Evaluation of methods to estimate parental contributions for the calculation of genetic worth and effective population size for lodgepole pine seed orchards

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Summary

This report summarizes estimates of effective population size (Ne) and genetic worth for growth (GWg) for seven lodgepole pine seed orchard crops over 5 years. Ne and GWg estimates using survey-based female and male contributions are compared with estimates using parental-clone ramet proportions (PCRP) and parental-clone ramet proportions adjusted by the expected production based on average ramet age. It is shown that survey-based data are the most reliable up to about mean orchard age 9. After age 9, adjustments based on expected production by average ramet age also provide reliable estimates. Estimates using only PCRP are reliable only in older orchards under specific circumstances.

Recommendations are provided to guide orchard managers preparing parental-clone gametic contribution estimates for seedlot registration under the *Chief Forester Standards for Seed* Use dated November, 2004.

Introduction

This report provides an analysis of data on parental-clone contributions to lodgepole pine seedlots from seven orchards over 5 years, and evaluates requirements for surveys to meet seedlot registration under the *Chief Forester Standards for Seed* Use dated November, 2004 (the Standards). Recommendations are provided.

Technical Report 25 (TR25) (Woods, 2005) outlines methods for estimating contributions to orchard seedlots from parental clones. These methods form the primary basis for the generally accepted scientific methodology requirement set out in the Standards. Under current practice in BC, seed orchard managers use methods from TR25 to estimate gamete contributions from parental clones and these data are used to estimate seedlot effective population size (Ne) and genetic worth (GW) following the methods described in Woods et al. (1996).

Several methods are described in TR25 to estimate both female and male gamete contributions from parental clones. In BC orchards the most commonly used methods are F1 for female contribution estimates and M2 for male contribution estimates. Methods F1 is described as a survey-based count of the number of cones on all orchard ramets, and M2 is described as a survey of 50% of the ramets in an orchard with an estimate of the amount of pollen on each ramet surveyed. Funda et al. (2011) have demonstrated a high correlation between survey-based estimates of male and female gametic contribution and gametic contribution estimates based on DNA analysis. As most orchards are quite large (1000 to 6000 ramets), the method F1 is often modified for operational purposes and only 50% of the orchard ramets are surveyed using a structured and unbiased system (typically every second orchard row is surveyed). Method F1 referenced in this paper generally refers to a 50% sample of orchard ramets.

TR25 also describes a method M1 for orchards older than 15 years from propagation. This method estimates the male contribution as the proportional number of ramets in the orchard for each parental clone, with adjustments for crown volume. It is considered acceptable only for western redcedar, lodgepole pine, and western white pine orchards older than 15 years. Funda et al. (2011) describe a method M0 that estimates male contribution solely on the proportional number of ramets in the orchard for each parental clone.

Surveys to estimate female and male contributions by parental clone are a requirement for seedlot registration under the Standards and are currently considered a cost of management. In addition to meeting seedlot registration requirements, there are other benefits to having data on clonal contributions to seedlots, including knowledge of which clones are good producers for ongoing roguing decisions. The cost of parental-contribution surveys is, however, substantial in large orchards. As most lodgepole pine orchards are very large (up to 6500 ramets in BC), a survey of 50% of the ramets is a significant cost.

This report summarizes data collected from seven SelectSeed Ltd. lodgepole pine seed orchards over 5 crop years and presents comparisons of Ne and GW estimated using methods F1M2, F1M0, and using the parental clone ramet proportion (PCRP) for both female and male contribution estimates. In addition, as expected female and male contributions to a seedlot increase with ramet age, a fourth method is used whereby PCRP is adjusted based on the average ramet age for each parental clone and estimates of Ne and GWg are made using these age-adjusted estimates. This method is further defined below and is referred to as the parental clone expected production (PCEP).

The motivation for this analysis is to better understand options for estimating gametic contribution and to determine whether PCRP or PCEP are reasonable surrogates for the commonly used method F1M2.

Methods

Operational data from female and male gametic contribution surveys were compiled for the crop years 2010 to 2014 for the seven lodgepole pine orchards shown in table 1. The orchards used for this analysis were all initially planted from 2001 to 2005. Some ramets were propagated as early as 1999, but most propagation was done from 2001 to 2005. Fill planting continued through to 2014 in most orchards. The average ramet age among the seven orchards differs and the average number of ramets for a clone in each orchard may also differ. These age differences are discussed further below.

Table 1. Orchards used in this analysis.

