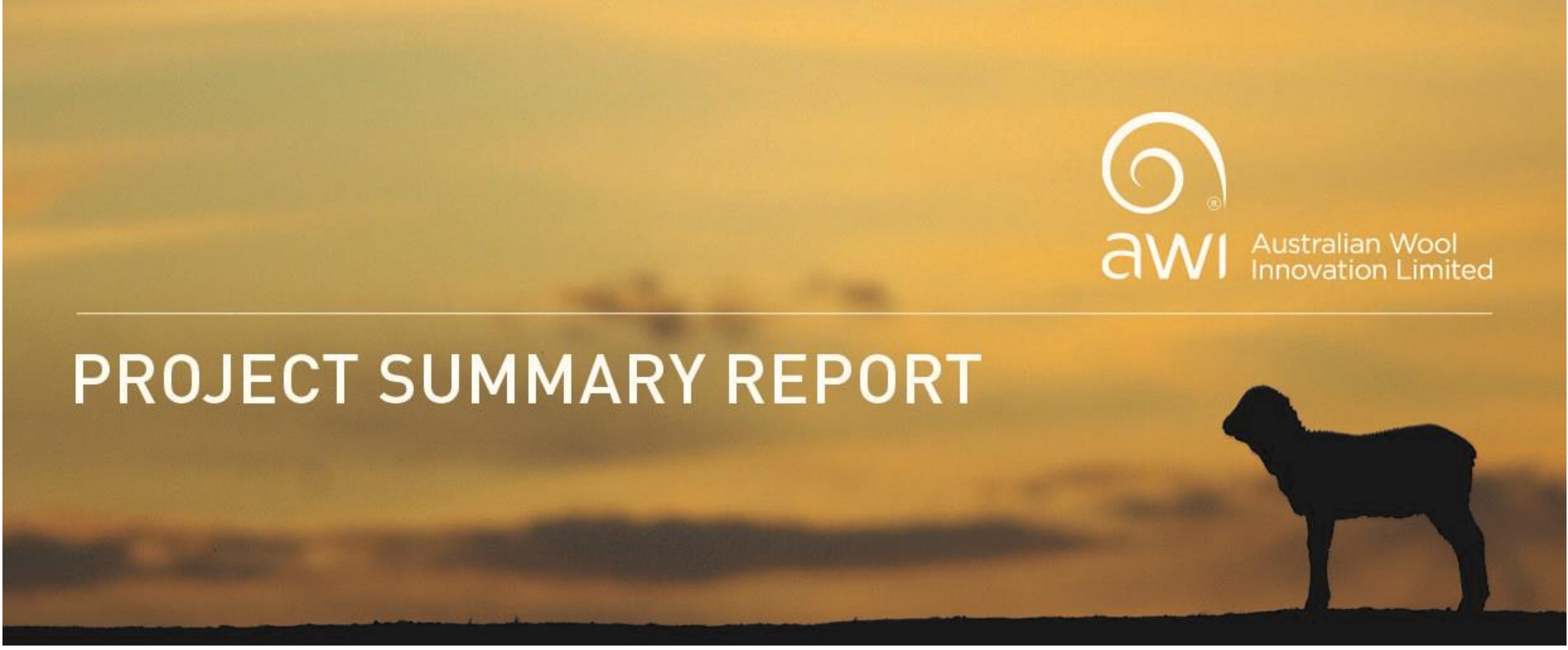

PROJECT SUMMARY REPORT

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Rate of Genetic Gain in Reducing Breech Flystrike - Update

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Contents

Executive Summary

General consensus within the wool industry is that breeding sheep more resistant to flystrike will be a critical component of programs to control breech strike in non-mulesed flocks as well as reducing the risk of strike in mulesed sheep. Since 2005, Australian Wool Innovation (AWI) has funded a major research program to identify optimal breeding strategies for improving breech strike resistance. Significant genetic variability amongst sheep in susceptibility to breech strike has been confirmed by the program, with the research also identifying key indirect selection criteria for improving resistance, in particular scores of breech wrinkle, dag and breech cover, with urine stain added more recently. Further R&D is continuing into additional factors such as odour and skin bacteria. Even if validated, they are not expected to be commercialised and used by industry for many years. Reliance on indirect selection methods is crucial for industry practice, as direct expression of breech flystrike is routinely suppressed by management interventions for good commercial and welfare reasons.

Predicted genetic reductions of 0.4 to 0.7 of a breech wrinkle score over 10 years in Merino ram breeding flocks under index selection have been reported, whilst still achieving reasonable genetic gains in productivity traits (Brown *et al*. 2010, Richards and Atkins 2010). In those studies, breech wrinkle score was added as a trait to MERINOSELECT selection indexes available at the time, with records of breech wrinkle scores assumed to be available as selection criteria, in addition to records for production traits. Richards and Atkins (2010) also concluded that reducing breech wrinkle in commercial flocks could take less time by selecting rams of higher genetic merit for breech wrinkle score and by ewe selection. However, until recently, no comprehensive study had been conducted on predicting genetic gains in reducing flystrike incidence itself, using all current information on breech indicator traits (breech wrinkle, dag and breech cover scores) across a number of Merino types and environments. In 2015, AWI commissioned project ON-00314, which examined:

- The rate of genetic gain (under selection for key productivity traits) that could be made in ram breeding and commercial flocks for reducing the incidence of breech strike in Merino sheep and associated breech indicator traits, breech wrinkle, dag and breech cover.
- Likely genetic changes in productivity traits in the face of differing selection emphasis on breech traits.
- Whether the rates of genetic gain are likely to differ across Merino sheep types which are often associated with differing breeding objectives and whether differing environments have an influence on reaching breeding targets.

At the time of conducting project ON-00314, the results available from the Mt Barker site of AWI's Research and Development program on breech strike were based on unmulesed young sheep that had not been crutched as yearlings. Under those conditions, the heritability of flystrike incidence was much higher (up to 0.5) than would be expected under more typical management, where young sheep are crutched prior to the onset of the main fly season.

This current study updates the work done in Project ON-00314, in particular by using revised genetic parameters based on data from crutched, unmulesed yearling sheep (Project ON-00169), to make the results more relevant to industry.

Ram breeding flocks

Predictions of genetic gain from within flock selection were undertaken based on the 'MTINDEX' modelling program (van der Werf 2015), using a batch code written in R by AGBU staff. Three breeding objectives were modelled, by using modifications of the Dual Purpose (DP+), Fibre Production (FP+) and Merino Production (MP+) indexes available from MERINOSELECT (Sheep Genetics 2018). Each index was modified by adding Flystrike Incidence (FSI) as a formal trait. These modified indexes, DP+FS1, FP+FSI and MP+FSI target, respectively, dual purpose, superfine/fine wool and fine/medium wool production systems. A large range of economic value options (selection emphasis) were examined for FSI, from zero to -$240 per strike/ewe/year in $20 increments, to cover the entire range of possible selection emphasis that could be considered in industry breeding programs. For all scenarios, full records of productivity traits and pedigree information were assumed to be available for use as selection criteria, as well as records of breech wrinkle, dag and breech cover scores. Predictions were conducted for 3 different assumptions (i) low heritability for FSI (ii) low heritability for FSI, but high heritability for Dag Score and (iii) medium heritability for FSI.

After 10 years of selection, predictions of genetic gain for flystrike incidence ranged from zero when the trait was given no selection emphasis, up to maximum reductions of 20, 19 and 21 strikes per 100 ewes/year for DP+FSI, FP+FSI and MP+FSI indexes, respectively, when the trait was given high selection emphasis and assumed to have medium heritability. When FSI was assumed to have low heritability, predictions of genetic gain were much lower, with maximum reductions of 6, 4 and 6 strikes per 100 ewes/year after 10 years of selection based on DP+FSI, FP+FSI and MP+FSI indexes, respectively. Comparing these predicted gains to the incidence of flystrike in Mediterranean conditions at Mt Barker in WA and the spring-summer rainfall environment in the Armidale area in NSW, they could potentially reduce flystrike in these two environments to low levels in most years.

The impact of selecting for lower FSI on the rate of genetic gain for productivity traits varied, depending on the trait considered. For economic values for FSI of -$70 per strike/ewe/year and less, genetic gains for fleece weight do not reduce below 50% of maximum gains possible and yet resulted in at least 80% or better of the maximum gain possible for FSI being predicted. Genetic gains for reductions in fibre diameter were only unfavourably impacted when using the FP+FSI index, when heritability of FSI was moderate and when high selection emphasis (≥ 66%) was placed on FSI, with economic values of -$160 per strike/ewe/year or greater. Genetic gains in number of lambs weaned reduce with greater economic values for FSI for selection with the DP+FSI index, however genetic gains predicted for reproduction are enhanced with increasing emphasis on reducing flystrike incidence when using the FP+FSI index and only marginally reduced at high economic values for FSI when using a MP+FSI index.

Genetic gains for reducing Worm Egg Count (WEC) became larger with increasing selection emphasis on reducing flystrike incidence, regardless of the index used or the level of heritability for FSI. Genetic gains for coefficient of variation in fibre diameter and staple strength were increasingly unfavourable with greater selection emphasis placed on reducing FSI, regardless of the index used or level of heritability for FSI assumed. However, the modest size of these adverse genetic changes could be reduced, or completely offset, by giving some selection pressure to these two traits.

In summary, there is a range of sensible economic values for FSI that could be used in breeding programs that would lead to meaningful reductions in FSI over a 10 to 15 year period, whilst retaining competitive levels of genetic gains for other important traits. In other words, breeders do not actually have to accept going backwards in genetic merit for any important trait when incorporating reducing flystrike incidence in their breeding objectives, but there will be a reduction of rates of genetic gain that can be made for some traits, in particular fleece weight, with gains reducing by 27% up to 50%

Finally, the predicted genetic gains in this study did not formally take account of the ability of ram breeders to utilise across-flock variation. There is considerable opportunity for ram breeders to exploit both across-flock and within-flock variation by utilising Australian Sheep Breeding Values available from the MERINOSELECT service offered by Sheep Genetics. This may enable greater rates of genetic gain than predicted in this study and assist breeders in better balancing genetic gains in reducing breech traits and flystrike incidence and genetic gains in productivity traits.

Commercial Flocks

In considering selection and culling strategies for commercial flocks, attention was focussed on the use of available ASBVs for breech traits; early breech wrinkle, late dag and early breech cover scores. These strategies included buying more elite rams within a ram source, changing ram sources to one that has more elite genetics for breech traits and culling ewe replacements on breech trait merit. Considered separately, the following potential changes through genetic (and phenotypic) improvement from using these strategies were identified:

- Buying more elite rams within a ram source, provided it is done consistently every year, can give useful genetic reductions over 10 years in scores of 0.24 in breech wrinkle, or 0.24 in dag or 0.16 to 0.24 in breech cover.
- Changing ram sources to one that is reliably more elite for breech trait genetics, but which also does not represent a compromise in productivity traits can also provide useful genetic reductions over 10 years of either 0.45 of a score in breech wrinkle, or 0.18 in dag score or 0.27 in breech cover score.
- Over 10 years, the likely changes from culling 20% of ewe replacements for single breech traits is more modest, being reductions in scores of either 0.14 in breech wrinkle or 0.08 in dag score or 0.06 in breech cover.

Results from AWI's R & D program on breech flystrike suggest that Merino sheep should have maximum individual scores of 2, 2 and 3 for breech wrinkle, dag and breech cover before the flock should be considered as not requiring mulesing. How long it will take to reach these targets will vary considerably across different sheep types and environments. In fine and superfine wool Merinos (18-19µ and finer) where there is likely to be a key focus on genetic reduction of fibre diameter, results from this study indicate that achieving long-term genetic reductions in breech traits may require more selection emphasis and take longer to achieve than in fine/medium wool and dual purpose sheep. In the meantime, use of chemical prevention, crutching and other managerial interventions will need to be continued and a possible move to breed fine rather than superfine wool sheep as an interim measure may also need to be considered. In addition, where Merino sheep are run in high dag environments and have average scores for dag of 3 or more, achieving a genetic reduction to a maximum score of 2 for any individual sheep in the flock appears not to be a realistic strategy using current breech traits as criteria in selection. The predicted minimum timeline for achieving a 1 score reduction is a minimum of 2 to 3 decades long or more. In lower dag environments, breeding to reduce dag is much more feasible, with genetic reductions of 0.1 to 0.2 in dag score predicted over 10 years from genetic gain from selection at the stud level, with greater reductions possible (0.5 of a score) by incorporating other ram buying and ewe culling strategies outlined above.

For breech wrinkle, achieving reductions of one full score within 10 years appear to be feasible for commercial producers with dual purpose and fine/medium sheep types if they are prepared to purchase elite rams from their existing stud, cull ewe replacements heavily on breech traits and change to a ram source with more elite genetics for their breeding objective. Achieving reductions of one full score in breech cover in commercial flocks may take longer (15 to 20 years) than is the case for breech wrinkle. Commercial producers with superfine sheep are currently more limited in making significant reductions in breech traits, particularly for breech wrinkle, as little genetic gains in breech traits are being achieved within that sheep type relative to fine/medium and dual-purpose sheep types.

In conclusion, sole dependence on genetic gains in ram breeding flocks is unlikely with current knowledge to deliver reductions of a full score in breech traits in a reasonable timeframe in commercial flocks. The other strategies outlined, of buying more elite rams, culling heavily on breech straits and possibly changing the ram source, also need to be seriously considered to reach the required scores for breech traits inside 12-15 years. Managers of commercial flocks may also need to consider setting up their own ram breeding nucleus and sourcing elite genetics via artificial breeding technologies if they want to more rapidly change their flock in preparation for ceasing mulesing.

Recommendations for improvements/refinements

- Publish more reliable genetic parameters for predictions, including whether the parameters vary across Merino types e.g. phenotypic variation for dag score.
- Derivation of an economic value for flystrike incidence for different wool-growing regions (and even within regions, if appropriate) would be of assistance in both prediction of genetic gain and in establishing formal breeding objectives to incorporate reducing flystrike incidence with current productivity and product quality traits.
- Development of new selection indexes that incorporate animal welfare / resilience traits, including flystrike incidence as part of index options by the MERINOSELECT service. Eventual inclusion of flystrike incidence as a reportable trait. This will need to include work on the appropriate analysis and presentation of the trait. Breeding values may need to be derived initially from indirect / indicator breech traits. In the medium to longer term, breeding values may also be able to be derived from a genomic association approach.
- Clients of Sheep Genetics should be given the option to publish their average breeding values (ASBVs) for their stud and ram buyers encouraged to seek average ASBVs for a stud or the drop or the groups of rams offered for sale.
- Active encouragement (extension and promotion) to industry to increase the number of sheep that are recorded for breech traits and for neck and body wrinkle.
- Explore the merit of direct progeny testing of leading industry sires for flystrike incidence, particularly for areas of high dag incidence. This should be done in conjunction with establishing a reference population for the development of genomic enhanced breeding values.
- Updating of the OFFM Calculator software created by NSW DPI for commercial flock predictions (basis of paper by Richards and Atkins 2010). This would allow updating of the predictions at the commercial flock level to be made more rapidly, at lower cost.
- If ram buyers are having difficulty accessing suitable flock ram genetics to more rapidly reduce breech flystrike incidence and keep improving flock productivity, establishing their own ram breeding nucleus and purchasing semen from elite sires may be more economically feasible for their particular breeding objectives, management regime and locality.
- Set target ASBVs to go non-mulesing.

1 Introduction/Hypothesis

General consensus within the wool industry is that breeding more resistant sheep will be a critical component of programs to control breech and tail strike in non-mulesed flocks as well as reducing the risk of strike in mulesed sheep. In 2005, AWI commenced funding of a major research program to identify optimal breeding strategies for improving breech strike resistance. The work has been conducted in two major sheep production zones, the summer rainfall zone of New South Wales and the Mediterranean climate of south-western Western Australia. Earlier phases of this work have confirmed the presence of significant genetic variability amongst sheep in susceptibility to breech strike. Also identified have been key indirect selection criteria for improving resistance, in particular scores of breech wrinkle, dag and breech cover, with urine stain added more recently. Reliance on indirect selection methods is crucial for industry practice, as direct expression of breech flystrike is routinely suppressed by management interventions.

Since 2012, the research has been examining the factors underlying unexplained variation in susceptibility to flystrike, to find additional indicator traits that can improve rates of genetic gain in flystrike resistance. Notwithstanding, the present state of knowledge on currently identified indicator traits has advanced to a point where the rates of genetic improvement for reducing the incidence of breech flystrike can be predicted with acceptable reliability.

The aim of this study is to conduct and report on a series of predictions of rates of genetic improvement for reducing the incidence of breech flystrike in Merino sheep.

