OBJECTIVES AND SELECTION CRITERIA FOR AUSTRALIAN MERINO SHEEP

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INTRODUCTION

Most of the sheep breeding research carried out in Australia has been concerned with the estimation of phenotypic and genetic parameters and with the evaluation of selection responses. Turner and Young (1969), Dolling (1970), Dun and Eastoe (1970) and Turner (1977) have given detailed coverage of all relevant findings. This information, derived mainly from random-bred and single-trait selection experiments, is valuable, and forms the general basis for currently recommended breeding programs. Research oriented towards definition of selection objectives and criteria has, however, been subject to less rigorous investigations. The economic importance of clean fleece weight, fibre diameter, reproductive performance and body weight as selection objectives has been recognized (Animal Production Committee, 1974), but precise definition of the biological and economic components of breeding goals has not been attempted.

Selection index theory (Hazel, 1943) offers a formal method of defining selection objectives and choosing selection criteria to predict the objectives. Traits which should be improved genetically because they have an important effect on economic returns are included in the *selection objective*. *Selection criteria* are those variates (characteristics) used in assessing the breeding value of individuals and selecting replacements. The selection criteria can be put together in a selection index, each of them weighted so that the correlation between the index (I) and the selection objective (T) is maximized. The use of selection indices in Merino breeding has been limited (Morley, 1955; Dunlop and Young, 1960; Turner and Young, 1969). In the present paper selection index theory has been used as an aid in defining the selection objective, choosing selection criteria to predict the objective, and in evaluating the consequences of using alternative objectives when the definition is not clear-cut. It is appreciated that further information is still required on genetic and economic parameters, but it is hoped that this presentation will provide a stimulus for more refined work on the definition of selection objectives and criteria for the Merino sheep industry.

SELECTION OBJECTIVES - GENERAL

The primary goal of most commercial sheep producers is to maximize monetary returns from their flock. Commercial flocks produce virtually all the wool and sheep meat in Australia (Alexander and Williams, 1973). They depend, however, on selection policies in studs for permanent genetic improvement (McGuirk, 1976). Hence it is essential that selection objectives in stud flocks include those traits influencing monetary returns in commercial flocks. Diverting selection pressure in studs to traits of no economic importance at the commercial level implies a waste of genetic resources.

In the Australian Merino industry the relative contributions of wool and sheep sales to total flock income varies because of the diversity of flock structures. Furthermore, Merino sheep are kept under a wide range of environmental conditions (Chapman *et al*, 1973). For these reasons there will not be a unique selection objective applicable or relevant to all Merino flocks.

In this paper the selection objective is defined for a breeding flock in which all surplus offspring are sold as lambs. Such a flock may be regarded as typical of sheep enterprises in the drier agricultural zones of South Australia (B.C. Jefferies, personal communication). All the methodology can, of course, be used to define the selection objective for other situations.

SELECTION CRITERIA - GENERAL

The variates (characteristics) included in a selection index must be measurable, preferably before breeding age is attained and at minimum cost and technical difficulty. Traits (characteristics) in the selection objective may or may not be used as selection criteria. Characteristics not in the objective can be used as selection criteria in the index. The contribution of the various selection criteria to the accuracy of the index as a predictor of the objective can be evaluated. In this paper, the consequences of using a number of alternative selection indices are examined. Characteristics to be included in the index were chosen so that they could all be measured before breeding life began (i.e. 18 months of age).

METHODS

1. Defining the Selection Objective (T)

Definition of the selection objective (T) involves specifying the traits to be improved and assigning economic values to each of them. In the following sections the traits included in the selection objective are defined, justification for their inclusion is given and the method of calculating the economic values is described.

(a) Traits in the objective

Gjedrem (1972) suggested that all traits of economic importance should be part of the objective. Traits are defined here as being of economic importance if they contribute to flock returns to the farmer. In a breeding flock in which all surplus offspring are sold as lambs, returns are generated by sale of wool, lambs and cast-for-age ewes. The sources of returns and traits influencing returns can be summarized as follows:

Return Source	Traits in the Selection Objective
Wool	Clean fleece weight (CFW), average fibre diameter (FD)
Surplus offspring	Number of lambs weaned (NLW), weaning weight (WW)
Cast-for-age ewes	Ewe bodyweight at 5½ years (EBW)

Turner (1977) concluded that clean wool weight, fibre diameter and lack of coloured fibres should be the objective of genetic improvement for wool production. For present purposes it is assumed that coloured fibres are absent in the flock. It is also assumed that variations in staple length in fleeces of 12 months' growth are not associated with variations in the price paid for the wool. It is recognized, however, that in flocks where this assumption is not valid staple length should become part of the selection objective.

