Effect of Sampling Status and Adjustment for Heterogeneous Variance on Bias in Bull Evaluations

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ABSTRACT

Holstein bulls were assigned to sampling categories (AI stud, AI nonstud, or non-AI) based on bull code, controller number, and age at semen distribution. The AI stud bulls were sampled through traditional progeny-testing programs of 13 AI organizations; AI nonstud bulls had AI semen collection reported by another organization or by multiple organizations. The non-AI bulls had no reported AI semen collection. Actual daughter yield deviations for these three groups of bulls were compared with expected performance (parent average) to provide an indication of whether evaluations were free from bias for daughter yield deviations. Mean difference of daughter yield deviation from parent average was close to 0 kg for animal model evaluations of all 22,930 bulls but was positively biased by 46 kg of milk for AI nonstud bulls. Mean PTA and reliabilities for parents were highest for AI stud bulls and lowest for non-AI bulls. The AI stud bulls varied least and were intermediate for mean management, approximated as mean daughter yield minus bull PTA. Management was highest for AI nonstud bulls, which suggested that adjustment for heterogeneous variance might reduce bias. However, the effect of this adjustment on mean difference of daughter yield deviation from parent average was small.
(**Key words**: bias, heterogeneous variance, sampling status, evaluation adjustment)

Abbreviation key: **DYD** = daughter yield deviation, **MCC** = Modified Contemporary Comparison, **NAAB** = National Association of Animal Breeders, **PA** = parent average, **REL** = reliability.

INTRODUCTION

During recent years, a commonly discussed topic relating to US genetic evaluations has been the possible overestimation of evaluations for bulls sampled outside typical AI organizations. Although considerable uneasiness has been expressed about non-AI evaluations, some of the truly outstanding bulls were discovered through non-AI sampling. Environmental correlation (interaction of herd and sire) has been considered for USDA genetic evaluations since the herdmate comparison (10). Accounting for environmental correlation was improved with the Modified Contemporary Comparison (MCC) (6, 7) and continues with the animal model (13). Presence of this random effect in a sire or animal model limits the impact of a large number of daughters from a single herd.

Cassell et al. (2) reported that herdmate comparison evaluations for milk yield for Holstein bulls with limited sampling were inflated by 119 kg compared with evaluations for bulls with multiherd sampling. They showed that nearly half of that bias (50 kg) would not have been included had the bulls been grouped using pedigree information as with the MCC. Norman et al. (9) documented that non-AI bulls had not been overestimated as a group with the MCC at the time they entered AI service in 1975 through 1978. However, later studies (5, 8) that compared early (non-AI) and latest (AI) MCC bull evaluations concluded that early evaluations were overestimated, especially for bulls born after 1975.

The general industry opinion is that some of the high ranking bulls in AI service based on non-AI sampling have positively biased evalu-

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ations. However, data are too few to determine whether evaluations are overestimated for non-AI-sampled bulls that are selected and enter AI service based on animal model information. Daughter yield deviation (**DYD**) could be compared with parent average (**PA**) to determine whether non-AI bulls are overevaluated. A higher DYD than expected from PA for a group of bulls would suggest selective treatment of daughters, positively biased DYD, and inflated PTA.

Many daughters of bulls sampled outside typical AI organizations are from herds with high phenotypic yield, which is positively correlated with herd phenotypic and genetic variances (12). Bulls of above average genetic merit and with a large percentage of daughters in herds with high variances generally will be overevaluated if variance levels are not considered (1). Adjustment for heterogeneous variance that was implemented by USDA during 1991 (14) reduced deviations in these high variance herds and may have reduced bias in these bulls' evaluations.

The purposes of this study were to compare DYD milk with PA for bulls in different sampling categories and to determine the effect of adjustment for heterogeneous variance on reducing evaluation bias.

MATERIALS AND METHODS

Data were July 1990 USDA-DHIA genetic evaluations for milk yield for 22,930 Holstein bulls. Only bulls with birth years of 1975 or later, with at least 10 evaluated daughters, with reliabilities (**REL**) of at least 50%, and with PA REL of at least 25% were included. Bulls with Canadian controllers or without a US registration number were excluded.

