BREEDING OBJECTIVES AND SELECTION CRITERIA FOR AUSTRALIAN PRIME LAMB PRODUCTION

J.E. Stafford and J.R.W. Walkley

Department of Agriculture and Fisheries, Adelaide, S.A. 5001

In its report (Dun *et al.*, 1970) "The Expert Panel on Selection of Breeding Stock for Sheep Meat Production" has outlined traits which can be included in breeding objectives for sheep meat production. "The Workshop on Improvement of Genetic Progress in Sheep Production" (A.P.C., 1974) agreed with Dun *et al.* (1970) that reproduction rate, growth rate, mature bodyweight, fleece weight, wool quality and freedom from economic faults should be included in the objective. Dun *et al.* (1970) also recommended selection practices which involve the use of independent culling levels.

In this paper selection index theory (Hazel, 1943) is used to define selection objectives for breeds which contribute to prime lamb production and to put together selection criteria in indexes to achieve these objectives.

Although selection index theory requires a number of assumptions many of these apply to other selection procedures also; because of this the most appropriate action when selecting for several traits will normally be to construct an index using available parameter estimates (Cunningham, 1969).

The following terminology is used in this paper: Traits are attributes which should be improved genetically because they have a direct effect on economic returns. All the important traits, together with the relative economic values are combined to form the selection objective. Selection criteria are those characteristics which are used to predict the breeding value for attaining the objective. In addition to contributing to the selection objective traits may be selection criteria.

THE STRUCTURE OF THE PRIME LAMB INDUSTRY

Some Australian prime lambs are produced in a single or two breed system but most are produced in a three breed system (Cannon *et al.*, 1973). One such system, outlined in Figure 1, is considered in this paper. The breed names are used throughout the paper, but the conclusions are likely to apply to other breeds that occupy their positions in Figure 1.

FIGURE 1: Structure of the lamb cross breeding system

Border Leicester ram x Merino ewe

↓

Poll Dorset ram x Border Leicester - Merino ewe

↓

Prime lamb for sale

The Poll Dorset and Border Leicester breeds are selected for prime lamb production and, whilst the Merino is usually bred for wool production (Cannon *et al.*, 1973) it could be selected for lamb production.

Typically, the prime lamb producer buys Border Leicester-Merino ewes and Poll Dorset rams to produce prime lambs. The aim of this paper is to show how returns to this prime lamb producer can be best improved by selection in the pure breeds on which his stock is based. Thus the objective for each pure breed is its contribution to the lamb producers return, and the value of each trait is its value to the lamb producer.

TRAITS WHICH ARE OF POTENTIAL VALUE TO THE PRIME LAMB PRODUCER AND SELECTION CRITERIA USED IN IMPROVING THEM

The traits of the Border Leicester-Merino ewe for which financial return is likely to be gained and the appropriate selection criteria are in Table 1a. Those of the lamb are in Table 1b. The meat production traits only, will be discussed in fuller detail.

TABLE 1: (a) Traits of the Border Leicester-Merino ewe which are of potential value to the prime lamb producer and selection criteria which may be used to achieve them

Trait	Potential Selection Criteria
Number of lambs weaned (taken as equivalent to number of lambs sold)	Lambs weaned per ewe joined, lambs born per ewe joined, number of hogget oestruses, hogget body weight, ram testicular size, ovulation rate.
Clean fleece weight	Clean fleece weight, greasy fleece weight.
Fibre diameter	Mean fibre diameter
Ewe body weight at ewe sale	Hogget weight, adjusted weaning weight, adjusted post weaning weight, post weaning growth.

(b) Traits of the lamb which are of potential value to the prime lamb producer and selection criteria which may be used to achieve them

Trait	Potential Selection Criteria
Sale weight (liveweight at 5/6 months)	Adjusted weaning weight (approximately 3/4 months), hogget weight (approximately 16 months) adjusted, post weaning weight (approximately 5/6 months), post weaning growth.
Carcass fatness	Eye muscle fat depth, condition score, live measurement of J110.
Lamb survival	Lambs weaned per lambs born on progeny test or ewe records.
Carcass conformation	Subjectively assessed conformation, weight for length ratio.
Eye muscle size) Fat colour, Tenderness) Flavour, Meat colour) Meat texture)	Direct measurement on progeny test

1. Number of lambs weaned

In some situations increasing the number of lambs sold will incur little extra cost and twins will be able to attain the same sale weight and price as singles; in other situations the returns will be less. Calculations from Thatchers (1977) paper show the value of one extra lamb sold to be from $1.70 to $15.60 depending on the time of lambing, ruling prices and the reproduction rate in the flock. He concluded that farmers were unlikely to receive lower returns when weaning percentages were increased. Hence number of lambs weaned should be included in the breeding objective.