Orch. #	Spp.	Zone	Elev.	Location	Average ramet-planting year
337	Pli	Nelson	Low	PRT Armstrong	2002
338	Pli	Thompson Okanagan	Low	PRT Armstrong	2003
237	Pli	Prince George	Low	Kettle River	2005
339	Pli	Thompson Okanagan	High	Tolko Eaglerock	2003
240	Pli	Bulkley Valley	Low	Sorrento	2004
241	Pli	Central Plateau	Low	Sorrento	2004
238	Pli	Central Plateau	Low	Kettle River	2004

Surveys of 50% of the ramets were conducted annually in all orchards by counting the number of cones (female method F1) or the number of pollen clusters (male method M2) on each ramet in every second orchard row. As set out in Woods (2005), the proportional female and male contributions to seedlots were calculated from survey data, and averaged by parental clone to estimate the proportional gamete contribution for parental-clone *i*, referred to as P_i. Effective population size (Ne) was then calculated as:

1 $$\mathrm{Ne} = \frac{1}{\sum_{i=1}^{n} \mathrm{P}_i^2}$$

where P_i is the proportional gamete contribution for parental clone *i*.

Genetic worth for growth (GWg) was calculated as the mean breeding value for growth across all parental clones, weighted by the proportional contribution of each clone to the seedlot (P_i):

2 $$\mathrm{GWg} = \sum_{i=1}^{n} P_i \, * BV_i$$

where BV_i is the breeding value for growth for parental clone *i*.

In a situation where each parental clone in the orchard contributes to the orchard seedlot exactly in proportion to the number of ramets in the orchard, *Pi* is estimated as the number of ramets from clone *i* (R_i) divided by the total number of ramets in the orchard across all clones *n*, as follows:

3 $$Pi = \frac{Ri}{\sum_{i=1}^{n} R_i}$$

With the PCRP method, identical male and female contributions are assigned to each parental clone, and this is evaluated relative to F1M2 for estimating both Ne and GWg.

Method F1M0 is mathematically intermediate between F1M2 and PCRP, as it uses the same female estimate as F1M2 and the same male estimate as PCRP. Therefore, Ne and GWg estimates using method F1M0 are expected to fall between estimates using the other two methods. Because of this, results for F1M0 are presented initially in Tables 4 and 5, but are not considered in most subsequent analysis and discussion.

Expected seed production from a ramet increases with ramet age. This age-production relationship is currently used in lodgepole pine species plans to predict future orchard seed production (Woods 2014) (Table 2). This generalized age-production relationship was used to refine predictions of gametic contributions from parental clones based on the average age of the ramets representing each clone in an orchard. Following this method, the average age of all ramets representing each parental clone in an orchard was determined for the years 2010 to 2014. The expected production from all ramets representing each parental clone was then calculated for each year using the age-production relationship in Table 2. This method of estimating age-adjusted parental contribution is referred to as the Parental Clone Expected Production (PCEP). Parental-clone contributions using PCEP were then used to estimate GWg and Ne. With the PCEP method, parental-clone contributions are estimated as:

4 $$\mathrm{AP}i = \mathrm{S}_i * \mathrm{R}_i \,/ \sum_{i=1}^{n} (\mathrm{S}_i * \mathrm{R}_i)$$

Where AP_i is the age-adjusted proportional contribution to a seedlot from parental clone *i* in an orchard with *n* clones,

S_i is the expected age-adjusted production per ramet for clone *i* based on the average age of ramets in the orchard representing clone *i* and using the per-ramet production expectation shown in Table 2, and

R_i is the number of ramets in an orchard from clone *i* .

Estimates of AP_i are substituted for P_i in formulae 1 and 2 above to estimate Ne and GWg, respectively.

Table 2. Lodgepole pine expected annual production in seedlings by ramet age. This generalized relationship is used in species plans developed for the Forest Genetics Council of BC (Woods 2014). Expected production is expressed in seedlings and considers sowing factors.

Ramet age (years)	1	2	3	4	5	6	7	8	9	10	11	12	13	14 +
Expected production (seedlings) (S_i)	0	0	0	10	65	180	300	450	650	775	900	1050	1300	1500

This method recognizes that orchard ramets are not all the same age. In addition, as breeding programs continually advance with higher-gain selections, it is common that later-propagated parental clones have a higher breeding value than the orchard average. This may result in over-estimates of GWg when the PCRP method is used, relative to F1M2. Female and male inputs for the four methods listed here are summarized in Table 3.

Table 3. Summary of methods used to estimate female and male parental-clone contributions (P_i).

Method	Female Pi estimate method	Male Pi estimate method
F1M2	Survey	Survey
F1M0	Survey	Ramet proportion by clone
PCRP	Ramet proportion by clone	Ramet proportion by clone
PCEP	Ramet proportion adjusted by age and expected production	Ramet proportion adjusted by age and expected production

Data were tested for statistical significance using a randomized block split-plot design with Method (Table 3) as the main-plot factor, Age from Planting as the split-plot factor, and an interaction between Method and Age. Type 3 tests of fixed effects were performed, and specific contrasts were tested at all ages between the F1M2 method and the PCRP and PCEP methods. Significance tests were not performed using production year as a split-plot factor, as this is less meaningful and less universally applicable than comparisons using average ramet age.