A bull was considered to be AI affiliated if he had a bull code number reported through the National Association of Animal Breeders (**NAAB**). Bulls without an NAAB bull code number were assigned non-AI sampling status and considered to have been sampled through natural service (although semen possibly may have been collected and used but not reported through NAAB). The AI-affiliated bulls were separated into two sampling classes: AI stud and AI nonstud.

Bulls that were classified as AI stud 1) were from 13 AI organizations, 2) had their semen release date before they were 40 mo old as reported through NAAB, and 3) had only one NAAB bull code number, which corresponded to the reported NAAB controller number. For this study, controllers 3 and 15 were combined with 8, and controller 17 was combined with 21.

All other AI-affiliated bulls were assigned to the AI nonstud group. A few bulls classified as AI nonstud in this study were bulls that entered regular AI service after being sampled in circumstances other than AI and as defined in other studies (2, 3, 5, 9). Some of those non-AI bulls had semen collected and should have been in the AI nonstud group, but the collection was not reported to NAAB. Such bulls that later entered regular AI service were properly classified as AI nonstud, but the others were classified as non-AI. Thus, a bull with semen collected but not reported tended to be classified as AI nonstud only if his daughters' performance was favorable compared with that expected and to be classified as non-AI if performance was modest or negative. Programs of the 13 AI organizations that resulted in a bull receiving an additional bull code number would cause that bull to be classified as AI nonstud even though sampling was managed by a disinterested party. A few individual bulls may be classified incorrectly because of unusual circumstances, but their impact on correct interpretation of results would be small. Four subsets of AI nonstud bulls were defined for determining differences between DYD and PA for milk yield.

In 1990, NAAB added a sampling code to its crossreference program to identify how bulls were sampled (11). Bulls with semen distributed to at least 40 herds were designated as 1) stud sampled (code S) if they were sampled by an organization that owned or leased the bull and that both processed and marketed semen or else as 2) multiherd sampled (code M). Other bulls reported to NAAB and any bull not reported as S or M by 3 yr of age was designated as other sampling (O code). Bulls not reported to NAAB had no code assigned. A crosstabulation of bulls by sampling code and sampling status category is in Table 1 based on data from January 1993 evaluations. Although assigned NAAB codes generally corresponded with sampling status categories (Table 1), the recent NAAB implementation of sampling codes resulted in no assigned code for most of the bulls in this study. In addition, assignment of NAAB sampling codes for some (generally older) bulls was unreliable. Therefore, NAAB sampling codes were not used to define sampling status in this study.

Bulls in each sampling status group were compared for daughter performance (DYD) for milk yield relative to expected yield (PA): DYD − PA. Few bulls in the non-AI group were sampled with the intention of developing a bull for which AI organizations would have a marketing interest. Such bulls had semen collection that was not reported. Thus, mean DYD − PA was not expected to be large for the non-AI group. For AI stud bulls, DYD − PA also was expected to be small, because these bulls have a large number of daughters in many diverse herds, and, therefore, environmental effects (primarily feeding and care) are randomized rather well. Mean DYD − PA for the AI nonstud bulls was expected to be largest because of possible bias, and mean DYD − PA was computed for subsets of AI nonstud bulls to provide further information.

Because the study's objective was to determine differences in apparent bias estimated as DYD − PA according to sampling group, the most accurate PA was needed. Use of PA from the same semiannual evaluation as DYD ensured that the PA was the most current available but also was affected by son DYD, an undesirable situation. However, using the PA prior to a son's evaluation would have excluded the most current data, and such PA would have been calculated based on information from the previous evaluation system (the MCC) rather than from the animal model. Although DYD − PA may be closer to 0 than from an independent PA that excluded son merit, differences among sampling groups should still be observable even if smaller.

TABLE 1. Numbers of bulls for sampling status and National Association of Animal Breeders (NAAB) sampling code reported for January 1993 evaluations.

Sampling status	NAAB Sampling code[1]			
	S	M	O	None
AI Stud	1280	6	51	6425
AI Nonstud	44	212	533	2000
Non-AI	0	0	0	12,379

[1]S = Stud sampled, M = multiherd sampled, and O = other sampling.