If a ewe is to be selected prior to first lambing, or if a ram is to be selected, the selection criteria of number of lambs born or weaned per ewe joined are based on ancestor records, usually those of the dam. Selection can be on a single record or on multiple records (Turner, 1977).

Ch'ang and Rae's (1972) results show that hogget bodyweight is a suitable criteria for indirect selection for reproduction rate in the Romney ewe. With Merinos, genetic parameters found by Young *et al.* (1963) show that more genetic progress can be made by direct selection (Turner, 1969).

The number of hogget oestruses, testicular size and ovulation rate are potential selection criteria for number of lambs weaned (reviewed by Bindon and Piper, 1976) but as yet estimates of necessary genetic parameters are incomplete.

2. Ewe bodyweight

According to market reports the heavier ewe will command a higher price at the end of her breeding life. However, the genotype causing a ewe to be heavier at this time may also be expected to cause her to be heavier when bought as a hogget. Thus the gain at sale would be likely to be offset by the need to pay more for the ewe when it is bought. Since ewes of heavier bodyweight require more food for maintenance an increase in liveweight may result in extra cost to the producer for feed or for stocking rate foregone.

3. Sale weight of lambs

Calculations on the South Australian market reports for September-October 1978 show that higher prices are paid for heavier lambs, so sale weight of lambs should be included in the breeding objective.

The reports also show that the return for an extra kilogram of carcass weight is $0.67 for lambs of about 16 kg and $0.22 for lambs of about 19.5 kg so increased sale weight is of most value in small or medium lambs.

Selling carcasses instead of live sheep will enable the market to distinguish between heavy weight and overfatness. If this measure is adopted it is possible that heavier lambs will bring better returns provided the increased weight is not accompanied by increased fat.

Genetic increase in sale weight of lambs is achieved by selection for a weight, or weights in the constituent breeds. Weaning weight is taken at a time which is convenient for management and it needs to be adjusted for a number of environmental factors (Shelton and Campbell, 1962). Results of Ch'ang and Rae (1970) indicate that weights taken after weaning are likely to have higher heritabilities.

Some of the improvement achieved by selection for weaning weight will be by an improvement in the dam's mothering ability (Yeates and Pattie, 1970), that is, the dam's effect on the growth of the lamb, through milk production. An improvement of the mothering ability of the Poll Dorset breed is of no value to the lamb producer but such an improvement in the Border Leicester could be. It would be expected that selection based on post weaning weights would put more emphasis on the lamb's own ability to grow than would selection on weaning weights.

Olson *et al.* (1977) showed that, in feedlots, there is less need for adjusting post weaning 14-22 week gain for environmental effects than there is for post weaning weights. Under conditions of stud management in Australia, however, it appears from Gregory *et al.*'s (1978) data that adjustment of post weaning gains is desirable.

4. Carcass fatness

Analysis of Newmarket market reports indicate that there is little difference in the price paid for carcasses in the 16-19 kg weight range regardless of the fat thickness. Thus inclusion of carcass fatness in the breeding objective is not warranted unless one is predicting that there will, in future, be a price differential.

Such a differential is probable if carcass selling becomes popular, especially with heavy weight lambs. Consumer demand is swinging towards leaner meat, so a general reduction in fatness would be valuable to the industry as a whole. In light lamb production a fat reduction could be undesirable because a minimum fat cover is desired for keeping and shipping qualities (Smith and Carpenter, 1973). A number of carcass fatness parameters have high heritabilities (Botkin *et al.*, 1969), however a suitable live assessment of fatness has yet to be found.

Depth of fat over the eye muscle as measured by the "Scanogram", condition score and a live measurement of J110 (the depth from the surface of the fat to the thirteenth rib, 110 mm from the backbone), are three potential methods of assessment of fat in live animals; they have not been fully assessed but are all known to have limitations.

5. Carcass conformation

Hamilton *et al.* (1960) found that there was little or no within breed difference in prices of lambs sired by Dorset Horn and Cheviot rams of good and poor conformation.

Experimental evidence reviewed by Kirton (1976) shows only small differences occur in the distribution of retail joints and the proportion of muscle bone and fat with changes in carcass conformation, and no relationship between conformation and the proportion of economically important muscles or sheep meat palatability.