2 Literature Review

Flystrike remains one of the major diseases affecting the Australian sheep industry, estimated to cost $173 million annually (Lane *et al.* 2015). Flystrike in the breech (crutch and tail) region of the sheep accounts for the majority of flystrike incidence (Greeff *et al.* 2014), with surgical mulesing, regular crutching and application of insecticides either by preventative jetting or treatment of individual struck sheep remaining the predominant management procedures to control the problem. Docking tails at the optimal length, at the third palpable joint, to the tip of the vulva in ewes, is also critical to keeping breech flystrike to a minimum, regardless of whether the sheep are mulesed or not (Lloyd 2012).

With the practice of mulesing under scrutiny from social and ethical concerns (Blackman 2005; James 2006), in 2005 the wool industry rekindled its support in finding genetic solutions to controlling flystrike by investing in a major R, D and E program. Further, a considerable number of sheep breeders have been actively breeding animals more resistant to flystrike that are less reliant on mulesing. Published reports of the research work have progressively emerged over the last 10 years (Smith *et al.* 2009a; Greeff and Karlsson 2009; Brown *et al.* 2010; Greeff *et al.* 2014, 2018a, 2018b), along with accounts of other studies (Smith *et al.* 2009b, Richards and Atkins 2010; Bird-Gardiner *et al.* 2013, 2014, Hatcher and Preston 2015, 2017, 2018). These reports confirm that there is considerable genetic variation for breech flystrike and scores of breech traits including breech wrinkle, breech and crutch cover, dag and urine stain and that these traits could be useful indirect selection criteria (often called indicator traits). As incidence of flystrike is routinely suppressed by management interventions, indirect rather than direct selection is crucial for industry in achieving genetic reductions in incidence of breech flystrike.

Apart from contributing towards genetic reductions in the incidence of breech flystrike, favourable genetic changes in breech indicator traits can also provide other benefits. Selection for more wrinkle led to lower net reproduction rates in the Folds plus line at Trangie Research Centre in NSW (Dun 1964, Dun and Hamilton 1965, Turner and Young 1969) and sheep with lower skin wrinkle and breech cover scores in the breech strike selection lines at Mt Barker in WA had higher reproduction rates than sheep with higher scores (Greeff *et al.* 2012). Further, higher reproduction rate in Merinos in South Africa is genetically linked to less skin wrinkle (Matabesi-Ranthimo *et al.* 2018).

Although fleece weight is unfavourably related genetically with skin wrinkle (Mortimer *et al.* 2009), this antagonism is in the low to moderate range and can be readily offset by using appropriately balanced selection indexes, in the same way as simultaneous genetic gains have been made in fleece weight and fibre diameter, which are also antagonistically correlated (Richards and Atkins 2010). Urine stain is the most important cause of dark-fibre contamination in wool (Cottle 2010), so any genetic reductions in urine stain would be beneficial. In areas of high dag prevalence, reducing the level of scouring and associated dag formation improves returns from having less-soiled wool and reducing crutching costs, especially in unmulesed flocks (Larsen, Vizard and Anderson, 1995; Larsen, Tyrell and Anderson 2012). Furthermore, a genetic reduction in dag would also be of benefit in lessening the risk of carcase contamination, when sheep and lambs are consigned to an abattoir (Scobie *et al.* 2007).

From existing genetic knowledge of breech traits, Brown *et al.* (2010) and Richards and Atkins (2010) predicted genetic gains under index selection when breech wrinkle score is included in breeding objectives. Australian Sheep Breeding Values (ASBVs) for breech and body wrinkle have been routinely published by Sheep Genetics since before 2010. Both studies concluded that reductions of up to 0.4 to 0.7 of a wrinkle score are possible over 10 years as part of selection for multiple production (but not breech) traits, without seriously foregoing genetic gains in productivity, although Brown *et al.* (2010) advised that the use of across-flock variation in breech wrinkle will make the task easier than relying solely on within-flock selection. Richards and Atkins (2010) also reported that the time taken to reduce breech wrinkle in commercial flocks from using average stud rams could be reduced significantly by selecting rams of higher merit from the same stud and by ewe selection in commercial flocks. Neither Brown et al. (2010) nor Richard and Atkins (2010) studied the impact of breeding for lower dag score in high dag zones, most likely due to lack of data on dags at the time.

In 2010, Sheep Genetics added the routine issuing of ASBVs for breech cover and dag score, and further data collection within the AWI R, D and E program has enhanced the precision of genetic parameters available for estimating breeding values and for predicting genetic gains in dag score, breech wrinkle, breech cover and wool colour and to a lesser extent, urine stain. In 2015, as part of AWI Project ON-00314, predictions of genetic gains were conducted using breech wrinkle, breech cover and dag scores as indirect selection criteria for a large range of scenarios including different Merino sheep types and different wool-growing regions within Australia, to update and expand the earlier studies of Brown *et al.* (2010) and Richards and Atkins (2010).

Since conducting AWI Project ON-00314, a further updating of genetic parameters has become available from Project ON-00169, based on data collected from 2012 to 2016 on young crutched sheep at the Mt Barker site in Western Australia. The change made from recording un-crutched young sheep to crutched ones in 2012 allowed the information collected in the R, D & E program to be more typical of commercial industry practice. There have been significant changes in, for example, the heritability of breech strike under a regime of crutching of young sheep versus no crutching. As a result of these changes to the genetic parameters for breech flystrike and related traits, this project updates the earlier predictions made in AWI Project ON-00314.

3 Project Objectives

- Present scientifically-based practical on farm predictions of the genetic gain possible for reducing the incidence of breech strike comparable to mulesing, across a number of sheep types and in a number of regions differing in prevalence of known factors predisposing sheep to breech strike, while still expecting reasonable gains in the key economic traits.
- For each scenario considered, the final report will predict rates of genetic gain for key production, reproduction and wool quality traits, identifying any potential trade-offs between achieving genetic improvement for those traits and genetic improvement in lowering the incidence of breech strike.

4 Success in Achieving Objectives

The great majority of the objectives of the study were achieved. The only parts of the objectives that could not be addressed formally were:

- The inclusion of urine stain records as an additional selection criteria for predictions of genetic gain from ram breeding. Reliable genetic parameter estimates are not yet available to allow urine stain records to be included, yet R&D results have shown that urine stain can be major risk for breech strike in some regions.
- The inclusion of across-flock variation in the predictions of genetic gain from ram breeding. No readily available methodology known to the author is currently available to allow inclusion of both across-flock and within flock variation in predictions of genetic gain.

An unsuccessful attempt was made to comprehensively model genetic gain in reducing the incidence of flystrike in commercial flocks. The method involved creating a flystrike trait (as created for ram breeding flock predictions) and then calculating breeding values for flystrike incidence for all the 2016 drop animals in the MERINOSELECT database. The main issue with this approach is that only 20-30% of animals in the MERINOSELECT database have been recorded for breech indicator traits, so calculation of breeding values for flystrike incidence for animals without breech trait records was very inaccurate, relying mainly on correlations of flystrike with productivity traits. The nett effect of this approach is to create a bias so that fewer animals than normal were estimated to be elite for both resistance to flystrike and for productivity traits, leaving virtually no scope for commercial flock owners to select rams that are genetically resistant to flystrike, but also have good breeding values for productivity traits. Other drawbacks of this approach were the inability to adequately account for:

- The lack of pedigree information in commercial flocks
- Phenotypic selection (culling of ewes), and
- A focus on recording production traits only

This meant that the simple program designed struggled to incorporate independent culling among other tactical approaches that could be used in commercial flocks.

As a result, the methodology for predicting genetic gains in commercial flocks reverted to those employed in Project ON-00314.

5 Methodology

5.1 Genetic Gains in Ram Breeding Flocks

MTINDEX (van der Werf 2015), a spreadsheet model, was used for predicting genetic gains from within flock selection in Merino sheep, based on genetic parameters routinely used by the MERINOSELECT service, with some modifications (see section below on Genetic Parameters). Selection responses were modelled with three different MERINOSELECT indexes, modified to include flystrike incidence (FSI). The unmodified MERINOSELECT indexes (Fibre Production – FP+, Merino Production – MP+ and Dual Purpose – DP+) are available as standard options from the MERINOSELECT service offered by Sheep Genetics (Sheep Genetics 2018). The modified indexes were FP+ and flystrike incidence (FP+FSI), MP+FSI, and DP+FSI. The FP+ index places a large premium on micron, and aims to reduce fibre diameter and hold fleece weight constant and has a small negative emphasis on worm egg count. The MP+ index places a moderate premium on micron, and aims to reduce fibre diameter and increase fleece weight. The DP+ index places a small emphasis on micron with the aim to hold fibre diameter constant while increasing fleece weight with an additional emphasis on traits relevant to prime lamb production. The relative economic values for these indexes were as reported by Brown and Swan (2016).

The economic weighting given to flystrike incidence was varied from $0 to $240 /ewe/ year (in $20 increments) achieving a desired gain in fly strike prevalence from the three modified MERINOSELECT indexes. Samuel Walkom (AGBU) carried out the prediction work using an updated batch code, based on an earlier version written in R by Daniel Brown of AGBU.

Note that the breech indicator traits of breech wrinkle, dag and breech cover scores are not given an economic value per se, but their records are used as indirect selection criteria to predict genetic merit for the flystrike incidence trait.

5.1.1 Assumptions

The breeding program assumed a flock size of 500 breeding ewes with an age structure as outlined in Table 1. This was close to the optimum structure for maximising genetic gain (within 3%), which used only 2 and 3 year old rams, but the same number of ewe age groups.

Table 1: Flock Structure

Age	**2**	**3**	**4**	**5**	**6**	**Total**
Males	4	4	4	0	0	12
Females	108	104	100	96	92	500

It was assumed that replacement sires and ewes were all born and bred within the flock ie, within-flock selection only was used; across-flock variation was not considered, nor were existing ASBVs from the MERINOSELECT database. Further assumptions were:

1. 65% of the selection emphasis was placed on the index values and the remaining 35% on other information sources, such as visual assessments;
2. A weaning rate of 90%
3. Annual mortality rate of adult sheep of 4%
4. A generation interval of 2.97 years for males and 3.92 years for females
5. The 'Bulmer Effect' (Bulmer 1971) results in a 30% loss in genetic gain, via reductions in variance.
6. The proportion of males selected was 2% and 48% for females, giving selection intensities of 2.43 and 0.828 respectively.
7. Records were available on;
    - 30 half sibs for post-weaning weight (pwt),yearling weight (ywt), yearling clean fleece weight (ycfw), yearling fibre diameter (yfd) and yearling coefficient of variation of fibre diameter (yfdcv)
    - 30 half sibs for post-weaning worm egg count (pwec) (FP+ index only)
    - 30 half sibs for yearling yearling ultrasound fat depth (yfat) and yearling ultrasound muscle depth (yemd) (DP+ index only)
    - 15 half sibs for yearling staple strength (yss)
    - 7 half sibs for adult clean fleece weight (acfw), adult fibre diameter (afd) and adult coefficient of variation of fibre diameter (afdcv)
    - 5 half sibs for Number of lambs weaned (nlw)

This reflected a stud breeder undertaking best practice recording and measuring all the key traits within their breeding objective.

5.1.2 The fly strike trait

The units of the flystrike trait used here were count of strikes over the fly strike season per 100 ewes, which is 100 times the scale recorded in the breech strike selection lines at Mt Barker, WA and at Chiswick, near Armidale in NSW (AWI Project ON-00169, see Greeff et al. 2016 and AWI Project WP639, see Smith et al. 2016). Thus, the genetic gains represented for flystrike refers to the change in number of strikes per 100 ewes/year over a 10-year period. This report refers to the trait as Flystrike Incidence (FSI). Flystrikes in the breech area are the major source of FSI (Greeff et al. 2014).

5.1.3 Selection criteria

Selection criteria used by ram breeders within the industry are highly variable. The scenarios used in this analysis were based on highly proactive ram breeders who are recording all the traits of importance to a breeder using the relevent index.

This was expanded to include the ram breeder recording early breech wrinkle, early dag score and breech cover as correlated traits to reduce fly strike incidence. In this scenario it was assumed there was 30 half sib records available for each of these traits.

5.1.4 Genetic parameters

For the standard traits in MERINOSELECT, genetic predictions used the current Sheep Genetics parameters, with slight adjustments to the values made to take account of the most recent estimates coming from the studies of Hatcher and Preston (2017) and Hatcher and Preston (2018). For breech strike and breech indicator traits, the parameters were assembled with reference to all the available information from the AWI-funded research program on breech flystrike, plus a number of other independent studies. The final parameter set used in the study, when compared to the current Sheep Genetics set, featured the following adjustments to correlations between breech cover, breech wrinkle and body wrinkle with production traits:

For genetic correlations

1. A slight strengthening of the negative genetic relationships between weight and the above indicator traits
2. A change to a weak negative correlation between fleece weight and indicator traits
3. A strengthening of correlations between indicator traits and fibre diameter cv, staple length, fleece rot and fleece character
4. An incorporation of correlations between indicator traits and fleece dust penetration
5. Correlations within wrinkle and breech cover traits adjusted slightly

For phenotypic correlations

- These follow similar patterns to the genetic correlations but the magnitude of adjustments were much smaller

The main source of the updated genetic parameters between breech indicator traits (breech cover and breech wrinkle) and production traits was a paper by Hatcher and Preston (2018), with the genetic correlations listed in Appendix 1.

The genetic gain modelling was conducted under three scenarios where the heritability was for flystrike incidence was moderate ~0.20 as per the Smith (2016) analysis and low ~0.10 as per the Greeff et al. (2016) analysis. The third scenario is the same as the second, except that the heritability for dag score is high (0.30), to more closely model a situation where the incidence of dag is high, as in some Mediterranean environments in Australia.

5.1.5 Trade-offs between flystrike resistance and other traits

A concern often expressed within industry is that in breeding for reductions in the incidence of breech flystrike in Merino sheep, considerable reductions in fleece weight are likely. The comprehensive range of genetic predictions made in this project, using a wide range of different economic values for flystrike incidence, allowed the relationships between predicted genetic gains in reducing flystrike incidence and genetic gains in fleece weight and other traits to be illustrated.

5.2 Genetic Gains in Commercial Flocks

For commercial flocks, the options were considered for genetically reducing the incidence of breech flystrike and thereby either reducing the reliance on mulesing or removing the need for it entirely. These were:

1. Staying with the same ram source, but consistently buying more elite rams (compared with stud average) that have better breeding values (ASBVs) for breech indicator traits – early breech wrinkle score, early breech cover score or late dag score.
2. Changing the ram source to one that is genetically superior for indicator traits known to improve resistance to breech flystrike (lower dag, breech wrinkle, breech cover), whilst at the same time is also well-ranked for productivity traits.
3. In addition, a commercial flock owner may choose to screen out/cull a portion of their flock that is inferior for indicator traits. They could either buy in more resistant sheep or keep some of their better sheep longer to maintain their current ewe flock size.
4. Similar to 3, but a commercial flock owner screens out a nucleus of the most resistant sheep for breech flystrike indicator and productivity traits and establishes a ram breeding nucleus. Elite sires or semen for this flock are purchased.
5. Sell existing flock and purchase more resistant sheep.

Each of these options has its own benefits, costs and challenges. The rate of genetic change that could be made to a commercial owner’s flock under scenarios 1 to 3 has been explored. Option 4 is effectively a ram breeding option, which is discussed under the ram breeding scenario. Option 5 is difficult to assess, as it wholly depends on individual circumstances, rendering a generalised example almost useless.

Further methodology for each of the options for commercial flocks is described in the results section, for ease of reading and convenience.

6 Results and Discussion

6.1 Genetic Gains in Ram Breeding Flocks

The figures on the next pages show predicted gains for the main traits following 10 years of selection for each index studied. Flystrike incidence has been included as a trait in the breeding objective in each case (Figure 1). Genetic gains are shown for the productivity traits of fleece weight, fibre diameter, cv of fibre diameter, lambs weaned and worm egg count (Figures 2-7) and then the breech strike indicator traits (Figures 8-10). For Figures 2 to 10, genetic gain for the trait is plotted against genetic gain for FSI.

