Developing Breeding Objectives for Targhee Sheep

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(ABSTRACT)

Breeding objectives were developed for Targhee sheep at different levels of prolificacy and triplet survival. Economic weights (EW) were derived for estimated breeding values (BV) from National Sheep Improvement Program genetic evaluations for 120 d weaning weight (WW), maternal milk (MM), yearling weight (YW), fleece weight (FW), fiber diameter (FD), staple length (SL), and prolificacy (PLC; lambs born/100 ewes lambing). A commercial flock was simulated, accounting for nonlinear relationships between performance and profit. Ewes were assumed mated to sires of specified BV and profit was derived from lifetime performance of lambs and replacement females from that lamb crop. Economic weights were determined as change in profit from use of sires with BV that were one additive standard deviation above the mean for each trait [1.98 kg for WW, 1.62 kg for MM, 2.90 kg for YW, 0..36 kg for FW, 0.99 microns for FD, 0.74 cm for SL, and 17.58 lambs/100 ewes for LC], while holding all other BV at breed average. Separate breeding objectives were derived for different ways of meeting increased nutrient needs (P = purchase hay, R = rent pasture, and L= limited flock size) and for different market lamb values (D = discounting lamb value for heavy weights, ND = no discount for heavy lambs). Based on replicated simulations, relative EW did not vary with prolificacy or triplet survival ($P > 0.15$) but were affected by feed costs and lamb market values ($P < 0.01$). Selection indexes were derived within and across simulated scenarios, and correlation (r) among indexes of > 0.90 indicated that an index could be used across multiple scenarios with little loss of selection efficiency. Indexes derived within feed cost scenarios (P, R, and L) and lamb value scenarios (D, ND) were strongly intercorrelated ($r > 0.97$). Correlations among average indexes for feed cost scenarios (0.97 for R and P, 0.70 for R and L; 0.85 for P and L) indicated that two feed cost scenarios could be used depending on whether winter forage was limited (L) or not (NL).

The correlation between average indexes for these two scenarios was 0.78. Indexes were presented for combinations of feed cost and lamb value scenarios. Two indexes were suggested, representing the scenarios that apply to a large portion of Targhee producers. These indexes were for discounting heavy lambs with limited winter forage (D-L: 1.0 WW + 0.14 MM – 0.76 YW + 1.22 FW – 0.36 FD - 0.09 SL + 0.25 LC) and discounting heavy lambs with additional available forage (D-NL: 1.0 WW + 0.24 MM – 0.34 YW + 1.65 FW – 0.41 FD - 0.14 SL + 0.33 LC). For a standardized selection differential of one for the index, the expected changes in mean index value were $2.17 and $1.92 per ewe per generation for D-L and D-NL, respectively.

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Chapter 1 Introduction

Breeding objectives define the traits of importance and the direction of genetic improvement in livestock selection programs. Hazel (1943) demonstrated the incorporation of economic values into a breeding objective to calculate phenotypic selection indexes and estimate aggregate breeding values in livestock. When multiple traits are used to define the breeding objective, index selection has been shown to be more efficient than other forms of selection choosing genetically superior animals (Hazel, 1943; Hazel and Terrill, 1946). Economic values should be calculated for all traits based on the relative efficiency of female production and reproduction and the growth of young stock so that the entire production system is considered when determining the economic importance of traits of the breeding objective (Dickerson, 1976). When estimated breeding values for traits in the breeding objective are available from multi-trait genetic analyses, economic values for the traits can be used directly as weighting factors in a selection index (Schneeberger et al., 1992).

Many livestock industries have achieved sustained improvements in production efficiency through the development of programs for genetic improvement. In the sheep industry, breeding objectives have been developed for multiple-trait selection in various breeds, emphasizing a combination of prolificacy, growth, and wool characteristics (Amer et al., 1999; Simm et al., 1987; Ponzoni and Walkley, 1981; Kosgey et al., 2003). The American sheep industry has struggled, compared to other species, in developing genetic improvement programs; however, participation in national genetic evaluation programs has created the potential for such improvement programs to develop.

The Targhee breed is a medium-wool, dual-purpose breed with strong participation in the National Sheep Improvement Program (NSIP). The breed currently reports estimated breeding values for several production traits that are used to select for desirable meat, carcass, and fleece characteristics. Targhee flocks are located mainly in the Northwestern U.S. and exemplify a slowly growing trend to increase overall economic performance by use of genetic evaluation methodology. The Targhee breed does not have a clearly defined breeding objective that integrates the combined value of meat and wool production. Without a well-defined selection goal, Targhee producers risk making sub-optimal selection decisions that may result in less-than-maximum profitability.

The accumulation of animal production datasets from NSIP provides a unique opportunity to evaluate Targhee performance records. Thus the objective of this study was to create breeding objectives for different production levels in the Targhee breed and to derive predictions of net genetic merit from breeding values reported in the genetic evaluation.

Chapter 2 Literature Review

2.1 Breeding Objectives

Breeding objectives are developed to provide a clear statement of direction in animal improvement programs. In general terms, the purpose of a breeding objective is to identify the traits that affect some production goal and to allow selection of animals that will increase the frequency of alleles with favorable effects on these traits. In livestock production, animal productivity is commonly measured by income generated from the enterprise. For this reason, goals of selection usually include genetic change in traits that are more beneficial (profitable) for the livestock program. By identifying traits of economic importance, a breeding objective clarifies the role of genetics in defining profitability and facilitates development of selection strategies.

The concept and structure of a livestock breeding objective was formalized by Hazel (1943) who defined a breeding goal as a linear function of breeding values for economically important traits. The value of an animal is often based on the cumulative performance of multiple traits, and therefore the breeding objective addresses each trait according to its economic contribution. The breeding objective defines net genetic merit of individuals and takes the form

$$H = \Sigma\ a_i\ BV_i$$

where H is the breeding objective, BV is an individual's breeding value for an economically important trait, and a is the economic value of a one-unit change in the breeding value considering all other traits unchanged.

An individual's true breeding value for each trait in the breeding objective is not known. Hazel (1943) developed selection index methodology to predict the net genetic merit of individuals for the multi-trait breeding objective. Multiple sources of phenotypic information are used for traits that are either in, or correlated to, the traits in the breeding objective. A selection index takes the form

$$I = \Sigma\ b_i\ X_i$$

where I is the index value, X is the phenotypic information on a trait, and b_i is the regression factor correlating phenotypic values with the breeding objective. Traits in the index need not be the same as those in the breeding objective because genetic correlations are used to relate the trait performance to the goal. Hazel (1943) demonstrated the use of pathway relationships between an individual and the phenotypic records used in the index to determine correlation values that properly weighted phenotypic information. Selection index weightings are calculated as partial regressions of the breeding objective on each of the phenotypic measures. Therefore the weightings (b_i) are calculated to maximize the correlation between the index and the breeding objective.

The efficiency of an index is measured by the correlation between the index and the breeding objective. As traits are added or removed from an index, correlation values change. These changes determine which combination of traits in an index should be used to make selection decisions. Hazel (1943) gives an example of different indexes used to select swine for a breeding objective of improved growth rate and productivity. An index, which included a measure of mean litter weight was shown to be more efficient ($r = 0.404$) than an index that only included an individual's own performance records ($r = 0.363$). The higher correlation indicated that the value of including mean litter weight in selection resulted in a better prediction of the breeding objective.

To predict breeding values over a large number of contemporary groups, calculations are made using best linear unbiased prediction (BLUP) procedures (Henderson 1984). Similar to the selection index in that a number of phenotypic sources of information are used to predict a breeding value, the BLUP procedure differs by also accounting for fixed effects of genetically linked individuals, such as year or management unit on the performance of an individual. Because fixed effects are accounted for, predicted breeding values can be compared over a large population distributed across many management units.

Industry genetic evaluation programs often provide estimated breeding values of economically important traits using BLUP. Schneeberger et al. (1992) demonstrated that when the breeding values of goal traits are predicted by BLUP, values can be put directly into the breeding objective and weighed directly by their economic value. When breeding values of indicator traits are calculated from BLUP, a linear function of predicted breeding values for the indicator trait is used to predict the breeding value of the goal trait.

Golden et al. (2000) discusses the importance of estimating breeding values for all economically relevant traits (ERT) in the breeding objective, regardless of whether or not phenotypic measurements are available. Economically relevant traits are traits that directly influence the profitability of production. For example, in beef production, cow maintenance requirements have a direct effect on profit through feed consumption. Although measurements of maintenance requirements are difficult to collect, breeding values could be predicted from BLUP using phenotypic information on correlated traits. Industry genetic evaluations commonly provide estimated breeding values for traits that are directly measured, rather than economically relevant. Birth weight is an example of a trait for which estimated breeding values are calculated, yet it is not an ERT. The underlying economic value of birth weight is a predictor of either growth potential, or more commonly, the costs associated with dystocia. Birth weight could be considered an ERT provided that performance directly affects profit. For example, if profit is affected by changes in gestational nutrient requirements caused by change in birth weight, the trait could be considered as an ERT. Golden et al. (2000) indicated that the calculation of estimated breeding values for ERT would result in selection decisions more often being based on goal traits directly. Also ERT calculations would provide a basis for more customized selection programs because the traits in the breeding objective would remain constant while variations in economic weights could be developed for unique production systems.

2.2 Developing economic weightings

Development of a breeding objective requires a critical analysis of costs and returns associated with the production system. Dickerson (1970) used a profit equation that identified and evaluated all costs associated with female production and reproduction, and growth of progeny as well as all sources of revenue generated by the sale of progeny for meat and of milk, eggs, and/or wool from breeding females. The economic contributions of changes in biological performance were used to establish the effect of genetic change on profit. Distributing fixed and variable costs across an enterprise is challenging when considering the value of genetic change in both market and breeding animals because partitioning cost among different elements of performance is not always straightforward.

Profit functions may take different forms (Dickerson, 1970; Harris, 1970), each resulting in a somewhat different evaluation of the livestock system. Brascamp et al. (1985) calculated profit on a per female, per individual, and per unit produced basis assuming constant numbers of females, individuals, and units of product sold, respectively. Profit equations appropriate for calculating economic values of breeding objective traits should not be influenced by management decisions that are unrelated to genetic improvement. Smith et al. (1986) discussed the effect that the scale of an enterprise may have on a profit equation and suggests that profit that could be obtained from changing the size of an operation should not be considered in calculation of economic values. Therefore, genetic improvement that results in a change in profit should affect the efficiency of the production system on a per-unit of product basis.

Ponzoni (1988) evaluated profit as income minus expense, income divided by expense, and expense divided by income to derive economic weights of a breeding objective for Merino sheep. For each of the three different profit evaluations, production data was used to calculate profit and compare the consequences of using different equations in deriving a breeding objective. Ponzoni (1988) concluded that economic values were consistent for all three profit equations. This conclusion was in agreement with Brascamp et al. (1985) and Smith et al. (1986) where changes to the enterprise that were independent of selection did not influence profit when calculated as a function of either a difference or as a ratio.

Regardless of the form of the profit function, economic weights for goal traits are estimated by the partial derivative of profit with respect to each goal trait expressed at the population mean (Brascamp et al.,1985; Smith et al.,1986). When profit equations are linear, mean performance does not influence marginal economic values. If profit is non-linear, the value of genetic change is influenced more strongly by the current level of performance. Brascamp et al. (1985) suggests that most non-linear profit relationships can be generalized by a linear approximation because of slow changes in mean performance resulting from selection. However, there may be a need to develop different economic weightings based on mean performance of a trait (Amer et al.,1999 and 2001;

Wade et al.,2001). For example, Fogarty and Gilmour (1993) showed a non-linear relationship between profit and fiber diameter in sheep. When performance within a breed is close to a major price threshold, selection pressure to maintain or improve the trait is high. If performance for the same trait is not close to a price threshold, genetic gain from selection is not economically rewarded because improving performance does not increase product value. Differences in economic weights among production units are difficult to accommodate in a breeding objective without creating custom indexes for different production systems (Fogarty and Gilmour, 1993; Koots and Gibson, 1998; Amer, 2000).

The value of changing mean performance through selection may vary with breed type, management system, and market. Anticipated effects of genetic change are fairly insensitive to small errors in economic weights, especially when errors occur in traits that have only a small influence on the breeding goal. (Smith, 1983; Smith et al., 1986; Ponzoni, 1988). However, in situations where goal traits strongly influence index values, Smith et al. (1983) reported a strong negative correlation between selection using a correct index and one that had the economic value for one trait in the wrong direction.

Goddard (1998) reviewed changes in economic weights that resulted from effects of improved genetic performance on the supply and demand of commercial livestock. He suggested that the relationship between supply and demand is relatively elastic for livestock production, meaning that changes in animal performance have little affect on consumer demands. Amer and Fox (1992) discuss the benefits of genetic improvement for different industry segments as they relate to changes in supply and demand of livestock output. In an elastic market, consumer demands fluctuate more with genetic improvements of product quality rather than selection for quantity. In more integrated livestock breeding industries, such as poultry or swine, dissemination of genetic improvement to commercial breeders and shorter generation intervals influence the effect selection has on supply and demand. However, genetic improvements for livestock species that are less integrated occur at a slower rate and therefore shifts in supply and demand due to selection have little affect on economic weights (Goddard, 1998).

Although economic weights are usually robust to small changes in market demand, it is difficult to anticipate large market changes that could have a substantial influence on breeding goals. Economic values should be calculated with future production systems in mind. To avoid the need to predict future market trends, breeders have tried to develop biological objectives that define a breeding goal in terms of biological efficiency (Fowler et al., 1976). Biological indexes consist of measured traits that together describe basic biological functions (i.e., growth rate or feed conversion) associated with efficient animal growth. More efficient growing animals are desired in almost any market, therefore economic values are not needed when determining biological index values (Fowler et al., 1976). Simm et al. (1987) developed a biological index for lean growth in sheep by measuring rate of lean growth, carcass weight, and percentage of fat in the carcass, with selection based on the relative importance of lean growth in the production system. Economic objectives described by Fowler et al. (1976) may not account for differences in environments and may not precisely estimate non-linear economic values. Simm et al. (1987) explain the biological objective as a predictor of an underlying economic objective and therefore when economic values are estimated, an economic index would be preferred. Biological objectives may be desired when an interaction between environment and selection is expected within a population and economic and genetic parameters are not available across the different environments (Fowler et al., 1976). In an example for selection of growth rate in swine, Fowler et al. (1976) explain that an interaction between feeding regimen and selection may exist, where an economic index would select for different genotypes in an *ad libitum* feeding regimen verses a regimen with full access to feed for a limited time each day, especially if parameters are not available across feeding regimens.

