13 varied greatly from all of the other clones. Once again, clone #10 started to produce receptive flowers earlier than the other clones and end

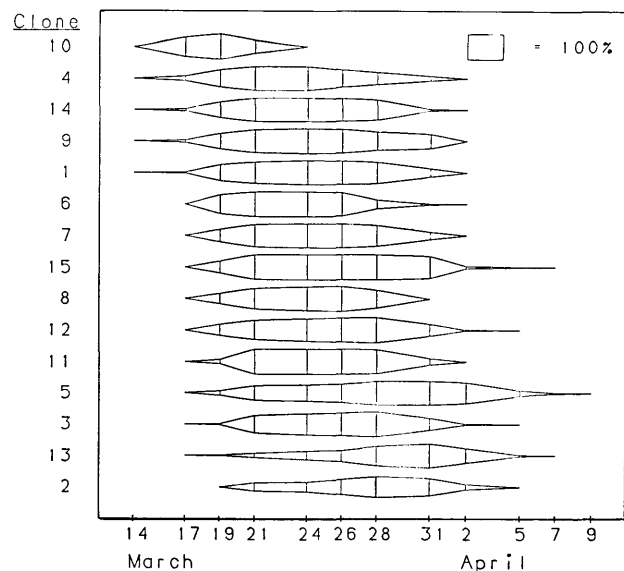


Figure 1. — Female reproductive phenology of first-generation loblolly pine seed orchard clones in 1986. The width of a horizontal band represents the percentage of observation branches containing receptive female strobili on the indicated census date.

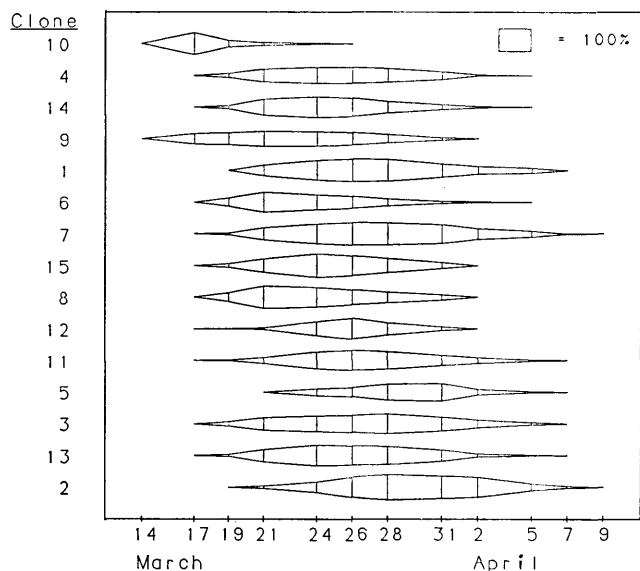


Figure 2. — Male reproductive phenology of first-generation loblolly pine seed orchard clones in 1986. The width of a horizontal band represents the percentage of observation branches containing male strobili shedding pollen on the indicated census date.

its flowering in a few days. Clone #13 began to produce some receptive flowers at about the same time as the rest of the orchard but didn't reach its peak as fast as the others.

Figures 1 and 2 show that the opportunities for cross-pollination varied among clone pairs. However, the degree of overlapping phenology would be difficult to judge by empirical techniques using phenograms even though the differences are visually apparent. The variation in phenology patterns is similar to that reported for *Pinus radiata* D. DON (GRIFFIN, 1984).

PO values for all clone pairs provided a quantitative measure of the overlapping phenologies that was con-

Table 1. — Pairwise PO values for a mature first-generation loblolly pine seed orchard.

Cross			PO	Cross			PO	Cross			PO
female	male			female	male			female	male		
1	X	2	.39	6	X	1	.44	11	X	1	.62
		3	.59			2	.25			2	.41
		4	.60			3	.44			3	.59
		5	.31			4	.51			4	.60
		6	.54			5	.20			5	.30
		7	.59			7	.43			6	.52
		8	.69			8	.69			7	.59
		9	.52			9	.55			8	.67
		10	.08			10	.08			9	.44
		11	.55			11	.41			10	.06
		12	.47			12	.43			12	.49
		13	.65			13	.51			13	.65
		14	.64			14	.61			14	.67
		15	.70			15	.62			15	.73
2	X	1	.70	7	X	1	.62	12	X	1	.68
		3	.73			2	.39			2	.46
		4	.60			3	.60			3	.65
		5	.70			4	.62			4	.61
		6	.39			5	.31			5	.35
		7	.68			6	.56			6	.55
		8	.45			8	.74			7	.64
		9	.37			9	.53			8	.67
		10	.03			10	.08			9	.50
		11	.70			11	.56			10	.07
		12	.50			12	.49			11	.59
		13	.66			13	.67			13	.71
		14	.51			14	.66			14	.65
		15	.51			15	.73			15	.69
3	X	1	.77	8	X	1	.55	13	X	1	.55
		2	.51			2	.33			2	.70
		4	.65			3	.55			3	.61
		5	.40			4	.57			4	.44
		6	.50			5	.26			5	.65
		7	.71			6	.60			6	.31
		8	.61			7	.53			7	.62
		9	.44			9	.54			8	.33
		10	.04			10	.08			9	.29
		11	.67			11	.52			10	.04
		12	.54			12	.49			11	.58
		13	.80			13	.63			12	.39
		14	.71			14	.66			14	.37
		15	.73			15	.71			15	.38
4	X	1	.46	9	X	1	.60	14	X	1	.55
		2	.28			2	.40			2	.34
		3	.51			3	.61			3	.53
		5	.26			4	.56			4	.54
		6	.60			5	.35			5	.25
		7	.45			6	.51			6	.56
		8	.77			7	.59			7	.53
		9	.62			8	.66			8	.68
		10	.12			10	.09			9	.54
		11	.46			11	.54			10	.09
		12	.47			12	.44			11	.49
		13	.57			13	.65			12	.46
		14	.69			14	.60			13	.59
		15	.67			15	.65			15	.66
5	X	1	.68	10	X	1	.07	15	X	1	.61
		2	.77			2	.02			2	.51
		3	.73			3	.13			3	.59
		4	.55			4	.15			4	.52
		6	.40			5	.00			5	.37
		7	.77			6	.21			6	.47
		8	.46			7	.09			7	.65
		9	.39			8	.19			8	.60
		10	.05			9	.37			9	.44
		11	.57			11	.05			10	.06
		12	.39			12	.02			11	.52
		13	.60			13	.11			12	.40
		14	.53			14	.14			13	.62
		15	.52			15	.14			14	.56