6.1.1 Flystrike incidence (FSI – Figure 1)

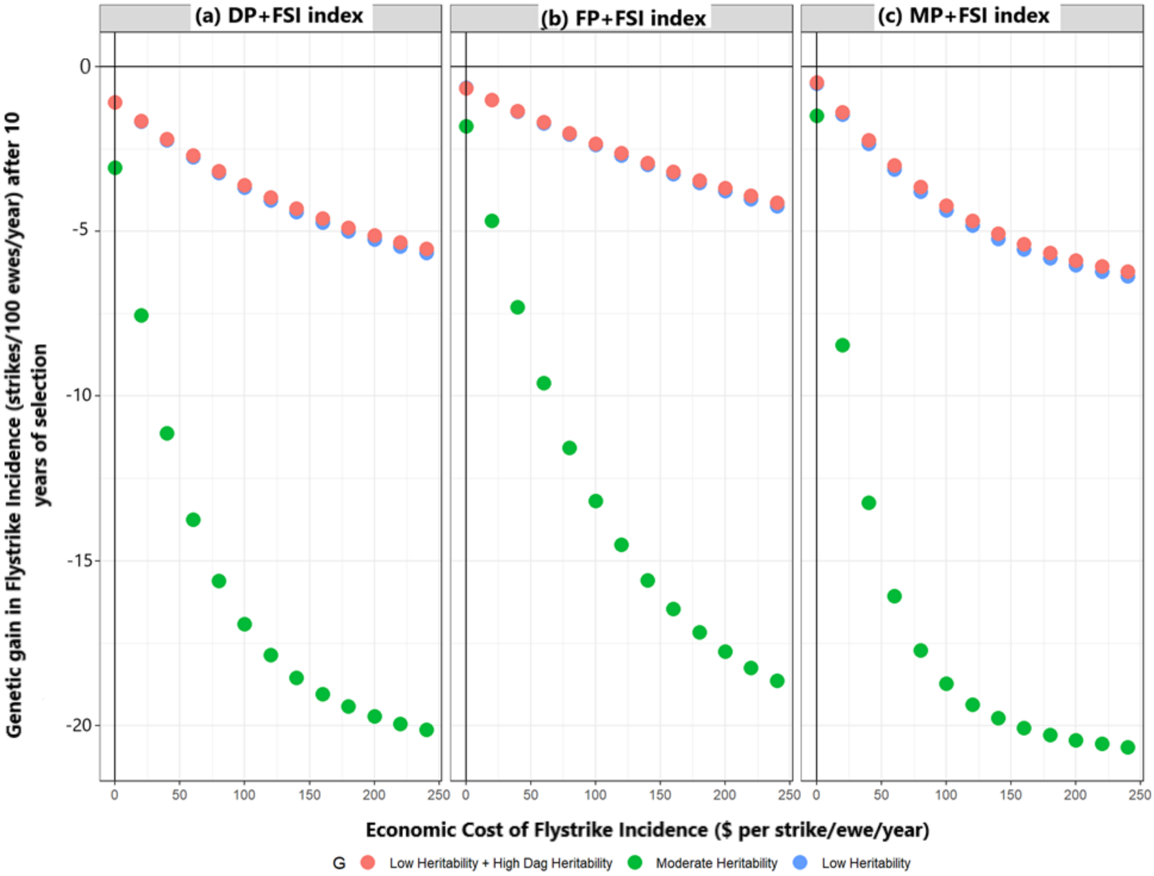

Figure 1: Predicted 10-year genetic gains in Flystrike Incidence (FSI) (strikes/100 ewes/year) using (a) a Dual Purpose Plus Flystrike Incidence (DP+FSI) index, (b) a Fibre Production Plus Flystrike Incidence (FP+FSI) index and (c) a Merino Production Plus Flystrike Incidence (MP+FSI) index, with economic values from 0 to -$240 per strike/ewe/year for FSI.

Under conditions with a prolonged fly season where breech flystrike has a medium heritability (20%), as at the CSIRO site at Chiswick near Armidale, NSW, predicted genetic gains in reducing FSI are 3 to 5 times as large as gains predicted where heritability for FSI is low (10%), such as in the Mediterranean environment at the Mt Barker site, in WA. When the heritability of FSI is medium, predicted genetic gains after 10 years of selection range from -2 to -3 to a maximum of -19 to -21 strikes/ewe per fly season, when the economic value for flystrike is increased from 0 to -$240 per strike/ewe. Gains are predicted to be slightly less for the FP+ index and slightly more for the MP+ index compared to gains from using the DP+ index At the highest economic value, most (80%+) of the selection emphasis available is being placed on reducing the incidence of flystrike (see Appendix 2).

When heritability for FSI is low, maximum genetic gains (associated with use of the highest economic value of -$240 per strike/ewe for FSI) are predicted to be -4 for the FP+FSI Index, -5.5 for the DP+FSI Index and -6.5 strikes per 100 ewes/year for the MP+FSI Index. When the heritability for dag score is assumed to be high, predicted genetic gains for FSI remain very similar compared to scenarios where the heritability for dag score is low.

Realistic range of economic values for FSI. Achieving maximum genetic gains for FSI would require sacrificing almost all selection emphasis to just one trait and ignoring all other traits, which is obviously not realistic. However, what is a more realistic range of economic values for FSI for use in breeding programs? This study did not specifically calculate economic values for FSI, but chose to examine the predicted consequences of selection across a wide range of desired gains for FSI. A very simplistic approach for determining what might be a realistic range of economic values for FSI is to be guided by the predicted trade-offs in genetic gain with other important traits, such as fleece weight. Note that there is an inherit issue with singling out trade-offs in genetic gain of only one trait, as it ignores the impact of selection on other important traits. Notwithstanding the deficiency of this approach, Table 2 below shows the genetic gains in FSI predicted (and the economic values for FSI) when obtaining 50% of the genetic gain for fleece weight when FSI is given no economic value (refer to Figure 2). In this case, the scenario is where the heritability for FSI is moderate, as in the spring-summer rainfall environment at CSIRO's Chiswick site near Armidale, NSW.

Table 2: Predicted genetic gain after 10 years of selection and corresponding economic values for Flystrike Incidence (FSI), when obtaining 50% of the genetic gain for fleece weight when FSI is given no economic value. The gain in FSI in brackets is as a percentage of maximum genetic gain for FSI. The heritability for FSI assumed is medium.

Index			**Economic Values for FSI**				
	-70	-80	-90	-100	-120	-140	-150
DP+FSI			-16 (81%)				
FP+FSI							-16 (86%)
MP+FSI	-17 (82%)						

For all indexes, with medium heritability for FSI, most (81% or greater) of the maximum genetic gains for reducing flystrike incidence are predicted to be achieved whilst still obtaining 50% of the genetic gain for fleece weight when FSI is given no economic value. When the heritability of FSI is low, the predicted genetic gains are much less overall, as discussed earlier. However, even when using the largest economic value for FSI of -$240 per strike/ewe per year, genetic gain for fleece weight is only reduced to 52%, 65% and 59% of gains (when FSI is given no economic value) for the DP+FSI, FP+FSI and MP+FSI indexes, respectively.

In summary, an upper limit for economic values for FSI in practice could be chosen where no more than 50% of the genetic gain for fleece weight, when FSI is given no economic value, is foregone. A lower limit is obviously zero economic value for FSI, but assuming a decrease in flystrike incidence is favoured, then economic values will need to be significant in magnitude. It is interesting to note that for almost all of the indexes and scenarios studied, at least 50% of the potential maximum genetic gains possible for FSI occur with economic values in the -$20 to -$60 range and do not involve foregoing more than 11%-43% (depending on the index and the heritability assumed for FSI) of the genetic gain possible for fleece weight when FSI is given no economic value. Thus, breeders can continue to improve the size of fleece cut even when reducing the FSI.

6.1.2 Fleece Weight (Figure 2)

The highest fleece weight gains are predicted when no economic value is assigned to the FSI trait. In addition to the key points made in the above section, when FSI has a low heritability (and thus low direct genetic gains possible via selection), genetic gains in fleece weight are predicted to be only marginally reduced (by less than 20%) unless the economic value for FSI is higher than -$80 per strike/ewe/year. The equivalent reductions in genetic gain for fleece weight when FSI has a moderate heritability and is given an economic value of -$80 per strike/ewe/year are predicted to be 46%, 27% and 54% for the DP+FSI, FP+FSI and MP+FSI indexes, respectively. At no stage did selection on FSI require or result in a decline in the fleece weight of the flock, with use of any of the modified MERINOSELECT indexes.

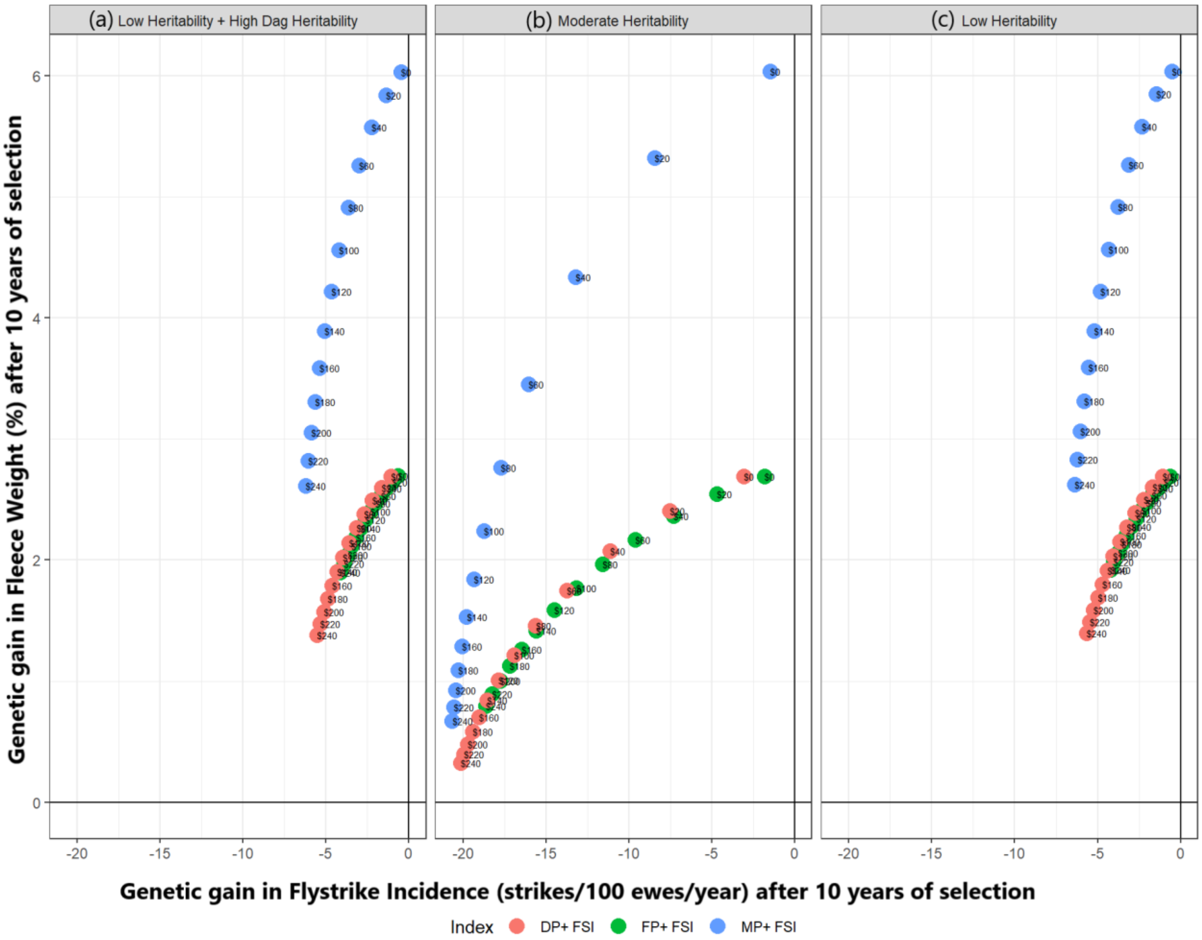

Figure 2: Predicted 10-year genetic gains in Fleece Weight (%) using a DP+FSI, FP+FSI, and MP+FSI index, with economic values from 0 to -$240/ewe for Flystrike Incidence (FSI). Gains are shown for (a) low heritability of FSI, but high heritability for dag score (b) moderate heritability for FSI and (c) low heritability for FSI and for dag score

6.1.3 Fibre diameter (Figure 3)

Increasing genetic gains in reducing FSI are complementary in general with increasing genetic gains in reducing fibre diameter, for economic values of FSI up to -$60. When increasing the economic value for FSI above -$80 and selecting with MP+FSI or FP+FSI indexes, genetic gains for fibre diameter start reducing. This is not the case when using a DP+FS index, where increasing the economic value for FSI also increases the genetic gain for fibre diameter. Unfortunately, it appears to be difficult with the FP+FSI index to obtain more than 50% of maximum genetic gains for FSI without sacrificing significant genetic gain in reducing fibre diameter. This trend is also evident when using the MP+FSI index as well, but is not so marked.

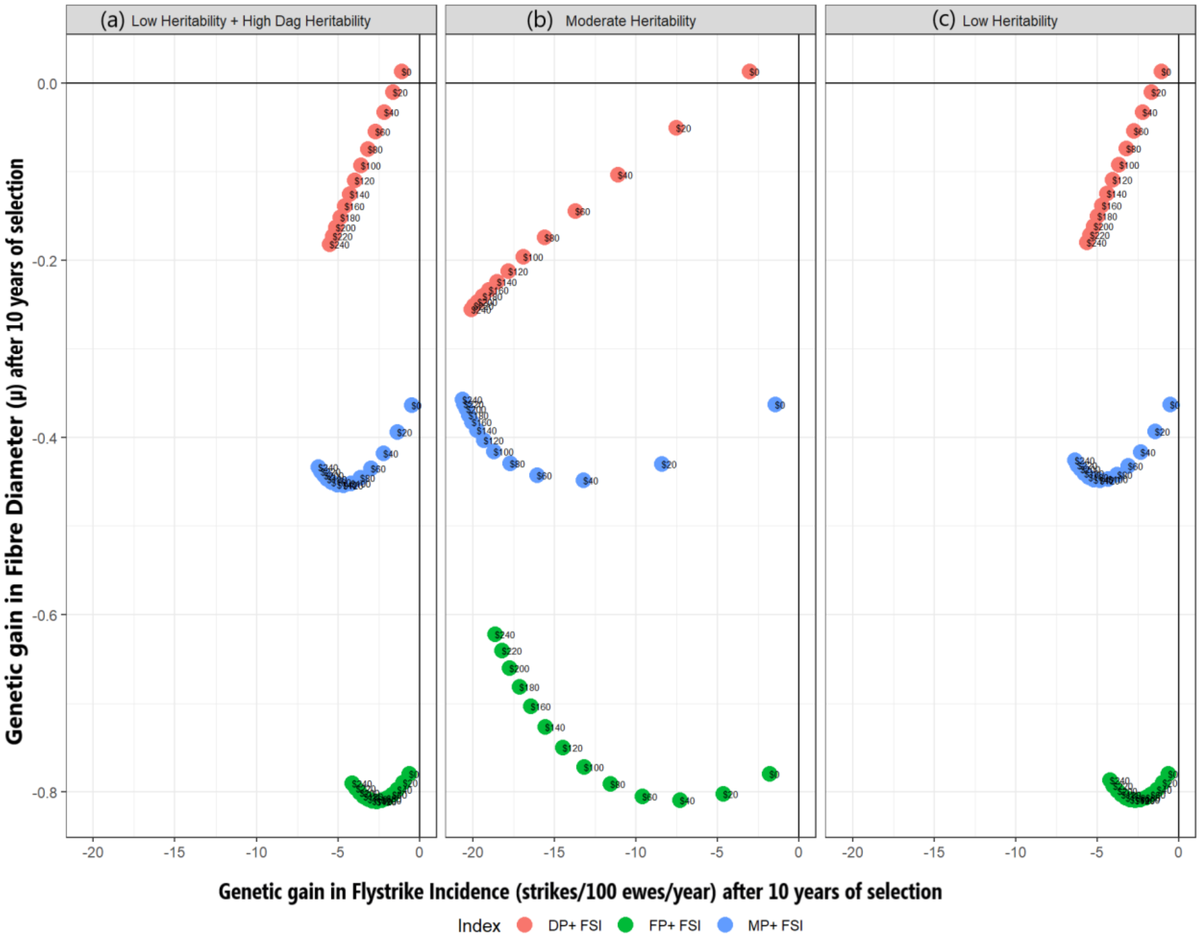

Figure 3: Predicted 10-year genetic gains in Fibre Diameter (µ) using a DP+FSI, FP+FSI and MP+FSI indexes, with economic values from 0 to -$240/ewe for Flystrike Incidence (FSI). Gains are shown for (a) low heritability of FSI, but high heritability for dag score (b) moderate heritability for FSI and (c) low heritability for FSI and for dag score

6.1.4 Coefficient of variation in fibre diameter (Figure 4)

Unlike the impact on genetic gains in Fibre Diameter, increasing genetic gains in FSI are consistently associated with decreasing genetic gains in the coefficient of variation in fibre diameter, regardless of the scenarios investigated. This is in contrast with the favourable relationship between body strike and FDCV. Depending on the specific breeding aims for FDCV, some counter-veiling selection pressure may be required (economic value given to the trait) to limit or reverse undesired changes in FDCV when genetically improving FSI.