Results

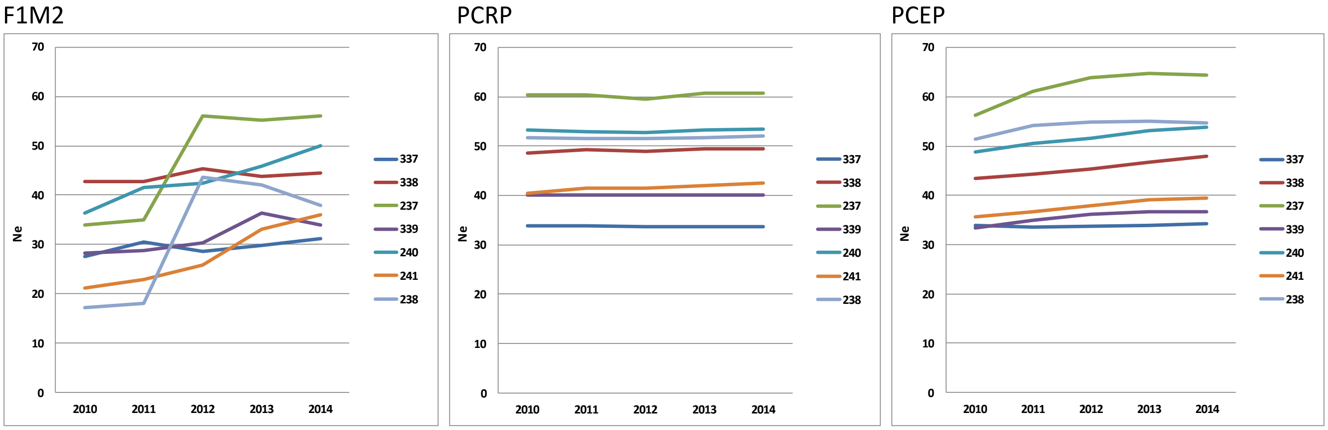
Effective population size shows a general increase from earlier to later crops using the survey method (F1M2). This increase with age is less evident for the PCEP method and, as expected, there is little change using the PCRP method, (Table 4 and Figure 1).

Table 4. Effective population size (Ne) by orchard, crop year, and method of estimating parental-clone proportional contribution[1].

			Ne by production year				
Orch. #	**Zone**	**Method**	2010	2011	2012	2013	2014
337	NE	F1M2	27	30	29	30	31
337	NE	F1M0	31	32	32	31	32
337	NE	PCRP	34	34	34	34	34
337	NE	PCEP	34	34	34	34	34
338	TO	F1M2	43	43	45	44	44
338	TO	F1M0	46	46	48	46	47
338	TO	PCRP	49	49	49	49	49
338	TO	PCEP	43	44	45	47	48
237	PG	F1M2	34	35	56	55	56
237	PG	F1M0	55	59	60	61	59
237	PG	PCRP	60	60	60	61	61
237	PG	PCEP	56	61	64	65	64
339	TO	F1M2	28	29	30	36	34
339	TO	F1M0	34	34	36	37	35
339	TO	PCRP	40	40	40	40	40
339	TO	PCEP	33	35	36	37	37
240	BV	F1M2	36	42	42	46	50
240	BV	F1M0	47	48	48	52	52
240	BV	PCRP	53	53	53	53	53
240	BV	PCEP	49	51	52	53	54
241	CP	F1M2	21	23	26	33	36
241	CP	F1M0	39	37	38	40	40
241	CP	PCRP	40	41	42	42	42
241	CP	PCEP	36	37	38	39	39
238	CP	F1M2	17	18	44	42	38
238	CP	F1M0	47	41	47	49	47
238	CP	PCRP	52	52	52	52	52
238	CP	PCEP	51	54	55	55	55

[1] Note that values may differ from those for registered seedlots in the Seed Planning and Registration System (SPAR), as supplemental mass pollination data were not considered here.

Figure 1. Ne for seven lodgepole pine seed orchards across 5 crop years calculated using the F1M2, PCRP, and PCEP methods. Data shown are from Table 4. F1M0 method excluded.