The full model for analysis of variance for DYD − PA included continuous variables of REL and birth year and a classification variable of sampling status. Solutions for AI stud bulls were set to 0. Analyses were conducted for evaluations released in July 1990 and for evaluations based on data for July 1990 evaluations but also adjusted for heterogeneous variance (14). Management, as approximated by mean daughter yield minus bull PTA, also was examined as an indicator of bulls likely to be affected by the heterogeneous variance adjustment.

RESULTS AND DISCUSSION

Overall number of bulls sampled by birth year (Table 2) was fairly consistent. Numbers of sampled AI stud and AI nonstud bulls increased over time, but number of sampled non-AI bulls decreased. Norman et al. (9) reported an increasing number of bulls entering AI service from 1975 through 1983 (birth years during the 1970s), but the percentage of those bulls sampled through natural service began to decrease during the 1980s. The shift from non-AI to AI sampling is a positive step for disease prevention, for dairy producer safety, and for genetic progress. Number of AI-affiliated bulls has increased from 1976 to 1984 by 50% for AI stud bulls and by 56% for AI nonstud bulls. Cassell et al. (3) also reported increasing numbers of AI-sampled bulls (corresponding to AI stud bulls in this study) through 1981 but decreasing numbers of non-AI bulls (corresponding to AI nonstud bulls). Differences from the study by Cassell et al. (3) resulted from different definitions of sampling categories and different restrictions placed on the bulls included in the studies.

Means and standard deviations of the July 1990 evaluations for milk yield for the 22,930 bulls are presented in Table 3 by sampling status. Mean birth year for AI-affiliated bulls was more recent than for non-AI bulls. Other studies (3, 5) also have reported that AI bulls sampled in traditional programs generally were younger than other AI bulls.

Means for PA, sire and dam PTA, and dam REL (Table 3) were highest for AI stud bulls

TABLE 2. Numbers of bulls for sampling status and birth year.

Birth year	Sampling status			All bulls
	AI Stud	AI Nonstud	Non-AI	
1975	474	125	1351	1950
1976	527	209	1528	2264
1977	535	205	1587	2327
1978	550	190	1406	2146
1979	730	252	1379	2361
1980	830	331	1265	2426
1981	832	336	1151	2319
1982	861	308	1097	2266
1983	859	326	891	2076
1984	795	327	557	1679
1985	746	175	166	1087
1986	23	5	1	29
All years	7762	2789	12,379	22,930

and lowest for non-AI bulls. Sire PTA for milk yield averaged 267 kg more than dam PTA; differences were less for AI stud (204 kg) and AI nonstud (252 kg) bulls and greater (310 kg) for non-AI bulls. Sire and dam PTA had similar variation for all sampling categories except dam PTA for AI nonstud bulls, which were more variable. Sire REL was extremely high (99%) for all sampling categories, and dam REL was quite high even for non-AI bulls (61%). Means for bull PTA, REL, and DYD also were highest for AI stud bulls and lowest for non-AI bulls.

Mean DYD – PA (Table 3) was –9 kg for AI stud bulls. Because AI organizations have no incentive for preferential treatment of bull daughters, DYD for AI stud bulls are expected to be relatively unbiased. Therefore, the negative mean for DYD – PA suggests that PA were inflated, likely because of inflated dam PTA. Ferris et al. (4) reported an increasing bias in MCC bull-dam evaluations over time.

TABLE 3. Means and standard deviations of July 1990 evaluations of milk yield for 22,930 Holstein bulls for sampling status.

Trait	Sampling status						All bulls	
	AI Stud		AI Nonstud		Non-AI			
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Birth year	1981	3	1981	3	1979	3	1980	3
PA,[1] kg	133	290	69	293	−198	272	−53	322
Sire PTA, kg	235	339	195	338	−43	338	80	364
Dam PTA, kg	31	341	−57	368	−353	334	−187	386
Sire REL,[2] %	99	1	99	3	99	4	99	3
Dam REL, %	70	9	67	10	61	8	65	10
PTA, kg	131	341	99	337	−193	296	−48	354
REL, %	80	9	69	11	56	6	66	14
DYD,[3] kg	125	367	106	376	−191	324	−48	379
DYD – PA, kg	−9	237	37	235	7	177	5	207
Management,[4] kg	8405	444	8867	688	8256	825	8380	727

[1]Parent average.

[2]Reliability.

[3]Daughter yield deviation.