2.3 Discounting for the expression of economic traits

The differences in time required to obtain profit from selection of different goal traits are accounted for by discounting economic values. Changes in profit due to selection occur when progeny express economically important traits. Changes in performance that result in more rapid changes in profit provide faster return from the selection decision compared to traits that take longer to be expressed and therefore result in delayed realization of changes in profit.

Hill (1974) describes economic values as a return on investment, where the investment is the selection decision. If all traits were expressed immediately upon selection, the true profit would be described by the economic values and rate of genetic change. In reality, changes in performance from selection are not realized quickly and economic traits are expressed at different rates over many years. Discounting adjusts economic values to express the value of future profit from genetic improvement at the time of selection. McClintock and Cunningham (1974) provide an example of discounting of future milk yield changes in dual-purpose cattle production. At the time of selection, if profit could be realized immediately the producer would receive increased income equal to the current value of each additional kilogram of milk yield. However, the return on the investment (i.e., increased milk yield) does not occur until 3 yr. after selection. Economic weights should reflect the current value of future changes in performance so the market value of the additional milk produced is reduced to reflect the current value of future production. Income from future production is multiplied by a factor of $1/(1+d)^t$ where d is the expected interest rate on an investment and t is the number of years required for the income to be realized. Smith (1978) considered interest and inflation rates as they influence the discounting rate in a breeding objective. The appropriate discounting rate was shown to be a flat interest rate, excluding adjustments for inflation, to account for the current opportunity cost of an improvement.

McClintock and Cunningham (1974) illustrated a discount gene flow method that accounts for profit from selection as it is observed over time in overlapping generations. The method adjusts effects of selection on profit in a breeding system for results obtained over many years and multiple matings. Discounted gene flow provides a cumulative value for goal traits, based on frequency of expression and time required for realizing profits from selection.

2.4 Indexes for Sheep Production

Hazel and Terrill (1946) developed an index to select for both improved wool and growth characteristics in Rambouillet sheep. Index selection was compared to selection based on visual performance. Two years of selection were analyzed in retrospect by comparing realized selection differentials of economically important traits. In year one, lambs were selected on general visual performance while the second year of selection was based on index values. Hazel and Terrill (1946) noted that index selection provided an objective basis to consistently emphasize traits that were both highly heritable and economically important. Comparisons of realized selection differentials indicated that more ewes of higher genetic merit for multiple traits were identified by index selection. Disadvantages of an index for livestock selection were also addressed, including the effort required to calculate index values and the inability of the index to identify reproductively unsound animals.

Givens et al. (1960) developed a specific breeding objective for sheep sired by Hampshire rams and bred for spring lambing in Virginia. In this environment, growth traits contributed the most to profit. Although an index was developed which included 120-day weaning weight, daily gain, and market grade, Givens et al. (1960) found that selection for daily gain alone resulted in nearly maximum economic gains.

2.5 Indexes for Growth

Breeding objectives that emphasized lean growth of slaughter lambs sired by terminal sire breeds were developed for sheep in New Zealand (Simm et al., 1987) and the United Kingdom (U.K.)(Simm et al., 1989). In both studies, total weights of both fat and lean in the lamb carcass were used as goal traits in the breeding objective. Ultrasonic measures of fat and muscle depth, and live weight were used as selection criteria Selection for increased percentage of lean weight on a lamb carcass was desired by selection for increased lean weight and decreased fat weight. Simm et al. (1989) estimated relative economic values for component traits of lean and fat were +3 and -1, respectively, resulting in an increase in carcass weight at a given age. Because of the genetic correlations between the two traits both lean and fat weight increased, however, fat weight increased at a much slower rate. These economic values differ from New Zealand breed weightings, which were +5.7 and –4.1 for lean and fat, respectively (Simm et al., 1987). Although goal traits were similar for both breeding objectives, the relative economic values reflect differences in environment, breed type, and market that are unique to each region.

2.6 Indexes for Reproduction

Economic values for ewe reproductive traits were calculated for multiple New Zealand sheep production systems by Amer et al. (1999). Ewe prolificacy and two lamb survival rate traits, birth to 24 hours and 24 hours to weaning, were considered as economically important traits for ewe selection. Economic values were dependent on the current performance level, survival rates for different litter sizes, and lamb slaughter endpoints. The economic values for lambs born per ewe lambing, over a range of production systems with different mean prolificacy rates, varied from $15.47 to $24.26 at a weight-constant endpoint and $11.55 to $18.98 at an age-constant endpoint, mostly reflecting survival rates for different litter sizes. The values for prolificacy were consistently higher (about $5.00 more) in scenarios where slaughter endpoints were based on a weight-constant value because smaller lambs at birth were not of less value at market. Economic values for survival were consistent over all production systems and marketing scenarios, ranging from $0.22 to $0.28 for survival to 24 hours and $0.31 to $0.36 for survival from 24 hours to weaning. At current levels of survival, increasing number born was beneficial However, as mean prolificacy increased to over 2.1 lambs per ewe, lamb mortality increased to the point where economic values for prolificacy were negative. Amer et al. (1999) also discussed the effect major prolificacy genes (e.g., Booroola and Inverdale) may have on economic values of reproductive traits. Increases in prolificacy resulting from a single copy of a gene are valuable in these populations. Addition of a second copy of such a gene decreases ewe reproductive efficiency due to the interaction between lamb mortality and prolificacy. The authors concluded that an index for ewe reproduction should concentrate on lamb survival to improve reproductive efficiency and that economic values for major genes affecting an intermediate optimal traits, like prolificacy, can be influenced by other traits, such as lamb survival.

2.7 Indexes for different breeds

Profit equations for two dual-purpose sheep breeds, Corriedale and Polwarth, were calculated for an Australian production system by Fogarty and Gilmour (1993). Traits that contributed most to the breeding objective were fat depth, lamb sale weight (as a measure of growth), and wool fiber diameter. Fogarty and Gilmour (1993) concluded that breeding objectives may be sensitive to both differences in trait mean performance and estimates of genetic parameters. Price differentials (value of a one-unit change in performance) for fiber diameter were dependant on the mean fiber diameter of the breed. Breeds with smaller mean fiber diameter should place stronger emphasis on further decreases in diameter, whereas breeds with larger mean fiber diameter realize little economic improvement from selection for decreased fiber diameter. Differences in heritability between breeds also affected selection index response, but changes in genetic correlations between traits had a much larger influence on selection. Fogarty and Gilmour (1993) discussed the importance of creating different indexes for different breeds and the use of breed selection to improve traits like fiber diameter, which have non-linear price differentials that are difficult to predict for multiple performance levels.

2.8 Indexes for different mating systems

Indexes have been evaluated to accommodate breeders who wish to make different mating decisions. Ponzoni and Walkley (1981) compared selection objectives for different Australian Dorset mating systems including the breed's use as a terminal sire, as a sire of crossbred females mated to a different sire breed, and as a sire of crossbred females mated to a Dorset sire. A measure of live weight alone was found to be sufficient to estimate genetic merit for terminal sire selection, although emphasis on live weight was a poor selection criterion for the other mating systems. Index values based on body weight, fleece characteristics, and number of lambs weaned as the criteria were calculated and compared with the selection objectives of each mating system. A single selection index was identified which optimized genetic gains for all mating systems. Multiple trait selection did not reduce the gain of sheep bred for terminal sire use and increased the merit of animals bred for ewe performance. Within the breed, one breeding objective was sufficient for selection in different mating systems.

2.9 Indexes for different production systems

Selection indexes for different Canadian production systems were presented by Gallivan et al. (1997). Breeding objectives differed for terminal sire and maternal breeds. Five indexes were reported: two for terminal sire breeds (with lambs slaughtered at heavy and light weights) and three for maternal breeds (with lambs slaughtered at heavy and light weights, and also with accelerated lambing). Although breeding objectives vary throughout the Canadian sheep industry, the indexes presented were sufficient to encompass a large portion of the diverse sheep breeding systems.

Conington et al. (2001) compared index calculations for intensive and extensive sheep production of hill sheep in the U.K. Breeding objectives were created to improve both maternal performance of the ewe and carcass quality of market lambs. Profit equations differed slightly between production systems due to differences in marketing endpoints. Extensive production systems captured less profit from genetic gain in almost every trait when compared to more intensive production systems. Costs of recording traits and expected returns from including each trait in an index were determined for each production system, resulting in different selection criteria for each production system index. Ultrasonic measures of carcass performance had positive effects on the rate of improvement in net merit in more intensive systems but not in extensive production.

2.10 Including feed intake as a goal trait

Feed intake is an economically important trait that is difficult to measure (Ponzoni, 1986). Indexes have included feed intake as a breeding objective trait. These indexes estimated the cost of dry matter as a function of either variable costs associated with producing one pound of pasture dry matter or as the purchase price of hay minus the cost of making and handling hay (Ponzoni, 1986; Simm et al., 1987). Economic values for pasture dry matter have also been calculated to reflect changes in stocking rate by placing the value of forage as the cost of adjusting herd size according to changes in feed requirements (Urioste et al., 1998).

Ponzoni (1986) used economic, phenotypic, and genetic parameters from literature to select for reduced feed intake. To calculate a genetic value for feed intake, correlations with other traits were assumed to be similar to correlations between live weight and other traits. However, milk production was reported to have a stronger association to feed intake, so the correlations between number reared, as an indicator of milk production, and feed intake were assumed larger (phenotypic and genetic correlations = 0.4) than those between number reared and live weight (phenotypic = 0.15, genetic = 0.25). This evaluation provided an economic estimate of the value of feed intake as a goal trait. The economic value for feed intake included variable costs associated with pasture production ($0.04/kg of dry matter) and the average expected consumption rate of an individual. By including feed intake in the breeding objective, its effect on profitability could be considered independently of live weight and reproduction. In an Australian Merino production system, Ponzoni (1986) concluded that exclusion of feed intake from the breeding objective reduced genetic gain in economic units by 30%.

2.11 Sub-indexes for sheep

In production systems where variations in market, management, and breed type are observed, Amer (2000) discussed the use of sub-indexes as an alternative to calculating multiple selection indexes. Sub-indexes are derived for goal trait groups that can then be combined to define an overall breeding objective. Each goal trait group is a subset of the full set of economically important traits. Traits within each goal-trait group are assumed to have consistent interrelationships to one another and to the sub-index, across breed types, management systems, etc. Individual sub-indexes can then be differentially weighted for a specific market or production system. In a cattle example, Amer (2001) uses a goal-trait group to define a sub-index for calf production. Twice as much emphasis is placed on the calf production sub-index when calves were raised for dual-purpose production versus when calves were raised only for slaughter. To effectively create goal-trait groups, genetic evaluations need to estimate breeding values for all traits of economical importance. This is similar to the recommendation of Golden et al. (2000) that estimated breeding values be calculated for all economically relevant traits. Amer (2000) emphasized that if estimated breeding values are available for economically important traits, goal-trait groups can be defined for a livestock industry.

Amer (2000) described a sub-index approach to selection for dual-purpose and terminal sire New Zealand sheep breeding objectives. Economic traits are combined and properly weighted based on their contribution to specific selection goals. For example, in a terminal sire index, a goal-trait group for growth was defined by carcass weight and direct effects of weaning weight, with economic weightings of $0.96 and $0.33, respectively. In a dual-purpose index, the goal-trait group for growth includes the following traits and economic weightings: carcass weight, \$1.06; direct effects of weaning weight, \$0.36; maternal effects on weaning weight, \$0.72; ewe feed intake, \$0.14; and ewe cull weight, \$0.04. The sub-index groups for growth are unique for each breeding system due to different economic contributions of each trait. Other goal-trait groups for the terminal sire index include sub-indexes for meat production and survivability while the sub-indexes for the dual-purpose breed include meat and wool production, survivability, reproduction, and disease resistance. Each sub-index has a group of economic traits and corresponding weights appropriate for the breeding objective. When differences in production exist between breed types, sub-index values are weighted differently to reflect the production system's selection goals.

2.12 Development of the Targhee breed

Breeders at the USDA U.S. Sheep Experiment Station in Dubois, ID established the Targhee sheep breed in 1926 (Terill, 1947). Targhee is a composite breed derived by mating Rambouillet rams to crossbred females produced by mating Corredale sires and crossbred Lincoln X Rambouillet ewes. Offspring of purebred Rambouillet rams crossed with Lincoln X Rambouillet ewes were also subsequently incorporated into the breed. The resulting combination of breeds thus included about three-fourths fine wool breeding (Rambouillet and Corridale) and about one-fourth long wool breeding (Lincoln). The Targhee is a polled, open-faced, dual-purpose breed that has been selected to produce tighter and finer fleeces while maintaining acceptable growth characteristics appropriate to the sub-optimal rangeland conditions commonly found in the Northwestern U.S. (Terrill, 1947).

2.12.1 Breed comparisons

The Targhee breed can be compared to other dual-purpose breeds of similar adult size (60 to 85kg). Lewis and Burfening (1988) compared Rambouillet, Columbia, and Targhee lamb performance in western range environments. Targhee ewes were slightly more prolific and weaned more lambs than Rambouillet and Columbia ewes. Lamb weights were similar across the breeds from birth to weaning but fleece quality differed among the breeds; Rambouillet wool was finer (18.5-24 microns) than Targhee (21-25 microns) and Columbia (25-31 microns) wool. When compared to a terminal-sire breed like Suffolk, lower lamb weights and rates of gain were reported for Targhee lambs (Rastogi et al., 1975), however, fleeces were much heavier and finer. More prolific breeds like Polypay and Finnsheep tend to have a smaller adult size and lighter lamb weights and have fleeces that are lighter and more course than the Targhee (Thomas, 2003).

2.12.2 *Within breed selection*

Selection within the breed originally concentrated on lamb growth and wool traits (Terrill, 1947). The U.S. Targhee Sheep Association was established in 1951 and a steady increase in the breeds' population has occurred (Bixby et al., 1994), with selection emphasis continuing on dual- purpose traits. Genetic evaluations of number born, 120-day weaning weight (both as a direct measure of animal performance and as a trait of the dam's milk production), yearling gain, fleece weight, fleece grade, and staple length are currently conducted for Targhee breeders by the U.S. National Sheep Improvement Program (NSIP) (Bradford, 2003). Estimates of genetic merit for these traits are available for individual animals considered for selection. Estimates of phenotypic and genetic parameters for NSIP Targhee data were presented by Notter and Hough (1997), and Rao and Notter (2000).

Chapter 3 Materials and Methods

3.1 General

The aggregate breeding value is commonly defined as a linear function of breeding values (BV) for economically important traits. The economic value for each trait is the partial regression coefficient of the aggregate breeding value on the BV of the trait (Hazel, 1943), and can be estimated as the effect of a one-unit change in BV holding all other BV constant. In this study, traits included in the breeding objective were those for which expected progeny differences (EPD) are calculated in the National Sheep Improvement Program (NSIP) Targhee genetic evaluation (Table 3.1). An animal's individual aggregate breeding value was then estimated by weighting each EPD by its economic value (Schneeberger et al., 1992).

