Flock Improvement using Selection. Part 1: Calculations without weights – by Karen Gerhart, Howling Oak Ranch St Croix Sheep

The usefulness of the St Croix breed is partly due to the moderately high prolificacy, early age at first breeding, and ability to breed year round shown by the St Croix ewe. Several methods for maintaining these important traits while also improving productivity of the flock as a whole are outlined below. All were derived from the Sheep Production Handbook (SPH, 1997) and have been used in our flock.

Flock productivity is influenced by many traits, only some of which respond well to selection. Low ewe fertility (number of ewes lambing) and poor lamb survival are generally indications of a problem in flock management. Ewe fertility has shown low heritability (0-10%), as has lamb survival, meaning that they are more linked to environmental causes than to genetic makeup. Both fertility and lamb survival respond quickly to improvements in nutrition and husbandry practices; adjusting nutrition and breeding management practices can quickly improve the number of pregnant ewes in a flock, as well as the number of lambs that survive the first few days after birth. (An exception would be a flock with a high degree of inbreeding, which might see a substantial increase in heterosis and corresponding reproductive traits by bringing in less related stock.)

Productivity traits that respond well to selection include prolificacy (number of lambs born per ewe lambing, or litter size), fertility of ewe lambs (age at first breeding), degree of seasonal breeding, pounds of lamb produced per ewe, and various measures of lamb growth (pre-weaning weight, post-weaning weight, growth rate). Keeping the ewes that perform well for these traits will improve a flock's production.

How can a shepherd determine which ewes are poor performers, in a way that is even-handed and might convince him or her to part with a favorite, for the good of the flock? We can use our breeding records – as purebred breeders, we have a record of the number of lambs registered per ewe. A more detailed analysis of our ewes is possible if we have more information, such as the date the ram was added, lamb birth dates, number of lambs born and raised per ewe, lamb birth weights, and lamb weights before and after weaning. These are the types of information collected for the NSIP (National Sheep Improvement Program).

First we'll look at some productivity traits that can be compared using flock records alone, without any lamb weights. These are ewe prolificacy, age at first breeding and rebreeding interval.

Estimating Prolificacy (litter size at birth)

Say that I have 3 ewes with different lamb production histories.

Ewe A gave birth to 1, 2, 0 and 2 lambs at ages 1, 2, 3, and 4 years;
Ewe B gave birth to 2, 3, and 0 lambs at 6, 7 and 8 years; and
Ewe C gave birth to 1, 2, and 2 lambs at 3, 4 and 5 years.

All three ewes have given birth to 5 lambs over 3-4 years. However, a young ewe that has not yet reached full body size is investing more (and thus has greater potential prolificacy) if she produces the same number of lambs as a mature ewe. Similarly, a prime-age ewe is expected to raise more lambs than a young or old ewe. A correction factor can allow more accurate measurement of each ewe's genetic potential. To make the correction, multiply the number of lambs produced by the age factor from Table 1, to effectively adjust all the ewes to the same age (4 years). Then add all the adjusted numbers for that ewe together, and divide by the number of times she has lambed.

Adjusted prolificacy (number of lambs born per lambing per ewe) using Table 1 according to the directions in the Sheep Production Handbook:

Ewe A: (1x1.45 + 2x1.15 + 2x1.00)/3 = 1.92
Ewe B: (2x0.95+ 3x0.95)/2=2.38
Ewe C: (1x1.05 + 2x1.00 + 2x0.95)/3=1.65

Table 1. Multiplicative adjustment factors for adjusting number of lambs born (litter size or prolificacy) for age of ewe

Age of Ewe at lambing (years)	Adjustment Factor
1	1.45
2	1.15
3	1.05
4	1.00
5 to 7	0.95
8+	1.00
Records are adjusted to a 4-year-old ewe equivalent. Any records that are zero (no lambs) should be deleted prior to adjustment.	