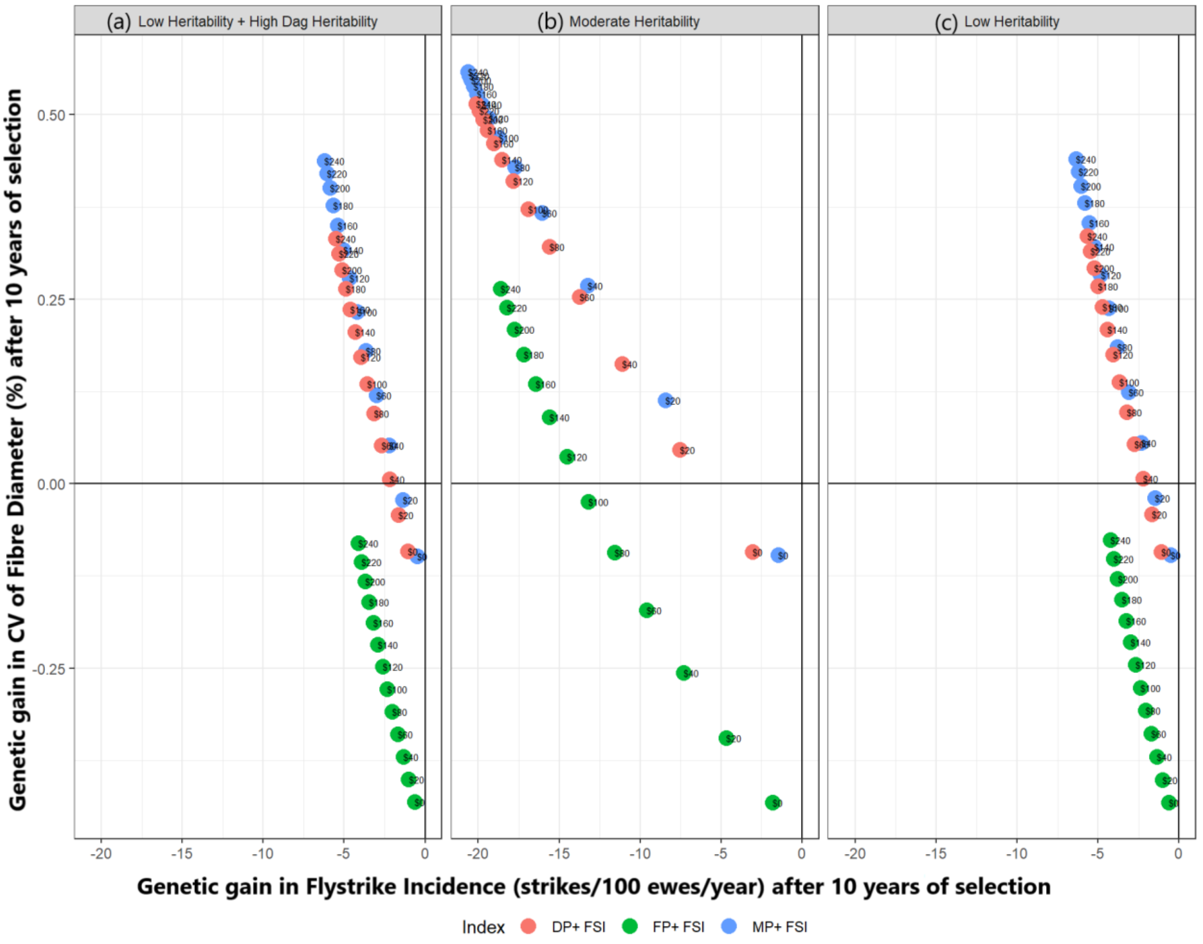

Figure 4: Predicted 10-year genetic gains in Coefficient of Variation for Fibre Diameter (µ) using a DP+FSI, FP+FSI and MP+FSI, with economic values from 0 to -$240/ewe for Flystrike Incidence (FSI). Gains are shown for (a) low heritability of FSI, but high heritability for dag score (b) moderate heritability for FSI and (c) low heritability for FSI and for dag score

6.1.5 Staple Strength (Figure 5)

Similar to the predictions for CV of Fibre Diameter, in all scenarios investigated, increasing genetic gains in FSI were associated with decreases in the rate of genetic gain for Staple Strength. The reductions predicted in Staple Strength with increasing selection emphasis on reducing FSI suggest that the results for CV of Fibre Diameter arise from increases in CV along the fibre, rather than across fibres.

Similar to comments regarding the coefficient of variation in fibre diameter, depending on the breeding aims for staple strength, some counter-veiling selection pressure on the trait may be required when breeding to reduce FSI. In other words, SS should be given an economic value, as part of the breeding objective. For both CV of Fibre Diameter and Staple Strength, the magnitude of the unfavourable genetic changes are relatively low, suggesting that it will not be difficult to counteract them.

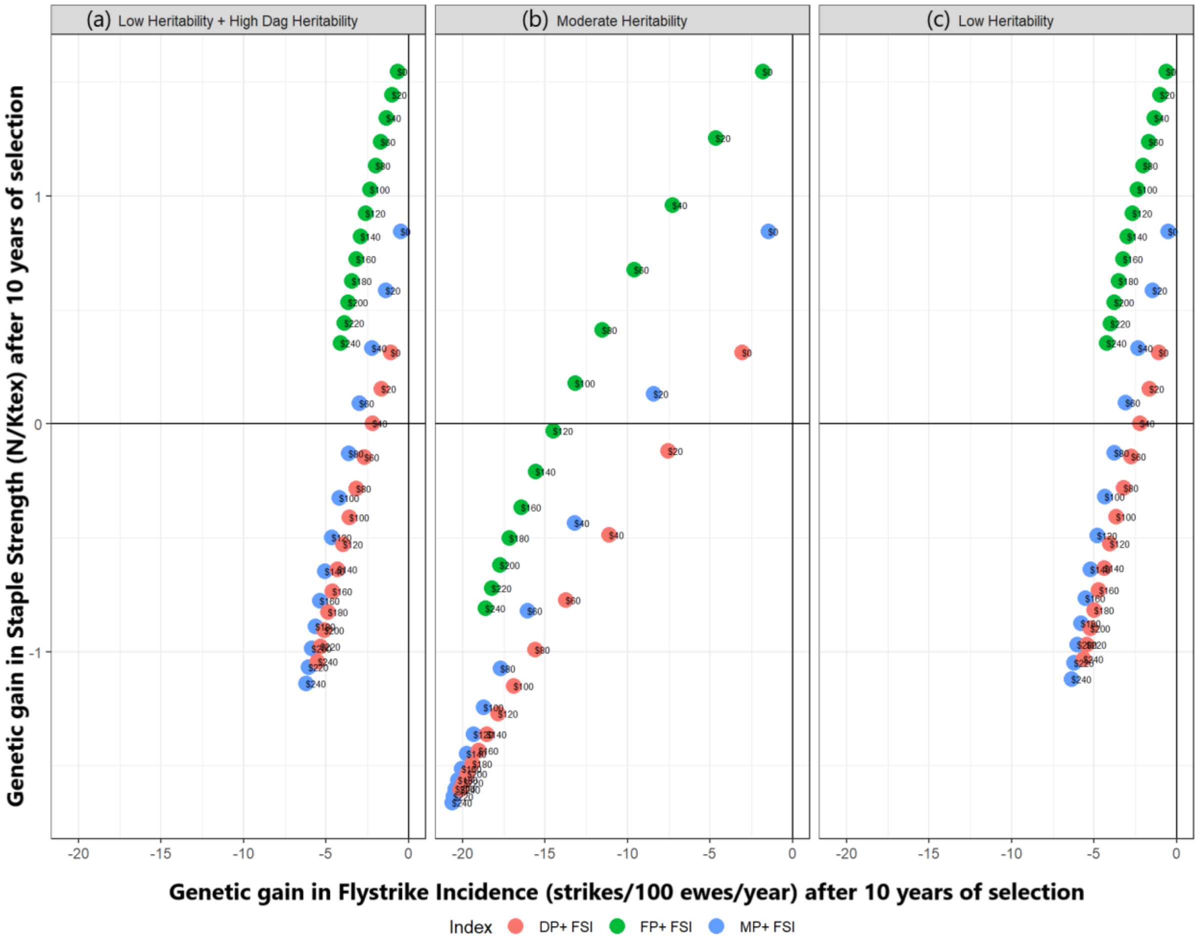

Figure 5: Predicted 10-year genetic gains in Staple Strength (N/Ktex) for a DP+FSI, FP+FSI, MP+FSI index, with economic values from 0 to -$240/ewe for Flystrike Incidence (FSI). Gains are shown for (a) low heritability of FSI, but high heritability for dag score (b) moderate heritability for FSI and (c) low heritability for FSI and for dag score

6.1.6 Reproductive Rate – Number of Lambs Weaned (Figure 6)

The predicted results for genetic gains in reproductive rate whilst selecting for reduced FSI are either positive or for little change in the rate of genetic gain for the Number of Lambs weaned trait as genetic gains for FSI are increased, except when using a DP+FSI index, where genetic gains reduce with economic values for FSI above -$40. In particular, when using a FP+FSI index, predicted genetic gains for reproductive rate continue to increase with increasing genetic gain for FSI up to an economic value of -$120 for FSI (when heritability for FSI is moderate) and taper off after that with little evidence of a decline. The situation for using an MP+FSI index is intermediate between the DP+FSI and the FP+FSI indexes, with genetic gains in reproductive rate maintained until the economic value for FSI increases above -$60.

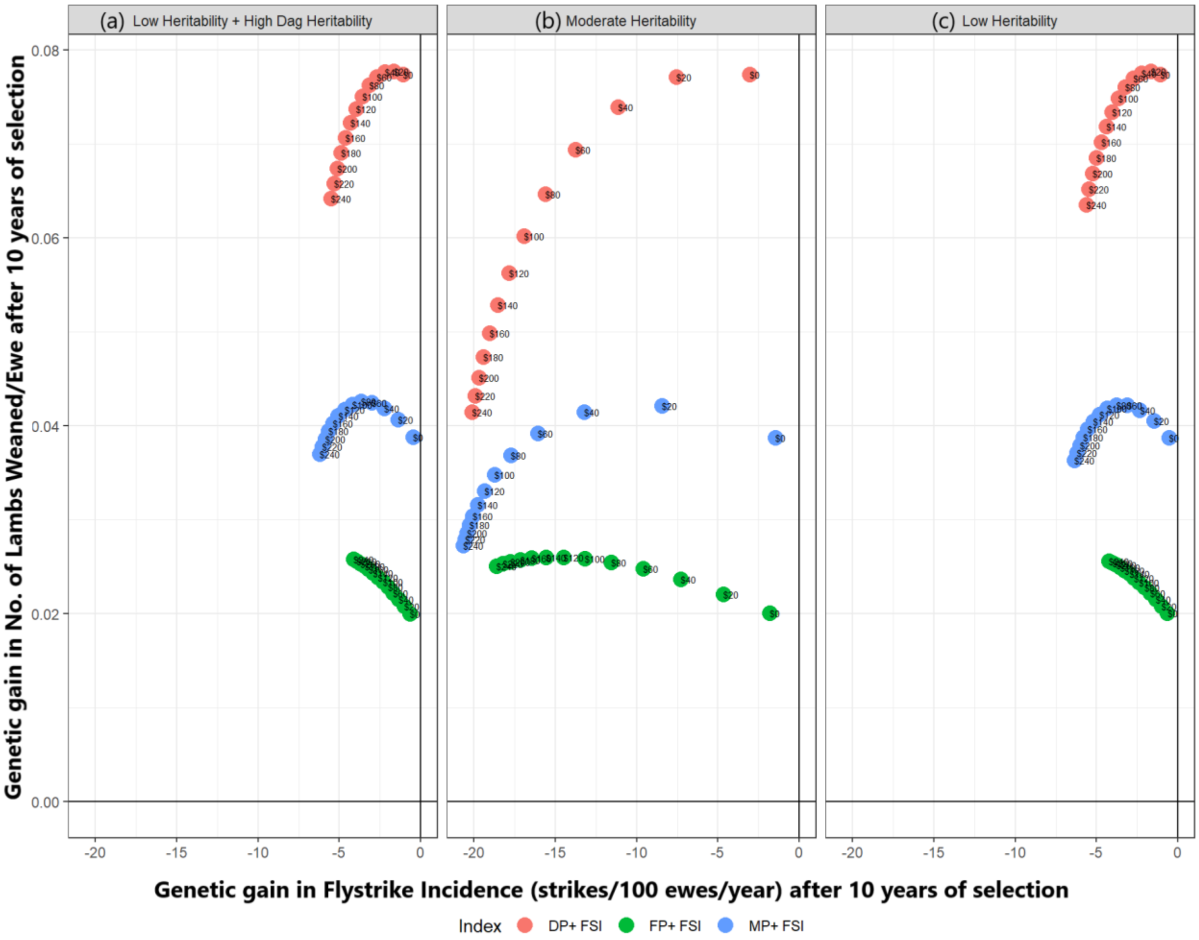

Figure 6: Predicted 10-year genetic gains in Lambs Weaned/Ewe Joined using a DP+FSI, FP+FSI and MP+FSI index, with economic values from 0 to -$240/ewe for Flystrike Incidence (FSI). Gains are shown for (a) low heritability of FSI, but high heritability for dag score (b) moderate heritability for FSI and (c) low heritability for FSI and for dag score

6.1.7 Worm Egg Count (Figure 7)

Positive results are predicted for genetic gains in WEC when selecting for reduced FSI, with increasing genetic gains for FSI associated with increasing favourable genetic gains for WEC, except at high economic values for FSI (> -$100), however even above those levels, there is not much evidence of a significant decline in genetic gain for WEC.

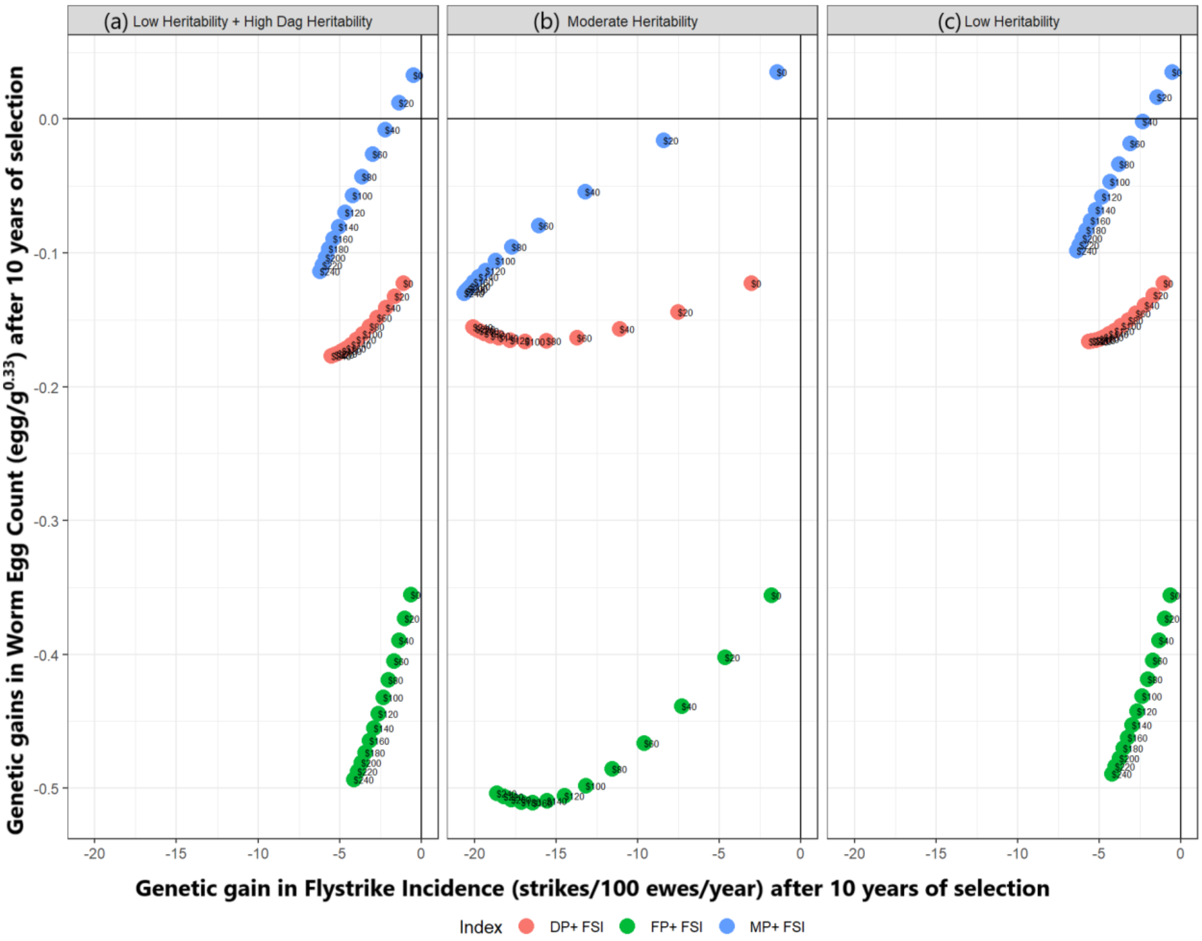

Figure 7: Predicted 10-year genetic gains in Worm Egg Count (egg/g0.33) using a DP+FSI, FP+FSI and MP+FSI index, with economic values from 0 to -$240/ewe for Flystrike Incidence (FSI). Gains are shown for (a) low heritability of FSI, but high heritability for dag score (b) moderate heritability for FSI and (c) low heritability for FSI and for dag score

6.1.8 Breech Wrinkle Score (Figure 8)

Breech Wrinkle Score is predicted to reduce the most after 10 years of selection using a DP+FSI Index (reductions from 0.3 to 0.4 of a score) and the least with a FP+FSI Index (from an increase of 0.1 to a reduction of 0.2 of a score), with predictions with a MP+FSI Index ranging from a small increase of 0.05 to a reduction of 0.25 of a score. Indeed, even when the heritability of FSI is medium, after 10 years of selection with a FP+FSI Index, it is only at economic values of -$60 and more for FSI that a reduction in Breech Wrinkle Score is predicted. With a low heritability for FSI, economic values of -$140 and more are required to obtain small reductions in Breech Wrinkle Score.