Thus it would appear that little is to be gained from further improvement of conformation and culling of those animals with extremely poor conformation may be all that is required. Subjective conformation assessment is satisfactory for this. Selection for weight for length ratio would need to be accurately assessed before use.

6. Other carcass quality traits

There are a number of other carcass quality traits in Table 1(b) which are possibly important in lambs but this importance is yet to be substantiated. In most cases there can be no direct gain to the producer by improvement as they cannot be assessed at sale.

TRAITS FOR INCLUSION IN THE BREEDING OBJECTIVE

The traits included in the breeding objective are those which have an important contribution to the income of the prime lamb producer.

Income is generated by the Border Leicester-Merino ewe and the prime lambs; these sources and the traits influencing income from them can be summarized as follows:

Income source	Traits in the selection objective
Border Leicester-Merino ewe	clean fleece weight (CFW), average fibre diameter (FD), number of lambs weaned (NLW), ewe bodyweight at sale (EBW)
Prime lamb	sale weight (SW)

1. Combination of traits into a breeding objective

Where two selected lines are crossed the male parent line will contribute

$$\tfrac{1}{2} G_S$$

and the female parent line will contribute

$$a\ G_D + \tfrac{1}{2} G_S$$

to the objective where G_D and G_S are the breeding values for the traits in the dam and lamb respectively and a is the relative economic value of G_D (Smith, 1964).

Similarly, in the three breed system the parent breeds of the female parent will both contribute

$$\tfrac{1}{2} a\ G_D + \tfrac{1}{4} G_S$$

Thus, using the methodology of Morris *et al.* (1979) the breeding objective (T) can be stated for each of the three breeds as:

$$T\ (\text{Poll Dorset}) = \tfrac{1}{2}\ a\ SW$$

$$T\ (\text{Border Leicester and Merino}) = \tfrac{1}{2} a_1\ CFW + \tfrac{1}{2} a_2\ FD + \tfrac{1}{2} a_3\ NLW + \tfrac{1}{2} a_4\ EBW + \tfrac{1}{4} a_5\ SW$$

where a, a_1, a_2, etc., are the relative economic values of each trait. Using the economic values calculated in Appendix 2 these objectives become

$$T\ (\text{Poll Dorset}) = \tfrac{1}{2}\ (2.29)\ SW$$

$$T\ (\text{Border Leicester and Merino}) = \tfrac{1}{2}\ (11.14)\ CFW + \tfrac{1}{2}\ (-1.15)\ FD + \tfrac{1}{2}\ (70.17)\ NLW + \tfrac{1}{2}\ (0.00)\ EBW + \tfrac{1}{4}\ (2.29)\ SW$$

SELECTION CRITERIA FOR THE BREEDING OBJECTIVE

The following selection criteria were chosen for initial inclusion in the index because they can be measured, are included in the objective or they are correlated with traits in the objective. Those chosen for the Border Leicester and Merino were clean fleece weight (CFW), greasy fleece weight (GFW), fibre diameter (FD), dam's number of lambs weaned (DNLW), dams number of lambs born (DNLB), hogget weight (HW) and adjusted weaning weight (AWW).

Those chosen for the Poll Dorset were adjusted weaning weight (AWW), hogget weight (HW) and post weaning weight (PWW), the last being a weight taken at a time equivalent to that of sale weight.

Once the selection objective for each breed was defined, a series of combinations of selection criteria were evaluated (see Tables 2 and 3). The different indexes were generated by the computer program SELIND (Cunningham and Mahon, 1977). The actual values used in the variance/covariance matrices were derived by using the estimates for the genetic parameters listed in Appendix 1. These parameter estimates were taken from the literature where possible, however some parameters especially those of EBW, SW and PWW were not available and these were estimated using values for similar characters as a guide.

The correlation of the index with the selection objective (r_{IT}) is a useful measure of the efficiency of an index since the genetic gain from selection is directly proportional to it. Comparison of indexes may also be made by comparing the genetic gain in each trait and the total gain in standard economic units (in this case dollars per ewe lifetime) that would result from one standard deviation of selection on the index (σ_I).

INDEXES FOR THE POLL DORSET

Selection criteria used were AWW, PWW and HW. The weightings of a number of alternative indexes, r_{IT} and σ_I are shown in Table 2.

