Final report

Fit To Join – ewe assessment tools

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Abstract

Maximising ewe and lamb survival and health during lambing to address both animal welfare and productivity imperatives is a high priority for the sheep industry. There remains an opportunity to improve lamb and ewe survival outcomes by rigorous ewe assessment and selection before joining. This will ensure all ewes joined are fit to rear healthy lambs.

The literature review carried out in the first phase of this project highlighted gaps in both information availability and dissemination of existing resources and information, and mis-information guiding standard industry sheep management practices. In the second phase of the project, case studies on three commercial sheep operations provided robust information on the production and economic benefits of assessing ewes pre-joining.

Unfit ewes in these case studies had a 4.4x higher risk of scanning empty and a 3x higher risk of dying between joining and scanning. Lambs from unfit ewes had a 21% higher risk of dying. These translated into significant modelled economic benefits for classing and culling ewes as unfit to join of between $4 and $8 per ewe.

There was a strong justification that assessing ewes for fitness to join results in improved animal welfare, productivity and financial outcomes for commercial sheep enterprises.

A fit to join toolkit targeted at sheep producers and their advisors has been developed. It includes an electronic ute guide (e-book), a series of four short instructional videos, and an MLA-style fact sheet. These resources will be promoted through existing sheep extension programs and will be freely available for download by producers and advisors through the MLA website.

Executive summary

Background

Maximising ewe and lamb survival and health during lambing to address both animal welfare and productivity imperatives is a high priority for the sheep industry. To date most research, development, extension and adoption (RDE&A) efforts have focused on improving ewe nutrition prior to joining and during pregnancy, and management during lambing and weaning. There remains an untapped opportunity to improve lamb survival outcomes by rigorous ewe assessment and selection before joining.

Often sheep producers are frustrated they cannot achieve their marking percentage goals, even though they're implementing industry best practice in the lead up to, and during, lambing. An underlying reason for this may be they are joining ewes unfit to rear a lamb.

A review of existing literature and industry information and ewe selection case studies carried out on three commercial operations (self-replacing Merino, composite and first cross), confirmed an opportunity to improve ewe and lamb survival outcomes by identifying and culling unfit ewes before joining.

Objectives

The objectives of this project were to:

- conduct an in-depth literature review on existing best practice guidelines of ewe selection processes
- coordinate and carry out three case studies on commercial sheep operations to quantify the impact of improved pre-joining ewe selection practices
- develop a producer-facing 'fit-to-join' extension package including:
    - a ewe selection 'ute' guide
    - a series of step-by-step 'how-to' videos to support producers and advisors in assessing ewes for fitness to join pre-lambing

Methodology

A review of existing literature and industry information was undertaken, followed by a three case studies, carried out on commercial operations (self-replacing Merino, composite and first cross). On each farm ewes were classed pre-joining and then followed through scanning and lamb marking. Ewe and lamb mortality, lamb marking and scanning percentages were analysed, along with the economic cost-benefit of ewe assessment pre-joining.

Results were compiled and incorporated into a 'fit-to-join toolkit' comprising electronic ute guide (e-book), a series of four short instructional videos, and an MLA-style fact sheet.

Results/key findings

Reproductive success in any sheep operation is a combination of conception rates and lamb survival.

This project identified that an opportunity exists to improve lamb and ewe survival outcomes through a simple, yet effective, ewe assessment and selection process pre-joining.

The key risk factors that impact on ewe and lamb survival include: udder health and structure, body condition score, lameness, teeth and age. Ewes assessed as 'fit to join' are more likely to rear healthy lambs, increasing marking percentages, enterprise profitability and animal welfare outcomes.

The analysis carried out across three commercial sheep operations indicated unfit ewes were four times more likely to scan empty and three times more likely to die between joining and scanning. Lambs from unfit ewes had a 21% higher risk of dying.

The economic benefit for classing and culling ewes as unfit to join was modelled at between $4 and $8 per ewe.

Benefits to industry

The sheep and wool industry can achieve substantial productivity, welfare and economic benefits if producers take action early (pre-joining) to assess their ewes for their fitness to join and then use a combination of strategic, targeted management and culling to ensure all ewes joined have the best chance of rearing healthy lambs.

Future research and recommendations

There is some evidence to suggest that selection based on a maiden ewe's previous reproductive performance will improve lamb survival outcomes. However, these studies are 20–30 years old and production systems and ewe flock management have changed considerably in this period. No studies could be found that quantified the repeatability of reproductive performance for mature ewes. Further research into repeatability of reproductive performance for both maidens and mature ewes is recommended.

To determine the uptake of the fit to join toolkit and obtain some data relevant to impact of this investment, it is recommended to track number of copies of the guide printed and disseminated, and monitor downloads or views of the videos.