In the Targhee, a non-linear relationship exists between profit and BV. Market prices for wool and lamb differ with the quality of fleece and weight of lamb at market, respectively. Also, litter size, which is categorically expressed, varies in its frequency distribution with ewe age. Therefore the change in profit from a genetic change in performance was influenced by the change in the shifting of phenotypic distributions of many traits. When performance is close to a major price break or litter size threshold, the value of shifting mean performance is likely higher then when performance is further away from a price break or litter size threshold. Phenotypic distributions were therefore predicted for each trait and the effect of a one-unit change in BV holding all other BV constant was derived by simulation as the changes in flock costs and returns.

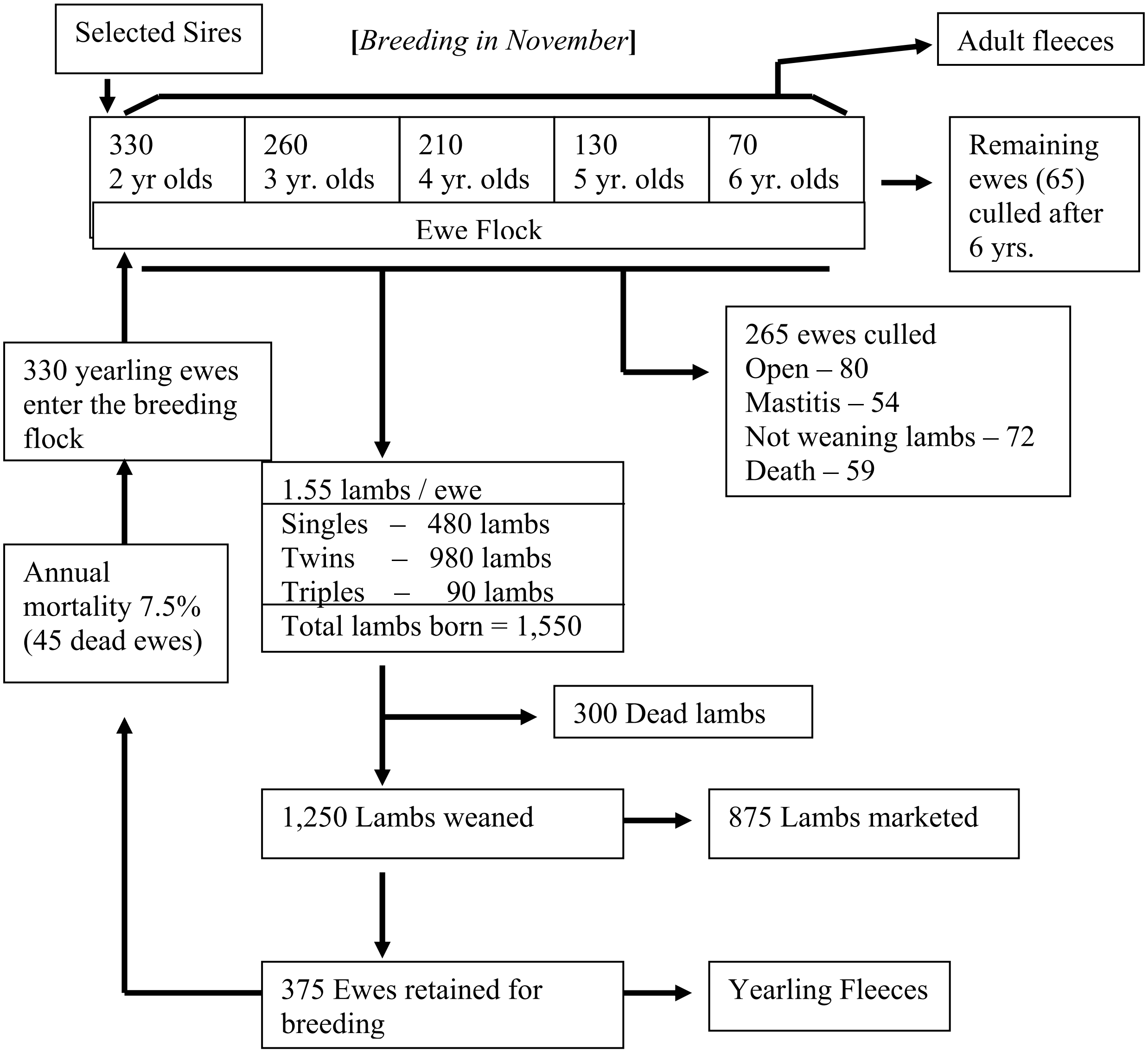
Table 3.1 Summary of traits in theTarghee NSIP genetic evaluation.

Trait	Abbreviation and units	Description	Additive standard deviation
Weaning weight	WW, kg	Weight at weaning (120 d)	1.980 kg
Maternal milk	MM, kg	A ewe's genetic value for milk production measured in lamb weaning weight	1.616 kg
Yearling weight	YW, kg	Weight at one year of age	2.896 kg
Fleece weight	FW, kg	Yearling fleece weight	0.358 kg
Fiber diameter	FD, microns	Fiber diameter of yearling fleece	0.986 microns
Staple length	SL, cm	Length of staple of a yearling fleece	0.742 cm
Percent lamb crop	PLC, lambs	Number of lambs born per 100 ewes lambing	17.576 lambs

3.2 Model

A commercial Targhee flock was simulated, representing a complete production system in a typical Montana Targhee environment (Figure 1). A base flock was generated and ewes were assumed mated to sires of specified BV to produce a single lamb crop. Costs and returns for this lamb crop were evaluated considering both lambs sold to market and the performance of selected ewes retained for breeding. Replacement ewe performance included an evaluation of the ewes' lamb production from the time they entered the breeding flock until the anticipated time of culling. Three generations of ewes are considered; generation zero (Gen 0) are the ewes in the base flock, generation one (Gen 1) are the progeny of Gen 0 mated to selected sires, and generation two (Gen 2) are the progeny of Gen 1 replacement ewes mated to breed average sires. A base-line level of profit was derived as income minus expenses (P = I – E) for a cohort of lambs by sires with mean BV for all traits set equal to the anticipated population mean.

Figure 3.1 Diagram of a typical Targhee production system with a base ewe flock of 1,000 ewes and an average lamb crop of 1.55 lambs per ewe lambing.



Economic values for each breeding objective trait were determined as the change in profit from exposing the base ewe flock to sires with EBV values that averaged one additive standard deviation more than the mean for each trait (Table 3.1), while holding EBV for all other traits at breed average. Breed estimates of additive variances were available in the literature (Notter and Hough, 1997; Rao and Notter, 2000; Bromley et al., 2000; Hanford et al., 2003); however, new estimates were calculated for this analysis (Table 3.1) using procedures presented by Notter and Hough (1997). The EPD's of sires that rank in the top 2-3% of the population for each trait generally differ from the population mean by approximately one additive standard deviation. Therefore, the changes in mean performance used to estimate profit can be obtained through intensive selection for a specific trait.

Three years of animal performance records (2000 through 2002) from four large Montana flocks participating in NSIP were analyzed to determine flock dynamics and phenotypic distributions of performance traits. The frequencies of ewes in each age category were similar among flocks (Table 3.2), so a constant ewe age distribution was assumed. Differences in prolificacy were observed in the data, with means for adult ewes in different flocks that ranged from 1.46 to 1.70 lambs born per ewe lambing. Three baseline levels of prolificacy (1.40, 1.55, 1.70 lambs per adult ewe for low, medium, and high levels, respectively) were therefore considered. Variation in flock prolificacy may be due to genetic and/or environmental differences. However, management plays a large role in the definition of phenotype for this trait, so differences were assumed to be environmental.

Ewes were randomly placed into fertility groups (pregnant or open) assuming 92% fertility within a breeding period of 34 d (two estrous cycles). Litter size was established for each pregnant ewe assuming the trait had an underlying normal distribution. Open ewes included all ewes that did not conceive or did not carry a lamb to term. Observed litter size data were used to establish the frequency of single, twin and triplet litters for each age group and flock prolificacy level. Frequencies of birth type were converted to an underlying normal distribution scale with a mean equal to zero and variance equal to one for 2-year-old ewes with a medium prolificacy level, where standardized values of 0.25 and 2.29 were the threshold values for changes in litter size from 1 to 2 and from 2 to 3. Frequency of birth types for other ewe age groups were then converted to an underlying scale with means adjusted for different levels of prolificacy (Table 3.2).

Changes in baseline prolificacy level were achieved by shifting the mean of the underlying scale for litter size to create the anticipated change in PLC. In the current population, a shift of +0.3 standardized units was equivalent to a PLC change of 15%. Incrementing of the PLC EPD was similar, with a change of +0.18 standardized units equaling a one additive standard deviation change of approximately 8.79% in PLC. After shifting the mean standardized values in each age group, new single, twin and triplet frequencies were determined based on the number of ewes above or below each threshold. Shifting the underlying mean of a normal distribution and using threshold values for type of birth resulted in values that were consistent with observed frequencies of singles, twins, and triplets in ewes of different ages (Table 3.2).

Table 3.2 Ewe age distribution and percent lamb crop by ewe age for flocks with different prolificacy levels

		Level of prolificacy [a, b]		
Ewe age	Frequency	Low	Medium	High
2	33%	1.28 (-*0.3*)	1.42 (*0.00*)	1.54 (*0.30*)
3	26%	1.40 (*0.05*)	1.52 (*0.35*)	1.70 (*0.65*)
4	21%	1.50 (*0.23*)	1.64 (*0.53*)	1.82 (*0.83*)
5	13%	1.55 (*0.33*)	1.70 *(0.65)*	1.84 (*0.93*)
6	7%	1.54 (*0.33*)	1.72 *(0.65)*	1.82 (*0.93*)

[a] Average lamb crops of 1.40 = Low, 1.55 = Medium, 1.70 = High lambs/ewe lambing

[b] Adjustment to the mean on the underlying scale of standardized values are in parentheses for each age group

Performance data from NSIP did not include measures of adult body weight. Actual body weights from 1 through 6 years of age were available from the Montana State University (MSU) Targhee flock data and were used to estimate changes in body size in adult ewes. A consistent phenotypic correlation of 0.60 was observed for body weights between adjacent years. Variation in predicted yearling weights, observed mean body weights and this correlation, were used to predict ewe body weights. Additionally, data was not available for determining management practices that are unique to the

Targhee breed Personal communication with extension specialists and producers helped identify management practices that are used in the system. For example, adult ewes are culled if they do not become pregnant or after 6 years of age, and ewe lambs are selected as replacements based on body weight. Both are common management practices for Targhee producers.

The simulation was modeled to derive phenotypic values of performance for a given system and production level. Phenotypic values for growth and fleece characteristics were assigned randomly to individuals in each simulation, while flock structure was maintained for each level of production with consistent ewe age distributions and ewe culling rates. Breeding values of individual animals were not determined. Instead, phenotypic distributions with different means were used to create flocks with different performance levels.

A flock was simulated based on the production system in Figure 3.1 where 5,000 ewes were randomly assigned to age, fertility, litter size, culling, and survival classes from a uniform distribution based on frequency values in tables 3.2 and 3.5. Fertility groups were then formed and open ewes were assumed culled.

Lamb survival was randomly determined for each litter size category based on mortality rates found in the literature (Vetter, 1960; Shelton, 1964; Iman and Slyter, 1996). Ewe age and lamb sex were assumed to not affect lamb survival (Smith, 1977; Ercanbrack and Knight, 1985; Iman and Slyter, 1996). Lambing date was calculated as 147 d after an assigned mating date; in each of the two simulated estrous cycles 70% of open ewes became pregnant at random throughout the anticipated 17-d estrous cycle (Kott and Thomas, 1987).

Table 3.3 Actual phenotypic means and variances of each production trait from NSIP data .

Traits	Means	Phenotypic variance
Fleece weight kg	3.91	0.26
Fiber grade, microns	22.21	1.85
Staple length, cm	8.51	0.98
Adj. Birth weight, kg	5.04	0.83
Adj. Weaning weight, kg	38.27	45.25
Yearling weight, kg	51.81	44.64
2 Year weight, kg	57.51	38.49
3 Year weight, kg	62.58	41.36
Adult weight, kg	65.70	49.88

Phenotypic measures of body weight and fleece characteristics were assumed to be normally and randomly distributed about a trait's mean. The mean and phenotypic variance for each trait was obtained from NSIP data on the Targhee breed (Table 3.3). Adjusted WW were assigned and then deterministically de-adjusted for type of birth and rearing, age of ewe, and sex of lamb using NSIP multiplicative adjustment factors (Bradford, 2003) to calculate unadjusted, phenotypic values of WW at a constant age. Phenotypic values for growth traits were stochastically generated for an individual when the trait was assumed correlated with the performance of other traits. Regression coefficients were calculated by multiplying the phenotypic correlation by the standard deviation of the trait being generated and dividing by the standard deviation of the correlated trait. For example, each lamb was randomly assigned a birth weight that was generated from a normal distribution with a mean of 5.04 kg and phenotypic standard deviation of 0.91 kg (Table 3.3). To correlate this trait with WW, birth weight for each lamb was corrected for the individuals WW by adding the regression of birth weight on WW to the individual's birth weight value. This birth weight was multiplied by one minus the square root of the squared phenotypic correlation between birth weight and WW. The resulting product was then added to the corrected mean birth weight to generate an individual's adjusted birth weight. A phenotypic correlation of 0.32 was assumed for birth weight and WW and the randomly assigned adjusted birth weights were then de-adjusted for type of birth and sex of lamb (Bradford, 2003) to determine phenotypic values.

Pre-weaning average daily gain (ADG) was calculated for each lamb by subtracting the raw values of birth weight from WW and dividing by a standard age of 120 d. Phenotypic values for market weight were then assumed to be the age of each lamb when the average age of the lamb flock was 150 d multiplied by its own ADG which was then added to its birth weight.

Yearling weight was calculated as the phenotypic 120 d WW plus a measure of post-weaning gain (PWG), where PWG was only determined for ewe lambs retained as replacements. Post-weaning gain is a measure of weight gain between 120 d WW and 1 yr of age and is recorded as kg of gain per day. A value of PWG was stochastically assigned assuming a phenotypic correlation of –0.23 between WW and PWG. Phenotypic values of PWG were multiplied by 245 d and added to the phenotypic WW to estimate YW (body weight at 365 d). Adult weights for 2, 3 and ≥4 years of age were also stochastically generated for each age class and assumed to be correlated with adjacent age class. Mean phenotypic weights for each age class, along with a phenotypic correlation of 0.60 between each annual weight, were based on MSU Targhee data.