TABLE 2: (a) Index weights and correlations (r_{IT}) between the indexes and the breeding objective for indexes PD1 to PD7 for the Poll Dorset

Selection Criteria	Index Number						
	PD1	PD2	PD3	PD4	PD5	PD6	PD7
AWW	0.02		0.12	0.03			1.00
PWW	0.15	0.16		0.10		1.00	
HW	0.19	0.19	0.23		1.00		
r_{IT}	0.60	0.60	0.59	0.55	0.58	0.55	0.48

(b) Genetic gains per generation (ΔG) for SW and total gain in dollars per ewe lifetime (σ_I) achieved by one standard deviation of selection on the index for indexes PD1 to PD7.

	Index Number						
	PD1	PD2	PD3	PD4	PD5	PD6	PD7
ΔG (kg)	0.64	0.64	0.63	0.59	0.62	0.58	0.51
σ_I ($)	1.48	1.48	1.45	1.34	1.42	1.34	1.17

It can be seen that where more than one weight is used r_{IT} is only slightly higher than for the best single weight of the combination, so selection on that weight is all that is warranted.

The r_{IT} of index PD7 is 17.2% lower than that of index PD5. Many stud owners would have to decide if the extra gain of $0.25 per generation warrants changes in management practise which would enable hogget weights to be taken. Taking a post weaning weight before hogget age may not be inconvenient. Selection on it would result in greater genetic gains than selection on adjusted weaning weight if the genetic parameters used here for PWW are applicable.

INDEXES FOR BORDER LEICESTER

Weightings for selection criteria and correlations with the selection objective for six indexes which are of potential use to breeders are given in Table 3(a). The genetic gain per generation in each individual trait that would result from one standard deviation of selection on the indexes and the value of the total gain are in Table 3(b).

TABLE 3: (a) Index weights and correlations (r_{IT}) between the indexes and the breeding objective for indexes BL2 to BL7 for Border Leicester

Selection Criteria	Index Number					
	BL2	BL3	BL4	BL5	BL6	BL7
CFW	1.74	1.74				
GFW			0.65	1.15		
FD	-0.45	-0.45				
DNLW		1.75				
DNLB	2.09		2.12	2.17	2.11	2.17
HW	0.32	0.32	0.33		0.35	
AWW				0.33		0.36
r_{IT}	0.38	0.38	0.33	0.27	0.32	0.26

(b) Genetic gain per generation for traits and total gain in dollars per ewe livetime (σ_I) achieved by one standard deviation of selection on the index for indexes BL2 to BL7

Trait	Index Number					
	BL2	BL3	BL4	BL5	BL6	BL7
CFW (kg)	0.0415	0.0414	0.0296	0.0395	0.0189	0.0163
FD (μ)	-0.1437	-0.1538	0.0620	0.0614	0.0526	0.0402
NLW	0.0154	0.0155	0.0154	0.0114	0.0164	0.0127
EBW (kg)	0.6974	0.6962	0.8148	0.5486	0.8391	0.5596
SW (kg)	0.2419	0.2399	0.2767	0.2116	0.2859	0.2222
σ_I	2.27	2.27	1.98	1.65	1.80	1.54

Index BL1 which is not reported in Table 3, included all the selection criteria and hence had the highest correlation with the selection objective (0.39) and the largest economic gain ($2.35).

Indexes BL2 to BL6 contain less criteria than BL1. The r_{IT} and economic gain (σ_I) for BL2, where four criteria are used, are only slightly lower than for BL1. For BL2 20.34% of the gain was in CFW, 7.29% was in FD, 47.93% was in NLW and 24.43% was in sale weight.

The small difference between the r_{IT} of BL1 and BL2 probably does not warrant the inclusion of the three additional traits in BL1.

A comparison of indexes BL2 and BL3 shows that the effect of using either DNLB or DNLW is similar.

The effect of using greasy fleece weight instead of clean fleece weight and fibre diameter can be seen by comparing indexes BL2 and BL4. Using clean fleece weight and fibre diameter is more costly than using greasy fleece weight so indexes BL2 and BL3 are most useful where the high potential effect of the sheep on the flock and industry warrants the cost of obtaining the more accurate assessment, as would be the case with stud rams. Indexes BL4 and BL6 may be used where the cost of measuring clean fleece weight and fibre diameter is not warranted, for example, with stud ewes.

Selection on adjusted weaning weight instead of hogget weight will not achieve the same rate of gain as can be seen by comparing indexes BL4 with BL5 and BL6 with BL7. Index BL5 is not a worthwhile alternative to index BL4 but index BL7 is one that can be used for culling at an early age.

PRICE SENSITIVITY

The relative economic values in the breeding objective for the Border Leicester were based on the 1978/79 season prices, a season of good prices. The differences in the genetic gain in each trait that would occur if different economic values are used to calculate the index can be investigated.