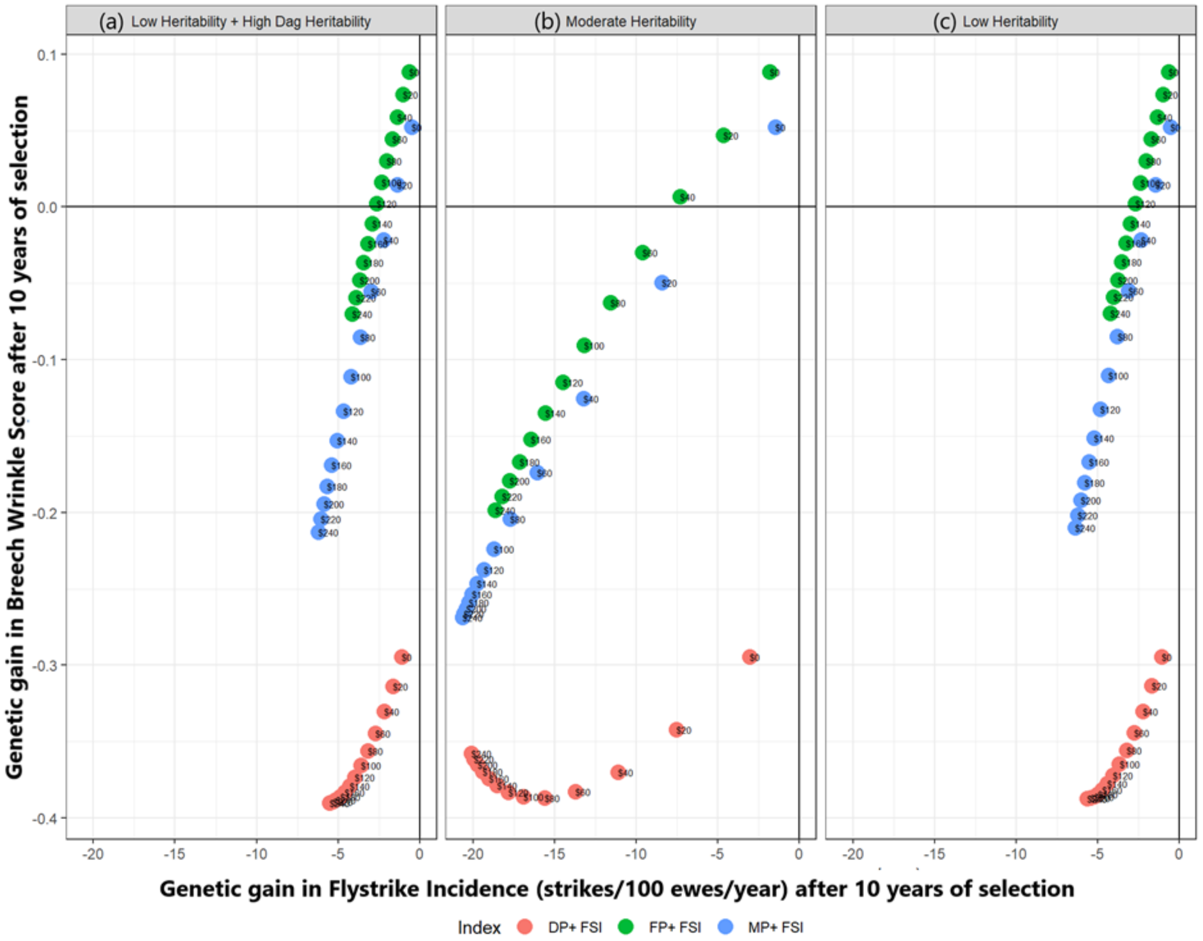

Figure 8: Predicted 10-year genetic gains in Breech Wrinkle Score vs genetic gains in Flystrike Incidence using a DP+FSI, FP+FSI and MP+FSI index, with economic values from 0 to -$240/ewe for Flystrike Incidence (FSI). Gains are shown for (a) low heritability of FSI, but high heritability for dag score (b) moderate heritability for FSI and (c) low heritability for FSI and for dag score

6.1.9 Dag Score (Figure 9)

Compared to results for Breech Wrinkle Score, Dag Score changes after 10 years of selection are predicted to be considerably lower with a DP+FSI Index, with a maximum reduction of 0.24 of a score when FSI has a moderate heritability, but are still 0.17 when the heritability of FSI is low. However, where the heritability of FSI is low and the heritability of Dag Score is high, Dag Score is predicted to reduce by 0.25 (at the maximum economic value for FSI of -$240) when using a MP+FSI index, more than the reduction in Breech Wrinkle Score. When FSI has a moderate heritability, predicted reductions in Dag Score with using a MP+FS index are similar to the reductions predicted for Breech Wrinkle Score (maximum of 0.26 vs 0.27).

After 10 years of selection with a FP+FSI index, Dag Score is predicted to reduce by more than Breech Wrinkle Score. Maximum reductions predicted are 0.23 when heritability is medium for FSI, 0.14 when heritability is low for FSI and 0.16 when the heritability for FSI is low, but high for Dag Score.

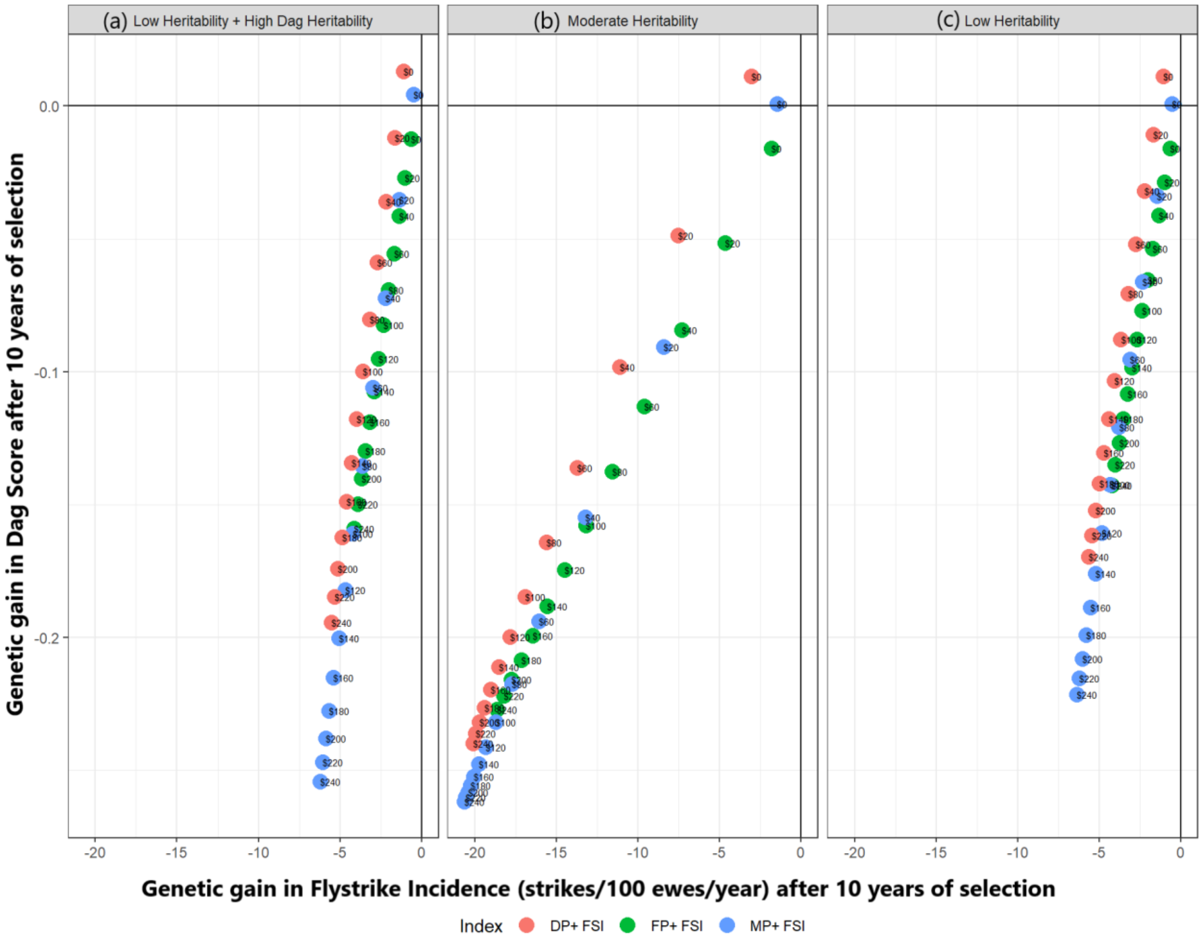

Figure 9: Predicted 10-year genetic gains in Dag Score using a DP+FSI, FP+FSI and MP+FSI index, with economic values from 0 to -$240/ewe for Flystrike Incidence (FSI). Gains are shown for (a) low heritability of FSI, but high heritability for dag score (b) moderate heritability for FSI and (c) low heritability for FSI and for dag score

6.1.10 Breech Cover Score (Figure 10)

Predicted changes for Breech Cover Score after 10 years of selection are similar in magnitude to the results for Breech Wrinkle Score using a DP+FSI index, but are considerably more when using a MP+FSI Index and particularly a FP+FSI index. Maximum predicted genetic reductions in Breech Cover after 10 years of selection are 0.36, 0.35 and 0.33 of a score for the DP+FSI, MP+FSI and FP+FSI indexes, respectively and are similar for both low and medium heritabilities of FSI.

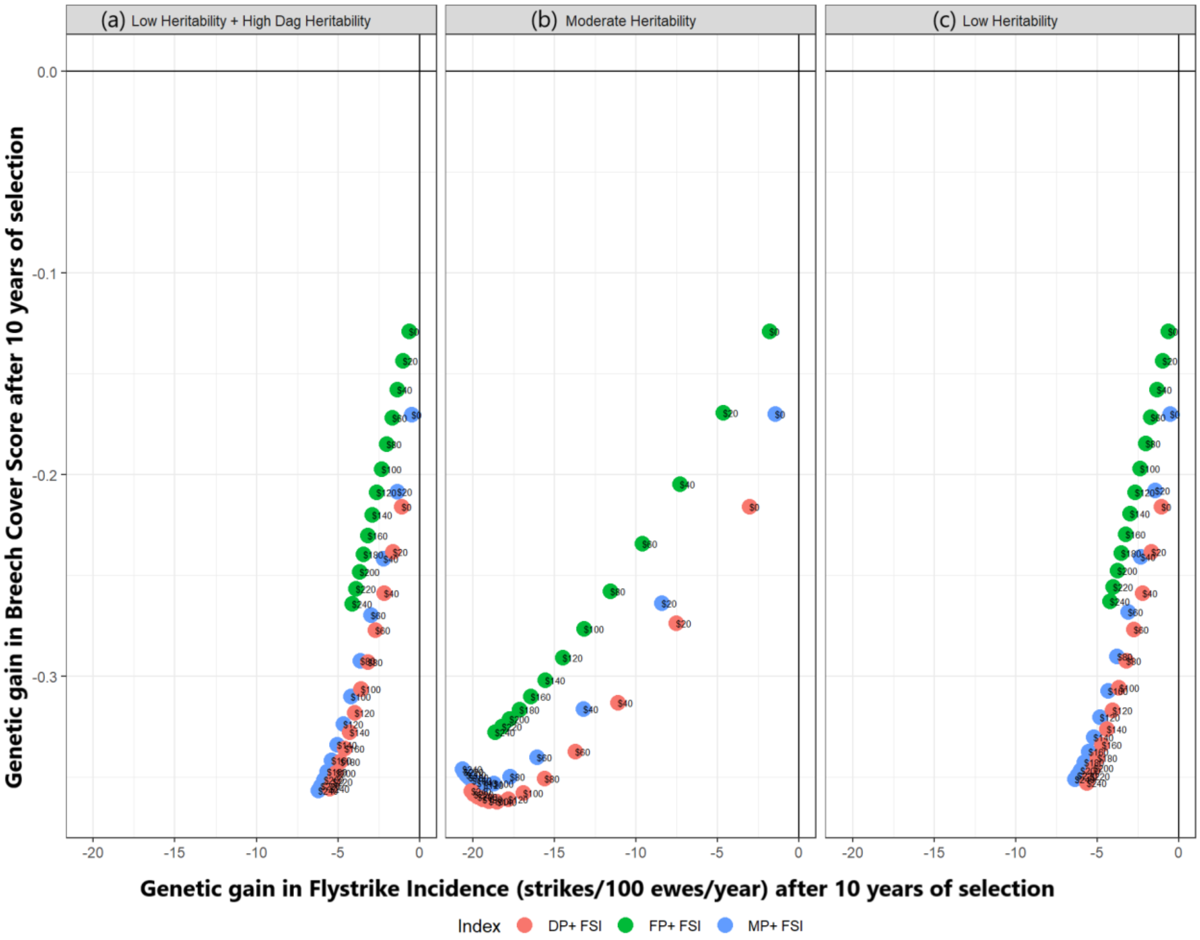

Figure 10: Predicted 10-year genetic gains in Breech Cover Score using a DP+FSI, FP+FSI and MP+FSI index, with economic values from 0 to -$240/ewe for Flystrike Incidence (FSI). Gains are shown for (a) low heritability of FSI, but high heritability for dag score (b) moderate heritability for FSI and (c) low heritability for FSI and for dag score

6.1.11 General discussion (ram breeding)

To reduce flystrike incidence by genetic means, it is clear that considerable selection emphasis is needed on the trait. How much emphasis depends on the breeding objective chosen, which relates to the type of sheep enterprise being run and the typical incidence of flystrike being experienced. This is best illustrated by an example. In the first example, a breeder in the spring-summer rainfall area near Armidale, NSW decides to attempt to reduce flystrike incidence in their stud flock by 10 strikes per 100 ewes per year over 10 years whilst at the same time also achieve a balance of genetic gains for productivity traits. This study suggests that breeding objective can be achieved by breeders using a MP+FSI or DP+FSI index with an economic value of at least -$40 for flystrike incidence. At that modest level of selection emphasis, at least 72% of the potential genetic gains in fleece weight (in the absence of selection emphasis on flystrike incidence) are still predicted to be achieved.

For breeders using a FP+FSI index who are pursuing a significant genetic reduction in fibre diameter and a reduction of 10 strikes per 100 ewes per year in flystrike incidence over 10 years, a higher economic value of about -$70 for FSI would be required. At that level, genetic gains in fleece weight are predicted to be 74% of that achievable when flystrike incidence is not part of the breeding objective.

For the example outlined above, the predicted genetic changes over 10 years using a MP+FSI index (economic value for FSI of -$40) are reductions of 0.37 of a score for Breech Wrinkle, 0.10 for Dag and 0.31 for Breech Cover. When using a DP+FSI index (and an economic value for FSI of -$40), predicted genetic changes over 10 years are score reductions of 0.37 for Breech Wrinkle, 0.10 for Dag and 0.31 for Breech Cover. From using a FP+FSI index (economic value for FSI of -$70), predicted genetic reductions are 0.05 of a score for Breech Wrinkle, 0.12 for Dag and 0.24 for Breech Cover. It is worth recapping that the breech indicator traits in this study were used as selection criteria for flystrike incidence and were not given economic values in their own right.

Across all scenarios studied, as selection emphasis for reducing flystrike incidence increased, there were increasingly unfavourable genetic changes predicted in both the coefficient of variation in fibre diameter and for staple strength. However, these genetic changes were not large and could be corrected with some selection emphasis given to these traits.