Phenotypic values for fleece traits were stochastically assigned from normal distributions where FW was assumed correlated to WW with a phenotypic correlation of 0.34. An individuals FD and SL were assumed to be correlated to their phenotypic FW with correlation values of 0.27 and 0.30, respectively. Phenotypic fleece characteristics for adult ewes were assigned just as yearling fleece values were determined. However, to estimate phenotypic values for FW and FD, the randomly assigned measures were adjusted for age of ewe.

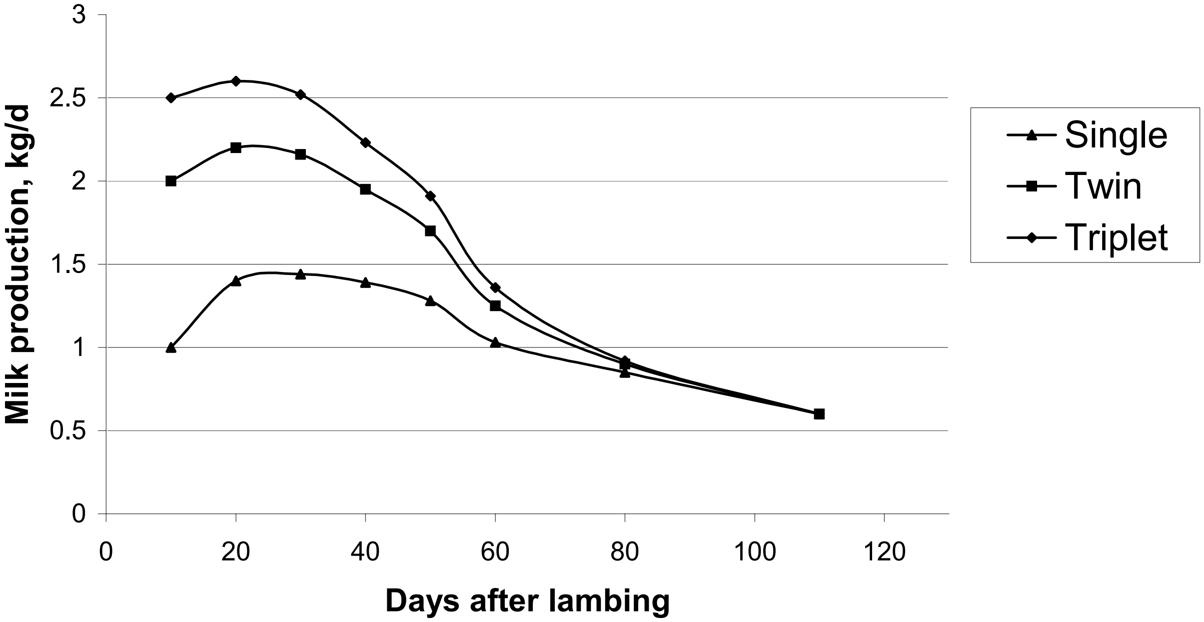
Energy requirements were deterministically calculated based on body weight, age, and sex, using ARC (1980) and NRC (1985) recommendations for sheep. Profit was calculated from changes in lamb market size, fleece characteristics, and feed intake, reflecting differences in both level of production and of prices for market lamb, wool and feed.

3.3 Lamb Performance

Average birth weights of 5.7 kg, 4.7 kg, and 4.1 kg for singles, twins and triplets, respectively, were simulated based on performance records in Montana flocks. Survival was assumed to differ with litter size. Lambs from single and twin litters were assumed to have survival rates of 90% and 80% respectively, while survival of triplet lambs was allowed to take values of 50 or 67%, depending upon lambing management (Kott and Thomas, 1987; Iman and Slyter, 1996). Both levels of triplet survival were considered for this analysis. Most pre-weaning lamb mortality occurs in the first 5 d of life (73%; Safford and Hoversland, 1960), and was assumed not to be influenced by age of ewe (Smith, 1977) or sex of lamb (Iman and Slyter, 1996; Ercanbrack and Knight, 1985), so rearing costs of lambs that died were not considered. Ewes were assumed to raise only their surviving lambs; fostering of lambs was not considered. Overall lamb survival was close to 80%, similar to literature values of 77.5% (Safford and Hoversland, 1960) and 83.4% (Shelton, 1964).

Lamb growth rates were modeled from NSIP production records. Energy requirements for the observed growth rates were estimated based on recommendations from ARC (CAB, 1980) and NRC (1985). Energy for maintenance and growth of lambs for the first 30 d of life was assumed to be derived only from consumption of milk. Mean lactation curves where calculated for ewes nursing singles, twins, and triplets from the results of Ramsey et al. (1994 and 1998) and were used to estimate milk consumption of lambs through the rearing period (Figure 3.2). Milk production of ewes rearing twins and triplets was increased by 60 and 100%, respectively, when compared to ewes of the same age rearing singles. Gross energy value of milk (kJ/kg) was calculated as [2035 + 34.45 * (g fat/kg)] (CAB, 1980). At an assumed average of 9.13% milk fat (Ramsey et al., 1998), the estimated energy content was 5.18 MJ/kg . When expected energy intake from milk production did not meet requirements for growth after 30 d, dry matter intake (DMI) from forage was assumed to meet predicted requirements.

Figure 3.2 Assumed lactation curves for Targhee ewes nursing single, twin, or triplet lambs



The total digestible nutrients (TDN) required for maintenance and gain of lambs was calculated from expected growth rates and predicted energy densities of gain (CAB, 1980). Energy density (ED) of gain was calculated as an average for ewe and wether lambs (CAB, 1980), and lamb growth was divided into four different lactation stages: 0 to 30, 31 to 60, 61 to 90, and 91 to 120 d. All TDN requirements for lambs during lactation were assumed to be met with milk and (or) forages.

Maintenance requirements of suckling lambs were assumed to be met by milk intake in lambs below 90 d of age. Excess nutrients from milk were used for lamb gain. Digestibility of gross energy at maintenance from milk was 95% while efficiency of ME use from milk for maintenance was 85% (CAB 1980). Average body weight of lambs in each lactation stage was used to calculate net energy (NE) for maintenance, based on ARC (1980) estimations, and the resulting calculation was multiplied by the number of days in each stage. Very little DMI was required for growth in the first 30 d, so NE for maintenance was calculated for milk-fed lambs as $[0.35(Wt/1.05)^{.75} + (0.0106*Wt)]$ (CAB, 1980). Net energy for maintenance of lambs on a mostly ruminant diet, where little milk is available and forage intake is the main source of energy, (>90 d) was calculated as [0.251(Wt/1.08)$^{.75}$ + (0.0106*Wt)] (CAB,1980). The NE for maintenance of lambs suckling during stages 2 and 3 of lactation (31 to 90 d) was calculated as the average of values for milk-fed and ruminant diets. In the fourth stage of lactation, milk did not meet maintenance requirements, so forage DMI was assumed to met additional needs. The average digestibility of available forage (summer range) was assumed to be 65% (NRC, 1985). The ME requirements from range was calculated as NE/0.85, and TDN requirements were calculated as ME/15.06 (assuming a constant 3.08 MJ of ME/kg TDN). The DMI was then determined as TDN divided by digestibility of the range.

Energy density (ED) of lamb gain was initially calculated for twin-born lambs as an average of ewes and wethers and adjusted for frame size. An adjustment of ED * 0.925 was used to account for a larger frame size than lambs considered by ARC (1980). A small percentage of suckling lambs were triplets, therefore ED was assumed to be the same for triplets and twins. Different calculations for ED are required for milk-fed versus ruminant lamb diets. Milk-fed ED = [(4.634 + 0.405 *Wt) *0.925] and was used for lambs <30 d, while ED of lambs on a ruminant diet was equal to [(3.25 +0.385 * Wt) * 0.925] (CAB, 1980). Energy density of lambs between 31 and 90 d was calculated as the average of the two equations. Single lambs were assumed to have ED values proportional to their increased body weight relative to twin lambs of the same age, so ED = (Single Wt / Twin Wt)*(Twin ED). Post-weaning ED values for market lambs were calculated for lambs consuming a ruminant diet, and ED for ewe lambs retained as replacements were calculated as: ED = [(2.1 +0.45*Wt) *0.925] (CAB, 1980). Average weights and estimated ED values for each stage of lamb production are summarized in Table 3.4.

Table 3.4 Average body weight and energy density values considered for multiple reared lambs at different stages of lamb production.

Stage of lamb growth	Average weight (kg)	Average energy density of gain (Mj/kg)
< 30 d	7.96	7.27
31-60 d	16.06	9.52
61-90 d	22.36	11.85
91-120 d	26.64	12.49
Post weaning market lamb	36.46	17.12
Post weaning replacement ewe	41.98	19.42

Daily energy requirements for lamb growth (MJ/d) were calculated as the product of daily gain (kg/d) and ED (Mj/kg). Milk NE not required for maintenance was used to meet NE requirements for gain using a digestibility of milk gross energy for gain of 93% and an efficiency of milk ME for gain of 70%. Additional requirements for gain not met by milk were achieved from DMI of range with an efficiency of ME for gain of 0.422 (CAB,1980). The ME from range DMI was converted to TDN assuming 3.08 MJ/kg.

Requirements for maintenance and gain in the post-weaning stage were assumed met from DMI of available winter range. Ewe lambs were selected for breeding at an average age of 150 d based on phenotypic size. Ewe lambs were sorted by body weight. The heaviest 54 to 63% (depending on number weaned and culling/death rates) of ewe lambs were assumed to be selected as replacement ewes. However, to account for subjective selection, it was assumed that a random 5% of the selected group would be removed and sold as market lambs (R. Kott, personal communication). Enough lambs were retained for breeding to maintain a constant ewe flock size. Mortality from weaning to first lambing was assumed to be constant at 7.5% annually. Ewe lambs were assumed to continue to grow at a restricted rate to an average yearling weight of 51 kg (R. Kott, unpublished MSU data).

Yearling fleeces were assumed to be harvested from replacement ewe lambs in February at an average age of 10 mo. Fleece weights of yearling lambs were modeled from NSIP production data, which are adjusted to a constant age of 365 d. Yearling fleece weights were then de-adjusted to account for age of lamb at shearing. Yearling mean fleece weight and fiber diameter values from observed data were 3.91 kg and 22.2

microns, respectively. Staple length was determined based on an observed mean value of 8.21 cm. Energy requirements for fleece growth (Mj/yr) were spread equally over the year and calculated as [(Fleece Wt. *0 .022 – 1.318)* 365] (CAB, 1980).

Market lambs were assumed to be sold in mid-September at an average age of 150 d. Market lamb weights were estimated by assuming the same growth rate as in the last portion of the nursing stage (91 to 120 d). The resulting mean market weight was 40 kg.

3.4 Ewe Production

Replacement ewes were bred to lamb for the first time at 2 yr of age and remained in the flock until culled for reproductive failure, health problems, age (after 6 yr), or death. Annual mortality of 7.5% for adult ewes was assumed (Nass et al., 1977; Walker et al., 1993). Reproductive failure includes all ewes not pregnant after one breeding season, and these ewes were assumed culled. A pregnancy rate of 92% was assumed for a breeding season starting November 1, which is consistent with other reports from the breed (91.3%, Iman and Slyter, 1993; 85 to 88%, Ercanbrack and Knight, 1998; 87%, Sagari et. al., 1993).

Ewes were assumed shorn before lambing. The mean fleece weight of adult ewes was 5.01 kg. Mean yearling fiber diameter (22.2 microns) was adjusted to predict adult fiber diameter by adding 0.7, 1.2, 1.6, 2.0, and 2.2 microns to the yearling mean for 2, 3, 4, 5, and 6 year old ewes, respectively (Atkins, 1990). Mean values and variation in staple length were assumed to be similar to those for yearling fleeces. Energy requirements for fleece growth in adult ewes were calculated in the same way as those for yearling ewes.

3.5 Ewe Growth

Growth of ewes was modeled from observed ewe weights in the MSU Targhee flock. Mean body weights for each ewe age group were determined and phenotypic correlations between each year’s weights were calculated. To estimate ewe growth, variation in weight in each year was assumed to account for 36% of the variation in the next year’s weight. Net energy required for gain was calculated from the ED equation for ruminant ewe lambs. Mean body weights of yearling, 2-yr-old, 3-yr-old, and mature (≥ 4 yr) ewes in the base flock were 51.1 kg, 57.6 kg, 62.6 kg, and 65.8 kg, respectively.

3.6 Gestation

Ewes were only charged for extra energy requirements for gestation in the last 60 d of gestation (CAB, 1980). Winter range was assumed available for the entire gestation period, and grain supplement was assumed provided for 30 d before lambing to meet the increasing energy requirements of gestation. Ewe body size and average litter birth weights were used to determine NE requirements for gestation (NRC, 1985; CAB 1980). A 5.45 kg fetus (single) would require 253 MJ of NE over the last 60 d of gestation. Fetal weight was determined as the total birth weight of all lambs born in a litter. An adjustment of 52.11 MJ of NE per kg of fetus was used for heavier or lighter litters (NRC 1985; CAB 1980).

3.7 Lactation

Milk production was assumed to follow the lactation curves in Figure 3.2. Supplementation of a grain / alfalfa hay mix was assumed to meet additional NE requirements for production in early lactation. The ME for milk production of each ewe was determined from ARC recommendations (CAB, 1980). Utilization of ME for milk production was 0.60, and milk yield followed the predicted lactation curve with an average production of 1.0, 1.6 and 2.0 kg/day for ewes nursing singles, twins and triplets, respectively. A baseline value of 1,900 MJ per lactation of ME for milk production was determined for an adult ewe nursing a single lamb (CAB, 1980). Requirements were adjusted based on predicted milk production; each additional kg of milk required an additional 7.9 MJ of ME (CAB, 1980).

3.8 Maintenance

Maintenance energy accounts for over 55% of total energy requirements for the adult ewe. The NE for maintenance was calculated with the same equation as that used for ewe lambs consuming a ruminant diet; therefore changes in body size had a large effect on maintenance requirements.

3.9 Dry Matter Intake

This system relied on summer and winter range to for all forage requirements, with winter range as the limiting resource. Winter range has an average TDN value of 55% (NRC 1985) and was assumed utilized from mid-August to mid-May. Summer forage was available for the remaining months with an average TDN value of 65% (NRC 1985).

Total energy requirements (MJ of ME) were calculated and categorized into those for suckling lambs, post-weaning market lambs, post-weaning replacement ewes, fleece growth, ewe growth, ewe maintenance, gestation, and lactation. Dry matter requirements were then estimated for summer and winter range, gestation supplementation (grain), and lactation supplementation (alfalfa / grain mix). Values for purchased feeds are listed in Table 3.5.