The number of surplus animals and the amount of meat per head are the two most important components of meat production (Turner, 1977). The number of lambs weaned largely determines the number available for sale. For the Australian Merino, at least at young ages, the amount of lean meat is closely correlated with preslaughter body weight (Tallis *et al*, 1964). Furthermore, the present meat marketing system provides little or no classification of the end product, so in practice weaning weight and ewe body weight are the only choices available.

(b) Economic values

Schlote (1977) has reviewed the methods used in the estimation of economic values. The procedure employed here was that of Morris *et al* (1979) and it corresponds roughly with method 3.2 (p 64) of Schlote (1977). The economic values are obtained from the marginal returns to the farmer per ewe lifetime. Returns are weighted by the frequency with which the trait is expressed in a ewe's lifetime and allowance is made for female replacement needs before lamb sales are calculated. Details of the calculations are given in Appendix 1. No allowance is made for possible increases in food intake which may result from genetic gain in some traits, except for increased maintenance requirements for heavier ewes.

(c) Numerical definition of the selection objective (T)

The selection objective (T) was defined in terms of dollars ($) return to the farmer per ewe lifetime, as suggested by Morris *et al* (1979). The assumptions involved are summarized in Appendix 1. T can be expressed as a linear function of the additive genetic merit of the traits in the objective. Given the economic values calculated in Appendix 1, the selection objective for Merino breeding can be written in the form of an equation:

$$T = 10.7\ G_{CFW} - 1.5\ G_{FD} + 53.9\ G_{NLW} + 0.94\ G_{WW} + 0.13\ G_{EBW}$$

2. Defining the Selection Criteria

Once T has been defined it is possible to compare the value of different selection criteria as predictors which provide a means of ranking individuals on the basis of their genetic merit. The selection criteria chosen were combinations of characters that could be recorded by breeders varying in the intensity of their use of objective measurement as an aid to selection. They were: Clean Fleece Weight (CFW); Fibre Diameter (FD); Dam's number of lambs weaned - one record (dam's NLW); Weaning Weight (WW); Greasy Fleece Weight (GFW); Dam's number of lambs born - one record (dam's NLB); 16 month bodyweight (16 month BW); Skin Wrinkle Score (Wr) and Face Cover Score (FC) (see Table 1 of Results).

2. Numerical Work

(a) Computation of selection indices and other relevant parameters

The heritability values and phenotypic and genetic correlations assumed are given in Appendix 2. They represent an approximate average of published estimates for the Australian Merino, except for those traits for which no information was available in this breed, in which case estimates were either taken from other breeds or guessed.

The computer program SELIND (Cunningham and Mahon, 1977) was used for carrying out all the computations. The sensitivity analysis and the restriction on fibre diameter were performed by altering the appropriate parameter values fed to the program. The genetic gains were calculated assuming a selection intensity of one standard deviation on the index, males and females being chosen on the basis of the same index.

(b) Sensitivity analysis

Prices and the relative values of wool and meat change considerably with time. Because breeding programs are long-term it is desirable to investigate the effect of changes in economic values on the selection index and on the genetic gain in the traits in the objective. Here the consequences of altering, firstly, the price of wool, secondly, the price of cast-for-age ewes, and thirdly, the price of lambs and cast-for-age ewes were investigated.

(c) Maintaining constant FD

The present recommendation is that selection for wool production should be based on clean fleece weight without change in fibre diameter (Turner, 1977). This can be achieved by means of a restricted selection index. If a trait is held constant, then its economic value is irrelevant (Kempthorne and Nordskog, 1959). However, the proper evaluation of the index requires that zero economic value be attached to any trait being held constant (Cunningham, 1972). The procedure used here was that of Cunningham *et al* (1970) and the economic value of FD was set at zero in the restricted index.