The effect of four different price combinations were considered. In the first combination (index S1) 1977 lamb prices and the 1979 wool floor price were used to calculate an alternative set of relative economic values (see Appendix 2). This simulates a year of lower prices for both wool and meat. In the second combination (index S2) a cost of 20¢ per kg was attributed to extra ewe bodyweight. Morris (1979) calculated that for a ewe being fed food value at $2.00 per year the ewe marginal lifetime food cost would be $0.13, so 20¢ is a high estimate of this cost. For the third combination (index S3), ewe bodyweight was valued at $0.30 per kilogram, a value which approximates that which applied in South Australian markets in December 1978 and does not make allowance for costs associated with the extra bodyweight. For the fourth combination (index S4) the value of each extra lamb was halved so that this value was $7.34 per lamb or $35.09 per ewe lifetime; this value is still within the range of Thatcher's (1977) calculations.

The selection criteria used in index BL2 were used to construct these indexes and index BL2 was used for comparison, as shown in Tables 4(a) and 4(b).

TABLE 4: (a) Index weights for indexes BL2, S1 to S4 and M

Selection Criteria	Index Number					
	BL2	S1	S2	S3	S4	M
CFW	1.74	1.25	1.76	1.70	1.95	1.69
FD	-0.45	-0.41	-0.45	-0.45	-0.34	-0.45
DNLB	2.09	1.60	2.07	2.12	1.05	2.07
HW	0.32	0.26	0.28	0.37	0.22	0.34

(b) Genetic gain per generation achieved by one standard deviation of selection differential on indexes S1 to S4, the total value of this gain (σ_I) and the gain achieved by index BL2 using the same relative economic values

Trait	Index Number					
	BL2	S1	S2	S3	S4	M
CFW (kg)	0.042	0.036	0.042	0.040	0.057	0.041
FD (μ)	-0.144	-0.180	-0.158	-0.126	-0.126	-0.153
NLW	0.015	0.016	0.015	0.016	0.013	0.015
EBW (kg)	0.697	0.691	0.664	0.737	0.658	0.610
SW (kg)	0.242	0.240	0.231	0.254	0.230	0.197

Small reductions in the genetic gains of some traits were accompanied by small increases in the genetic gains of others. In index S1 for example, there was more gain in fibre diameter and number of lambs weaned and less in clean fleece weight. In index S4 halving the value of number of lambs weaned would seem a drastic change, but even here the changes in genetic gain were not great. These results agreed with Rönningen's (1974) conclusion that "the efficiency of the index does not suffer much from relatively large errors in the economic values".

Return from ewe bodyweight occurs only once in a ewe's lifetime and the range in relative economic values of -0.20 to +0.30 dollars per kilogram would appear to encompass most situations that occur in Australia but the changes in the genetic gains achieved by using these two values were comparatively small. In these two cases EBW accounted for -6.24% and 8.90% of the total gain respectively so it would seem that ewe bodyweight is one of the less important traits.

INDEXES FOR THE MERINO

The objective for the Merino for prime lamb production is the same as for the Border Leicester. The variances for EBW, SW, HW and AWW used for the Border Leicester were those found by Ch'ang and

Rae (1970). The variances used by Ponzoni (1979) were different from these. The indexes for the Merino were calculated with the use of the latter author's variances for these and the selection criteria of all BL indexes except BL3. One of these, index M, which includes the selection criteria for BL2 is reported in Table 4.

In all cases the weightings for the indexes were similar to those of the BL index using the same selection criteria. The genetic gains for CFW, FD and NLW were similar to those of the equivalent BL index and those of EBW and SW were slightly lower. From this it seems that small differences in the variances of the bodyweights of different breeds or flocks will have a minor effect on the weightings of the index, but the genetic gains may be affected slightly. Thus the indexes in Table 3 may be applied to the Merino. This conclusion assumes the same genetic parameters for the two breeds; as there are insufficient estimates available for the Border Leicester no distinction is made.

VALUE OF GAINS TO THE LAMB PRODUCER

In both the Poll Dorset and the Border Leicester the economic gain is the extra income that the producer of crossbred lambs receives from genetic gains achieved in these two breeds from one standard deviation of selection on the index.