6.2 Genetic gain in commercial flocks

6.2.1 Scenario 1. Purchasing more elite rams from the existing source.

For this to be a viable option, the ram seller needs to be able to provide reliable information on the relative merits of their rams for breech traits/indicator traits for breech flystrike resistance. ASBVs on the MERINOSELECT website are the most accessible information on breech indicator traits. The next question is what variation in ASBVs is available for indicator traits from the ram source? It appears there are fewer sires available that rank well for breech traits that also rank high on productivity traits and indexes within the Ultra/Superfine category in MERINOSELECT than for the Fine/Fine-Medium and Medium/Strong categories (Lindon 2018). Further, genetic trends in breech traits for Superfines have been going backwards in recent years whilst breeders have concentrated on increasing fleece weight. For example, early breech wrinkle (ebrw) has increased from 0.0 in 2011 to +0.2 for the 2016 drop, whereas the flocks in the Medium wool category have changed from -0.4 in 2011 to -0.7 in the 2016 drop (Sheep Genetics 2018).

Breech wrinkle. Recent examples found include sale catalogues listed on the MERINOSELECT website for Clovernook (Walcha, NSW), Glenwood (Wellington, NSW), Turkey Lane and Ella Matta (Kangaroo Island, SA), Bellaine (Northern NSW), Petali (Walcha, NSW) – ranges of ASBVs for ebrw are shown in Table 3.

A flock ram buyer might expect to be able to purchase well-ranked rams on productivity with an ASBV for ebrw of -0.5 from at least 4 of the 6 example studs. Assuming a flock ram buyer's previous purchases were equal to the MERINOSELECT average of -0.2, this represents an improved breeding value of -0.3.

Table 3: Mean and lowest ASBVs for Early Breech Wrinkle Score (ebrw) in 4 ram sale catalogues shown on the MERINOSELECT website (accessed 19 February, 2019).

Stud	Wool type category	Lowest ASBVs for breech traits in sale catalogues		
		Early Breech Wrinkle Score - ebrw	Early Breech Cover Score - ebcov	Late Dag Score - ldag
Clovernook	Fine/Fine-Medium	-0.6	-0.7	-
Glenwood	Fine/Fine-Medium	-0.9	-0.3	-0.5
Turkey Lane	Fine/Fine-Medium	-0.6	-1.1	-
Ella Matta	Fine/Fine-Medium	-0.9	-0.4	-0.5
Bellaine	Ultra/Superfine	-0.9	-0.4	-
Petali	Ultra/Superfine	-0.9	-0.7	-

MERINOSELECT average ASBVs for ebrw, ebcov and ldag are -0.2, -0.1 and 0.1, respectively.

Assuming that the new rams purchased averaged -0.5 ASBV for ebrw and that the purchaser is a consistent client of the ram source, they will need to keep purchasing rams at least 0.3 ASBV scores below the MERINOSELECT drop average to maintain this advantage over time. As the results of this option will take time to work its way through the commercial flock, after 10 years of using this approach about 80% of the advantage should have been obtained, which is -0.24 ASBV.

These 6 examples are unlikely to represent typical situations for ram buyers, as only 30% or less of animals included in MERINOSELECT have breech trait records. However, the potential gains are large enough to indicate that this option is worth considering by commercial flock owners, as concluded by Richards and Atkins (2010). For breech cover and dag score, the minimum ASBVs available in the same sale catalogues for these traits are also shown in Table 3.

Dag Score. ASBVs for dag score are only available in 2 of the example stud catalogues listed in Table 3. For these 2 studs, an advantage of 0.3 in ASBV for ldag should be achievable below the MERINOSELECT average in genetic merit of purchased rams, whilst also selecting for high productivity. After 10 years of consistently using this approach, the commercial flock should have captured 0.24 in ASBV for ldag relative to purchasing rams that are average for their drop. This would not be achievable for the other 4 example studs, as no ASBVs are available. This is a general reflection of the smaller range of ASBVs available for ldag than ebrw and ebcov and likely also the smaller number of animals that have been recorded for the trait.

Breech Cover. Flock rams should be able to be obtained with ASBVs for ebcov that are 0.2 to 0.3 score lower than the MERINOSELECT average that otherwise rank well for productivity traits in the majority of the example ram sale catalogues. After 10 years of consistently using this approach, the commercial flock should have captured a reduction of 0.16 to 0.24 of ASBV score for ebcov relative to purchasing rams that are average for their drop.

6.2.2 Scenario 2. Changing the ram source to one that is genetically superior for indicator traits known to improve resistance to breech flystrike (lower dag, wrinkle, breech cover). The new stud may also have a greater rate of improvement in these traits over time.

Step 1. Identify superior studs that have breeding objectives closely aligned with the commercial flock. This is not necessarily easy to do. The MERINOSELECT service has public trait leader lists for individual animals and where agreed to by the breeder, public listings of all the animals recorded by that breeder. Some studs only have breech trait ASBVs listed for a portion of their recorded animals, for example, for sires entered into progeny testing schemes or research programs. Stud averages are not listed, although this is a planned enhancement in the future. However, if a stud has a number of animals ranking highly on trait leader listings, the probability is that that the average of the stud will tend to be better for the traits concerned as well than the average of the MERINOSELECT database.

Obviously, in searching for a stud more suited to the ram buyer, a range of traits need consideration, not just breech trait merit.

So, what is the likely range of ASBVs between studs of breech traits – e.g. breech wrinkle?

Breech Wrinkle. Stud A has five sires with ASBVs ranging from -1.6 to -0.7 in the top 50 for ebwr, with four being trait leaders for at least one of the MP, MP+, DP or DP+ indexes. Stud B has 4 sires with ASBVs ranging from -1.6 to -0.8, three of which are trait leaders for at least one index.

Assuming Stud A and B have stud averages approximately 0.7 ASBV for ebrw (about 2 genetic standard deviations) above (less favourable) their best listed sires e.g. top sires average -1.4 ASBV for ebrw, then the stud average is -0.7 ASBV for ebrw. The current MERINOSELECT database average for ebrw is -0.2 ASBV, which is 0.5 ASBV above (less favourable) the averages for Stud A and B. Thus the genetic advantage of these studs compared to the MERINOSELECT database average for ebrw is 0.5 ASBV units. Assuming that flock rams available reflect the stud averages, then a potential genetic advantage of 0.5 ASBV units in ebrw will be available to breed into a commercial flock.

If semen is available, then more elite sires may be accessible if suitable.

A further 3 studs on the MERINOSELECT database have, respectively 51, 30 and 10 rams with ASBVs of -1.0 or better (lower) for early breech wrinkle, all of which are trait leaders (top 10%) for the DP+ index. Again, this suggests that purchases of flock rams from these sources will provide potential gain of at least 0.3 up to 0.5 ASBV units in ebrw relative to the MERINOSELECT database average.

Dag Score & Breech Cover. For ldag, the top 50 sires for the trait have an ASBV range from -0.6 to -0.3. Stud C has four sires with ASBVs ranging from -0.6 to -0.3, two of which are trait leaders for at least one of the MERINOSELECT indexes. Stud E has 3 sires with ASBVs ranging from -0.6 to -0.3 for ldag, with all being trait leaders for at least one of the MERINOSELECT indexes. Studs C and E averages might be 0.2 ASBV for ldag less than the listed sires, leaving an advantage of -0.2 ASBV better than the database average and the likely average breeding value of flock rams from these studs.

For ebcov, the top 50 sires for the trait in MERINOSELECT have an ASBV range from -1.6 to -0.3, but not as many sires are measured for this trait as ebwr. In the top 50 for ebcov, Stud C has six sires with ASBVs for ebcov ranging from -1.6 to -0.3, which are all trait leaders for at least one of the MERINOSELECT Indexes. Stud D has nine sires with ASBVs for ebcov ranging from -1.0 to -0.3, eight of which are trait leaders for at least one of the MERINOSELECT Indexes. Compared to the MERINOSELECT database average for ebcov of -0.1, there is at least a 0.7 ASBV score advantage for ebcov for elite sires, and 0.3 ASBV score advantage for Stud C and D averages and their flock rams.

Step 2. Replace existing ram flock with rams from new stud source. This can either be done all at once, or phased-in over 2-3 years. It is assumed that a focus is maintained on productivity traits, so merit in breech traits is not viewed in isolation to productivity when purchasing rams or semen.

Swapping ram source all at once in the first year. How long does it take for the genes from the new sires to filter into the flock?

With 4 breeding ewe age groups and changing all the ram flock over at once, it takes about 4½ years (from first joining with new rams) to get 50% of the new genes into the hogget & adult flock and about 6½ years to get 75% incorporation (Figure 11). After 10 years, at least 90% is incorporated. So, in addition to the ram sources' long-term rate of genetic gain that the commercial flock follows as a result of continual use of that ram source (and a lag of about 2 sheep generations), after 10 years, the flock could also have 0.45 score reduction in ASBV for ebwr, or 0.27 reduction in ASBV for ebcov, or 0.18 reduction in ASBV for ldag. The slower the ram flock is changed over and the more ewe age groups that are retained, the slower will be the incorporation of new genes.

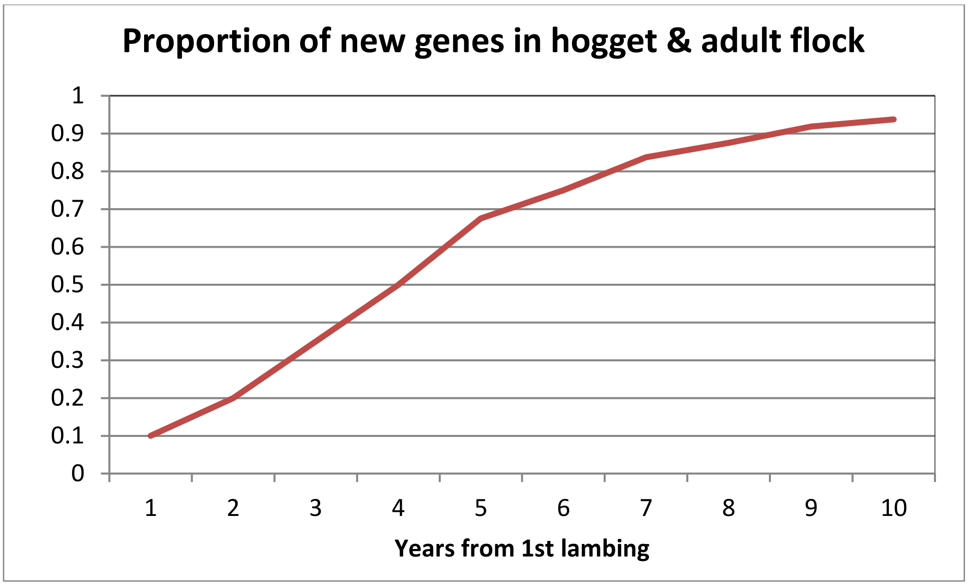

Figure 11: Proportion of genes from a new ram source plotted for the number of years from first lambing, assuming 4 ewe age groups and the ram source is completely changed over in first year. For time from first joining, add half a year.

Cost of changing ram source. A complete change of ram source in one year is not a minor investment. For a medium-sized commercial flock of 2,000 Merino ewes mated at the rate of 1.5-2% of rams, this represents 30 to 40 rams to be purchased in one year, roughly $25,000 to $40,000 worth and obviously more for larger flocks. There may be difficulty sourcing that many rams from a new source all at once unless it is a large stud and it may also significantly increase demand/prices for rams. Depending on the actual size of the ewe and ram flock and the interests of the owner/manager, it is worth considering the establishment of a ram breeding nucleus to breed flock ram requirements. The use of higher merit rams and/or semen from elite sires in this scenario over a ram breeding nucleus becomes more feasible. This initially would involve screening out of a nucleus from the ewe flock, addressed later. Essentially, the rates of genetic gain achievable are the same as in the ram breeding sector, also addressed later.

6.2.3 Scenario 3. In addition to following Options 1 and particularly 2, a commercial flock owner may choose to screen out/cull a portion of their flock that is inferior for indicator traits. They could either buy in more resistant sheep or keep some of their better sheep longer.

Screening out ewes or culling has benefits not only in the current flock that remains, but also in the progeny, depending on the selection intensity that can be applied. For determining the benefit in the current flock, the repeatability of the traits concerned is the critical parameter. In the absence of repeatability estimates, heritability estimates can be used as lower limits for repeatability (see Table 4).

Table 4: Heritability estimates for breech strike indicator traits.

Trait	Heritability ± s.e.	Source
Early breech wrinkle score - ebwr	0.47 ± 0.05	Brown *et al.* 2010
Late dag score - ldag	0.25 ± 0.03	Brown *et al.* 2010
Urine stain (ustain) at various ages marking weaning yearling	 0.27 ± 0.06 0.55 ± 0.09 0.81 ± 0.14	Greeff *et al.* 2014
Early breech cover score - ebcov Yearling breech cover score - ybcov	0.26 ± 0.03 0.18 ± 0.10	Brown *et al.* 2010 Bird-Gardiner *et al.* 2014
Yearling crutch cover score - yccover	0.47 ± 0.09 0.57 ± 0.06	Bird-Gardiner *et al.* 2014, Greeff *et al.* 2014

Screening of ewes implies that flock numbers will be reduced considerably, at least in the short-term, unless the aim is to establish a ram breeding nucleus. See earlier in the section on ram breeding flocks for predicted genetic gains from nucleus breeding. This section focusses on what can be achieved by culling ewes within a stable flock structure, where flock numbers are maintained.

Simple culling – based on one trait only. An example of culling on breech wrinkle only has been used. Ideally, one would combine the key culling traits (breech traits and productivity traits) in a selection index, but that means collection of information on traits like fleece weight and fibre diameter, plus individual identification of animals, not routinely practised in commercial flocks. Hence, only independent culling, one trait at a time, is considered. For calculation of response in the current flock, the following formula is used:-

Response in Current Flock = intensity x repeatability x variability,

Table 5 shows responses in the current flock, for a range of culling rates.

Table 5: Culling rates, selection intensities and response in the current breeding ewe flock when selecting for either breech wrinkle, dag or breech cover alone.

Culling Rate	Intensity of Selection	Response (score)		
		Breech Wrinkle	Dag	Breech Cover
10%	0.1947	-0.08	-0.04	-0.03
15%	0.274	-0.11	-0.06	-0.05
20%	0.3496	-0.14	-0.08	-0.06
25%	0.4233	-0.17	-0.09	-0.08
30%	0.4963	-0.19	-0.11	-0.09
35%	0.5694	-0.22	-0.13	-0.10
40%	0.6434	-0.25	-0.14	-0.12
45%	0.7191	-0.28	-0.16	-0.13
50%	0.7973	-0.31	-0.18	-0.14

When culling is for several traits, responses in any one trait will be lower. The culling rate achievable in a flock is dependent on the net reproductive rate, death rates and flock structure. See Table 6 below for typical scenarios for retention of 4 age-groups of ewes – 2, 3, 4 and 5 year olds, with 90% of 2 year-old ewes surviving to 5½ years of age (cull-for-age timeline), which is an approximate ewe death rate of 3.5% annually.

Table 6: Culling and ewe replacement rates possible according to the number of lambs weaned/ewe joined.

Lambs Weaned/Ewe Joined %	**Ewe Replacement Rate %**	**Culling Rate %**
80%	73%	27%
85%	69%	31%
90%	65%	35%
95%	61%	39%
100%	58%	42%
105%	56%	44%
110%	53%	47%
115%	51%	49%
120%	49%	51%

In most, if not all flocks, some of the culling would need to be done on traits other than breech strike indicator traits and typical production traits e.g. constitution/conformation faults – feet, teeth, shoulders etc. etc. This could amount to 10% or more of the total drop, reducing the available proportion to be culled on breech strike indicator traits & productivity. Ideally, culling in a commercial flock would be with an index combining all the traits considered important, but is difficult in practice as mentioned earlier. Culling emphasis on only one trait or 2 traits is likely to lead to a reduction in production traits. For example, the genetic correlation between ebwr and ycfw is +0.3. If the phenotypic correlation is only half the size i.e. +0.15, then an intense culling on ebwr would be expected to phenotypically reduce cfw. To quantify this, the following equation was used:

$CR_{2.1}$ = Regression of acfw (Trait 2) on ebrw x direct response in ebrw (Trait 1)

= Phenotypic Correlation$_{2.1}$ x Phenotypic SD$_2$/Phenotypic SD$_1$ x t x Phenotypic SD$_1$ x i

Or $r_p \times SD_2/SD_1 \times t \times SD_1 \times i$, which simplifies to $r_p \times SD_2 \times t \times i$

$= 0.18 \times 0.56 \times 0.47 \times (-0.3496) = -0.017$ kg

Where t = repeatability of ebrw, i = selection intensity. Have used a 20% culling rate in this worked through example.

At $20.36/kg clean (AWEX Indicator, 20 February, 2019), this gives a reduction of fleece value of $0.35/head/per year, assuming no change in wool quality traits.

6.2.4 Summary of effectiveness of strategies available to commercial flocks (Table 7).

Table 7: Effectiveness of strategies for improving breech traits in commercial flocks.