Feed costs were valued as 10-yr averages of regional prices for each feed type (NASS, 2003). However, the cost of forage DM can vary greatly, depending on how both summer and winter range are valued. Feed costs were estimated for three scenarios, with additional range requirements met by purchasing hay, renting more rangeland, or scaling the flock size to maintain a constant level of winter forage consumption. All scenarios assume that baseline production was operated at a level that fully utilized available range. For renting rangeland, a ewe was assumed equal to 0.35 animal units (AU) (MontGuide. 1997). The cost associated with each scenario represented different levels of range value. When winter range consumption was maintained by scaling back the flock size, the effective cost of additional energy was high, while renting additional range represented a much lower cost.

Reducing flock size was considered when changes in performance increased the requirements for winter DMI. This placed a biological cost on range because it assumed a constant level of range DMI by the flock, regardless of any production level changes. When more DM is required for an increase in production, fewer ewe lambs were assumed to be retained for breeding to account for additional forage requirements. Therefore, economic values were calculated as the revenue from production over a fixed level of range DM. Availability of winter range was assumed to control flock size and to be the limiting feed resource. When flock size was reduced due to an increase in performance, reductions in alfalfa hay and grain supplementation were assumed to lower feed costs. However, when less summer range was utilized, potential revenue from unused DM was assumed not to be realized. Differences in forage costs with a constant winter forage resource were calculated after determining animal performance. The reduction in the number of ewe lambs retained for replacements was determined by the percentage change in winter range requirements to support the predicted increase in performance. Lambs that were not retained for breeding were assumed sold at an average market lamb price.

3.10 Income

Revenue from fleece, market lamb, and cull ewe sales were considered as sources of income for the flock. Prices are summarized in Table 3.5 and represent averages over the past 10 years. Values of fleece and market lambs ($/kg) depend on fiber diameter and body weight, respectively, while cull ewe value is assumed constant at $ 0.66/kg.

Wool falling into the fine-wool category (<23 microns) is worth more per kg than course wool (>25 microns) (Table 3.5). Revenue from the entire flock distribution of fleece value was considered to account for non-linear pricing of wool relative to fiber diameter. Staple length also influences wool value, with fibers of less than 7.35 cm having a decreased value (R. Kott, personal communication). However, in the current population the number of fleeces below that threshold was very small. Staple length therefore did not influence economic values.

Market lamb value ($/kg) was based on phenotypic weight. A value of $1.69/kg was used for lambs sold at ≤ 43 kg (Table 3.5). A reduction in value was also considered for animals over 43 kg. Lambs that weighed more than 43 kg were valued as though they weighed 43 kg, with a constant value of $ 72.67. No options for retained ownership or alternative marketing were considered.

Income generated over multiple years of production was discounted to its current value, using the discount method in McClintock and Cunningham (1974) and a discount rate of 5.0%.

3.11 Economic Values

Economic values of performance traits were determined as an average of twenty replications of the simulation for each combination of prolificacy level (3), triplet survival rate (2), forage cost (3), and lamb value (2). Economic values represent the change in profit from a standardized change in performance for a specific trait. To express these values in EPD units, index weightings for each trait were calculated as the economic value of a trait divided by one additive standard deviation for that trait (Table 3.2). For convenience, index weightings were further converted to a relative weighting with respect to WW by expressing index weights of each trait as a proportion of the WW index weight. Selection indexes were then developed with the resulting index weights for each set of economic values.

3.12 Statistical Analysis

Economic values for each trait were compared over all simulation replicates using the mixed models procedure in SAS (SAS Inst., Inc., Cary, NC). Effects of prolificacy, triplet survival, forage cost, lamb value, and their interactions on each trait's economic values were determined. When economic values did not significantly differ across a factor, the economic values for each trait were averaged together. Replicated simulations did not consider the full range of stochastic variables that might be anticipated to contribute to variation in costs and returns among different flocks. For example, replicated flocks assumed the same ewe age distributions, with similar mean values of performance. Residual variances are therefore likely underestimates of the true values and resulting F-tests may overestimate significance levels. For this reason, only effect and interactions that were significant at $P<0.001$ were considered indicative of differences in breeding objectives. Correlations between breeding objectives were used as an alternative measure of similarity of breeding objectives (Smith, 1983). Final indexes were determined by correlating index values from individual scenario combinations with indexes that were averaged over various sets of scenarios.

Table 3.5 Overview of production parameters

Production and Management variables	Values	Production and Management variables	Values
Average lamb crop per ewe for different prolificacy levels		Average ME/kg	
Low	1.40 lambs	Grain (Barley)	11.464 MJ/kg
Medium	1.55 lambs	Alfalfa hay	7.6149 MJ/kg
High	1.70 lambs	Grass hay	8.20 MJ/kg
Culling rates		Economic value of feed ($/kg)	
Mastitis [a]	0.09	Grass hay	$.074/kg
Did not wean lamb [b]	0.08	Alfalfa hay	$ 0.085/kg
Reproductive failure	0.08	Renting rangeland	$ 12.90/month/AU
Age	0.07	Grain (Barley)	$ 0.0798/kg
Annual ewe mortality post-weaning [c]	0.075	Market prices	
		Market lamb value [d]	$ 1.69/kg
Pre-weaning mortality		Fleece price	
Single	0.10	Fine (<23 microns)	$ 1.77/kg
Twins	0.20	Medium (23-25 microns)	$ 1.65/kg
Triplets	0.33 and 0.50	Course (>25 microns)	$ 1.54/kg
		Adult ewe cull value	$ 0.664/kg
Average TDN values			
Winter range	0.55		
Summer range	0.65		
Grain (Barley)	0.76		
Alfalfa hay	0.58		
Grass hay	0.55		

[a] Frequency of mastitis = 0.06 for age 3 and 4.

[b] Frequency of not weaning a lamb = 0.12 for age 5 and 6.

[c] Annual ewe mortality = 0.125 for age 5 and 6.

[d] Lambs > 43kg = $72.67/head

Chapter 4 Results

Table 4.1 compares simulated adjusted phenotypic means and standard deviations for production traits with values observed from NSIP animal records. Prolificacy levels for the simulation were also derived from observed records, where overall frequencies of different birth types varied among flocks. Table 4.2 shows simulated and actual NSIP flock frequencies of single, twin, and triplet litters for three levels of flock prolificacy. A total of 2,102 lambing records from four flocks over 3 years were used to obtain actual frequencies of single, twin, and triplet births. Three levels of average PLC were observed for the NSIP flocks, ranging from 1.45 to 1.70. Frequencies represent the proportion of each litter type among ewes that lambed for each age category. Older ewes had an increased proportion of multiple births. Based on the values in tables 4.1 and 4.2, the simulation was an adequate representation of a Targhee production system.

Table 4.1 Mean performance levels from four NSIP Targhee flocks and for the simulated base flock.

	Actual NSIP performance data		Simulated performance data	
Trait	Mean	Standard. Dev.	Mean	Standard. Dev.
Fleece weight, kg	3.91	0.51	4.03	0.55
Fiber grade, microns	22.21	1.36	22.25	1.38
Staple length, cm	8.51	0.99	8.53	1.02
Adj. Birth weight, kg [a]	5.04	0.92	4.94	0.93
Adj. Weaning weight, kg [a]	38.27	6.73	38.31	6.18
Yearling weight, kg	51.81	6.68	51.12	6.54
2 Year weight, kg	57.51	6.20	57.64	6.26
3 Year weight, kg	62.58	6.43	62.59	6.39
Adult weight, kg	65.70	7.06	65.84	6.94

[a] Weights are adjusted for sex of lamb, type of birth, type of rearing, age of the dam, and age of lamb for weaning weight. Lamb weights are adjusted to a based of a ewe lamb born and reared as a single from an adult ewe (>3 yr.) and weaning weights at 120 d.

Table 4.2 Average percent lamb crop (PLC) and proportions of single, twin, and triplet litters by ewe age for different flock prolificacy levels.

	Actual NSIP flock means				Simulated Performance			
		Frequency of litters				Frequency of litters		
Ewe age, yr	Average PLC	Single	Twin	Triplet	Average PLC	Single	Twin	Triplet
2	1.45	0.657	0.331	0.010	1.40	0.722	0.271	0.007
3		0.606	0.391	0.003		0.600	0.388	0.012
4		0.494	0.498	0.008		0.453	0.526	0.021
≥ 5		0.441	0.534	0.025		0.468	0.509	0.023
2	1.56	0.662	0.331	0.007	1.55	0.616	0.370	0.014
3		0.352	0.625	0.023		0.472	0.500	0.028
4		0.367	0.595	0038		0.339	0.613	0.048
≥ 5		0.268	0.704	0.028		0.346	0.607	0.047
2	1.70	0.464	0.524	0.012	1.70	0.479	0.498	0.023
3		0.329	0.656	0.015		0.344	0.614	0.042
4		0.235	0.687	0.078		0.255	0.660	0.085
≥ 5		0.301	0.577	0.122		0.260	0.648	0.092

Simulated lamb production for specific prolificacy and survival levels is summarized in tables 4.3 through 4.8 by showing the weighted average of weaning weights and market lamb values of lambs assumed born from flocks of 5,000 ewes. Weights and values are shown for the base flock and for the flock after a change of one additive standard deviation in sire EBV for each trait in the breeding objective. Changes in EBV for fleece traits did not effect lamb production and are not shown. Both generation 1 (a single lamb crop from the base ewe population) and generation 2 (the lifetime performance of lambs sired by breed average rams and born from generation 1 ewes retained for breeding) are presented with and without discounting prices of heavy lambs. Generation 2 lamb values were also discounted for time until expression. Numbers of lambs weaned for the first generation lamb crop do not vary with selection so only the second-generation lamb numbers are reported. Weighted averages of market lamb value are shown for both 1st and 2nd generation lambs sold to a market that discounts heavy lambs and a market that does not discount heavy lambs.

Table 4.3 Number of lambs weaned and average weaning weight and market value of lambs in generations (Gen) 1 and 2 for a high-prolificacy high-survival flock before and after selection of rams for improved performance.

	Generation 2 [b]	Average weaning weight, kg		Average lamb market value, $ [c]			
Trait changed [a]	lambs weaned	Gen 1	Gen 2	D- Gen 1	D- Gen 2	ND- Gen 1	ND- Gen 2
None	6237	32.95	32.93	$ 62.11	$ 52.00	$ 65.11	$ 54.46
WW	6237	33.83	33.35	$ 63.33	$ 52.50	$ 66.96	$ 55.20
MM	6237	32.96	33.62	$ 62.16	$ 52.82	$ 65.16	$ 55.68
YW	6237	32.93	32.93	$ 62.11	$ 51.99	$ 65.08	$ 54.44
PLC	6488	32.92	32.52	$ 62.07	$ 51.55	$ 65.06	$ 53.76

[a] Denotes no changes (None)or a change of one additive standard deviation in weaning weight (WW), maternal milk (MM), yearling weight (YW), and percent lamb crop (PLC).

[b] Number of generation 1 lambs was constant at 6,183.

[c] Values are with (D) or without (ND) discounting of prices for heavy lambs.

Table 4.4 Number of lambs weaned and average weaning weight and market value of lambs in generations (Gen) 1 and 2 for a high-prolificacy low-survival flock before and after selection of rams for improved performance.

	Generation 2 [b]	Average weaning weight, kg		Average lamb market value, $ [c]			
Trait changed [a]	lambs weaned	Gen 1	Gen 2	D- Gen 1	D- Gen 2	ND- Gen 1	ND- Gen 2
None	6130	33.05	33.03	$ 62.27	$ 52.17	$ 65.33	$ 54.69
WW	6130	33.91	33.46	$ 63.42	$ 52.67	$ 67.15	$ 55.44
MM	6130	33.06	33.73	$ 62.24	$ 52.97	$ 65.34	$ 55.91
YW	6130	33.05	33.03	$ 62.23	$ 52.16	$ 65.29	$ 54.67
PLC	6332	33.06	32.69	$ 62.25	$ 51.83	$ 65.32	$ 54.13

[a, c] See Table 4.3 for abbreviations

[b] Number of generation 1 lambs was constant at 6,083

Table 4.5 Number of lambs weaned and average weaning weight and market value of lambs in generations (Gen) 1 and 2 for a medium-prolificacy high-survival flock before and after selection of rams for improved performance.

	Generation 2 [b]	Average weaning weight, kg		Average lamb market value, $ [c]			
Trait changed [a]	lambs weaned	Gen 1	Gen 2	D- Gen 1	D- Gen 2	ND- Gen 1	ND- Gen 2
None	5829	33.64	33.64	$ 62.78	$ 52.66	$ 66.50	$ 55.62
WW	5829	34.48	34.08	$ 63.85	$ 53.14	$ 68.28	$ 56.40
MM	5829	33.61	34.36	$ 62.75	$ 53.44	$ 66.44	$ 56.87
YW	5829	33.63	33.65	$ 62.75	$ 52.66	$ 66.48	$ 55.61
PLC	6096	33.62	33.20	$ 62.76	$ 52.27	$ 66.43	$ 54.89

[a, c] See Table 4.3 for abbreviations

[b] Number of generation 1 lambs was constant at 5,796

Table 4.6 Number of lambs weaned and average weaning weight and market value of lambs in generations (Gen) 1 and 2 for a medium-prolificacy low-survival flock before and after selection of rams for improved performance.

	Generation 2 [b]	Average weaning weight, kg		Average lamb market value, $ [c]			
Trait changed [a]	lambs weaned	Gen 1	Gen 2	D- Gen 1	D- Gen 2	ND- Gen 1	ND- Gen 2
None	5763	33.71	33.73	$ 62.82	$ 52.80	$ 66.64	$ 55.82
WW	5763	34.60	34.16	$ 63.93	$ 53.27	$ 68.43	$ 56.57
MM	5763	33.69	34.45	$ 62.85	$ 53.58	$ 66.57	$ 57.09
YW	5763	33.69	33.73	$ 62.81	$ 52.79	$ 66.55	$ 55.80
PLC	6004	33.70	33.31	$ 62.86	$ 52.44	$ 66.60	$ 55.11

[a, c] See Table 4.3 for abbreviations

[b] Number of generation 1 lambs was constant at 5,736

Table 4.7 Number of lambs weaned and average weaning weight and market value of lambs in generations (Gen) 1 and 2 for a low-prolificacy high-survival flock before and after selection of rams for improved performance.