This amount of selection in Poll Dorsets on index 6 leads to a genetic improvement of 0.58 kg in sale weight of the lamb and this is worth $1.34 per ewe lifetime. In the Border Leicester the same amount of selection on index 2 gives an improvement of 0.24 kg in sale weight and this together with improvement in other traits accounts for $2.27 extra income per ewe lifetime. Here, selection in the Poll Dorset will have a greater effect on the sale weight of the lamb than in the Border Leicester and selection in the Border Leicester will contribute more economic gain for the lamb producer.

LIMITATIONS

This analysis has assessed the selection objectives and criteria which improve the return to the prime lamb producer. A limitation for the stud breeders is that it does not include objectives which may increase <u>their</u> income, for example reproduction rate and dystocia in the Poll Dorset.

No account has been taken of the effect of ewe's mothering ability on lamb growth rate. If account were taken it would possibly:

a) Increase the importance of the Border Leicester and Merino in improving lamb sale weight, and

b) Increase the importance of selection on adjusted weaning weight in the Border Leicester and Merino, this being the weight taken at the end of suckling.

In the analysis single records only were used for reproductive traits whereas, in practice, many non Merino studs would have multiple records available.

This analysis is dependent on the assumption made by Smith (1964) that performance on crossing is the sum of the contribution of the parent lines. No account has been taken of the possible effects that selection in pure breeds will have on the gains that are obtained from heterosis.

TRAITS TO BE MONITORED

There are a number of faults which occur in sheep and it is best to remove those sheep in which these faults are bad. Such faults are those of soundness of wool or body, carcass conformation and gross divergences from breed type which would threaten the registration of stud animals.

CONCLUSIONS

For the Poll Dorset the trait of major importance to the prime lamb producer is sale weight of the prime lamb for which one weight is a satisfactory selection criterion.

For the Border Leicester and Merino breeds traits which contributed most to the breeding objective were number of lambs weaned, clean fleece weight, fibre diameter and sale weight. An increase in ewe body weight appears to have little or no relative economic value, and the association of values with it gave little change to the genetic gains achieved by the index. An index including clean fleece weight, fibre diameter, dam's number of lambs born or weaned and hogget weight is appropriate for rams, indexes with fewer criteria can be used for ewes with a small loss in genetic gains.

Problems that occur in this type of analysis centre around the scarcity of genetic information, especially genetic and phenotypic correlations. It is uncommon for reports to give these correlations for fleece characteristics, reproductive characteristics and growth characteristics on the one set of data. Estimates of genetic parameters are scarce for non Merino breeds of sheep in the Australian literature.

ACKNOWLEDGEMENTS

We would like to thank Dr. R.W. Ponzoni for the valuable advice and help that he has given us in preparing this paper, Dr. C.A. Morris for making available the paper "Objectives for sheep improvement" prior to publication and Leona Coleman for assistance in preparation of the manuscript.

REFERENCES

ANIMAL PRODUCTION COMMITTEE (1974) Report on workshop on improvement of genetic progress in sheep production, December 1974.

BINDON, B.M. and PIPER, L.R. (1976) Assessment of new and traditional techniques of selection for reproduction rate. In: *Sheep Breeding*. Proc. Int. Congr., Muresk and Perth, August. Tomes, G.J., Robertson, D.E. and Lightfoot, R.J. (Eds). Western Australian Institute of Technology, Perth. pp 357 to

BOTKIN, M.P., FIELD, R.A., RILEY, M.I., NOLAN, J.C. Jr. and ROEHRKASSEE, G.P. (1969) Heritability of carcase traits in lambs. *J. Anim. Sci.* 29: 251-255.

CANNON, D.I., THATCHER, L.P., and THOMAS, I.R. (1973) The mutton and lamb industries. In: *The Pastoral Industries in Australia.* Sydney University Press.

CH'ANG, T.S. and RAE, A.L. (1970) The genetic basis of growth, reproduction and maternal environment in Romney ewes: I Genetic variation in hogget characters and fertility of the ewe. *Aust. J. Agric. Res.* 21: 115-129.

CH'ANG, T.S., and RAE, A.L. (1972) The genetic basis of growth, reproduction, and maternal environment in Romney ewes: II Genetic covariation between hogget characters, fertility and maternal environment of the ewe. *Aust. J. Agric. Res.* 23: 149-165.

CUNNINGHAM, E.P. (1969) Animal Breeding Theory. Institute of Animal Genetics and Breeding, Agricultural College, Norway. (Landbruksbokhandelen/Universitetsforlaget/Vollebekk/Oslo).

CUNNINGHAM, E.P. and MAHON, G.A.T. (1977) SELIND, a fortran computer program for genetic selection indexes. Users guide.