Strategy	Change Predicted over 10 years	Comment
1. Buy better rams from existing ram source, but also maintain a focus on productivity	Either: 0.24 reduction in ebrw Or: 0.24 reduction in ldag Or: 0.16 to 0.24 reduction in ebcov	Keep buying rams 0.3 ABSV score points less than drop average to retain advantage. May be able to do better, depending on stud source Where available, keep buying rams 0.3 ASBV score points less than drop average to retain advantage. Not many studs record dag, so this option may not be widely available Keep buying rams 0.2-0.3 ABSV score points less than drop average to retain advantage
2. Change to a better ram source	Either: 0.54 reduction in ebrw Or: 0.18 reduction in ldag Or: 0.27 reduction in ebcov	New source is 0.6 of a score lower in ebrw and all existing rams are replaced at once New source is 0.2 of a score lower in ldag and all existing rams are replaced at once New source is 0.3 of a score lower in ebcov and all existing rams are replaced at once
3. Culling effects (20% cull, on one trait only)	Either: 0.14 reduction in ebrw Or: 0.08 reduction in ldag Or: 0.06 reduction in ebcov	Likely to depress clean fleece weight by 0.017 kg/head. Culling by index could avoid decreasing other traits, but is costly

In buying rams, a focus also needs to be maintained on productivity traits in addition to seeking out animals with higher genetic merit for breech traits, but examples suggest that there is scope to achieve a balance. Note that if more than one breech indicator trait is targeted, less gain in each trait will be achieved.

If changing ram sources, the suitability of the new source in terms of genetic merit for production and quality traits, in addition to merit from breech flystrike indicator traits, is critical. Ram sources that are currently superior for breech traits have achieved that by past selection efforts and are more likely to be making genetic gain currently in those traits, so the benefit of changing ram sources may be two-fold. Firstly, gains from crossing to a new source that is currently genetically superior and secondly obtaining long-term genetic gains in breech traits from the new ram source that may not be being achieved by the old ram source.

6.2.5 Summary of total genetic gains possible over 10 years in commercial flocks

Tables 8-10 give the total predicted changes over 10 years, if a grower:

- Changes ram sources to a stud with the best available genetic merit for breech wrinkle, or dag score or breech cover
- Chooses a new stud that is achieving gains similar to that predicted in this study

Table 8: Total Gains Predicted in Breech Wrinkle Score over 10 years. Genetic trend gains are from index selection for the 3 breech indicator traits and productivity traits, whereas the gains from changing studs is estimated from when there is a specific focus on Breech Wrinkle and productivity traits only.

Index used	**EV for FSI**	**Genetic Trend from new stud**		**Genetic gain: changing stud**	**Total**	
		Low h^2	**Medium h^2**		**Low h^2**	**Medium h^2**
DP+FS	0	-0.29	-0.29	-0.45	-0.74	-0.74
	-40	-0.33	-0.37	-0.45	-0.78	-0.82
	-60	-0.34	-0.38	-0.45	-0.79	-0.83
	-80	-0.36	-0.39	-0.45	-0.81	-0.84
	-160	-0.38	-0.37	-0.45	-0.83	-0.82
FP+FS	0	0.09	0.09	-0.45	-0.36	-0.36
	-40	0.06	0.01	-0.45	-0.39	-0.44
	-60	0.04	-0.03	-0.45	-0.41	-0.48
	-80	0.03	-0.07	-0.45	-0.42	-0.52
	-160	-0.01	-0.15	-0.45	-0.46	-0.60
	-240	-0.07	-0.20	-0.45	-0.52	-0.65
MP+FS	0	0.05	0.05	-0.45	-0.40	-0.40
	-40	-0.02	-0.13	-0.45	-0.47	-0.58
	-60	-0.06	-0.17	-0.45	-0.51	-0.62
	-80	-0.09	-0.20	-0.45	-0.54	-0.65
	-160	-0.17	-0.25	-0.45	-0.62	-0.70

Table 9: Total Gains Predicted in Dag Score over 10 years. Genetic trend gains are from index selection for the 3 breech indicator traits and productivity traits, whereas the gains from changing studs is estimated from when there is a specific focus on Dag Score and productivity traits only.

Index used	EV for FSI	Genetic Trend from new stud		Genetic gain: changing stud	Total	
		Low h^2	Medium h^2		Low h^2	Medium h^2
DP+FS	0	0.01	0.01	-0.18	-0.17	-0.17
	-40	-0.03	-0.10	-0.18	-0.21	-0.28
	-60	-0.05	-0.14	-0.18	-0.23	-0.32
	-80	-0.07	-0.16	-0.18	-0.25	-0.34
	-160	-0.13	-0.22	-0.18	-0.31	-0.40
FP+FS	0	-0.02	-0.02	-0.18	-0.20	-0.20
	-40	-0.04	-0.08	-0.18	-0.22	-0.26
	-60	-0.05	-0.11	-0.18	-0.23	-0.29
	-80	-0.07	-0.14	-0.18	-0.25	-0.32
	-160	-0.11	-0.20	-0.18	-0.29	-0.38
	-240	-0.14	-0.23	-0.18	-0.32	-0.41
MP+FS	0	0.00	0.00	-0.18	-0.18	-0.18
	-40	-0.07	-0.16	-0.18	-0.25	-0.34
	-60	-0.10	-0.19	-0.18	-0.28	-0.37
	-80	-0.12	-0.22	-0.18	-0.30	-0.40
	-160	-0.19	-0.25	-0.18	-0.37	-0.43

Table 10: Total Gains Predicted in Breech Cover Score over 10 years. Genetic trend gains are from index selection for the 3 breech indicator traits and productivity traits, whereas the gains from changing studs is estimated from when there is a specific focus on Breech Cover and productivity traits only.

Index used	EV for FSI	Genetic Trend from new stud		Genetic gain: changing stud	Total	
		Low h^2	Medium h^2		Low h^2	Medium h^2
DP+FS	0	-0.22	-0.22	-0.27	-0.49	-0.49
	-40	-0.26	-0.31	-0.27	-0.53	-0.58
	-60	-0.28	-0.34	-0.27	-0.55	-0.61
	-80	-0.29	-0.35	-0.27	-0.56	-0.62
	-160	-0.33	-0.36	-0.27	-0.60	-0.63
FP+FS	0	-0.13	-0.13	-0.27	-0.40	-0.40
	-40	-0.16	-0.21	-0.27	-0.43	-0.48
	-60	-0.17	-0.23	-0.27	-0.44	-0.50
	-80	-0.19	-0.26	-0.27	-0.46	-0.53
	-160	-0.23	-0.31	-0.27	-0.50	-0.58
	-240	-0.26	-0.33	-0.27	-0.53	-0.60

MP+FS	0	-0.17	-0.17	-0.27	-0.44	-0.44
	-40	-0.24	-0.32	-0.27	-0.51	-0.59
	-60	-0.27	-0.34	-0.27	-0.54	-0.61
	-80	-0.29	-0.35	-0.27	-0.56	-0.62
	-160	-0.34	-0.35	-0.27	-0.61	-0.62

These predicted gains represent permanent changes in the genetics of the flock. Potential gains from using other strategies are revisited below. The key points from the predicted gains outlined in Tables 12-14 are:

- Score reductions in breech wrinkle are predicted to be the largest, ranging from 0.44 to 0.84 over 10 years when selection emphasis is placed on reducing flystrike incidence and a commercial producer changes to a stud with elite genetics for lower breech wrinkle. The highest predicted gains are those where a DP+FS index has been used by a stud, followed by the MP+FS index, with the least gain involving a FP+FS index, with total genetic gains of -0.44 to -0.52 of a score in early breech wrinkle ASBV over 10 years.
- Predicted genetic changes in dag score reduction are generally a little less than half than those predicted for breech wrinkle score.
- Predicted genetic changes in breech cover reduction are a little less than those for breech wrinkle, although reductions of up to 0.62 for both DP+FSI and MP+FSI indexes and up to 0.52 for a FP+FSI Index are possible when high selection emphasis is given to reducing flystrike incidence and a commercial producer changes to a stud with elite genetics for lower breech cover.
- The level of heritability for flystrike incidence (low or medium) only has a small impact on the genetic gains for breech indicator traits, with the medium heritability scenario predicted to contribute between 0.05 and 0.08 of a score additional gain compared with a low heritability scenario.

As outlined earlier in this report, commercial growers can also obtain gains by:

- Consistently purchasing rams within a stud which are more elite (e.g. 0.5 ASBV score lower for breech wrinkle) than the stud average for breech indicator traits. Reductions in score of 0.24 in breech wrinkle, or 0.18 in dag or 0.27 in breech cover over 10 years are potentially available. If such purchases are not consistent year by year, then the genetic gain from this approach will be diminished.
- Each year practising culling of replacement hogget ewes on breech indicator traits. These gains are phenotypic in nature, made up of both genetic and permanent environmental effects. Potential gains over 10 years are score reductions of 0.14 in breech wrinkle, or 0.08 in dag or 0.06 in breech cover are available if a 20% cull on single breech indicator traits are practiced each year.

6.2.6 Application of results to different sheep types and different regions

Scenarios considered as part of the study were:

- Fine wool sheep (18-19 micron) in a region with high prevalence of dags
- Fine wool sheep (18-19 micron) in a region with low prevalence of dags but high Worm Egg Count (WEC)
    - *The FP+FSI Index is closest to the breeding objectives for flocks in the first two scenarios, although an MP+FSI index may also be relevant*
- Medium wool sheep in the Wheat belt, with low dag and low WEC prevalence
    - *The MP+FSI Index is closest to the breeding objectives for these flocks*
- Dual Purpose sheep in a region of high dag and high WEC prevalence
    - *The DP+FSI Index is closest to the breeding objectives for these flocks*

High prevalence of dags. With the phenotypic level of dags higher than in low dag areas, a genetic reduction of dags to a level that is likely to keep breech fly strike susceptibility down to a reasonable level is a considerable challenge in terms of time and effort. It could also mean that more selection emphasis is needed for genetically reducing incidence of dags, with less scope available for selection emphasis on other traits.

A dag score average of 3.12 on a 5 point scale (Visual Breech Scores booklet, AWI) prior to hogget shearing (as reported by Greeff *et al.* 2014 at Mt Barker, WA), is considered high. A much lower mean value of 1.8 was reported for ldag by Brown *et al.* (2010) based on records in the MERINOSELECT database contributed by flocks in a range of localities around Australia. A mean value of 1.6 dag score was reported in the Chiswick breech strike selection lines (J. Smith, unpublished) and is considered a low value.

I will assume that a high dag environment has a mean dag score of 3.0 or higher. To be considered a low dag environment, I will assume that no individual sheep has a dag score exceeding 2. This implies that the mean dag score needs to be 1.5 or lower.

For Worm Egg Count, what is high prevalence and what is low prevalence? Again, the Mt Barker flock would be considered high prevalence, with WEC means of 439 and 353 epg at weaning and in spring, respectively (Greeff *et al.* 2014). But what is low prevalence? Perhaps 0 to 50 epg? As WEC can be highly variable in higher rainfall areas, perhaps the division into high and low WEC is somewhat arbitrary. It may be more sensible to regard areas where parasitism from gastro-intestinal nematodes is common as potentially high WEC areas. Also, haemonchus contortus areas like the New England area are likely to be more challenging than non-haemonchus areas, where the predominant species is Trichostrongylus, such as the winter rainfall areas of southern Australia. What does high WEC mean when trying to genetically reduce susceptibility to breech flystrike? There are possibly several issues:

- High WEC may raise the prevalence of dags. However, there are a number of areas where WEC prevalence is high, but dag prevalence is low e.g. the New England area of northern NSW.
- High WEC may mean that some selection effort in ram breeding is devoted to reducing WEC, however that would not be the case in commercial flocks
- If WEC levels and levels of gastrointestinal nematodes are keep well under control by good worm management practices, I do not see that in an area of phenotypically high WEC that is well-controlled by management, that high WEC *per se* should hinder efforts to genetically reduce susceptibility to breech flystrike.

Target for breech indicator traits. One of the conclusions of AWI's Breech Flystrike Prevention Genetic Research, Development and Extension Program is that a target for breeding of a sheep flock that does not need to be mulesed is for the flock to have individual scores not exceeding 2, 2 and 3 for breech wrinkle, dag and breech cover respectively. For such a flock, the average scores for breech traits will need to be considerably less than the maximum score for individual animals, with mean values needing be 1.5, 1.5 and 2.2, respectively or less. The exact target to reach is ultimately a judgement about the level of risk the flock owner is prepared to accept and provide for in terms of management strategies and interventions, such as the degree of culling achievable, the timing of shearing, the number of crutchings, preventative fly treatments and the frequency of monitoring for flystrike and treating of individual cases.

How long it would take a flock to reach a set target of 1.5, 1.5 and 2.2 (for breech wrinkle, dag and breech cover scores, respectively) to cease mulesing is a function of the starting point of the flock and the rate of change in breech trait scores that can be achieved over time. For example, a flock that averages breech trait scores of 2.5, 2.5 and 3.2 (average wrinkle, medium to high dag and average breech cover) would have to undergo a reduction of one score each for breech wrinkle, dag and breech cover to reach the target, whereas a flock that averages breech trait scores of 2.3, 1.8 and 3 (low wrinkle, average dag and low breech cover) would only have to undergo score reductions of 0.8 for both breech wrinkle and breech cover, and 0.3 of a score for dag. Note that Brown *et al.* (2010) reported average scores of 2.5, 1.8 and 3.5 for early breech wrinkle, late dag and early breech cover in their study of data from 156 Merino flocks in the MERINOSELECT database, so the values chosen in the examples above reflect typical starting points for many flocks.

To address this question, Tables 11-13 list the predicted time in years to reduce breech indicator trait scores down to a target of minus 1 of an Australian Sheep Breeding Score. This is shown for each of the 3 indexes examined (DP+FSI, FP+FSI and MP+FSI), with 5-6 different levels of economic values used for flystrike incidence (FSI). Predictions are shown when 1) a commercial flock is a long-term client of a stud that is achieving the gains predicted in this study for ram breeding flocks, 2) in addition to scenario 1, the commercial grower buys elite rams from the stud and culls 20% of ewe replacements and 3) in addition to the gains from scenario 1 and 2, the commercial grower changes over to a new stud/ram source. Tables 11a, 12a and 13a show predictions when the heritability for FSI is assumed to be low, whereas Tables 11b, 12b and 13b show predictions when the heritability for FSI is assumed to be medium. Note that Table 11a and 11b for Breech Wrinkle Score use the 2016 genetic trend values (Lindon 2018) as a starting point, where the Medium wool category in the MERINOSELECT database already has a value of -0.7 ASBV for ebrw, meaning that the gain required is a reduction of 0.3 of a score. In contrast, in the Fine wool category, the required reduction of 0.9 of a score and in the Superfine category the required reduction is 1.2 of a score. For Dag and Breech Cover Scores, there is currently little diversity evident in genetic trends across the Medium, Fine and Superfine wool categories in the MERINOSELECT database (and all are close to zero), so that the score reductions required across all three categories has been assumed to be 1 full score in each case.