	Generation 2 [b]	Average weaning weight, kg		Average lamb market value, $ [c]			
Trait changed [a]	lambs weaned	Gen 1	Gen 2	D- Gen 1	D- Gen 2	ND- Gen 1	ND- Gen 2
None	5431	34.46	34.50	$ 63.51	$ 53.45	$ 68.05	$ 57.17
WW	5431	35.36	34.95	$ 64.53	$ 53.90	$ 69.89	$ 57.97
MM	5431	34.49	35.22	$ 63.51	$ 54.19	$ 68.11	$ 58.48
YW	5431	34.45	34.50	$ 63.53	$ 53.46	$ 68.02	$ 57.18
PLC	5679	34.47	33.97	$ 63.51	$ 52.95	$ 68.04	$ 56.19

[a, c] See Table 4.3 for abbreviations

[b] Number of generation 1 lambs was constant at 5,364

Table 4.8 Number of lambs weaned and average weaning weight and market value of lambs in generations (Gen) 1 and 2 for a low-prolificacy low-survival flock before and after selection of rams for improved performance.

	Generation 2 [b]	Average weaning weight, kg		Average lamb market value, $ [c]			
Trait changed [a]	lambs weaned	Gen 1	Gen 2	D- Gen 1	D- Gen 2	ND- Gen 1	ND- Gen 2
None	5395	34.48	34.55	$ 63.54	$ 53.54	$ 68.12	$ 57.29
WW	5395	35.41	35.00	$ 64.59	$ 53.99	$ 70.06	$ 58.08
MM	5395	34.51	35.28	$ 63.56	$ 54.27	$ 68.14	$ 58.59
YW	5395	34.49	34.56	$ 63.51	$ 53.54	$ 68.05	$ 57.30
PLC	5627	34.50	34.04	$ 63.53	$ 53.05	$ 68.14	$ 56.33

[a, c] See Table 4.3 for abbreviations

[b] Number of generation 1 lambs was constant at 5,337

Changes in mean performance of fleece characteristics from selection for increased FW and SL and decreased FD are summarized in Table 4.9 and were similar over all prolificacy and lamb survival levels. Average measures of yearling fleeces are presented for both first and second generation lambs. Table 4.10 represents the average value of fleeces for generation 1 and generation 2 as well as the proportion of fine (<22.0 micron), optimal (≥ 22.0 and < 25.0 microns), and course (≥ 25.0 microns) fleeces. Values are discounted to account for time until expression. Ewes retained from the first generation lamb crop also had a cull value that was assumed to not differ among production levels. Changes in mean performance for growth traits had little effect on average adult weights and the discounted value of culled ewes ranged from $ 34.32 to $34.70 per ewe among selected groups.

Table 4.9 Average performance in adult and yearlings before and after selection for improved fleece characteristics [a].

Trait	Base Flock		After Selection		
				Yearling [c]	
Changed [b]	Adult	Yearling	Adult	Gen 1	Gen 2
FW, kg	5.00	4.00	5.17	4.18	4.09
FD, microns	23.55	22.26	23.05	21.77	22.02
SL, cm	8.56	8.56	9.03	8.94	8.74

[a] Values are averaged over all prolificacy and survival levels.

[b] Denotes a change of one additive standard deviation in fleece weight (FW), fiber diameter (FD), and staple length (SL).

[c] Generation 1 (Gen 1) and adult values represent fleece characteristics of progeny of rams selected for improved trait performance, Generation 2 (Gen 2) are progeny of Gen 1 ewes.

Table 4.10 Average value of a fleece and percentage of fine, optimal (opt.), and course fleeces before and after selection for improved fleece characteristics. [a, b]

	Generation 1								Generation 2			
	Yearling				Adult				Yearling			
Trait [c]		Wool Quality (%)				Wool Quality (%)				Wool Quality (%)		
Changed	Value, $	Fine	Opt.	Course	Value, $	Fine	Opt.	Course	Value, $	Fine	Opt.	Course
None	$ 6.55	71.14	27.00	2.85	$ 7.09	36.29	47.42	16.29	$ 5.55	69.96	27.71	2.34
FW	$ 6.83	70.69	26.88	2.43	$ 7.32	48.74	46.51	17.28	$ 5.66	70.51	26.74	2.75
FD	$ 6.59	81.15	17.93	0.92	$ 7.17	36.21	42.06	9.20	$ 5.56	77.65	20.86	1.49
SL	$ 6.54	69.93	27.90	2.17	$ 7.08	35.98	47.05	16.97	$ 5.53	69.40	27.76	2.84

[a] Wool quality is defined as fine (< 22.0 microns), optimal (≥ 22.0 and < 25.0 microns), and course (≥ 25.0 microns).

[b] Proportions and values are averaged over all production levels

[c] See Table 4.9 for abbreviations.

Changes in dry matter intake (DMI) are shown in Table 4.11 for flocks which purchase additional forage required to support increased performance or which have a fixed amount of winter range and therefore must reduce ewe numbers to accommodate increased performance. Estimates of DMI are presented for each feed source and for lambs and ewes of different generations. First generation lambs are progeny of the base flock and sired by rams selected for improved performance. Adult ewes represent those progeny of the selected rams retained as replacements in the flock. The performance of the progeny of these retained adult ewes, over the adult ewes productive life, are second generation lambs. Feed consumption for each category is expressed as the average DMI (kg) required per ewe bred in the base ewe flock.

Total receipts and costs associated with use of different sire types are shown in Table 4.12 for each forage cost scenario and with and without discounting of prices for heavy lambs. All values are discounted for time until expression. Both income and costs are expressed as the expected values associated with a single mating in the base population and includes lambs produced from those matings and lambs produced by replacement ewes retained from those matings. Changes in feed cost and receipts represent the changes in profit used for determining economic values for each trait, and are represented in Table 4.12 as proportional returns above feed costs relative to the base flock.

Table 4.11 Amount of feed consumed (kg dry matter per ewe bred in the base flock) when increased nutrient requirements are met by purchasing additional forage or reducing ewe numbers. [a]

		Winter Forage			Summer Forage			Lactation Mix	Gestation Mix
Scenario [b]	Trait Changed [c]	Gen 1	Adult	Gen 2	Gen 1	Adult	Gen 2	Adult	Adult
	None	152.24	318.24	148.38	41.97	214.22	42.24	85.26	31.36
Purchase forage	WW	155.58	318.42	150.53	43.25	214.18	42.88	85.42	31.41
	MM	152.24	318.26	150.30	41.97	216.57	42.24	86.34	31.36
	YW	156.16	318.57	154.19	41.97	214.17	42.24	85.49	31.53
	FW	152.39	318.50	148.44	41.97	214.29	42.24	85.28	31.36
	FD	152.21	318.25	148.38	41.97	214.23	42.35	85.26	31.36
	SL	152.23	318.26	148.38	41.97	214.23	42.35	85.26	31.36
	PLC	152.23	319.61	150.31	41.97	216.33	43.54	86.27	32.75
Reduce flock size	WW	152.24	311.58	148.38	43.25	209.58	41.96	83.59	30.74
	MM	152.24	318.26	148.38	41.97	216.57	42.24	86.34	31.36
	YW	152.24	310.56	148.38	41.97	208.79	41.18	83.34	30.74
	FW	152.24	318.18	148.38	41.97	214.07	42.20	85.19	31.33
	FD	152.21	315.25	148.38	41.97	214.23	42.35	85.26	31.36
	SL	152.23	318.26	148.38	41.97	214.23	42.35	85.26	31.36
	PLC	151.58	318.23	148.38	41.97	215.40	43.35	85.90	32.61

[a] Amounts are averaged over all prolificacy and survival levels.

[b] Purchased forage represents the average feed intake when purchasing hay or renting pasture. Reduced flock size refers to scaling the flock size to utilize a fixed resource.

[c] See tables 4.3 and 4.9 for abbreviations.

Table 4.12 Total cost and returns of different forage cost and market lamb value scenarios. [a]

Forage Cost	Trait Changed [b]	Feed Costs ($)	Receipts ($) [b] D	Receipts ($) [b] ND	Relative returns above feed cost [b] D	Relative returns above feed cost [b] ND
	None	$ 86.73	$ 117.68	$ 122.99	100.0	100.0
Purchased Hay	WW	$ 87.37	$ 119.52	$ 125.64	103.9	105.5
	MM	$ 87.19	$ 118.30	$ 123.99	100.5	101.5
	YW	$ 87.59	$ 117.75	$ 123.04	97.5	97.8
	FW	$ 86.77	$ 117.82	$ 123.13	100.3	100.3
	FD	$ 86.72	$ 118.11	$ 123.43	101.4	101.2
	SL	$ 86.73	$ 117.63	$ 122.95	99.8	99.9
	PLC	$ 87.45	$ 119.90	$ 125.05	104.9	103.7
Renting Pasture	WW	$ 87.35	$ 119.52	$ 125.64	103.9	105.6
	MM	$ 87.03	$ 118.30	$ 123.99	101.0	101.9
	YW	$ 87.19	$ 117.75	$ 123.04	98.7	98.9
	FW	$ 86.82	$ 117.82	$ 123.13	100.2	100.1
	FD	$ 86.70	$ 118.11	$ 123.43	101.5	101.3
	SL	$ 86.77	$ 117.63	$ 122.95	99.7	99.8
	PLC	$ 87.20	$ 119.90	$ 125.05	105.7	104.4
Reduce flock size	WW	$ 86.67	$ 119.05	$ 125.18	104.6	106.2
	MM	$ 86.65	$ 117.76	$ 123.44	100.5	101.5
	YW	$ 86.61	$ 115.97	$ 121.16	94.9	95.3
	FW	$ 86.72	$ 117.87	$ 123.20	100.6	100.6
	FD	$ 86.73	$ 118.07	$ 123.39	101.3	101.1
	SL	$ 86.73	$ 117.62	$ 122.92	99.8	99.8
	PLC	$ 86.85	$ 119.25	$ 124.38	104.7	103.5

[a] Scenarios are averaged over all prolificacy and survival levels.

[b] See tables 4.3 and 4.9 for abbreviations.

Economic values for each breeding objective trait are displayed in tables 4.13 and 4.14 for all prolificacy, survival, forage cost, and lamb marketing scenarios. Economic values express the expected change in returns above feed costs per ewe bred in the base population from selection to improve a specific trait.

Table 4.13 Economic values associated with a one additive standard deviation change in traits without discounting of heavy lambs for each forage cost, prolificacy, and survival combination. [a]

			Traits [b]						
Forage Costs	Prolificacy	Survival	WW	MM	YW	FW	FD	SL	PLC
Purchased	H	H	2.139	0.596	-0.804	0.101	0.454	-0.010	1.145
Hay	H	L	2.186	0.617	-0.819	0.103	0.476	0.144	1.367
	M	H	1.984	0.480	-0.867	0.109	0.421	-0.361	1.389
	M	L	1.968	0.499	-0.794	0.100	0.393	0.064	1.577
	L	H	1.916	0.518	-0.811	0.102	0.439	-0.086	1.237
	L	L	1.860	0.556	-0.793	0.100	0.492	-0.010	1.331
Renting	H	H	2.168	0.767	-0.393	0.049	0.482	-0.058	1.361
Pasture	H	L	2.226	0.791	-0.409	0.051	0.506	0.137	1.622
	M	H	2.003	0.638	-0.467	0.059	0.449	-0.403	1.636
	M	L	1.981	0.655	-0.393	0.049	0.413	0.008	1.843
	L	H	1.915	0.660	-0.420	0.053	0.464	-0.113	1.477
	L	L	1.858	0.699	-0.395	0.050	0.516	-0.031	1.587
Reduce	H	H	2.369	0.567	-1.778	0.224	0.402	-0.043	1.031
flock size	H	L	2.405	0.592	-1.804	0.227	0.410	0.116	1.258
	M	H	2.220	0.459	-1.759	0.221	0.363	-0.403	1.308
	M	L	2.214	0.484	-1.695	0.213	0.348	0.019	1.501
	L	H	2.170	0.506	-1.612	0.203	0.394	-0.137	1.220
	L	L	2.105	0.549	-1.589	0.200	0.460	0.026	1.323

[a] Denotes the high (H), medium (M), and low (L) levels of prolificacy and survival.
[b] See table 3.1 for abbreviations.

Table 4.14 Economic values associated with a one additive standard deviation change in traits with discounting of heavy lambs for every forage cost, prolificacy, and survival combination. [a]

			Traits [b]						
Forage Costs	Prolificacy	Survival	WW	MM	YW	FW	FD	SL	PLC
Purchased	H	H	1.361	0.196	-0.805	0.101	0.452	-0.106	1.238
Hay	H	L	1.399	0.259	-0.786	0.099	0.457	0.052	1.477
	M	H	1.180	0.174	-0.790	0.099	0.467	-0.033	1.595
	M	L	1.186	0.135	-0.804	0.101	0.362	-0.037	1.744
	L	H	1.040	0.107	-0.791	0.099	0.432	-0.046	1.410
	L	L	1.003	0.097	-0.766	0.096	0.442	-0.151	1.526
Renting	H	H	1.391	0.367	-0.394	0.050	0.480	-0.154	1.454
Pasture	H	L	1.439	0.432	-0.376	0.047	0.487	0.045	1.733
	M	H	1.199	0.332	-0.389	0.049	0.494	-0.075	1.843
	M	L	1.199	0.292	-0.403	0.051	0.382	-0.093	2.011
	L	H	1.038	0.248	-0.399	0.050	0.456	-0.073	1.650
	L	L	1.001	0.240	-0.368	0.046	0.467	-0.172	1.782
Reduce	H	H	1.592	0.184	-1.703	0.214	0.405	-0.139	1.151
flock size	H	L	1.620	0.249	-1.697	0.213	0.397	0.026	1.392
	M	H	1.414	0.172	-1.597	0.201	0.414	-0.074	1.542
	M	L	1.433	0.157	-1.590	0.200	0.341	0.047	1.651
	L	H	1.286	0.114	-1.497	0.188	0.392	-0.094	1.423
	L	L	1.242	0.109	-1.467	0.185	0.415	-0.116	1.547

[a] Denotes the high (H), medium (M), and low (L) levels of prolificacy and survival.
[b] See table 3.1 for abbreviations.

Table 4.15 show the results of a statistical analysis to determine if the different levels of prolificacy, triplet survival, forage costs, and lamb values had significant effects on each trait's economic values. Differences that were significant at $P<0.001$ were assumed to indicate that economic values for a trait differed depending upon the production levels or economic scenarios. Tests of significance were based on variation among replicated simulation, which likely underestimates the variation that would actually exist among different production units. This is the reason that $P<0.001$ was assumed as the critical level for determining significance.

Table 4.15 Tests of significance for effects of production level and economic scenarios on economic values for each trait.