According to these calculations, Ewe B is the superior producer, and Ewe C is lagging in her lamb production. But Ewes A and B have failed to lamb during one breeding cycle, while ewe C has had lambs every year (or every time she was exposed to a ram). While the SPH formula is technically correct, in that prolificacy can only be measured when a ewe has lambs, I don't like their formula because it does not penalize ewes A and B for failing to lamb in one year (or season). If their formula is changed so that the adjusted number of lambs is divided by the number of potential lambing events (instead of the number of actual lambings), we get my preferred estimate of a ewe's "effective" prolificacy:

Adjusted "effective" prolificacy (number of lambs born <u>per breeding season</u> per ewe):

Ewe A: (1x1.45 + 2x1.15 + 2x1.00)/**4** = 1.44
Ewe B: (2x0.95+ 3x0.95)/**3**=1.59
Ewe C: (1x1.05 + 2x1.00 + 2x0.95)/3=1.65

When calculated this way, Ewes B and C both have a similar effective prolificacy, while Ewe A has produced somewhat fewer lambs per breeding season. I feel that this is a more accurate view of the relative production value each of these ewes.

In general, the SPH recommends a target average prolificacy of 2 (2 lambs born per ewe per lambing) for a commercial flock. If St Croix sheep are to be used as a maternal breed – that is, to improve lamb production and vigor in commercial operations – the breed would likely benefit from selection for a higher prolificacy (> 2 lambs born per ewe). That being said, it is important to evaluate the nutritional status of your flock before trying to increase the number of lambs born per ewe – raising your flock's prolificacy is appropriate only if there is sufficient feed for ewes with multiple lambs. Because not all flocks have sufficient resources for a ewe to successfully raise triplet lambs, not every flock owner should try to increase prolificacy.

Age at First breeding

The age when a ewe first breeds is strongly correlated to her lifetime lamb production. That is, ewes that lamb at a young age tend to produce more lambs over their lifetime than do ewes that begin producing lambs when older. The St Croix ewe will breed early and often: St Croix ewes have given birth for the first time when as young as 10 months of age. However, lambs born to such a young ewe are less likely to survive; if they do survive they place great demands on the mother's metabolism. While there is no ideal age for a ewe to have her first lamb – it depends in large part on the resources available to support the young ewe and her lamb(s) – most shepherds keep ewe lambs away from rams until they are 7-8 months of age or more.

Ewe lambs that are exposed to a ram at 7-8 months will lamb at 12-13 months. If the flock has good nutrition, such ewes can successfully raise lambs while continuing to grow themselves. Alternatively, ewe lambs can be kept from the ram until 12 months of age, when a substantial proportion of their growth is complete. Few shepherds delay breeding ewe lambs past 12 months of age; ewes that do not lamb before 24 months of age tend to have problems with conception for the rest of their lives.

In our flock management system, the ewe lambs are first exposed to a ram at around 7 months of age; winter-born ewe lambs tend to breed within 1-2 months but fall-born ewe lambs are more variable. We use birth dates to keep track of the age at which a ewe produces her first lamb, and do not penalize ewe lambs as long as they breed for the first time prior to 12 months of age. We sort our pregnant ewe lambs into their own pasture where they get more supplemental feed than the mature ewes up to the time that they lamb. We also supply creep-feed for the lambs to reduce their demands upon the ewe. This high-input system makes sense in our situation, because we have to supply supplemental feed for most of the year regardless of the ewe's breeding status; it may not be appropriate for flocks in a low-input system where there is a more reliable source of pasture but ewe lambs grow to mature size more slowly.

Selection for year-round breeding

Another valuable trait of the St Croix breed that can be preserved and improved via selection is the ability to breed at any time of year. Assuming that you allow your ewes to breed in more than one season, selection can be based on the interval (in days) between lambs, and / or the interval between when the ram was added and when the ewe was bred. Candidates for culling are ewes that have longer than average intervals between lambs, suggesting that they are more seasonal in their breeding or need more time for recovery. Longer rebreeding intervals are especially noteworthy if the ewe is also producing relatively few lambs at each breeding (low to average prolificacy).

We use lamb birth dates to estimate the date when a ewe was bred (average gestation length in sheep is 147 days). Any ewe that did not breed within the first two cycles (34 days) after the addition of the ram gets a 'black mark' – meaning that she has a strike against her that may result in her being culled from the flock, unless she is excelling in other areas.