RESULTS

Table 1 shows the index weights and correlations between I and T for indices 1 to 6. Their effectiveness as predictors of T can be compared in terms of r_{IT}. The comparison of I_1 with I_2 shows that dam's NLW and dam's NLB are equally effective criteria, while the comparison of I_1 with I_3 indicates that 16 month BW is a slightly better criterion than WW but the difference is small. The comparisons I_1 with I_4 and I_5 with I_6 show that considerable increases in accuracy can be achieved by including Wr and FC as selection criteria.

The genetic gains per generation for the traits in the objective and the total gain in economic units (σ_I) achieved by one standard deviation of selection in indices 1 to 6 are shown in Table 2. Indices in which FD is actually measured produce a reduction in FD (I_1 to I_4), while those in which it is not measured result in an increase in FD. I_4 and I_6 give the largest total gains in economic units.

TABLE 1: Index weights and correlations (r_{IT}) between index and selection objective for indices 1 to 6.

Selection Criteria**	Index Number*					
	I_1	I_2	I_3	I_4	I_5	I_6
CFW	4.10	4.10	3.59	5.62		
FD	-0.93	-0.93	-0.97	-0.89		
Dam's NLW	2.80		2.73	2.51	2.84	2.54
WW	0.54	0.54		0.21	0.55	0.20
GFW					2.13	4.40
Dam's NLB		3.34				
16 month BW			0.50			
Wr				-2.21		-2.55
FC				-2.0		-1.76
r_{IT}	0.36	0.36	0.39	0.50	0.27	0.45

* e.g. = Index number 1 = I_1 = 4.10 CFW - 0.93 FD + 2.80 NLW + 0.54 WW

** CFW = clean fleece weight; FD = fibre diameter;
NLW = number of lambs weaned; WW = weaning weight;
GFW = greasy fleece weight; NLB = number of lambs born;
BW = body weight; Wr = skin wrinkle score; FC = face cover score.

TABLE 2: Genetic gain per generation in clean fleece weight (CFW), fibre diameter (FD), number of lambs weaned (NLW), weaning weight (WW), and ewe body weight (EBW) and total gain in economic units (σ_I), achieved by one standard deviation of selection on the index for indices 1 to 6.

Trait	Index Number					
	I_1	I_2	I_3	I_4	I_5	I_6
CFW (kg)	0.1035	0.1040	0.0881	0.1358	0.0858	0.1220
FD (microns)	-0.4617	-0.4635	-0.4401	-0.3167	0.0988	0.0198
NLW	0.0218	0.0215	0.0279	0.0413	0.0215	0.0427
WW (kg)	0.4440	0.4476	0.5779	0.5547	0.5949	0.6232
EBW (kg)	0.5996	0.5984	0.9540	0.9481	0.8337	1.0840
σ_I ($ per lifetime)	3.47	3.47	3.76	4.80	2.59	4.31

Table 3 shows the results of the sensitivity analysis when I_4 is taken as a basis for comparison. The effect of different relative values of wool and sheep meat on the genetic gain per generation was studied by halving the prices of clean wool (S_1), of cast-for-age ewes (S_2), and of lambs and cast-

TABLE 3: Sensitivity to different market prices. Genetic gain per generation in clean fleece weight (CFW), fibre diameter (FD), number of lambs weaned (NLW), weaning weight (WW) and ewe bodyweight (EBW) achieved by one standard deviation of selection on the index (index I_4 taken as a basis for comparison).

Trait	Basic I_4	Half the price of clean wool S_1 *	Half the price of cast-for-age ewes S_2 *	Half the price of lambs and cast-for-age ewes S_3 *
CFW (kg)	0.1358	0.0940	0.1356	0.1545
FD (microns)	-0.3167	-0.4498	-0.3315	-0.3848
NLW	0.0413	0.0438	0.0411	0.0353
WW (kg)	0.5547	0.5492	0.5401	0.4558
EBW (kg)	0.9481	0.9288	0.9273	0.7853

* Selection criteria as in I_4

for-age ewes at the same time (S_3). Halving the price of cast-for-age ewes has virtually the same effect as doubling food costs associated with ewe maintenance requirements. Both changes result in $V_5 \simeq 0.0$. Changes in the relative economic values of the traits in the objective result in comparatively smaller alterations in the rates of genetic gain achieved in them. For example, in I_4 the economic value of CFW is twice as large as in S_1 but the genetic gain in CFW is only 30% greater (I_4 taken as a basis). Setting the economic value of EBW equal to 0.0 had a negligible effect on the genetic gains achieved (I_4 vs S_2). By halving the price of lambs and cast-for-age ewes the genetic gains in CFW and FD increased by 14% and 21% respectively, while those for NLW, WW and EBW decreased by 14%, 18% and 17% respectively (I_4 vs S_3).