	Trait [a]						
Effect	WW	MM	YW	FW	FD	SL	PLC
Prolificacy (Pro)	***	***					***
Survival (Surv)							***
Forage Cost (FC)	***	***	***	***			***
Lamb Value (LV)	***	***	***		*		***
Pro X Surv							
Pro X FC	***	*	***				***
Pro X LV	***	***			***	*	***
Surv X FC							
Surv X LV		*		***	**	***	
FC X LV	***		***				*

[a] See table 3.1 for trait abbreviations.
$^{*}P< 0.05$, $^{**}P<0.01$, $^{***}P<0.001$

Economic values can be considered separately for each scenario to give a large number of potential breeding objectives or averaged across various sets of scenarios to reduce the number of different breeding objectives. Table 4.16 presents breeding objectives averaged over all levels of ewe prolificacy and lamb survival for each lamb value and forage cost scenario. The weightings were converted to represent the economic value of an EPD unit for each trait. Breeding objectives that are calculated for each level of ewe prolificacy, lamb survival, forage cost, and lamb value scenario are listed in the appendix (Tables 6.1 and 6.2). An overall breeding objective was also calculated by averaging across all economic scenarios. A separate breeding objective was calculated as the average of the two forage cost scenarios involving procurement of additional feed to support additional production and contrasted to the breeding objective involving reductions in ewe numbers. Two levels of lamb value and two levels of forage cost (reducing ewe numbers or acquiring additional feed) were used to calculate a breeding objective for each forage cost by lamb value scenario.

Table 4.16 Breeding objectives (on an EPD scale) averaged across levels of prolificacy and triplet survival for different market lamb value and forage cost scenarios.

	EPD for: [a, b]						
Scenario	WW	MM	YW	FW	FD	SL	PLC
Overall [c]	1.703	0.497	-0.658	0.668	-0.880	-0.175	0.169
Lamb Value							
Discounting	1.291	0.266	-0.638	0.648	-0.873	-0.178	0.178
No Discount	2.112	0.730	-0.678	0.687	-0.888	-0.170	0.159
Forage Cost							
Purchase Hay	1.617	0.436	-0.554	0.563	-0.894	-0.129	0.162
Renting Pasture	1.632	0.631	-0.277	0.281	-0.946	-0.221	0.190
Scaled flock size	1.855	0.427	-1.142	1.159	-0.801	-0.176	0.155
Not scaled [d]	1.626	0.532	-0.416	0.422	-0.920	-0.175	0.176
Lamb Value by Forage Cost							
Discount x Scaled	1.445	0.202	-1.102	1.118	-0.799	-0.157	0.165
Discount x Not scaled	1.214	0.297	-0.407	0.413	-0.909	-0.191	0.185
No Discount x Scaled	2.266	0.651	-1.181	1.199	-0.803	-0.191	0.145
No Discount x Not scaled	2.035	0.770	-0.425	0.431	-0.930	-0.163	0.167

[a] See table 3.1 for trait abbreviations.

[b] Weightings for each trait are economic values for a one-unit change in EPD.

[c] Breeding objective weightings for each trait when all scenarios are averaged together.

[d] Weightings are averaged over purchased hay and renting pasture scenarios.

Breeding objectives derived for each prolificacy, survival, forage cost, and lamb value combination were correlated with each other and with each average breeding objective from Table 4.16. Correlations among individual breeding objectives ranged from 0.429 to 0.999. Tables 4.17 and 4.18 show correlations of individual breeding objectives with the average breeding objectives in Table 4.16. The overall breeding objective had correlations with individual breeding objectives that ranged from 0.802 to 0.995. Correlations with individual breeding objectives with average breeding objectives ranged from 0.859 to 0.998 for the two lamb value scenarios, and from 0.941 to 0.998 for the three forage cost scenarios. When the two forage cost breeding objectives that involved acquiring additional feed (purchased hay and renting pasture) were averaged, their correlations with individual breeding objectives ranged form 0.907 to 0.996. The smallest range of correlations was between the feed by lamb value breeding objectives (where feed value again was averaged for acquired feed and scaling scenarios) and their respective individual breeding objectives (0.968 to 0.999).

Intercorrelations between average breeding objectives in Table 4.16 were calculated, where strong correlations (> 0.90) indicate selection for different breeding objectives would have similar results (Smith, 1983). The correlation between objectives derived with or without discounting of lamb value was 0.915 and the intercorrelations among average forage cost breeding objectives were 0.97 between rent and purchase, 0.70 between rent and scale, 0.85 between purchase and scale, and 0.78 for scale and acquired additional feed (not scaled). Intercorrelations among lamb value by forage cost breeding objectives were less strong, indicating each breeding objective would result in somewhat different selection criteria.

Table 4.17 Correlations between individual and average breeding objectives when lamb value is not discounted for heavy lambs. [a]

			Correlations with average breeding objectives [b]				
Forage Cost	Prolificacy	Survival	Overall	LV	FC	FC*	LV x FC
Purchased Hay	H	H	0.933	0.983	0.949	0.962	0.990
	H	L	0.951	0.989	0.966	0.979	0.996
	M	H	0.981	0.998	0.988	0.985	0.983
	M	L	0.981	0.993	0.992	0.996	0.988
	L	H	0.969	0.997	0.979	0.982	0.990
	L	L	0.975	0.997	0.985	0.988	0.991
Renting Pasture	H	H	0.869	0.935	0.964	0.943	0.984
	H	L	0.890	0.944	0.979	0.961	0.991
	M	H	0.931	0.967	0.992	0.983	0.997
	M	L	0.928	0.957	0.996	0.985	0.992
	L	H	0.913	0.958	0.987	0.974	0.996
	L	L	0.918	0.957	0.992	0.979	0.995
Reduce flock size	H	H	0.893	0.884	0.961	0.961	0.993
	H	L	0.922	0.904	0.975	0.975	0.999
	M	H	0.908	0.873	0.989	0.989	0.997
	M	L	0.942	0.905	0.990	0.990	0.996
	L	H	0.935	0.914	0.978	0.978	0.999
	L	L	0.946	0.920	0.980	0.980	0.998

[a] See table 4.12 for prolificacy and survival abbreviations.

[b] Averaged across all scenarios (overall) or separately for each lamb value (LV), forage cost (FC), or LV x FC combination. FC comparisons also include a breeding objective derived as the average of the renting pasture and purchased hay scenarios (FC*).

Table 4.18 Correlations between individual and average breeding objectives when lamb value is discounted for heavy lambs. [a]

			Correlations with average breeding objectives [b]				
Forage Cost	Prolificacy	Survival	Overall	LV	FC	FC*	LV x FC
Purchased Hay	H	H	0.995	0.982	0.993	0.969	0.981
	H	L	0.993	0.984	0.993	0.977	0.993
	M	H	0.973	0.996	0.967	0.941	0.988
	M	L	0.961	0.995	0.952	0.923	0.980
	L	H	0.960	0.997	0.949	0.913	0.972
	L	L	0.953	0.995	0.941	0.907	0.971
Renting Pasture	H	H	0.951	0.896	0.998	0.995	0.968
	H	L	0.946	0.901	0.996	0.992	0.973
	M	H	0.951	0.935	0.977	0.981	0.991
	M	L	0.950	0.947	0.963	0.971	0.993
	L	H	0.954	0.948	0.967	0.975	0.995
	L	L	0.947	0.948	0.959	0.967	0.993
Reduce flock size	H	H	0.802	0.859	0.981	0.981	0.988
	H	L	0.846	0.904	0.990	0.990	0.997
	M	H	0.841	0.915	0.977	0.977	0.999
	M	L	0.845	0.922	0.974	0.974	0.998
	L	H	0.827	0.906	0.971	0.971	0.999
	L	L	0.833	0.916	0.966	0.966	0.997

[a] See table 4.12 for prolificacy and survival abbreviations.

[b] Averaged across all scenarios (overall) or separately for each lamb value (LV), forage value (FC), or LV x FC combination. FC comparisons also include a breeding objective derived as the average of the renting pasture and purchased hay scenarios (FC*).

Table 4.19 shows indexes for different production scenarios for the Targhee breed. Index values are scaled to an index weighing of 1.0 for the WW EPD, and index weightings represent the value of a change of one EPD unit for each trait. Weightings are averaged over all prolificacy and survival scenarios. Expected change in mean index values are also listed in Table 4.19, representing the change per generation for a standardized index selection differential of one. The expected change in progeny breeding values associated with selection for indexes are listed in Table 4.20 and only includes those indexes that are most strongly correlated with all individual breeding objectives. Indexes were calculated for two different forage cost scenarios: a scaled flock size index averaged over both lamb value scenarios, and an unscaled index that is averaged over both the purchased hay and renting pasture scenarios as well as the lamb value scenarios. Four indexes that represent different lamb value by forage cost scenarios are also shown in Table 4.19. The indexes are specific for scenarios where lamb value is either discounted or not and flock size is either scaled or not scaled. Also included in Table 4.19 are indexes for lamb value averaged over forage cost scenarios. Although indexes for different lamb value scenarios are highly correlated with individual breeding objectives (Tables 1.17 and 4.18) other indexes presented provide more optimal selection for different production levels.

Table 4.19 Index values for each trait (on an EPD scale) averaged over different market lamb value and forage cost scenarios.

	EPD for: [a,b]							Change
Scenario	WW	MM	YW	FW	FD	SL	PLC	($) [d]
Overall	1	0.293	-0.385	0.392	-0.517	-0.103	0.099	2.00
Lamb Value								
Discount	1	0.206	-0.494	0.502	-0.675	-0.138	0.138	1.93
No Discount	1	0.346	-0.319	0.325	-0.420	-0.081	0.075	2.17
Forage Cost								
Purchase	1	0.270	-0.343	0.348	-0.552	-0.081	0.100	1.92
Renting	1	0.386	-0.169	0.172	-0.579	-0.135	0.116	2.21
Scaled	1	0.230	-0.613	0.624	-0.431	-0.093	0.083	2.21
Not scaled [c]	1	0.328	-0.255	0.260	-0.566	-0.108	0.108	2.05
Lamb value by Forage cost								
Discount x Scaled	1	0.140	-0.763	0.774	-0.553	-0.109	0.144	2.17
Discount x Not scaled	1	0.245	-0.335	0.340	-0.749	-0.157	0.152	1.92
No Discount x Scaled	1	0.287	-0.521	0.529	-0.354	-0.084	0.064	2.26
No Discount x Not scaled	1	0.378	-0.209	0.212	-0.457	-0.080	0.082	2.26

[a] See table 3.1 for trait abbreviations.

[b] Index weightings are for EPD values of each trait.

[c] Weightings are averaged over all purchased hay and renting pasture scenarios.

[d] Expected change of mean index value per generation assuming a selection differential of one.

Table 4.20 Expected changes in EPD values of each breeding objective trait per generation associated with selection of one standard deviation in an index. [a]

Scenario	WW	MM	YW	FW	FD	SL	PLC
Scaled	0.08	0.13	-0.90	-0.03	-0.19	-0.02	5.48
Not Scaled	0.47	0.17	0.25	0.01	-0.13	-0.01	6.63
Discounted – Scaled	-0.07	0.05	-0.98	-0.04	-0.17	-0.01	6.54
Discounted – Not Scaled	0.30	0.10	-0.03	-0.01	-0.15	-0.01	7.44
No Discount – Scaled	0.22	0.19	-0.66	-0.02	-0.18	-0.02	4.94
No Discount – Not Scaled	0.60	0.22	0.48	0.02	-0.11	-0.01	5.71

[a] See table 3.1 for trait abbreviations.

Chapter 5 Discussion

5.1 Lamb Crop Performance

Each flock simulated in this study represented a slightly different distribution of litter sizes (Table 4.2) and phenotypic weaning weights (Tables 4.3 through 4.8). Table 4.3 represents the average performance of 20 flocks at the highest level of prolificacy and best triplet survival. These flocks have, on average, the smallest lambs at weaning because of the larger proportion of lambs born and reared as twins and triplets. Flocks that raised fewer triplet lambs, therefore, market, on average, larger lambs. Tables 4.3 through 4.8 show the average WW of lambs raised in flocks of different prolificacy levels. Flocks that had the fewest singles also had, on average, the lowest average lamb weights.

After selection, changes in lamb weights were consistent across prolificacy levels. However, the results in tables 4.3 through 4.8 for number of lambs weaned show that selection for PLC increased the number of second-generation lambs by 5.6, 4.9, and 4.5% for low, medium, and high prolificacy flocks, respectively. This response in lambs weaned was related to differences in birth type distributions (Table 4.2). When selected for PLC, highly prolific flocks in tables 4.3 and 4.4 had a larger increase in frequency of triplet births, compared to flocks with lower prolificacy, but higher mortality rates for triplet lambs decreased the proportional change in lambs weaned. This is in agreement with Amer et al. (1999) where the interaction between lamb mortality and prolificacy was considered to calculate economic values for reproductive efficiency. Selection for PLC in medium prolificacy flocks (Tables 4.5 and 4.6) increased both twin and triplet births while only slightly decreasing the proportion of single births.

Management practices that influence triplet survival affect the average performance of the lamb crop. Flocks with higher triplet survival rates wean more lambs that are, on average, lighter. However, the number of lambs weaned with respect to different prolificacy levels is influenced by triplet survival rates, where highly prolific flocks have larger losses in numbers than a lowly prolific flock. When triplet survival is low, flocks that had a lower frequency of triplet births are less affected by lamb mortality.

Selection for improved maternal performance was realized in the second-generation lamb crop. Direct traits like WW and YW were expressed in both generations. However, when both WW and YW are included in the selection objective, YW differences arise only from differences in postweaning growth, so average weaning weights in each generation were unchanged by selection on YW.

Wool characteristics were expressed in both ewe lambs retained for breeding and the adult ewe flock (Tables 4.9 and 4.10). Selection to improve FD in adult fleeces provides the opportunity for more improvement in value due to large proportional changes in course and optimal fleeces relative to changes achieved by yearling fleeces. The proportion of fine fleeces in yearling lambs was much higher than in adult ewes. The distributions of adult and yearling fleeces in Table 4.10 indicate close to a 7% reduction in course wool and a 12% increase in fine wool was expected in the adult ewe population as a result of selection for FD, while selection in yearling fleeces reduced course wool by 1 to 2% and increased fine wool by 8 to 10%.

5.2 Feed Requirements

Changes in feed requirements from selection (Table 4.11) reflect either the additional feed required for improved performance, or the net effects on DMI associated with limiting flock size to fit a fixed amount of winter forage. For example, DM requirements for winter forage increased by 3.34 kg per base ewe bred from selection to improve WW (Table 4.11). When winter forage was assumed to be limited, this requirement was met by reducing the flock size by 2.15% so fewer ewe lambs were selected for breeding. This reduction in breeding ewes in the selected generation resulted in a decrease in DMI of the adult ewe flock by 6.84 kg of winter forage per ewe bred in the base flock.

Selection for YW resulted in the largest increase in requirements for winter forage as shown by the DMI values in the purchased feed scenario of Table 4.11. When an increase in nutrient requirement resulted in a reduction in ewe numbers, selection for YW resulted in the fewest replacement ewe lambs retained, resulting in smaller future lamb crop sizes and a reduction in DMI. Conversely, selection for fleece traits had very little impact on forage DMI.