[4]Daughter mean yield – bull PTA.

Although the USDA animal model system allows progeny information to contribute to dam evaluations to reduce bias, preferential treatment of cow families, especially those with many embryo transfer daughters, still will bias evaluations. The mean DYD – PA of 37 kg for AI nonstud bulls suggested that DYD were inflated or biased upward for these bulls. Inflation of PTA for dams of AI nonstud bulls probably was similar to that for AI stud bulldams. Therefore, estimated mean effect of preferential treatment for AI nonstud bulls was 46 kg (37 + 9). Mean DYD – PA was 7 kg for non-AI bulls, which suggests little preferential care of their daughters.

The estimate of 46 kg of bias for AI nonstud bulls may be conservative. Older bulls that entered a regular AI program based on positively biased evaluations from early daughters had that apparent bias diluted by later, unbiased data. A second reason for the conservative estimate of bias is that some bulls included as AI nonstud were sampled by organizations that collected semen and conducted progeny testing under an arrangement with one of the full-service AI organizations. Those bulls would be expected to have no more bias than AI stud bulls. Also, a bull that may have been sampled by 1 of the 13 AI organizations and then obtained by another of the 13 would be included as AI nonstud. However, bulls with semen collected but not reported were in the AI nonstud category only if they were selected by an AI organization, generally because of a high PTA, which would also suggest a favorable DYD – PA. Mean DYD – PA was +165 kg for 154 AI nonstud bulls that had 1 of the 13 AI organizations as controller, a controller number matching the single bull code number, and semen released at ⩾40 mo of age. Mean DYD – PA was +192 kg for 53 AI nonstud bulls with multiple bull code numbers and semen released at ⩾40 mo of age. These groups of bulls were expected to have positive DYD – PA, at least until their evaluations included later daughters. Bulls with semen reported as released when they were <40 mo of age were more numerous; 648 such bulls with 1 of the 13 controllers (but a different or multiple bull code numbers) had mean DYD – PA of 60 kg milk, and the 1934 bulls without 1 of the 13 controllers had mean DYD – PA of 14 kg. Results for these four subsets are presented because the AI nonstud bulls were a varied population. Bulls with semen released at a young age had a smaller DYD – PA than did bulls with semen released when older. These older bulls may have biased DYD as well as truly superior DYD, and further study is required to distinguish between them.

Mean for management (Table 3) was highest for AI nonstud bulls and lowest for non-AI bulls. The relatively low standard deviation for management for AI stud bulls suggests that the herds in which those bulls were sampled were more uniform (less extreme) than for other sampling categories. The high mean for management for AI nonstud bulls is consistent with the higher yield and residual variance suspected for herds in which these bulls are sampled. Standard deviation for management was largest for the non-AI group, likely because non-AI bulls often are sampled in only one or two herds; however, fewer progeny also may be partly responsible.

Means and standard deviations for July 1990 evaluations adjusted for heterogeneous variance are in Table 4. For all traits and sampling categories, means were similar to

TABLE 4. Means and standard deviations of July 1990 evaluations of milk yield adjusted for heterogeneous variance by sampling status.

Adjusted trait	Sampling status						All bulls	
	AI Stud		AI Nonstud		Non-AI			
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
PA,[1] kg	138	289	68	293	−202	285	−54	329
PTA, kg	136	351	98	336	−198	310	−49	366
DYD,[2] kg	130	383	106	373	−197	341	−49	393
DYD − PA, kg	−8	248	38	232	5	186	5	215

[1]Parent average.

[2]Daughter yield deviation.

those in Table 3, which indicates that the adjustment had little effect on them. However, the difference between AI stud and non-AI in means for PA, PTA, and DYD did increase slightly, and standard deviations for these traits generally increased. Although adjustment for heterogeneous variance increased differences among bulls, the hypothesized reduction in evaluation bias for AI nonstud bulls from implementation of this adjustment was not observed. Adjustment for heterogeneous variance in the USDA animal model system (14) considers both residual and genetic variances. Although deviation of standardized lactation yield is reduced for high variance herds, this deviation is afforded more weight because of the higher heritability assumed for those herds. Thus, the impact of the adjustment is less than for systems in which only residual variance is considered. Correlations between PA, DYD, and PTA with and without the adjustment were .995 and higher; for individual bulls, maximum absolute changes because of adjustment were 155 kg for PA, 288 kg for DYD, and 191 kg for PTA.