The consequences of holding FD constant are shown in Table 4 in terms of genetic gain per generation achieved for the traits in the objective and of total gain in economic units (σ_I). I_4 is used as a basis for comparison. The genetic gain in CFW, WW and EBW increased by 18%, 10% and 11% respectively, while that for NLW decreased by 3%. The total gain in economic units was slightly reduced (4%) when FD was held constant.

TABLE 4: Genetic gain per generation in clean fleece weight (CFW), fibre diameter (FD), number of lambs weaned (NLW), weaning weight (WW) and ewe body weight (EBW) holding FD constant (index I_4 taken as a basis for comparison) and total gain in economic units (σ_I) achieved by one standard deviation of selection on the index.

	CFW (kg)	FD (microns)	NLW	WW (kg)	EBW (kg)	σ_I ($/ lifetime)
I_4	0.1358	-0.3167	0.0413	0.5547	0.9481	4.80
FD held constant*	0.1607	0.0	0.0399	0.6101	1.0554	4.59

* Selection criteria as in I_4

DISCUSSION

1. The Value of Selection Indices as Predictors of the Objective

Because of costs, use of clean fleece weight and fibre diameter measurements is recommended for ram selection, and greasy fleece weight for ewe selection (Turner, 1977). Therefore I_1 to I_4 could be appropriate indices for rams, and I_5 and I_6 for ewes. The consequences of using these alternative indices are summarized in Tables 1 and 2. In Table 2 it is assumed that the selected sheep are one standard deviation above the mean in index score. This selection intensity can be achieved by selecting from the best 6% of rams with no selection of ewes.

A useful measure of the efficiency of an index is r_{IT}, since the genetic gain from selection is directly proportional to this correlation. Where two characteristics have the same (or very similar) value as selection criteria the decision as to which one should be used can be based entirely on practical considerations and the choice will not have major genetic or economic consequences (e.g. dam's NLW vs dam's NLB, WW vs 16 month BW).

Probably the most interesting feature of Tables 1 and 2 is the substantial increase in r_{IT} and σ_I which takes place when Wr and FC are included as selection criteria (I_4 vs I_1 and I_6 vs I_5). Gjedrem (1967) showed that recording additional characters may increase the selection efficiency of the traits in the objective. Traditionally in Merino breeding in Australia, skin wrinkles and face cover score have been considered faults in themselves (Dun and Eastoe, 1970) or as alternative criteria in selection for improved reproductive rate (Turner, 1969). However, they have not been considered as traits which could provide additional information in a selection index. The inclusion of Wr and FC as selection criteria can result in an improvement of the order of 39% and 67% in the efficiency of ram and ewe indices respectively. In terms of total gain in economic units (σ_I), the corresponding increases are of the same magnitude (see Table 2). Ram indices which do not include Wr and FC as selection criteria (I_1 , I_2 and I_3) are less efficient than the ewe index which does (I_6). This fact casts doubts on the necessity of incurring costs associated with the estimation of yield and fibre diameter, even for rams.

I_4 was compared with an index which included all the selection criteria listed in Table 1. The index including all traits was 4% more efficient than I_4. This difference is not large enough to warrant the inclusion of the additional traits. Assuming a generation interval of 3.5 years, I_4 would result in a genetic gain per year of approximately 0.04 kg of CFW, -0.1 microns in FD, 0.012 lambs, 0.16 kg of WW and 0.27 kg of EBW.

Some sections of the industry have been keen to use selection indices combining fleece and body characteristics (Shepherd, 1976). Because those indices have not been developed in a formal way, it is irrelevant to compare them with the ones presented here.

2. Relative Importance of Traits in the Objective

The relative importance of each trait in the selection objective can be derived from the percentage of total gain in economic units accounted for by gain in each trait. The two most important were NLW and CFW in that order. The relative contribution of each trait varied from one index to another, but NLW and CFW had always by far the greatest importance, whilst EBW was always the least important trait. In index I_4, for example, the percentage contributions of CFW, FD, NLW, WW and EBW were 30.2, 9.9, 46.4, 10.9 and 2.6 respectively.