Table 4.11 shows an increase in DMI of both summer and winter forage with selection for PLC in the purchased-feed scenario. If winter forage intake of adult ewes is held constant, fewer first-generation ewe lambs will be retained for breeding, to account for additional gestation requirements, resulting in less intake of winter forage by the lambs. Selection for MM had no impact on winter forage DMI in the first generation. All lactation requirements come from summer range or a lactation supplement, therefore changes in winter range DMI from selection for MM only occur in the second generation ewe lamb crop.

5.3 Revenue and Expenses

Average market lamb value for both lamb value scenarios are listed in tables 4.3 through 4.8. Discounting for heavy weights represents Targhee producers that typically market lambs to feedlots and do not retain ownership through to slaughter. Lamb sold in this market had a lower value per lamb than in a non-discounting market because heavy lambs (>43 kg at market) were not as profitable for the feedlot. A reduction in value per kg represented the less efficient gain and fewer kilograms of total gain heavy lambs express in the feedlot.

Selection for improved growth and prolificacy effected average lamb value. The overall differences of average lamb market value in tables 4.3 through 4.8 show that selection for WW increased average lamb value. However, changes in average lamb value were not as large with discounting for heavy lambs (about +$1.10) compared to markets without discounting (about +$1.84). Smaller increases in lamb value were achieved for selection for MM, but only in the second generation lamb crop. Average lamb value in tables 4.3 through 4.8 was unaffected by selection for YW, since increasing this trait adds no phenotypic changes to market lambs. Selection for improved PLC decreased the average value of a second generation lamb. Increased prolificacy, however, lowered the number of lambs receiving a discounted price, depending upon the current flock prolificacy level. Total value of the lamb crop was increased by selection for PLC because the additional lambs weaned in the second generation resulted in more market lambs sold.

On average, yearling lamb fleeces were about 1 kg lighter than adult fleeces, and, although yearling wool was of higher quality, total value per fleece is slightly higher for adult fleeces (Table 4.10). When selecting for improved performance, the greatest improvement in fleece value, as shown in Table 4.10, comes from increasing FW because value is added for every unit increase in the trait. The changes in average fleece value vary with ewe age when selecting for FD because older ewes have courser fibers (Atkins, 1990). Fleece value depends on the fiber diameter distribution in yearling and adult fleeces. Fogarty and Gilmour (1993) show differences in economic values for FD that depend on how close the mean FD is to a major economic threshold valued. In Table 4.10, adult fleeces have the greatest increase in value when selecting for FD. This is because the fiber diameter distribution in adults allows a larger proportion of fleeces to move into higher quality categories. Differences in wool value are smaller for yearlings because the proportional changes in fleece quality are not as large and therefore fewer individuals cross a major economic threshold value for wool quality (Table 4.10). In the current analysis, Targhee producers benefit from selection for decreased FD partly because 75% of the wool produced by a flock comes from adult ewes. Economic values for FD may change in the current population if either different FD ranges were used to define wool value differences or if the price differentials between quality levels changed.

Changes in fleece value for selection to improve SL were trivial. In the base flock SL performance is acceptable for the current market, and there is a relatively small amount of phenotypic variation in the trait. Thus, very few fleeces were discounted for short staples (< 7.35 cm). A premium in wool value is not assumed for long SL and therefore selection for this trait adds no additional revenue to the system.

5.4 Feed Costs

Feed costs were calculated as the average value of each feed source, however forage cost are difficult to quantify in a range system because differences in land value can influence the assumed cost of forage grazed. In this simulation it was assumed that stocking rates maximized use of the available forage and any additional DM requirements of forage were either acquired, or accounted for by reducing flock size. Three forage cost scenarios were presented representing different ways of meeting additional forage requirements: two for acquiring additional feed and one assuming winter forage resources were limited. Similar to Ponzoni (1986), a scenario that valued forage DM as the cost of purchasing hay was used. This scenario represents those producers who raise and/or purchase hay to meet additional needs. In years when range is limited due to drought, purchasing hay is an option to avoid culling animals. However, for producers who completely rely on rangeland to meet all forage requirements, the value of hay does not represent the cost of acquiring addition rangeland. Since the actual value of rangeland varies with producer and location, the cost of renting rangeland per animal unit was considered as a second forage cost scenario. When access to winter forage resources was limited, forage costs were calculated as the decrease of income associated with the reduction in flock size and placed a biological value on forage DM. In this scenario, selection for a more feed efficient ewe would be desired. In an extensive range environment, this may be a valid way to consider the costs of changing performance through selection, since fewer inputs are generally considered in this type of system. This is in agreement with Connington et al. (2001) where selection for ewe performance traits were more important than lamb growth traits.

The purchasing hay scenario had the highest cost of feed per ewe bred, while renting pasture represented the lowest feed costs (Table 4.12). The relative returns above feed costs in Table 4.12 represent the change in profit from selection when different forage cost and lamb value scenarios were considered. Although forage costs associated with reducing flock size were lowest, the loss in production from fewer replacement ewes resulted in less profit than other scenarios, and represented the highest cost of forage when compared to flocks with no change in performance.

5.5 Economic Values

The economic values in tables 4.13 and 4.14 indicate that increasing preweaning growth is economically advantageous while increased yearling weight is not. With a genetic correlation of 0.74, selection for WW is associated with undesirable positive correlated effects on YW. The economic values in tables 4.13 and 4.14 indicate that selection on both traits, but in opposite directions, were required to achieve the most profitable performance. Improving MM through selection increased preweaning gain without influencing YW, however, the additional lactation costs were more than the costs of direct improvement in WW. Improvement in fleece weight and fiber diameter can be achieved at a low feed cost and would be included in all breeding objectives. However, SL adds very little value to the aggregate breeding value and in the current wool market would likely not receive emphasis in most breeding objectives.

The economic values of the traits in tables 4.13 and 4.14 reflect the relative change in profit from selection. When heavy lambs were not discounted, the economic values of WW and MM were approximately \$0.80 and \$0.40 higher, respectively, compared to a market that discounts heavy lambs. When heavy lambs were discounted, economic values for PLC were at their highest level. Forage costs also plays a large role in determining the economic value of YW. Economic values all negativly reflect the energy requirements for YW, and this trait was strongly selected against in the high forage cost scenario.

The differences in economic values for PLC indicate a possible optimal level of performance for the trait. In these simulations the economic value of increasing PLC tended to be larger for a medium level of prolificacy, while the smallest economic values were in highly prolific flocks with high levels of triplet survival (Tables 4.13 and 4.14). Shifts in the distribution of litter size, along with lamb survival, are likely to account for smaller proportional increases in number of lambs weaned in the highly prolific flocks. Although selection for PLC is profitable for all scenarios, it is more profitable for flocks that can increase number of lambs born without greatly increasing the number of triplet births, due to higher mortality and decreased market weight of triplets. Similar to the current results, Amer et al. (1999) also calculated economic values that varied with flock prolificacy and survival. However, in this study changes in market lamb value and forage costs have a larger impact on economic value than effects of prolificacy and survival.

The economic values that were significantly different for each trait over different production levels or economic scenarios are shown in Table 4.15. Simulated flocks were replicated for each production level combination, however, each economic assumption (lamb price X forage costs) was applied to every replicated flock. Variation among replicated simulations is likely to be smaller than variation among actual flocks, so a more strict significance value of $P < 0.001$ was used to identify important differences in economic values among the scenarios. Table 4.15 shows that the economic values for growth traits and PLC consistently differed among lamb value and forage cost scenarios.

5.6 Breeding Objectives

Different levels of flock performance were considered for this analysis, although differences in weightings for each trait in the individual breeding objectives mostly reflected the economic assumptions and not differences in flock production levels. For this reason, breeding objectives in Table 4.16 were calculated by averaging economic values over different production levels.

Correlations among breeding objectives (Table 4.17 and 4.18) indicate that an overall index for the breed would not properly select animals for all flocks. A single breeding objective would more clearly define selection goals, but producers over several different scenarios would benefit from more customized indexes. Values in Tables 4.17 and 4.18 indicate that the breeding objectives for different forage cost scenarios were different enough to warrant separate indexes for flocks that can acquire additional forage as needed and for flocks with limited forage availability. In the current analysis, breeding objectives for specific lamb value by forage cost scenarios were generally very similar across the simulated ewe prolificacy and lamb survival levels. Having more indexes may select animals more efficiently for specific production conditions, but if fewer indexes can be used with similar outcomes, it is more practical for breeders to select animals for an aggregate breeding value in order to avoid confusion associated with a large number of breeding objectives.

5.7 Index Values

The indexes in Table 4.19 were calculated for the likely range of Targhee production scenarios and result in selection outcomes that are similar to selection for breeding objectives customized to include additional effects of ewe productivity and lamb survival. The forage cost indexes for scaling flock size and not scaling in Table 4.19 contrast the differences in selection indexes when flocks have, or do not have, access to addition forage resources. Although all traits in these indexes were selected in the same direction, with respect to the other index, specific weightings for each trait differed between indexes. For example, in Table 4.20 the expected changes per generation in WW, YW and FW for flocks with a restricted forage resource were lower (0.08 kg, -0.90 kg, and -0.03 kg per generation, respectively) than the expected changes from an index that assumes access to additional forage (0.47 kg for WW, 0.25kg for YW, and 0.01 kg for FW). Additionally, the changes in PLC, shown in Table 4.20, were expected to be higher when additional forage was available, with an expected change in progeny EPD of 6.63 lambs per 100 ewes, compared to 5.48 lambs per 100 ewes when forage was limited.

Indexes are also shown in Table 4.19 for each combination of forage cost and lamb value. The expected changes in profit from selection on these indexes are more variable than those that consider only forage cost indexes for scaled and not scaled scenarios. The expected change in WW from Table 4.20 was -0.07 kg with discounting of heavy lambs and limited forage availability. Changes in WW were positive for all other scenarios. The expected change in profit from selection was higher for indexes that were calculated without discounts for heavy lambs. The expected genetic change in PLC and pre-weaning growth traits (WW and MM) for these indexes largely contributes to the changes in profit. Regardless of the index, changes in genetic values of fleece traits remains consistent, however, changes in growth and prolificacy traits are more variable depending upon the economic assumptions.

Chapter 6 Conclusions

Indexes should be adopted that meet the needs of a large portion of Targhee producers. Although some Targhee producers sell lambs that are not discounted for heavy weights, a major portion of flocks do not have that option. However, there may be differences in how flocks value their forage. Some producers have access to additional rangeland while others may purchase or raise there own hay. Others have a higher cost associated with forage, either through the investment in their own land, or the competing use of forage in other enterprises. Indexes that provide optimal selection outcomes and fit the scenarios common to most Targhee flocks are the indexes for discounting heavy lambs with limited forage resources and for discounting heavy lambs with available forage. Selection using these two indexes in the Targhee breed includes scenarios that cover a wide range of Targhee flocks.

Chapter 7 Appendix

Appendix Table 7.1 Index values associated with EPD for each breeding objective when no discount of lamb value is considered for all forage cost prolificacy, and survival combination. [a]

			Traits [b]						
Forage Cost	Prolificacy	Survival	WW	MM	YW	FW	FD	SL	PLC
Purchased Hay	H	H	1	0.341	-0.257	0.261	-0.426	-0.012	0.060
	H	L	1	0.346	-0.256	0.261	-0.437	0.176	0.070
	M	H	1	0.296	-0.299	0.304	-0.426	-0.486	0.079
	M	L	1	0.311	-0.276	0.281	-0.401	0.087	0.090
	L	H	1	0.331	-0.289	0.294	-0.460	-0.120	0.073
	L	L	1	0.366	-0.291	0.297	-0.531	-0.014	0.081
Renting Pasture	H	H	1	0.433	-0.124	0.125	-0.446	-0.071	0.071
	H	L	1	0.435	-0.126	0.127	-0.456	0.164	0.082
	M	H	1	0.390	-0.159	0.163	-0.450	-0.537	0.092
	M	L	1	0.405	-0.136	0.137	-0.419	0.011	0.105
	L	H	1	0.422	-0.150	0.153	-0.487	-0.157	0.087
	L	L	1	0.461	-0.145	0.149	-0.558	-0.045	0.096
Reduce flock size	H	H	1	0.293	-0.513	0.523	-0.341	-0.048	0.049
	H	L	1	0.302	-0.513	0.522	-0.342	0.129	0.059
	M	H	1	0.253	-0.542	0.551	-0.328	-0.484	0.066
	M	L	1	0.268	-0.523	0.532	-0.316	0.023	0.076
	L	H	1	0.286	-0.508	0.517	-0.365	-0.168	0.063
	L	L	1	0.320	-0.516	0.525	-0.439	0.033	0.071

[a] Denotes the high (H), medium (M), and low (L) levels of prolificacy and survival.
[b] See table 3.1 for abbreviations.

Appendix Table 7.2 Index values associated with EPD of each trait for breeding objectives when discounting lamb value for all forage cost, prolificacy, and survival combination. [a]

			Traits [b]						
Forage Cost	Prolificacy	Survival	WW	MM	YW	FW	FD	SL	PLC
Purchased	H	H	1	0.176	-0.404	0.410	-0.667	-0.208	0.102
Hay	H	L	1	0.227	-0.384	0.391	-0.656	0.099	0.119
	M	H	1	0.181	-0.458	0.464	-0.795	-0.075	0.152
	M	L	1	0.139	-0.463	0.471	-0.613	-0.083	0.166
	L	H	1	0.126	-0.520	0.526	-0.834	-0.118	0.153
	L	L	1	0.118	-0.522	0.529	-0.885	-0.402	0.171
Renting	H	H	1	0.323	-0.194	0.199	-0.693	-0.295	0.118
Pasture	H	L	1	0.368	-0.179	0.181	-0.680	0.083	0.136
	M	H	1	0.339	-0.222	0.226	-0.827	-0.167	0.173
	M	L	1	0.298	-0.230	0.235	-0.640	-0.207	0.189
	L	H	1	0.293	-0.263	0.266	-0.882	-0.188	0.179
	L	L	1	0.294	-0.251	0.254	-0.937	-0.459	0.201
Reduce	H	H	1	0.142	-0.731	0.743	-0.511	-0.233	0.081
flock size	H	L	1	0.188	-0.716	0.727	-0.492	0.043	0.097
	M	H	1	0.149	-0.772	0.786	-0.588	-0.140	0.123
	M	L	1	0.134	-0.759	0.772	-0.478	0.088	0.130
	L	H	1	0.109	-0.796	0.809	-0.612	-0.195	0.125
	L	L	1	0.108	-0.808	0.824	-0.671	-0.249	0.140

[a] Denotes the high (H), medium (M), and low (L) levels of prolificacy and survival.

[b] See table 3.1 for abbreviations.

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