Least squares solutions (Table 5) from analysis of variance for DYD − PA for AI nonstud and non-AI bulls differed significantly ($P < .01$) from solutions for AI stud bulls, regardless of adjustment for heterogeneous variance. Effects of birth year and REL were both significant ($P < .01$) and similar to the full model for both unadjusted and adjusted evaluations, although effect of birth year was larger for adjusted evaluations.

Results from the full model were affected by confounding among variables. As shown in Table 3, the three sampling categories differed in means for birth year and REL. However, solutions for the full model (Table 5) were equal for AI nonstud and non-AI bulls, a result of confounding primarily because of lower REL for non-AI bulls. A higher DYD − PA was associated with younger bulls (later birth year) and with bulls having higher REL. Bulls with high DYD − PA are more likely to be returned to service and to achieve higher REL. Although effects for birth year and REL were significant ($P < .01$) for the full model, those effects and sampling category contributed relatively little to explaining variation in DYD − PA as shown by the low R^2 (1%) for unadjusted and adjusted evaluations. Excluding either birth year or REL from the model showed

TABLE 5. Least squares solutions for sampling status categories, estimates of birth year and reliability (REL) effects, and R^2 for model and data analyzed for variance of daughter yield deviation minus parent average.

Data and sampling category included	Model effects included	Sampling status solutions[1] AI Stud	AI Nonstud	Non-AI	Birth year	REL	R^2
July 1990 evaluations		(kg)			(kg/yr)	(kg/%)	(%)
All	All	0	67**	67**	1.2**	2.1**	1.0
	All − REL	0	45**	15**	−.4	. . .	.4
	All − birth year	0	65**	62**	. . .	1.9**	1.0
	Sampling status	0	45**	15**	. . .	. . .	.4
AI Stud	All	. . .	. . .	. . .	2.3*	5.0**	2.9
AI Nonstud	All	. . .	. . .	. . .	2.5	2.2**	1.1
Non-AI	All	. . .	. . .	. . .	1.6*	−1.0**	.2
July 1990 evaluations adjusted for heterogeneous variance							
All	All	0	69**	69**	2.7**	2.2**	1.0
	All − REL	0	46*	14**	1.0*	. . .	.4
	All − birth year	0	66**	59**	. . .	1.9**	.9
	Sampling status	0	46**	13**	. . .	. . .	.4
AI Stud	All	. . .	. . .	. . .	5.4**	5.4**	2.9
AI Nonstud	All	. . .	. . .	. . .	3.0	2.2**	1.0
Non-AI	All	. . .	. . .	. . .	2.3**	−1.0	.3

[1]Sampling status solutions and significance are relative to AI-stud group.

*$P < .05$.

**$P < .01$.

that REL was much more important than birth year for explaining variation.

For both unadjusted and adjusted evaluations, analyses within sampling categories (Table 5) showed that effects of birth year and REL were significant ($P < .05$) except for birth year for AI nonstud bulls. Birth year and REL effects were positive within sampling categories except for non-AI bulls. For those bulls, higher DYD – PA was associated with lower REL.

Adjustment for heterogeneous variance had little effect on R^2 for each model or for each sampling category. For analyses within sampling categories, R^2 were highest for AI stud bulls and lowest for non-AI bulls. Perhaps birth year and REL explained more variation in DYD – PA for AI stud bulls because their sampling conditions were more uniform.

In general, birth year and REL effects were not large; for example, a difference of 2 kg between DYD and PA for a 1-yr difference in birth year or a 1% change in REL is of marginal practical importance. Data for means were sufficient to show differences in DYD – PA among sampling categories. Tests of significance were conducted merely to determine possible explanations for those differences.

The most consistent and potentially important result is that considerable variation in DYD – PA could not be accounted for by sampling status, birth year, or REL. Although bias (DYD – PA $\neq$ 0) occurred for AI nonstud bulls, the low R^2 for all sampling categories indicated that considerable variation existed for DYD – PA among bulls within category because of Mendelian sampling and because of finite numbers of daughters. Thus, although the bias for AI nonstud bulls has been shown, the evidence is clearly insufficient to assume that all evaluations of such bulls are overestimated.