3. Sensitivity Analysis

The sensitivity analysis was conducted primarily to study the effect of different relative prices for the traits in the selection objective. Several authors (see Ronningen, 1974; Vandepitte and Hazel, 1977) have concluded that moderate deviations from the "true" economic values are unlikely to have serious effects. The results presented in Table 3 seem to confirm this conclusion. The imposition of rather drastic changes in the relative economic values resulted in comparatively smaller alterations in the rate of genetic gain of the traits in the objective (Table 3). The changes in the relative economic values of wool and sheep meat studied here represent rather extreme situations; changes of a smaller magnitude would have even smaller effects.

The results of the sensitivity analysis can serve another purpose besides the study of the effects of price fluctuations. It was stated earlier that in the calculation of the economic value for the various traits in the breeding objectives, no allowance had been made for possible increases in food intake which may result from genetic gain in some traits, except for increased maintenance requirements for heavier ewes. Considering the traits included in T, genetic gains in NLW, WW and EBW may result in increased grazing intake, but genetic gains in CFW and FD are not likely to result in substantial increases in feed requirements (Turner, 1977). If allowances are made for increases in food intake associated with higher reproduction rate and heavier weaning weights, the additional food costs should be subtracted from the gross returns associated with those traits. This would have the effect of reducing their economic values in relation to the ones obtained when increases in food intake are ignored. In S_3 (Table 3) the economic values of NLW, WW and EBW were drastically reduced by halving the price of lambs and cast-for-age ewes. As seen earlier, in terms of the genetic gains achieved for each trait the differences between I_4 and S_3 are comparatively small. Allowance for increased food costs would probably result in a reduction of smaller magnitude. Therefore, it seems that ignoring possible increases in intake associated with gains in NLW, WW and EBW would be of little consequence in terms of genetic gains. However, this point is worthy of further consideration before final conclusions are drawn.

4. Maintaining Constant FD

If it is accepted that the price of wool changes with fibre diameter, then from an individual farmer's point of view there seems to be no good reason why he should keep fibre diameter constant in his flock. However, from a national point of view it may be convenient to continue to produce a range of wool finenesses in proportions similar to those being produced at present. Turner (1973, 1977) has compared the economic implications of selecting for reduced FD with those of selecting for increased CFW. However, the approach taken in this paper of simultaneously selecting for both traits appears to be more reasonable. The consequence of maintaining constant fibre diameter was an increase in the genetic gain in CFW, WW and EBW, which was achieved at the expense of no gain at all in FD and of a slight decrease in gain in NLW (Table 4). Holding FD constant resulted in a reduction of 4% in σ_I. This is likely to be of no major significance, but it nevertheless indicates that the recommendation of holding FD constant should perhaps be re-examined.

OTHER SHEEP CHARACTERISTICS

There are a number of sheep characteristics usually considered by breeders in their selection programs and frequently ignored by scientists in the formulation of breeding plans. The economic importance of physical traits related to the structural soundness of the animals, such as malformations of jaws, backs, legs and feet, has not been adequately assessed in Merino sheep. An interesting contribution though was that of Dun and Hamilton (1966) who studied the importance of close hocks in Merino breeding and concluded that close hocks are unlikely to handicap Merino sheep in any of its productive functions. In view of this finding it seems appropriate to stress the need to obtain factual evidence on the inheritance and on the relationship between other alleged constitutional faults and economically important traits.

One aspect that concerns many sheep breeders is uniformity within their flocks in wool type and also body size. Howe and Connors (1978) reported the results of an experiment designed to investigate the response to selection for reduced between-sheep variation in fibre diameter. Their conclusion was that selection with that aim resulted in no economic advantages. It was wasted effort which limited the intensity of directional selection for the economically important traits (see also Bottomley, 1979). The results were in agreement with theoretical expectations which suggested that response to selection for uniformity in quantitative traits is low. Breeders also attempt to reduce the variation in fibre diameter and staple length over the body of the sheep. Turner (1977) has presented sufficient evidence showing that this is also wasted effort as far as the Australian Merino is concerned. Thus it appears that uniformity should not be considered as part of the selection objective.