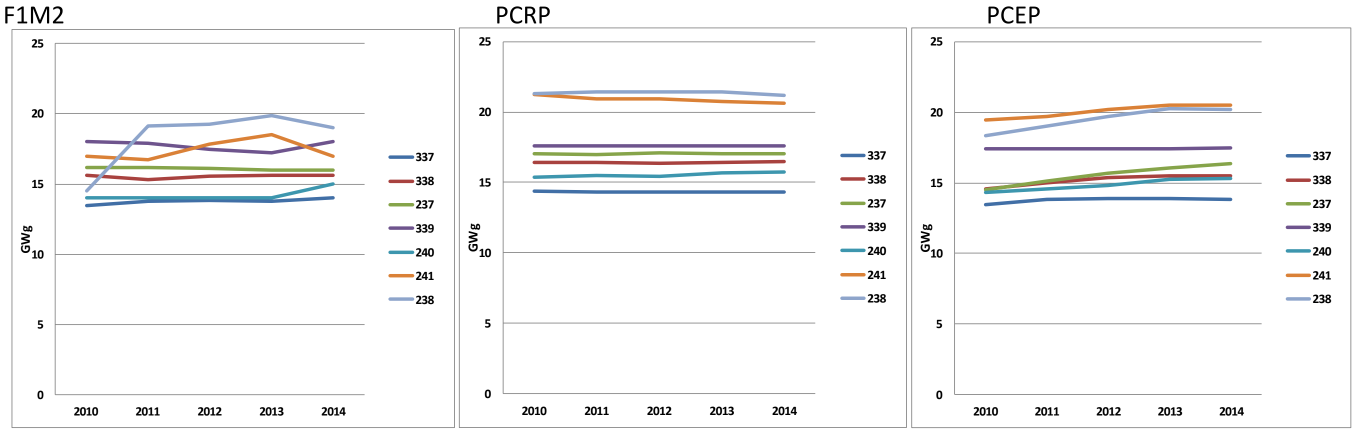


GWg values show a small increasing trend using the F1M2 method and the PCEP method for most orchards, while there is little change with crop year for the PCRP method (Table 5, Figure 2).

Table 5. Genetic worth for growth (GWg) by orchard, crop year, and method of estimating parental-clone proportional contribution.

			GWg by production year				
Orch. #	Zone	Method	2010	2011	2012	2013	2014
337	NE	F1M2	13	14	14	14	14
337	NE	F1M0	14	14	14	14	14
337	NE	PCRP	14	14	14	14	14
337	NE	PCEP	13	14	14	14	14
338	TO	F1M2	16	15	16	16	16
338	TO	F1M0	16	16	16	16	16
338	TO	PCRP	16	16	16	16	16
338	TO	PCEP	15	15	15	16	15
237	PG	F1M2	16	16	16	16	16
237	PG	F1M0	17	17	16	17	17
237	PG	PCRP	17	17	17	17	17
237	PG	PCEP	14	15	16	16	16
339	TO	F1M2	18	18	18	17	18
339	TO	F1M0	18	18	17	17	18
339	TO	PCRP	18	18	18	18	18
339	TO	PCEP	17	17	17	17	17
240	BV	F1M2	14	14	14	14	15
240	BV	F1M0	15	15	15	15	15
240	BV	PCRP	15	15	15	16	16
240	BV	PCEP	14	15	15	15	15
241	CP	F1M2	17	17	18	19	17
241	CP	F1M0	19	19	19	20	19
241	CP	PCRP	21	21	21	21	21
241	CP	PCEP	19	20	20	20	21
238	CP	F1M2	14	19	19	20	19
238	CP	F1M0	20	19	20	20	19
238	CP	PCRP	21	21	21	21	21
238	CP	PCEP	18	19	20	20	20

Figure 2. GWg for seven lodgepole pine seed orchards across 5 crop years calculated using the F1M2, PCRP, and PCEP methods. Data shown are from Tables 5. F1M0 method excluded.



The Ne and GWg data presented above are organized by crop year. However, the seven seed orchards analyzed differ in average ramet age by up to 3 years (Table 1). Although ramet age is considered in PCEP estimates of expected production at the clonal level, it is useful to show these by the average orchard ramet age from planting, as this is more meaningful to illustrate trends in Ne or GWg as orchards mature. For most of the orchards used in this analysis, higher breeding value second-generation selections were brought into the orchard population later than first-generation selections. This results in higher-gain clones tending to have younger ramets. Ne estimates are shown graphically in Figure 3, and GWg estimates are shown in Figure 4; both by average ramet age. Differences among Ne estimates are highly significant from ages 6 to 9 ($p<0.001$) for contrasts between estimates using F1M2 and both PCRP and PCEP. The significance level of these differences weakens at age 10, and by age 12 the differences are less strongly significant ($.005<p<.03$). Differences among GWg estimates for contrasts between the F1M2 and the PCRP method are significant ($p<0.05$) for ages with adequate sample representation (ages 7 through 11), however, contrasts between the F1M2 and PCEP method are not significant at any age.

Figure 3. Ne for seven lodgepole pine seed orchards across 5 crop years estimated using the F1M2, PCRP, and PCEP methods and organized by the average ramet age-from-planting in each orchard.