sistent with visual approximations (Table 1). The mean PO values for a given seed parent (Table 2) ranged from 0.12 for clone #10 to 0.58 for clone #3. The indices varied

greatly among any one seed parent's pollinators. For instance, clone #3 had pollinator indices that ranged from 0.04 to 0.80.

Table 2. —PO values for all clones serving as both female and male parents.

Clone Number	Female		Male	
	mean	(min. - max.)	mean	(min. - max.)
1	.52	(.08 - .69)	.56	(.07 - .77)
2	.54	(.03 - .73)	.41	(.02 - .77)
3	.58	(.04 - .80)	.56	(.13 - .73)
4	.50	(.12 - .77)	.54	(.15 - .65)
5	.53	(.05 - .77)	.34	(.00 - .70)
6	.44	(.08 - .69)	.48	(.21 - .60)
7	.54	(.08 - .74)	.56	(.09 - .77)
8	.50	(.08 - .71)	.59	(.19 - .77)
9	.52	(.09 - .66)	.47	(.29 - .62)
10	.12	(.00 - .37)	.07	(.03 - .12)
11	.52	(.06 - .73)	.51	(.05 - .70)
12	.56	(.07 - .69)	.43	(.02 - .54)
13	.45	(.04 - .70)	.60	(.11 - .80)
14	.49	(.09 - .68)	.57	(.14 - .71)
15	.49	(.06 - .65)	.60	(.14 - .73)

For individual clones acting as pollinators, the average overlap with all female strobilus patterns ranged from 0.07 for clone #10 to 0.60 for clones #13 and #15 (Table 2). Ranges of pollinator index values varied from 0.75 for clone #2 to 0.09 for clone #10 (Table 2). Clearly, this orchard did not have synchronous flowering patterns.

Discussion and Conclusions

Management of seed orchards includes selecting clones for orchard establishment, selecting clones for roguing, evaluating seed crop quality, protecting the orchard from outside pollen, and evaluating the usefulness of controlled pollination or supplemental mass pollination. Having a measure of the flowering synchrony of each clone with the remainder of the clones in the orchard plays an important role in assessing the genetic value of the orchard crop. However, measuring and expressing phenological relationships is difficult, time consuming and the results are often ambiguous. The index presented in this study provides a simple, useful quantitative expression of phenological relationships among clones.

The average index value of all pollinators that contribute to a specific seed parent serves as a measure of the potential for foreign pollen to contaminate that parent's seed crop. The average index value of a given pollinator measured for all possible seed parents is an indicator of the contribution of that pollen parent to the seed crop. The index values of the $t(t-1)/2$ possible clone pairs are clear indicators of which clones are in flowering synchrony and which are not. Those that are not may be candidates for roguing or if they are of high genetic value, may be retained for supplemental mass pollination or other controlled pollination techniques. Also, flowering attributes might be used in conjunction with numbers of ramets or seed production in selection indices.

“Long-term, multi-year monitoring programs using an index of phenological overlap will provide a quantitative measure of the orchard's phenological stability. Young orchards or orchards of clones from diverse environments or

widely separated geographic locations can be expected to be phenologically unstable or in poor synchronization and hence to have low index values. However, as a seed orchard matures or as the asynchronous clones are removed from the orchard, the index values can be expected to increase and finally to stabilize at some maximum value. Supplemental mass pollination to ameliorate specific problems can be incorporated into the index calculation and will alleviate many of the problem areas. Non-targeted use of supplemental mass pollination may either have no effect on the index values or may aggravate the asynchronous conditions.

Annual weather patterns may cause changes in index values of some orchards and others may be found to be extremely stable despite changing environments. Overall, a tracking system of phenological stability that utilizes both the flowering patterns and frequency distributions of the individual clones' gamete contributions (GRIFFIN, 1984) is a good method of gaining an understanding of a particular orchard. It is also useful for evaluating the efficacy of cultural practices such as orchard cooling (EL-KASSABY, 1987) that are invoked to mitigate the effects of the flowering problems.

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