Because labour costs are so high in Australia some breeders have become interested in selection for "easy-care" features. Turner (1976) mentioned that skin wrinkle and face cover score were likely to be associated with labour costs. There is, however, no published information on the variation of running costs associated with variations in these traits. Dun and Eastoe (1970) reported that skin wrinkle was associated with time required for shearing. Preliminary calculations performed by the present author showed, however, that under current economic circumstances the inclusion of time required for shearing in the selection objective was not warranted.

Blowfly strike results in one of the major production costs of the Australian Merino industry. Successful breeding for resistance to fleece-rot and body strike could result in considerable savings. McGuirk *et al* (1978) have reviewed the current status of knowledge in this area and described current research aimed at gaining further understanding of the problem and at finding selection criteria which might be useful in breeding resistant sheep. At present it is not known precisely which traits should be selected for production of more resistant sheep.

Selection for CFW will result in a correlated response in percentage clean yield. Beyond certain limits an increase in yield may be undesirable because it may increase susceptibility to fleece-rot, dust penetration and weathering. There is likely to be an optimum percentage clean yield for each environment (Turner, 1977) but at present these percentages are not known. A selection index which includes yield in the objective and which prevents it from changing can be devised.

Piper *et al* (1978) have indicated the possibility of improving resistance to internal parasites through breeding. However, this aspect is not sufficiently understood for it to be incorporated in the definition of a selection objective or for appropriate selection criteria to be decided.

A number of skin characteristics, some of which are associated with wool traits, have been studied (Jackson *et al*, 1975; Turner, 1977; Rendel and Nay, 1978). Although our knowledge about these traits is still incomplete, we could investigate their value in a selection index by using available estimates of the relevant phenotypic and genetic parameters. So far, they have been considered only as characters on which culling at an early age (e.g. weaning) could be based, with clean wool weight and fibre diameter at 15-16 months determining final selection.

Land (1974) and Bindon and Piper (1976, 1977) have discussed sheep characteristics which could be used as selection criteria for the improvement of reproductive rate. Provided estimates of phenotypic and genetic parameters for those characteristics were available, their value in a selection index could be investigated. In this area, knowledge concerning the Australian Merino is far from adequate.

CONCLUSIONS

Breeding objectives and selection criteria were defined in this paper for a very simple production system involving a breeding flock in which all surplus offspring were sold as lambs. The relevance of this definition to other production systems (e.g. offspring sold at a later age, or running wethers in addition to ewes) is not known and certainly warrants investigation.

A single set of phenotypic and genetic parameters was used (Appendix 2). Estimates were taken from the literature but available information proved to be incomplete. For example, no estimates are available for EBW. There is a need for more estimates on several traits that are (or may be) either breeding objectives or selection criteria. The effect of possible errors in the parameters used was not investigated here but it warrants attention. Furthermore, the heritability of some traits is likely to change with age (e.g. for NLB and NLW). This problem was ignored in this paper but it deserves attention.

The estimation of economic values made here was probably suboptimal, but very little work has been done in Australia on methods of estimating economic values for Merino sheep. There seems to be a strong need for research in this area.

Under the genetic and economic assumptions made in this paper it was shown that NLB and NLW are of similar value as selection criteria. Similarly, WW and 16 month BW were almost equally effective. The inclusion of Wr and FC substantially increased the efficiency of the indices. An index including CFW, FD, dam's NLW, WW, Wr and FC proved to have near maximum efficiency, followed closely by one including dam's NLW, WW, GFW, Wr and FC. The need for costly measures of CFW and FD is open for discussion.

The two most important traits in the breeding objectives were NLW and CFW in that order, followed by FD and WW which were equally important. EBW was the least important.

Economic values may change from time to time or vary from one area to another. However, it is not feasible for the breeder to breed for specific market situations. The results of the sensitivity analysis were encouraging in that they indicated that changes in the economic values have comparatively smaller effects in the genetic gain achieved in the traits in the objective. They also suggested that ignoring possible increases in food costs which may result from genetic gain in some traits is likely to be of little consequence, though this aspect deserves further investigation.

The present recommendation of maintaining FD constant is questionable. It results in no economic advantage to the farmer. A decision as to whether FD ought to be restricted or not should perhaps be based upon considerations of total amount of response to selection in economic units likely to be achieved either way.