DUN, R.B., AUSTEN, K., BUTTERFIELD, R.M., MAPLE-BROWN, J.I., TURNER, H.N. PATTIE, W.A., REDDIN, J.W. and SCOTT, W.J. (1970) Selection of breeding stock for sheep meat production, report of expert panel. *J. Aust. Inst. Agric. Sci.* 36: 30-36.

GREGORY, I.P., ROBERTS, E.M., and JAMES, J.W. (1978) Genetic improvement of meat sheep: 5. Heritability of post weaning weight and gain in Dorset and Border Leicester sheep. *Aust. J. Exp. Agric. Anim. Husb.* 18: 63-69.

HAMILTON, B.A., PATTIE, W.A. and GODLEE, A.C. (1966) A comparison of Dorset Horn and Cheviot sires of both good and poor conformation for prime lamb production. *Proc. Aust. Soc. Anim. Prod.* 6: 206-209.

HAZEL, L.N. (1943) The genetic basis for constructing selection indexes. *Genetics.* 28: 476-490.

KIRTON, A.H. (1976) Growth, carcase composition and palatability of sheep. In: Proceedings of the Carcase Classification Symposium, Adelaide, May 1976.

MORRIS, C.A., CLARKE, J.N., ELLIOT, K.H. and JOHNSON, D.L. (1979) Objectives for sheep improvement. In: *New Zealand Sheep Production, Processing and Marketing,* 1: New Zealand Institute Agriculture Science. [In press].

OLSON, L.W., DICKERSON, G.E. and GLIMP, H.A. (1976) Selection criteria for intensive market lamb production: Growth traits. *J. Anim. Sci.* 43: 78-89.

PATTIE, W.A. (1965a) Selection for weaning weight in Merino sheep. 1. Direct response to selection. *Aust. J. Exp. Agric. Anim. Husb.* 5: 353-360.

PATTIE, W. A. (1965b) Selection for weaning weight in Merino sheep. 2. Correlated responses in other production characters. *Aust. J. Exp. Agric. Anim. Husb.* 5: 361-368.

PONZONI, R.W. (1979) Objectives and selection criteria for Australian Merino sheep. Proceedings of the First Conference of the Australian Association of Animal Breeding and Genetics, Armidale, 1979.

RONNINGEN, K. (1974) The utilisation of selection index in animal breeding. Proc. 1st. World Conference on Genetics Applied to Livestock Production. I: pp 565-577.

SHELTON, M. and CAMPBELL, F. (1962) Influence of environmental adjustments on heritability of weaning weight of range Rambouillet rams. *J. Anim. Sci.* 21: 91-94.

SMITH, C. (1964) The use of specialised sire and dam lines in selection for meat production. *Anim. Prod.* 6: 337-344.

SMITH, G.C. and CARPENTER, Z.L. (1973) Post mortem shrinkage of lamb carcases. *J. Anim. Sci.* 36: 862-867.

THATCHER, L. (1977) It's worth increasing the weaning percentage in a prime lamb flock. *J. Agric., Victoria.* 75: 47-52.

THOMPSON, J.M., PATTIE, W.A. and BUTTERFIELD, R.M. (1977) An evaluation of the 'SCANOGRAM' as an ultrasonic aid in assessing carcase composition of live sheep. *Aust. J. Exp. Agric. Anim. Husb.* 17: 251-255.

TURNER, H.N. (1969) Genetic improvement for reproduction rate in sheep. *Anim. Breed. Abstr.* 37: 545-563.

TURNER, H.N. (1977) Australian Sheep Breeding Research. *Anim. Breed. Abstr.* 45: 9-31.

TURNER, H.N. and YOUNG, S.S.Y. (1969) *Quantitative Genetics in sheep breeding.* Cornell University Press, Ithaca.

YATES, W.J. and PATTIE, W.A. (1970) The effect of genetic improvement within pure breeds on the performance of their crossbred lambs. *Proc. Aust. Soc. Anim. Prod.* 8: 154-158.

YOUNG, S.S.Y., TURNER, H.N. and DOLLING, C.H.S. (1963) Selection for fertility in Australian Merino sheep. *Aust. J. Agric. Res.* 14: 460-478.