Productivity traits such as a ewe's prolificacy, age at first reproduction, and ability to lamb year-round can be calculated using flock records and used to determine which ewes are the better producers. By eliminating the poor producers in your flock, you can increase lamb production and help maintain the strengths of the St Croix sheep breed. Flock productivity can be improved more rapidly by collecting additional information on each ewe's productivity, such as lamb weights, as I'll outline in part 2.

Flock Improvement using Selection. Part 2: Calculations involving weights– by Karen Gerhart, Howling Oak Ranch St Croix sheep

The economic success of a commercial sheep operation is almost completely determined by just three factors: the cost of feed and care, the total weight of lambs raised per ewe, and the price the shepherd can get for those lambs. The St Croix sheep has the advantage that it is prolific and produces vigorous lambs, increasing the number of lambs raised per ewe; however, the St Croix also has a relatively slow growth rate. Selecting for faster growth in lambs would seem likely to improve a flock's economic return by causing the flock to produce more pounds of lamb. In practice, however, selection for fast growth often inadvertently favors ewes that raise fewer lambs. A shepherd who wishes to improve growth while maintaining prolificacy, fertility, and early reproduction would seem to need detailed records and a complicated selection protocol to be sure that gains in one trait were not offset by losses in another.

Selection for litter weight weaned (that is, total weight of lambs weaned per ewe) allows for substantial improvement in flock productivity without any apparent genetic losses in other traits, according to research on responses to selection using multiple sheep breeds (Ercanbrack and Knight, 1998, J Anim Sci 76:1311-1325). [A small reduction in wool production was found but is not relevant to those of us raising hair sheep.] Improvements in litter weight weaned correlated with improved prolificacy, greater lamb survival, higher lamb weights at weaning, higher fertility, and better survival of the ewe during pregnancy. Total weight of lambs weaned per ewe is a very suitable trait for selection within a St Croix flock, as it is expected to allow the shepherd to use variation in one trait to maintain the strengths of the St Croix ewe (fertility, prolificacy, early reproduction and lamb vigor) while also improving lamb growth. Its calculation is also relatively simple, requiring only normal flock records plus birth weights and weaning weights for all lambs.

In a selection program, progress will be proportional to the accuracy with which we measure genetic potential for the chosen traits. If we wish to retain the ewes that raise the most pounds of lamb, or if we wish our flock to produce faster-growing, heavier lambs, our progress will be proportional to the accuracy with which we measure genetic potential for lamb growth. While genetics certainly contribute to the growth rate of a lamb, many environmental factors are also involved. To the extent that we can correct for this non-genetic variation, we can improve our estimates of a sheep's breeding value, and thus improve our ability to retain the best genetics in our flocks. Some of the environmental factors that affect lamb growth are the age of its mother, the type of birth and rearing (single, twin, triplet, etc), and the sex of the lamb. When comparing growth rates of lambs, it is therefore helpful to mathematically "remove" these environmental affects. The Sheep Production Handbook has correction factors that can be used to adjust for each of these variables. (I find it easiest to use a computer spreadsheet program like Excel to do these calculations.)

All the lambs included in a group for calculation purposes (a 'cohort') should be raised in a similar environment. That is, the corrections below won't let us accurately compare fall lambs with spring lambs, creep-fed with non-creep fed, or our flock's lambs with

someone else's lambs. To compare lambs within a cohort, we first need to adjust all the lambs to the same age. Flocks that provide creep feed and wean early often wean at 90 days, so we'll calculate the 90 day weight of a lamb, but the same calculations could be used for lambs weaned at 120 days. First we'll correct the recorded weights to a common lamb age.

Age adjusted weight =[(actual weight – birth weight) / (age when weighed)]* adjustment age (90 days, in this example) + birth weight

For example, to calculate the age adjusted weight for a lamb that weighed 7.7 pounds at birth, and 52 pounds at 95 days of age: [(52-7.7)/95] [this is her growth rate] * 90 days + 7.7 pounds = 49.7 pounds.