Even among stud breeders making intensive use of objective measurement as an aid to selection it is common practice to cull a certain proportion of rams for various reasons before the actual measurements are performed. The use of an index (say I_4) would still rank the remaining rams in the same order independently of the preliminary culling, but the prediction equations for genetic and economic gains no longer apply (Yamada, 1977). If the selection criteria used for the preliminary culling were known, some form of multi-stage selection index could perhaps be developed to accommodate this situation.

There is a need to obtain factual evidence on the association between some characteristics considered important by breeders and the productive and reproductive functions of Merino sheep.

Response to selection for uniformity in a quantitative trait is likely to be very low and of no economic significance. Breeders should not waste their effort and genetic resources on breeding for uniformity.

There is a need to investigate the economic implications of breeding for "easy-care" features and to define their role in the context of a formal definition of selection objectives and selection criteria.

Further work is needed to determine desirable levels of percentage clean yield in different environments.

Research on characters (e.g. follicle depth, testis size, etc.) with the potential of becoming useful selection criteria should continue.

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APPENDIX 1

UNDERLYING ASSUMPTIONS AND CALCULATIONS FOR THE DERIVATION OF ECONOMIC VALUES

The method used was that of Morris *et al* (1979) with some minor modifications. The units of T are $ return to the farmer per ewe lifetime. Running costs are assumed to remain unchanged in the selected flock and its progeny. Allowance is made for the marginal cost of increased food intake for the maintenance of heavier ewes. This cost is accumulated over a ewe's lifetime and charged against the marginal returns from the sale of heavier ewes. No consideration has been given to other possible increases in food intake that may result as a consequence of selection.

The prices assumed for wool, lambs and ewes represent net prices to the farmer. They were chosen with the assistance of colleagues from the South Australian Department of Agriculture and Fisheries. The values used were:

Clean fleece weight ($ per kg)	2.00
Fibre diameter (price change ($) of 1 kg of clean wool per micron change in fibre diameter)	0.08
Weaner lambs (30.0 kg liveweight, $ per head)	14.00
Cast-for-age ewes (50.0 kg liveweight, $ per head)	12.00

The flock structure assumed is that of a breeding flock in which all wether lambs and surplus female offspring are sold as lambs.

Trait Expression During Ewe's Lifetime

1. *Number of Matings per Lifetime*

If the breeding flock consists of four age groups and the mortality rate for ewes is 2.2% (Turner and Young, 1969), then the proportion of two-tooth ewes in the flock can be calculated as:

$$\frac{1.0}{1 + 0.978 + 0.9565 + 0.9354} \simeq 0.26$$

and the number of matings per lifetime equals

$$1/0.26 \simeq 3.85$$

2. *Fleece Production Per Lifetime*

Given that lambing takes place in April-May and shearing in August-September, and that ewes are shorn after their final lambing, then, the number of years of fleece production per lifetime is

$$3.85 + 1 = 4.85$$

Lambs are shorn at four months of age, before being sold as weaners. The correlated response to selection in lamb fleece weight is assumed to be ¼ of the response in ewe fleece weight. Lamb wool price is assumed to be ⅔ of the price of fleece wool. The average lamb marking percentage in South Australia during the period 1955 to 1975 was approximately 78% (Anonymous, 1955-1975). Then,

$$(3.85)\ (0.78)\ (0.25)\ (0.66) \simeq 0.5$$

Crediting the lamb's wool production to the ewe's lifetime fleece production the total number of annual expressions of fleece production per ewe lifetime can be calculated as:

$$4.85 + 0.5 = 5.35$$

3. *Lamb Production Per Lifetime*

The total number of lambs weaned per ewe lifetime is (3.85) x (0.78) ≃ 3.0. The number of female replacements required per ewe, assuming the flock size remains constant, is equal to 1.0.

So, the number of lambs on which returns from greater weaning weights are based equals 3.0 - 1.0 = 2.0.

4. *Ewe Marginal Food Cost*

Assume that ewe body weight is 50 kg, and that maintenance requirements are proportional to (body weight)$^{0.75}$; $(50.0)^{0.75} = 18.803$; $(51.0)^{0.75} = 19.084$.