APPENDIX 1: PHENOTYPIC AND GENETIC PARAMETERS FOR SELECTION OBJECTIVES AND CRITERIA

Breed	CFW	FD	NLW	EBW	SW	NLB	GFW	HW	AWW	PWW
Border Leicester and Poll Dorset										
h^2	0.4	0.5	0.1	0.45	0.30	0.15	0.35	0.45	0.25	0.30
σ^2_p	0.25	4.7	0.22	25.4	15.2	0.15	0.28	25.4	12.25	15.2
Merino										
h^2	0.4	0.5	0.1	0.45	0.3	0.15	0.35	0.45	0.25	
σ^2_p	0.25	4.7	0.22	20.25	11.0	0.15	0.28	20.25	9.00	
Phenotypic correlations (above diagonal) / Genetic correlations (below diagonal)										
CFW		0.2	0.0	0.3	0.18	0.0	0.85	0.3	0.2	
FD	0.25		0.1	0.13	0.1	0.1	0.13	0.13	0.1	
NLW	0.0	-0.1		0.15	0.12	0.7	0.0	0.15	0.12	
EBW	0.2	0.1	0.25		0.74	0.12	0.3	0.7	0.65	
SW	0.24	0.1	0.2	0.86		0.12	0.20	0.75	0.85	1.00
NLB	0.0	-0.1	0.8	0.2	0.2		0.0	0.12	0.12	
GFW	0.75	0.16	0.0	0.2	0.2	0.0		0.30	0.20	
HW	0.2	0.1	0.25	0.8	0.86	0.2	0.2		0.65	0.75
AWW	0.25	0.1	0.2	0.75	0.95	0.2	0.08	0.75		0.85
PWW					1.00			0.86	0.95	

Major sources consulted were Turner (1978), Pattie (1965a, 1965b), Ch'ang and Rae (1970, 1972) and Turner and Young (1969).

APPENDIX 2:

CALCULATION OF ECONOMIC VALUES

The calculation of economic values was based on the method of Morris *et al.* (1979) using dollars returned to the prime lamb producer per ewe lifetime.

It is assumed that ewes are bought off shears prior to the first joining and sold off shears after the fifth lambing. Thus assuming a death rate of 2.2 percent the average number of shearings and lambings for each ewe is 4.78. Further, it is assumed that 1.0 lamb is sold for each ewe mated.

The base values were those that prevailed during the 1978 South Australian lamb season. Thus lamb values were assessed from the September - October market reports and the wool values from the Australian Wool Corporation sale reports of the first four months of 1979.

ECONOMIC VALUE OF CLEAN FLEECE WEIGHT

Net value of (27 micron) wool per kg		\$2.33
Average number of shearings		4.78
Therefore the value of one extra kilogram of wool = (\$2.33)×(4.78)	=	\$11.14 per kg

ECONOMIC VALUE OF FIBRE DIAMETER

Value per micron		-\$0.08
Number of shearings per ewe		4.78
Kilograms of wool produced per ewe		3.00
Value of 1 extra micron decrease in fibre diameter = (4.78)×(3.00)×(-0.08)	=	-\$1.15 per micron

NUMBER OF LAMBS WEANED

Assuming that twins can be brought to the same weight and sold for the same price as singles the value of each extra 16 kg lamb produced is taken as \$14.68 and for 4.78 lambings = \$70.17.

EWE BODY WEIGHT

It is assumed that the extra return gained by selling heavier body weight ewes is completely offset by the extra cost to buy the ewes and hence the value is \$0.00.

LIVEWEIGHT AT SALE

For a kilogram of liveweight increase on a 16 kilogram lamb the producer receives $0.48. If there is one lamb sold for each ewe joined the lifetime return for an extra kilogram of lamb sold is (4.78)x(0.48) = $2.29.

OTHER ECONOMIC WEIGHTINGS

Indexes were produced using the selection criteria CFW, FD, DNLB and HW as done with index BL2, but with different relative economic values to those for BL2.

These relative economic values were:

Index S1: Prices for lambs were the average of those reported for South Australia for September-October 1977, prices for wool were the Australian Wool Corporation's 1979 floor price less shearing cost.

Relative economic values were

wool weight	$ 8.22 per kilogram
fibre diameter	-$ 1.15 per micron
lambs weaned	$53.92 per lamb
ewe bodyweight	$ 0.00 per kilogram
sale weight	$ 2.00 per kilogram

Index S2: Relative economic values for CFW, FD, NLW and SW were the same as in index BL2. A cost of $0.20 per kilogram EBW was included to cover feeding costs.

Index S3: Relative economic values for CFW, FD, NLW and SW were the same as in index BL2. The relative economic value EBW was $0.30 per kg.

Index S4: Relative economic values for CFW, FD, EBW and SW were the same as in index BL2. That of NLW was halved giving a relative economic value of $35.09 per ewe lifetime.

* * *