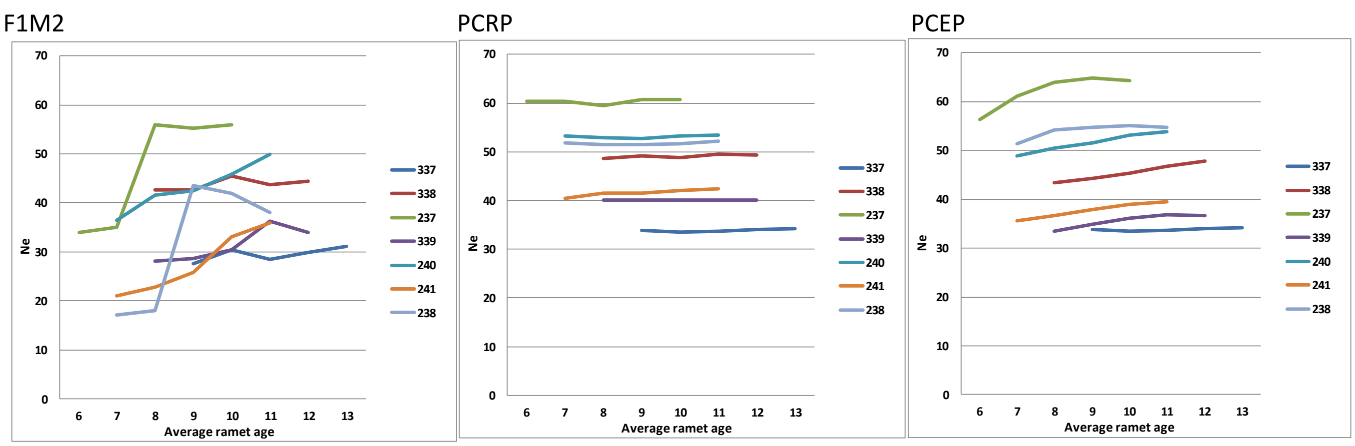
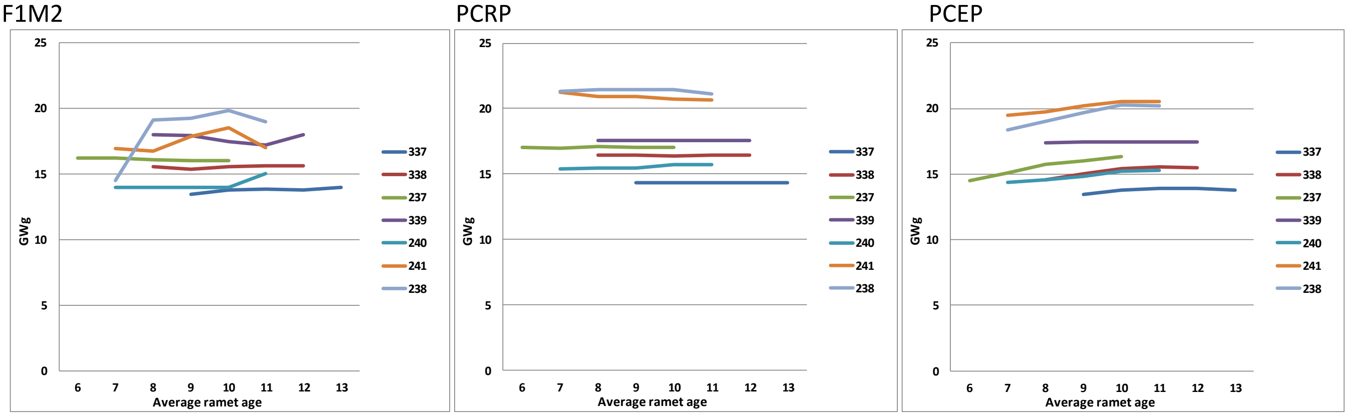


Figure 4. GWg for seven lodgepole pine seed orchards across 5 planting years estimated using the F1M2, PCRP, and PCEP methods and organized by the average ramet age-from-planting in each orchard.



Method F1M2 is currently the standard practice used in BC orchards for estimating parental gametic contributions. Expressing Ne and GWg estimates for PCRP and PCEP as a percentage of estimates using the F1M2 method provide a useful comparison on a standardized basis (Figures 5 and 6) (see appendix 1 for data tables). These percentage values also allow the calculation of an average across the seven orchards.

Figure 5. Ne for seven lodgepole pine seed orchards across 5 crop years calculated using the PCRP, and PCEP methods, expressed as a percentage of Ne calculated using the F1M2 method and organized by the average ramet age from planting in each orchard.