Then, the increase in maintenance requirements per 1.0 kg increase in ewe bodyweight can be calculated as:

$$\frac{19.084 - 18.803}{18.803} = 0.0149 \text{ or } 1.49\%$$

If the cost of feeding a ewe is \$1.50 per year, (\$1.50) x (0.0149) = \$0.02235 is the increase of food cost per 1.0 kg increase in ewe bodyweight. Then, the ewe marginal lifetime food cost is equal to:

$$(\$0.02235)\ (4.85) \simeq \$0.11$$

Computation of Economic Values

A selection objective for Merinos can be defined as a linear function of the additive genetic merit for clean fleece weight (CFW), fibre diameter (FD), number of lambs weaned (NLW), weaning weight (WW) and ewe bodyweight (EBW). Algebraically this can be expressed as:

$$T = v_1\ G_{CFW} + v_2\ G_{FD} + v_3\ G_{NLW} + v_4\ G_{WW} + v_5\ G_{EBW}$$

where the v's are economic values, that is, changes in return to the farmer per ewe lifetime per unit increase in CFW, FD, NLW, WW and EBW. For example, V_1, represents the change in return to the farmer per ewe lifetime per unit change in CFW. The G's are breeding values.

The economic values were based on the estimates of net prices to the farmer given earlier, and were calculated as follows:

v_1 = (expressions of fleece production) x (price per kg of clean wool in dollars)

= (5.35) x ($2.00) = $10.70 per kg change in clean fleece weight.

v_2 = (expressions of fleece production) x (average clean fleece weight) x (price change of one kg of clean wool per micron change in fibre diameter)

= (5.35) (3.5) (-$0.08) ≃ -$1.5 per micron change in fibre diameter.

v_3 = (number of matings per lifetime) x (price of one lamb)

= (3.85) x ($14.00) = $53.9 per additional lamb weaned.

v_4 = (number of lambs available for sale per ewe lifetime) x (price per kg of live lamb)

= (2.0) ($0.47) = $0.94 per kg change in weaning weight.

v_5 = (price per kg of ewe bodyweight) - (food costs)

= ($0.24) - ($0.11) = $0.13 per kg change in ewe bodyweight.

The equation defining the selection objective for Merino breeding can now be written as:

$$T = 10.7\ G_{CFW} - 1.5\ G_{FD} + 53.9\ G_{NLW} + 0.94\ G_{WW} + 0.13\ G_{EBW}$$

APPENDIX 2: Phenotypic and genetic parameters for clean fleece weight (CFW), fibre diameter (FD), number of lambs weaned (NLW), weaning weight (WW), ewe body weight (EBW), greasy fleece weight (GFW), number of lambs born (NLB), 16-month body weight (BW), skin wrinkle score (Wr) and face cover score (FC)

	CFW (kg)	FD (microns)	NLW	WW (kg)	EBW (kg)	GFW (kg)	NLB	16 mth BW (kg)	Wr (score 0-13)	FC (score 1-6)
Mean	3.5	23.0	0.78	30.0	50.0	5.3	0.88	48.0	4.0	3.0
Heritability	0.4	0.5	0.1	0.25	0.4	0.35	0.15	0.4	0.5	0.4
Phenotypic Variance	0.25	4.7	0.22	9.0	20.25	0.28	0.15	20.25	1.5	1.0
CFW		0.2	0.0	0.25	0.3	0.85	0.0	0.3	0.2	0.0
FD	0.25		0.1	0.1	0.13	0.13	0.1	0.13	0.14	-0.11
NLW	0.0	-0.1		0.12	0.15	0.0	0.7	0.15	-0.2	-0.1
WW	0.25	0.1	0.2		0.35	0.25	0.12	0.35	-0.08	-0.28
EBW	0.2	0.1	0.25	0.7		0.3	0.12	0.7	-0.08	-0.28
GFW	0.75	0.16	0.0	0.25	0.2		0.0	0.3	0.3	0.0
NLB	0.0	-0.1	0.8	0.2	0.2	0.0		0.12	-0.2	0.0
16 mth BW	0.2	0.1	0.25	0.9	0.8	0.2	0.2		-0.08	-0.28
Wr	-0.15	0.18	-0.3	-0.25	-0.25	0.2	-0.2	-0.25		0.08
FC	-0.2	-0.2	-0.3	-0.5	-0.5	-0.1	-0.1	-0.5	0.14	

phenotypic correlations (above diagonal)
genetic correlations (below diagonal)