Table 11a: Predicted time for reducing Breech Wrinkle to an average Australian Sheep Breeding Value of -1, using 2016 genetic trends as a base (Lindon 2018) for the Medium, Fine and Superfine wool type categories in MERINOSELECT. EV for FSI is economic value for Flystrike Incidence. Heritability (h2) for FSI is low. Note 'n.a.' means not achievable

Index & Trait Focus ***Sheep Type***	**EV for FSI**	**Time in Years to meet Breech Wrinkle Score Target**		
		Genetic Trend Only	**PLUS use Elite Rams & Cull Young Ewes**	**PLUS Change Stud**
DP+FS: Reproduction ***Medium/Dual Purpose***	0	10	5-7	<5
	-40	9	5	<5
	-60	9	5	<4
	-80	8	5	<4
	-160	8	4	<4
FP+FS: Fibre Diameter ***Superfine/Fine Wool***	0	n.a.	n.a.	n.a.
	-40	n.a.	n.a.	n.a.
	-60	n.a.	n.a.	n.a.
	-80	n.a.	n.a.	n.a.
	-160	n.a.	n.a.	336
	-240	172	117	53
MP+FS: Fleece Weight ***Fine/Med. Wool***	0	n.a.	n.a.	n.a.
	-40	416	236	32
	-60	164	95	13
	-80	106	61	10
	-160	54	31	9

Table 12: Predicted time for reducing Breech Wrinkle to an average ASBV of -1, using 2016 genetic trends as a base (Lindon 2018) for the Medium, Fine and Superfine wool type categories in MERINOSELECT. EV for FSI is economic value for Flystrike Incidence. FSI h2 is medium. Note 'n.a.' means not achievable

Index & Trait Focus ***Sheep Type***	**EV for FSI**	**Time in Years to meet Breech Wrinkle Score Target**		
		Genetic Trend Only	**PLUS use Elite Rams & Cull Young Ewes**	**PLUS Change Stud**
DP+FS: Reproduction	0	10	5-7	<5
Medium/Dual Purpose	-40	8	5	<5
	-60	8	5	<4
	-80	8	5	<4
	-160	8	4	<4
FP+FS: Fibre Diameter	0	n.a.	n.a.	n.a.
Superfine/Fine Wool	-40	n.a.	n.a.	n.a.
	-60	402	275	124
	-80	174	119	54
	-160	79	54	24
	-240	60	41	19
MP+FS: Fleece Weight	0	n.a.	n.a.	n.a.
Fine/Med. Wool	-40	72	42	10
	-60	52	30	7
	-80	44	25	7
	-160	35	21	5

Table 13: Predicted time to reduce Dag by one score. FSI h2 is low. 'n.a.' means not achievable

Index & Trait Focus ***Sheep Type***	**EV for FSI**	**Time in Years to reduce Dag Score by 1**		
		Genetic Trend Only	**PLUS use Elite Rams & Cull Young Ewes**	**PLUS Change Stud**
DP+FS: Reproduction	0	n.a.	n.a.	n.a.
Medium/Dual Purpose	-40	313	213	156
	-60	193	131	96
	-80	142	96	70
	-160	77	52	38
FP+FS: Fibre Diameter	0	n.a.	425	313
Superfine/Fine Wool	-40	n.a.	166	124
	-60	n.a.	126	93
	-80	n.a.	98	77
	-160	92	63	40
	-240	45	48	35
MP+FS: Fleece Weight	0	n.a.	n.a.	n.a.
Fine/Med. Wool	-40	151	103	76
	-60	105	72	53
	-80	83	36	27
	-160	53	31	23

Table 14: Predicted time to reduce Dag by one full score. FSI h2 is medium. Note ‘n.a.’ means not achievable

Index & Trait Focus	**EV for FSI**	**Time in Years to reduce Dag Score by 1**		
Sheep Type		**Genetic Trend Only**	**PLUS use Elite Rams & Cull Young Ewes**	**PLUS Change Stud**
DP+FS: Reproduction ***Medium/Dual Purpose***	0	n.a.	n.a.	n.a.
	-40	102	70	35
	-60	73	50	25
	-80	61	42	21
	-160	46	31	16
FP+FS: Fibre Diameter ***Superfine/Fine Wool***	0	n.a.	n.a.	313
	-40	119	81	60
	-60	89	60	44
	-80	73	51	37
	-160	50	34	25
	-240	44	30	22
MP+FS: Fleece Weight ***Fine/Med. Wool***	0	n.a.	n.a.	n.a.
	-40	65	44	32
	-60	52	35	26
	-80	46	31	23
	-160	40	30	20

Table 15: Predicted time to reduce Breech Cover by one full score. FSI h2 is low

Index & Trait Focus	**EV for FSI**	**Time in Years to reduce Breech Cover Score by 1**		
Sheep Type		**Genetic Trend Only**	**PLUS use Elite Rams & Cull Young Ewes**	**PLUS Change Stud**
DP+FS: Reproduction ***Medium/Dual Purpose***	0	46	36	24
	-40	39	30	20
	-60	36	28	18
	-80	34	27	18
	-160	30	23	15
FP+FS: Fibre Diameter ***Superfine/Fine Wool***	0	78	60	40
	-40	63	50	32
	-60	58	45	30
	-80	54	42	28
	-160	44	34	22
	-240	38	30	19
MP+FS: Fleece Weight ***Fine/Med. Wool***	0	59	46	30
	-40	42	32	21
	-60	37	29	19
	-80	34	27	18
	-160	30	22	15

Table 16: Predicted time to reduce Breech Cover by one full score. FSI h2 is medium

Index & Trait Focus ***Sheep Type***	**EV for FSI**	**Time in Years to reduce Breech Cover Score by 1**		
		Genetic Trend Only	**PLUS use Elite Rams & Cull Young Ewes**	**PLUS Change Stud**
DP+FS: Reproduction ***Medium/Dual Purpose***	0	46	36	19
	-40	32	25	13
	-60	30	23	12
	-80	29	22	12
	-160	28	21	11
FP+FS: Fibre Diameter ***Superfine/Fine Wool***	0	78	60	40
	-40	49	38	25
	-60	43	33	22
	-80	39	30	20
	-160	32	25	17
	-240	31	24	16
MP+FS: Fleece Weight ***Fine/Med. Wool***	0	59	46	30
	-40	32	25	16
	-60	29	23	15
	-80	29	22	15
	-160	28	22	15

Key Points are:

- If a commercial flock is just relying on genetic gains achieved by their stud as a single strategy, the timelines for targets for breech traits are very long – measured in decades. This is especially the case in environments where the incidence of flystrike has a low heritability. Unless a stud is placing considerable emphasis on reducing flystrike incidence, in most cases the targets for reducing breech trait scores will not be achieved.
- The use of additional strategies by commercial flock owners, including consistent purchasing of elite rams for breech indicator traits, heavy culling of replacement ewes on breech traits and changing to a new ram source with elite genetics for breech traits will all reduce the time it takes to reduce breech trait scores. In the best case, using all these strategies, the goal of reducing Breech Wrinkle to the target of minus 1 (Australian Sheep Breeding Value is possible within 5 years when using a DP+FSI MP+FSI index in Medium wool/Dual Purpose sheep.
- Achieving reductions of one full score in Breech Wrinkle or Breech Cover appears to be more difficult and take considerably longer (a minimum of 16 to 25 years and the use of high economic values of -$160 to -$240 for reducing flystrike incidence) in Super-fine and fine wool Merino sheep in breeding programs where genetic reduction in fibre diameter forms a key focus of the breeding objective.
- Even with the use of all strategies (genetic gain by studs, purchasing of more elite rams from a stud, ewe culling and changing ram source), reducing Dag Score is

predicted to take longer than reducing Breech Wrinkle or Breech Cover. The shortest times taken to reduce dag score by one unit are predicted to be in the range of 20 to 25 years. This requires heavy selection emphasis to be placed on reducing flystrike incidence (economic values of -$80 or more).

7 Impact of Wool Industry – Now & in 5 Years' Time

Genetic parameters (heritabilities, correlations and variances), estimated from data obtained from the Breech Flystrike Resource Flocks in WA and NSW, have been critical to the success of this project in predicting genetic gains in reducing breech flystrike incidence in different environments, management systems and Merino sheep types.

The results of this project are immediately applicable to the Australian wool industry, through provision of realistic assessments to ram breeders and commercial wool producers (and other stakeholders) of the likely time necessary to genetically change flocks to a point where surgical mulesing and undue reliance on chemical treatments is unnecessary. The predicted genetic gains for reducing breech flystrike incidence are provided in the context of balancing these with maintaining competitive genetic gains for productivity traits, reflecting commercial conditions under which woolgrowers operate.

Within the next five years, better tools will likely be available to ram breeders and commercial wool producers to better exploit the knowledge provided by this project, via the implementation of selection indexes from MERINOSELECT that include welfare traits, including flystrike incidence. These, together with more widespread recording of skin wrinkle, dag, breech cover and urine stain scores and other initiatives to improve the accuracy and availability of ASBVs will have a significant and positive impact on the wool industry in reducing breech flystrike incidence and its reliance on surgical mulesing and chemical treatments.

8 Conclusions and Recommendations

8.1 Ram Breeding Flocks

Predictions of genetic gain were carried out for 3 breeding objectives, by using modifications of the Dual Purpose (DP+), Fibre Production (FP+) and Merino Production (MP+) indexes available from the MERINOSELECT Service. For each index, the modification consisted of adding another trait, Flystrike Incidence (FSI). These modified indexes, DP+FS1, FP+FSI and MP+FSI are targeted, respectively, at dual purpose, superfine/fine wool and fine/medium wool production systems. A large range of economic values (selection emphasis) were given to FSI, from zero to -$240/ewe in $20 increments, to cover the entire range of possible selection emphasis that could be considered in industry breeding programs. For all scenarios, it was assumed that full records of productivity traits and pedigree information were available for use as selection criteria, plus records of breech wrinkle, dag and breech cover scores. Predictions were conducted for 3 different assumptions (i) heritability for FSI is low (ii) heritability for FSI is low, but heritability for Dag Score is high and (iii) heritability for FSI is medium. These differing assumptions aligned with the 2 environments where AWI has conducted long-term research on the genetics of breech flystrike, at Mt Barker in Western Australia, a Mediterranean environment with predominately winter rainfall and another near Armidale in NSW, in a spring-summer rainfall environment.

After 10 years of selection, predictions of genetic gain for flystrike incidence ranged from zero when the trait was given no selection emphasis, up to maximum reductions of 20, 19 and 21 strikes per 100 ewes/year for DP+FSI, FP+FSI and MP+FSI indexes, respectively, when the trait was given high selection emphasis and assumed to have medium heritability. When FSI was assumed to have low heritability, predictions of genetic gain were much lower, with maximum reductions of 6, 4 and 6 flystrikes per 100 ewes/year after 10 years of selection based on DP+FSI, FP+FSI and MP+FSI indexes, respectively. Again these maximum gains were predicted when FSI was given high selection emphasis, with an economic value of -$240 per strike/ewe/year. For comparison, the average incidence of flystrike of the AWI breechstrike selection lines at the Mt Barker site, in WA ranged from 4 to 9.5 strikes per 100 ewes per year across years (young sheep were crutched prior to the main fly risk period) and averaged 9.9 strikes per 100 ewes per year over 10 years in adult ewes (2 to 7 years of age) for breech strikes at the CSIRO, Chiswick site, near Armidale, NSW. Hence, the magnitude of predicted gains over 10 years in reducing FSI could potentially reduce the level of flystrike in these two environments to low levels in years of average flystrike incidence.

When using very high economic values for FSI (-$240 per strike/ewe/year), genetic gains for fleece weight are predicted to be reduced to only 11-30% of maximum gains possible (under index selection when FSI has no economic value) when the heritability of FSI is medium, but reductions are less (52-65% of maximum gains in fleece weight) when the heritability of FSI is low. There is less compromise however for genetic gains in fibre diameter, with reductions enhanced for all economic values for FSI when using a DP+FSI index. When using the FP+FSI index, the rate of reduction in fibre diameter becomes less for economic values of FSI greater than -$80 per strike/ewe/year and greater than -$200 for the MP+FSI index. Genetic gains in number of lambs weaned reduce with greater economic values for FSI for selection with the DP+FSI index, however genetic gains predicted for NLW are enhanced with increasing emphasis on reducing flystrike incidence when using the FP+FSI index and only marginally reduced at high economic values for FSI when using a MP+FSI index.

Genetic gains for reducing Worm Egg Count (WEC) are enhanced as increasing selection emphasis is placed on reducing flystrike incidence, regardless of the index used or the level of heritability for FSI. Of the remaining production traits reported, genetic gains for coefficient of variation in fibre diameter and staple strength are increasingly unfavourable with greater selection emphasis placed on reducing FSI, regardless of index used or level of heritability for FSI. However, the modest size of these adverse genetic changes could be reduced, or completely offset, by giving some selection pressure to these two traits.

In summary, considering the nett effect of selection for reducing flystrike incidence on other important traits, it is clear that there is a range of sensible economic values for FSI that could be used in breeding programs that would lead to appreciable reductions in FSI over time, whilst retaining competitive levels of genetic gains for other important traits.

8.2 Commercial Flocks

Although genetic gains in commercial flocks are the same as in the studs they source rams from, their genetic merit lags behind by an average of 2 sheep generations.

As breeding values are not currently available for flystrike incidence, in considering ram buying and sheep culling strategies for commercial flocks, attention was focussed on the use of available ASBVs for breech traits, in particular for early breech wrinkle, late dag and early breech cover scores. These strategies included buying more elite rams within a ram source, changing ram sources to one that has more elite genetics for breech traits and culling ewe replacements on breech trait merit. When these are considered separately, the following potential changes through genetic (and phenotypic) improvement were identified:

- Buying more elite rams within a ram source, provided it is done consistently every year, can give useful genetic reductions over 10 years in scores of 0.24 in breech wrinkle, or 0.24 in dag or 0.16 to 0.24 in breech cover.
- Changing ram sources to one that is reliably more elite for breech trait genetics, but which also does not represent a compromise in productivity traits can also provide useful genetic reductions over 10 years of either 0.45 of a score in breech wrinkle, or 0.18 in dag score or 0.27 in breech cover score.
- Over 10 years, the likely changes from culling 20% of ewe replacements for single breech traits is more modest, being reductions in scores of either 0.14 in breech wrinkle or 0.08 in dag score or 0.06 in breech cover.

To convert these potential changes into a timeline for flock owners, targets need to be defined. In terms of breeding Merinos that do not require mulesing, conclusions from AWI's R & D program on breech flystrike are that a flock should reach a target of maximum individual scores of 2, 2 and 3 for breech wrinkle, dag and breech cover. How long this will take will vary considerably across different sheep types and environments.

In fine and superfine wool Merinos (18-19µ and finer) where there is likely to be a key focus on genetic reduction of fibre diameter, achieving long-term genetic reductions in breech traits appear to require more selection emphasis and take longer than it will in fine/medium wool and dual purpose sheep. Where Merino sheep are run in a high dag environment and have average scores of 3 or more, achieving a genetic reduction in dag to a maximum score of 2 for any individual sheep in the flock appears not to be a realistic strategy using current breech traits as criteria in selection. This is the case even when a commercial flock utilises all the strategies examined, as the predicted minimum timeline for achieving a 1 score reduction is a minimum of 2 to 3 decades or more. In lower dag environments, breeding to reduce dag is much more feasible, with genetic reductions of 0.1 to 0.2 in dag score predicted over 10 years from genetic gain from selection at the stud level, with greater reductions possible (0.5 to 0.7 of a score) by incorporating other strategies outlined above.

For breech wrinkle, achieving reductions of one full score within 10 years appear to be feasible for commercial producers with dual purpose and fine/medium sheep types if they are prepared to purchase elite rams from their existing stud, cull ewe replacements heavily on breech traits and change to a ram source with more elite genetics. This is aided ram breeders if they place a medium to high emphasis on reducing flystrike incidence, although this needs to be considered together with the trade-off in lower genetic gains for fleece weight and other important traits. Achieving reductions of one full score in breech cover in commercial flocks may take longer (15 to 20 years) than is the case for breech wrinkle. Commercial producers with superfine sheep are more limited in making significant reductions in breech traits, particularly for breech wrinkle.

In conclusion, although long-term genetic trend in ram breeding flocks obviously provides gains in commercial flocks, sole dependence on this source of improvement is very unlikely with current knowledge to deliver reductions of a full score in breech traits in a reasonable timeframe. The other strategies outlined of buying more elite rams, culling heavily on breech traits and possibly changing the ram source also need to be seriously considered to reach the required scores for breech traits inside 10 to 15 years.

Finally, the predicted genetic gains in this study did not formally take account of the ability of ram breeders to utilise across-flock variation. There is considerable opportunity for ram breeders to exploit both across-flock and within-flock variation by utilising Australian Sheep Breeding Values available from the MERINOSELECT service offered by Sheep Genetics. This may enable greater rates of genetic gain than predicted in this study and assist breeders in ameliorating the compromise in genetic gains in reducing flystrike incidence and breech wrinkle and fleece weight (and other traits), as mentioned by Brown et al. (2010).

8.3 Recommendations for improvements/refinements

- More reliable genetic parameters to be published and available for predictions, including whether the parameters vary across Merino types e.g. phenotypic variation for dag score.
- Derivation of an economic value for flystrike incidence for different wool-growing regions (an even within regions, if appropriate) would be of assistance in both prediction of genetic gain and in establishing formal breeding objectives to incorporate reducing flystrike incidence with current productivity and product quality traits.
- Development of new selection indexes that incorporate animal welfare / resilience traits, including flystrike incidence as part of index options by the MERINOSELECT service. Eventual inclusion of flystrike incidence as a reportable trait. This will need to include work on the appropriate analysis and presentation of the trait. Breeding values may need to be derived initially from indirect / indicator breech traits. In the medium to longer term, breeding values may also be able to be derived from a genomic association approach.
- Clients of Sheep Genetics should be given the option to publish their average breeding values (ASBVs) for their stud and ram buyers encouraged to seek average ASBVs for a stud or the drop or the groups of rams offered for sale.
- Active encouragement (extension and promotion) to industry to increase the number of sheep that are recorded for breech traits and for neck and body wrinkle.
- Explore the merit of direct progeny testing of leading industry sires for flystrike incidence, particularly for areas of high dag incidence, as these are the areas where it is most difficult to breed sheep suitable for being left unmulesed. This should be done in conjunction with establishing a reference population for the development of genomic enhanced breeding values.
- Updating of the OFFM Calculator software generated by NSW DPI for commercial flock predictions (basis of paper by Richards and Atkins 2010). This would allow updating of the predictions at the commercial flock level to be made more rapidly, at lower cost.
- If ram buyers are having difficulty accessing suitable flock ram genetics to more rapidly reduce breech flystrike incidence and keep improving flock productivity, establishing their own ram breeding nucleus and purchasing semen from elite sires may be more economically feasible for their particular breeding objectives, management regime and locality.

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