Now that we've corrected for age, we can correct for environmental affects – that is, the age of the ewe, the number of other lambs she raised simultaneously, and the sex of the lamb. The Sheep Production Handbook (1997) provides the correction factors shown in Table 1 (effectively adjusting any lamb to a single ewe lamb born to a 3-6 year old ewe).

So, if our ewe lamb in the example above was born and raised as a twin from a 3-year old ewe, we'd look up in Table 1 Lamb sex = ewe, # lambs born, raised = 2-2, and ewe age = 3 to get an adjustment factor of 1.19. We then multiply her 90-d adjusted weight (49.7 pounds) by 1.19 to get an adjusted weight of 59.1 pounds. This weight is expected to be a more accurate estimate of the ewe lamb's genetic potential than was her actual weight, as it gives her "credit" for the disadvantage of being a twin.

Table 1. Multiplicative adjustment factors for adjusting lamb pre-weaning and weaning weights to a common age of dam, lamb sex, and lamb type of birth-rearing. Lambs born in litters of more than 3 should use the triplet adjustment factors. Lambs born as singles and reared as twins should use the twin (2-2) adjustment, and lambs born as singles or twins and raised as triplets should use the triplet (3-3) adjustment factors.

For use on weights at 30, 60, 90, and 120 days							
		# lambs born , raised					
Lamb sex	Ewe age	1-1	2-1	2-2	3-1	3-2	3-3
Ewe	1	1.13	1.29	1.38	1.4	1.51	1.8
	2, >6	1.08	1.19	1.29	1.28	1.38	1.54
	3 - 6	1	1.1	1.19	1.18	1.27	1.36
Ram	1	1.02	1.15	1.21	1.23	1.31	1.53
	2, >6	0.98	1.08	1.17	1.16	1.25	1.38
	3 - 6	0.91	1	1.08	1.07	1.15	1.23
Wether	1	1.1	1.25	1.33	1.36	1.45	1.72
	2, >6	1.05	1.16	1.26	1.25	1.35	1.5
	3 - 6	0.98	1.08	1.16	1.15	1.24	1.33

Total Weight of Lambs Weaned per Ewe

Once the lamb weights have been adjusted for age and maternal affects, add all the lamb weights for each ewe together to get total pounds of lamb raised per ewe. An example of some typical results from our flock is shown below (Table 2). It appears that ewes C and D are performing well, while the performance of ewes A and B is less impressive. While somewhat informative, one season's weights have limited value as they provide an extremely narrow view of a ewe's production.

Table 2. Total weight of lambs weaned per ewe for one season (data from St Croix ewes at Howling Oak Ranch).

Ewe ID	Age	# lambs	Total Weight of lambs
A	1	2	95
B	2	1	83
C	3	2	130
D	3	2	107

We pool data across several breeding seasons for each ewe in an effort to increase the reliability of our estimates of ewe productivity (Table 3). To do so, we must treat different cohorts of lambs as roughly comparable, and if our management or the food resources available to the ewes and lambs vary dramatically from season to season, this may not be a legitimate assumption. That risk is offset somewhat if all the ewes compared have multiple seasons of data collected, so that each ewe has likely been sampled under better and worse conditions. Certainly multiple samples per ewe allow us to draw much firmer conclusions about an individual ewe's performance. In this instance, I would conclude that Ewe A is young and promising; Ewe B is a solid

Table 3. Total weight of lambs weaned per ewe over several breeding seasons, along with the across-season average for each of 4 ewes (data from St Croix ewes at Howling Oak Ranch).

Ewe ID	Breeding Season #	# lambs	Total Weight of lambs	Average Total Lamb Weight
A	1	2	95	102.5
	2	2	110	
B	2	1	83	102
	3	2	117	
	4	2	111	
	5	2	95	
C	1	2	94	106
	2	2	85	
	3	2	130	
	4	2	115	
D	2	1	59	83.9
	3	2	107	
	4	2	90	
	5	1	78	

producer; Ewe C is exemplary; and Ewe D is lagging in production. Therefore, daughters of ewes A, B and C are good candidates for replacement ewes, while sons of ewe C are good candidates for flock sires. Ewe D is a candidate for culling and her sons and daughters are also unlikely to perform well.