Figure 1 shows a minimal trend of DYD – PA by birth year of bull. Mean DYD – PA tended to increase slightly over time for non-AI bulls and to decrease for AI stud bulls. The reason for the large negative DYD – PA for AI stud bulls born during 1985 is not known. Meinert and Pearson (5) found that, on average, the first evaluation of an AI-sampled bull was lower than subsequent evaluations. No trend for DYD – PA was found for AI nonstud bulls, which is in contrast to the results of other studies (5, 8) that showed a change in bias over time for bulls entering AI service from other than traditional sampling programs. However, the bulls considered in those studies were only a portion of the bulls included in this study's AI nonstud category, and a different indicator of bias was used (change in evaluation rather than difference from PA).

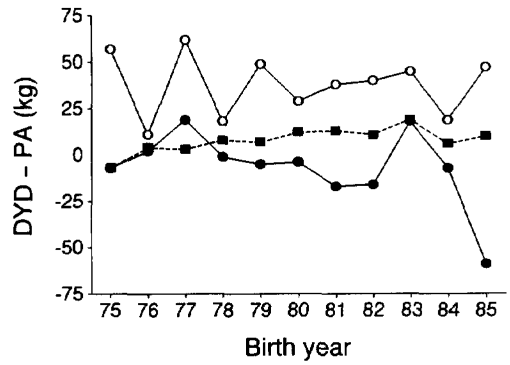

Figure 1. Mean daughter yield deviation minus parent average (DYD – PA) of milk yield for bull birth year (1975 to 1985) and sampling status category: AI stud (●), AI nonstud (○), non-AI (■).

One reason for studying mean DYD – PA by year was to determine whether a change was noticeable when bulls returned to service. According to the mean number of herds per bull (not reported), mean birth year for bulls that received widespread use was 1980 for AI stud bulls but 1977 for AI nonstud bulls. Thus, decisions on returning a progeny-tested bull to AI service were made at younger ages for AI stud bulls than for AI nonstud bulls. Meinert and Pearson (5) reported that the mean age of bulls that reached a Repeatability of .90 was 9.7 yr for AI-sampled bulls and 10.8 yr for non-AI-bulls. No pattern suggested a change in DYD – PA for bulls too young to have second crop daughters compared with older bulls. An analysis of mean annual DYD according to bull age would be required to explore that situation fully.

CONCLUSIONS

Assignment of bulls to sampling categories based on NAAB bull code, controller number, and age at semen distribution was useful for this study, but future studies will have access to NAAB sampling codes. Additional data on AI nonstud bulls with widespread use based on their animal model evaluations also will become available so that stability of their evaluations can be examined further.

Comparison of DYD and PA from animal model evaluations showed that daughter performance for AI nonstud bulls is positively biased by 46 kg of milk. Most AI nonstud bulls do not enter AI marketing. Those that do would have positive DYD – PA because the purpose of progeny testing is to identify animals that receive a favorable sample of genes. Whether the apparent bias in the AI nonstud group is representative of bulls selected to enter active AI service, whether bulls with the largest biases are selected rather than those with the most favorable gene samples, or whether AI sire analysts are able to discern the level of bias in a bull's evaluation is not known.

For AI stud bulls, DYD – PA of –9 kg of milk suggested that PA of those bulls were slightly inflated. Although the direction of that bias was expected, the size was smaller, especially considering industry concern about inflation of evaluations for elite cows. As expected, mean parent PTA and REL were highest for AI stud bulls and lowest for non-AI bulls. The AI stud bulls varied least and were intermediate in mean management (daughter mean yield – bull PTA). Management was highest for AI nonstud bulls, which suggested that adjustment for heterogeneous variance might reduce bias. However, effect of this adjustment on mean DYD – PA was small.

Analysis of variance generally suggested slightly larger DYD – PA for younger bulls and bulls with higher REL. However, effect of birth year was not significant for AI nonstud bulls, those bulls of most interest in this study. Low R^2 showed that, although AI nonstud bulls appeared to be positively biased for DYD, variation unaccounted for by sampling status, year, or REL was considerable. Therefore, AI nonstud bulls should be considered cautiously for matings but not dismissed.

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