Ne as a percentage of PCRP / F1M2 **Ne as percentage of PCEP / F1M2**

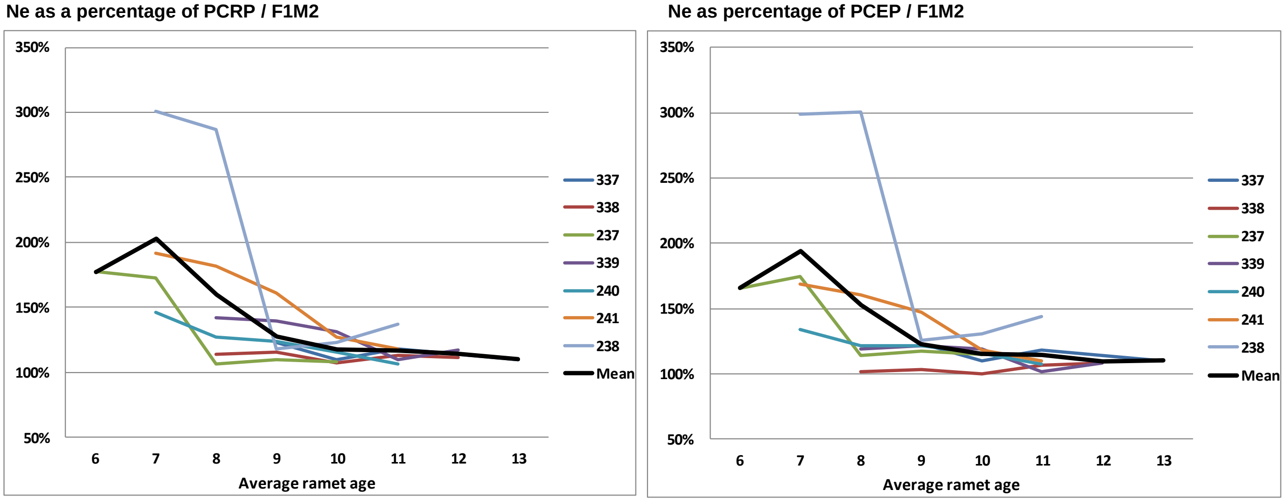
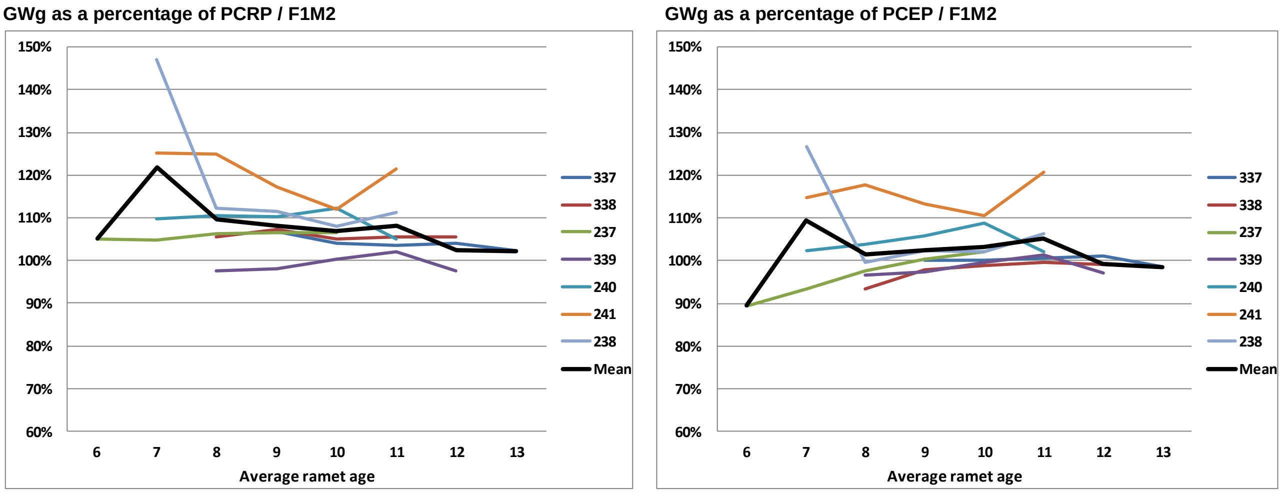


Figure 6. GWg for seven lodgepole pine seed orchards across 5 crop years calculated using the PCRP, and PCEP methods, expressed as a percentage of Ne calculated using the F1M2 method and organized by the average ramet age from planting in each orchard.



Discussion

Previous work by El-Kassaby et al. (1996), Funda et al. 2011, and orchard managers through operational surveys, has shown that clonal reproductive success is highly variable and that the proportional gametic contribution of orchard clones based on the number of ramets in a seed orchard may result in inaccurate estimates. This is observed for BC species such as interior spruce where very large crops can occur in mast years with little to no seed production in other years. For these species the variability among orchard parental clones may also be very high, with some clones producing very large crops while others have no or very small crops. This variability is recognized in TR25 and survey methods are included to estimate parental-clone contributions to a seedlot. Funda et al. (2011) demonstrate using DNA analysis that these survey methods provide a reasonably accurate estimate of actual parental-clone contributions.

With lodgepole pine, annual crop variability is observed to be substantially less than for some other conifer species in BC. Similarly, the variability among orchard clones is lower, although it is well documented in orchard parental contribution records that considerable clone-to-clone variation exists. As lodgepole pine observations show less variability than for other species, the question investigated here is whether Ne and GWg estimates using parental-clone ramet proportion (PCRP) or expected production for each parent clone based on both the number of ramets and the average age of the ramets (PCEP), are reasonably accurate and unbiased relative to survey-based estimates (F1M2).