Total weight of lambs weaned per ewe is my preferred selection criterion because this trait encompasses several reproductive characteristics important to the St Croix breed, including ewe fertility and prolificacy, lamb survival, and lamb growth. Selection based on the single trait of individual lamb weaning weight will likely result in more rapid improvement of lamb weaning weights within a flock, but may also cause erosion of other important reproductive traits such as prolificacy. Nonetheless, it too is easily calculated and often used in selection programs.

Weights of individual lambs

Lamb weights can be compared at about 60 days of age, when they are an index of a ewe's milk production, or lamb weights can be compared at or after weaning. The later weights more accurately reflect the lamb's genetic potential for growth, in that they are less influenced by the performance of the ewe. To compare growth among lambs, first calculate adjusted lamb weights as in the previous example. Then calculate the average lamb weight, and subtract this average from each lamb's weight to get the number of pounds each lamb outperformed (or underperformed) compared to average:

Weight difference between the ewe lamb (from the beginning of this article) and the average lamb: adjusted weight of ewe lamb = 59.1 lbs; average adjusted weight of all lambs in the cohort = 54.0 lb; 59.1 – 54.0 = 5.1 pounds.

We can calculate a rough Estimated Breeding Value (EBV) by multiplying the weight calculated above by the heritability for this trait. An EBV gives us an idea of this ewe's genetic merit. The heritability for 90-day weights is 25%, or .25 (from Table 4).

EBV = (difference between individual and cohort average) * heritability of trait = 5.1 pounds x .25 = 1.3 pounds.

We are almost done. However, this ewe will contribute only one-half of the genetic influence on her progeny (with the ram contributing the other half), so we can convert the EBV into an EPD (estimated progeny difference) by dividing by 2.

EPD = EBV/2 = 1.3 pounds / 2 = 0.65 pounds.

Thus, this ewe lamb is expected to produce lambs that weigh about 0.6 pounds more than the average lamb in our flock at 90 days of age.

This EPD is similar to those calculated by the National Sheep Improvement Program (NSIP) – except that the NSIP program improves the accuracy of the EPD estimate by

using complex mathematics involving information on the ewe's relatives and related maternal traits.

A simpler alternative to calculating an EPD is to divide each lamb's weight by the average lamb weight, to get a percent performance; lambs with a score of above 1 demonstrated above average growth. For our sample ewe lamb: 59.1/54 = 1.09 so this lamb is 9% larger than the average lamb (or 109% of the average lamb's weight).

Table 4. Heritabilities of Various Traits (from Sheep Production Handbook, 1997, p. 61). Higher values mean that the trait is more heritable, while lower values mean that environmental affects tend to overwhelm the affects of genetics in determining the phenotype.

Traits		Percentage
Reproductive		
	Ewe fertility	5[a]
	Prolificacy[b]	10
	Scrotal circumference	35
	Age at puberty	25
	Lamb survival[c]	5
	Ewe productivity[d]	20
Growth		
	Birth weight	15
	60-day weight	20
	90-day weight	25
	120-day weight	30
	240-day weight	40
	Preweaning gain (birth to 60 d)	20
	Postweaning gain (60-120 d)	40

[a] May increase to 10% in ewe lambs, in ewes lambed in the fall, and in ewes lambed in the spring in flocks with low fertility

[b] Lambs born per ewe lambing

[c] May increase to 10% in flocks with low lamb survival

[d] Pounds of lamb weaned per ewe exposed

Summary Various sorts of information collected during routine record keeping, as well as lamb weights, can be used to help a shepherd determine which ewes in the flock are most productive and which should be culled. Selection will be most rapid when the data are corrected for environmental influences and reflect the genetics of the individual accurately. Single-trait selection can result in rapid progress, but includes the risk that other important traits are being lost. Total weight of lambs weaned per ewe encompasses various aspects of reproduction; selection based on this trait is suitable for the St Croix breed, as it is expected to improve individual lamb weaning weights without sacrificing other important aspects of lamb production. Rough EPDs can be calculated using lamb weights and heritability estimates.