Effective population size

Ne estimates using the F1M2 method, as expected, increase with average ramet age in each orchard. This increase is due to more parental clones coming into both male and female production as orchards age. Despite variable average ramet age for orchard clones, there is a trend in the orchards studied here for Ne estimates to stabilize when the average ramet age reaches 9 or 10 years (Figure 3). Ne estimates using the PCRP method are initially substantially higher than F1M2 estimates (Figure 5) with a large amount of variability. However, the F1M2 and PCRP estimates begin to converge by average ramet age 9 and are similar by age 11. The same trend is observed with PCEP estimates, although they converge somewhat sooner. Figure 5 also shows that the mean relative estimate of Ne across seven orchards using PCEP is closer to the F1M2 estimate than is the estimate using PCRP. This is expected, but the differences are small.

Under the Standards, Ne must exceed a minimum of 10 (Snetsinger 2004). For orchards investigated in this analysis, PCRP-estimated Ne ranged from 34 to 61, and PCEP-estimated Ne ranged from 33 to 65. F1M2-estimated Ne ranges from 17 to 56. By average ramet age 9, the lowest survey-based estimate of Ne for any orchard was 26, easily exceeding the minimum Ne of 10 in all years. The convergence of estimates using PCRP and PCEP with estimates using F1M2 surveys (Figure 5) suggests that the large majority of the clones in the orchard are contributing to seedlots by about average age 9. The purpose of a minimum Ne of 10 for seedlot registration under the Standards is to ensure that Crown land planting in BC is done with seedling populations that exceed a minimum threshold for genetic diversity. Therefore, the goal when estimating parental-clone contributions should be to ensure unbiased and reasonably accurate estimates that provide assurance that the minimum is exceeded. The data presented here show that survey-based parental contribution estimates are necessary at young orchard ages, but that these may be reliably replaced with PCEP or PCRP estimates as orchards age.

Genetic worth

Parental-clone variability in gametic contributions to a seedlot is not expected to impact GWg estimates unless there is a significant correlation between clonal breeding values and a clone’s propensity to produce pollen and cones (fecundity). In other analyses conducted with data from these orchards little or no such correlation is apparent, therefore, the expected GWg values calculated using F1M2 data are expected to be approximately equal at all ages to the GWg estimates using PCRP and PCEP. The variability and error in GWg estimates is expected to be higher at younger orchard ages, however, as fewer parental-clones are contributing to the seed crop. As orchards age and more parental-clones contribute, variability is expected to drop, with less error in GWg estimates. Therefore, the expectation for the methods discussed here is that the PCRP and PCEP estimates of GWg will cluster around the F1M2 estimates with reducing variability as orchards age to 8 or 9 years and more ramets begin production. Values shown in Figure 6 generally support these expectations.

There is, however, a trend for PCRP-based GWg estimates shown in Figure 6 to be higher than survey-based estimates. This is explained by the history of propagation and planting in all orchards used in this analysis, and in particular in orchards 238, 240, and 241. In all orchards, early propagation was limited by scion availability and the initial propagation utilized a large number of parental clones to achieve the ramet numbers necessary to meet orchard size needs. Some parental clones had lower breeding values than was preferred. Over subsequent years, advanced-generation selections and increased availability of scion material allowed propagation of new and replacement ramets using only higher-breeding-value clones. Therefore, younger ramets in the orchard have a higher average breeding value than older ramets. The PCRP method for estimating parental-clone contributions only considers the number of ramets. As younger ramets also have a higher average breeding value, PCRP-based estimates inflate GWg. This tendency is largely gone by average ramet age 11 or 12 in these orchards, but this illustrates an issue with PCRP-based estimates of genetic worth in multi-aged or advancing-front orchards where new higher-gain material is added over time. With an ongoing expectation that younger ramets will have higher breeding values, GWg estimates using PCRP will be over-estimated. This clear bias is problematic, as these estimates are used in timber supply analyses.

Estimates using the PCEP method show little to no bias compared to estimates using the PCRP method. As both ramet number per parental clone and ramet production with age are considered, parental clones with younger ramets are given less weight when developing proportional contribution estimates. In Figure 6 the clustering of values both above and below the level expected with perfect congruence between PCEP and F1M2 methods (100% line), is illustrated. In addition, there is no evidence of bias towards higher or lower GWg estimates.

This analysis considered GWg, but the estimation of genetic worth for other traits such as wood density or pest resistance is expected to follow the same trends. Secondary traits, such as wood density in many BC programs, are often weighted in selection procedures to prevent a drop in the population average. This results in little average difference in density breeding values between early and later selections in breeding programs and a corresponding small difference is expected in seedlot genetic worth for density (GWd) as an orchard ages. The recommendations made here for GWg could also apply to secondary traits such as GWd.

Recommendations

Seed orchard operations are businesses that continually seek operational efficiencies. For this reason, the methodology used to estimate parental contributions to seedlots was reviewed here to better understand if the current practice of estimating parental-clone contributions to a seedlot using annual cone and pollen contribution surveys could be modified in some circumstances for lodgepole pine. Results show that Ne estimates were made with reasonable accuracy after orchard average age 9 using both the PCRP and the PCEP method. For GWg, however, the PCRP method resulted in an upward bias in GWg estimates due to the common practice of replacing or adding orchard ramets from higher breeding value parental clones. The PCEP method does not show this bias and after orchard age 9 provides a reliable estimate of genetic worth.

Several methods or combinations of methods could be used to estimate parental-clone gamete contributions. Excluding DNA analysis techniques, which are too costly for operational estimates of Ne and genetic worth, some combination of survey, PCRP and PCEP for both female and male contribution could be considered. Also important is the average orchard age at which each method is used.

The following recommendation is made for estimating lodgepole pine parental-clone gamete contributions to a seedlot for registration purposes under the Standards.

Use method F1M2 unless one of the following circumstances applies:

1. For orchards with an average ramet age greater than 9 years from planting and where fewer than 25% of the ramets are less than 8 years from planting:

    Use of the F1M2 or the PCEP method for estimating gametic contributions for parental clones is acceptable. A combination of a survey for cones (F1) and method PCEP for pollen, or a survey for pollen (M2) and method PCEP for cones is also acceptable.

2. For orchards with an average age from planting of 15 years or more and where less than 25% of the ramets are younger than 11 years:

    Use of the F1M2, PCEP, or PCRP method for both female and male parental-clone contribution estimates is acceptable. Any combination of the three methods for cone and pollen parental-clone contribution estimates may be used.

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Appendix 1

Table 6. Ne calculated using the PCRP and PCEP methods expressed as a percentage of Ne calculated using method F1M2 for seven lodgepole pine seed orchards. Values are shown by the average age from planting of ramets in each orchard.

					Ne using PCRP as % Ne using F1M2 by average orchard age								Ne using PCEP as % Ne using F1M2 by average orchard age							
Orch. #	Spp.	Zone	Elev.	Location	6	7	8	9	10	11	12	13	6	7	8	9	10	11	12	13
337	Pli	NE	Low	PRT				123%	110%	118%	114%	110%				123%	110%	118%	114%	110%
338	Pli	TO	Low	PRT			114%	115%	108%	113%	111%				102%	104%	100%	107%	108%	
237	Pli	PG	Low	KRSO	177%	173%	106%	110%	108%				166%	174%	114%	117%	115%			
339	Pli	TO	High	Tolko			142%	139%	132%	110%	118%				119%	122%	119%	101%	108%	
240	Pli	BV	Low	SORR		146%	127%	124%	116%	107%				134%	121%	122%	116%	108%		
241	Pli	CP	Low	SORR		192%	182%	161%	127%	118%				169%	161%	147%	118%	109%		
238	Pli	CP	Low	KRSO		301%	286%	118%	123%	137%				299%	301%	126%	131%	144%		
				Mean	177%	203%	160%	127%	118%	117%	114%	110%	166%	194%	153%	123%	116%	115%	110%	110%

Table 7. GWg calculated using the PCRP and PCEP methods expressed as a percentage of GWg calculated using method F1M2 for seven lodgepole pine seed orchards and organized by the average age from planting of ramets in each orchard.

					GWg using PCRP as % GWg using F1M2 by average orchard age								GWg using PCEP as % GWg using F1M2 by average orchard age							
Orch. #	Spp.	Zone	Elev.	Location	6	7	8	9	10	11	12	13	6	7	8	9	10	11	12	13
337	Pli	NE	Low	PRT				107%	104%	103%	104%	102%				100%	100%	100%	101%	99%
338	Pli	TO	Low	PRT			105%	107%	105%	105%	106%				93%	98%	99%	100%	99%	
237	Pli	PG	Low	KRSO	105%	105%	106%	107%	107%				89%	93%	98%	100%	102%			
339	Pli	TO	High	Tolko			98%	98%	100%	102%	98%				97%	97%	100%	101%	97%	
240	Pli	BV	Low	SORR		110%	111%	110%	112%	105%				102%	104%	106%	109%	102%		
241	Pli	CP	Low	SORR		125%	125%	117%	112%	121%				115%	118%	113%	111%	121%		
238	Pli	CP	Low	KRSO		147%	112%	111%	108%	111%				127%	99%	102%	102%	106%		
				Mean	105%	122%	110%	108%	107%	108%	102%	102%	89%	109%	101%	102%	103%	105%	99%	99%

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