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1. Background

Maximising ewe and lamb survival and health during lambing to address both animal welfare and productivity imperatives is a high priority for the sheep industry.

Often sheep producers are frustrated they cannot achieve their marking percentage goals, even though they're implementing industry best practice in the lead up to, and during, lambing. An underlying reason for this may be they are joining ewes unfit to rear a lamb.

To date most research, development, extension and adoption (RDE&A) efforts have focused on improving ewe nutrition prior to joining and during pregnancy and management during lambing and weaning. There remains an untapped opportunity to improve lamb survival outcomes through rigorous ewe assessment and selection before joining. This approach will ensure all ewes joined are fit to rear healthy lambs. Factors such as udder condition and lameness are key selection traits, however, there is a lack of robust data for other traits (e.g. teeth, past lambing performance).

Selection and management of ewe lambs pre-joining and post-lambing is critical to ensure their fitness for lambing the following year. Research also indicates that older ewes are more susceptible to specific health issues (e.g. metabolic disorders), yet the traditional 'cast-for-age' culling, in isolation, carried out by many producers does not withstand scientific scrutiny.

The results of an extensive literature review and the findings from three commercial case studies have been collated into a 'fit-to-join' extension toolkit aimed at sheep producers and their advisors to assist in decision-making processes for ewe selection pre-joining. These tools have been designed to be incorporated into existing extension activities as complementary resources (e.g. Lifetime Ewe Management, Bred Well Fed Well, Picking Performer Ewes and Towards 90), or to be used as standalone resources accessible through the MLA website and Making More from Sheep program.

2. Objectives

Objective number	Objective description	Achievement details
1	Conducted an in-depth literature review on existing best practice guidelines of ewe selection processes – completed in MLA final report format	Successfully completed (milestone 2).
2	Completed and reported on a minimum of three (a minimum of one Merino and one maternal prime lamb flock) producer case studies quantifying the impact of improved pre-joining ewe selection practices	Successfully completed (milestone 4).
3	Development of 4x short instructional videos. Storyboards approved by MLA Comms team	Successfully completed. Video topics include ewe assessment overview, assessing udders, assessing feet and assessing older ewes.
4	Development of a ewe fit to join ute guide, consistent with the MLA style guide	Successfully completed. Interactive linked pdf also suitable for printing.
5	Development of a ewe 'fit to join package' (on-line and face to face optionality) collated and available for industry use – to be developed with input from the MLA Adoption Team	Successfully completed. Extension and adoption integration plan developed and input from MLA adoption team and AWI obtained to ensure resources fit for purpose. Resources additional to ute guide and videos include PPT slides (brief, long and short presentations) and two-page factsheet.
6	Submitted a final report to MLA incorporating details of deliverables 1-5 and detailing monitoring, evaluation and communications metrics and activities	Successfully completed. Producers were surveyed on likely adoption during the case study phase. A summary has been provided of producer engagement during the pilot review process. An extension and adoption integration plan was developed to enable the knowledge and tools to be integrated into existing ewe reproduction extension and adoption programs. Implementation of this plan has commenced, with engagement of existing sheep reproduction program developers occurring. Uptake of the resources will occur beyond the timeframes for submission of this final report.
7	Submission of a PowerPoint Presentation to MLA detailing project process, outcomes and remaining gaps	Successfully completed. Three PPT slide decks prepared for ongoing use in sharing project findings (brief, long and short presentations).
8	Completion of a one-hour webinar on project outcomes to MLA and industry stakeholders	Successfully completed. Sheep Reproductive Strategic Partnership webinar, invited to present at Australian Sheep Vets conference (June 2022) and Livestock Advisor Updates south and west (September and October 2022)

3. Methodology

This project consisted of three separate, but linked, phases:

- a review of existing literature and industry information
- coordinated ewe selection case studies on three commercial farms
- the development of extension materials to communicate the outcomes of the project and guide producers (and their advisors) in the effective selection of ewes that are 'fit to join'.

The methodology for each phase of the project is outlined in this section.

3.1 Literature review

A scan of the scientific literature and industry resources was carried out to form the basis of the literature review. The literature review covered the following topics relevant to ewe health at joining (fitness to join and successfully rear a lamb):

a. udder health
b. body condition score (BCS)
c. lameness
d. dentition
e. previous ewe performance (lambs reared)
f. age-specific assessment criteria (i.e. ewe lambs and older ewes).

The available literature was summarised to provide a basis for the project team to determine if:

- the project could duplicate already available tools or information
- there was a gap in tools and information regarding ewe fitness to join, whether there was sufficient published information to enable recommendations to be confidently made in preparing fit to join resources.

3.1.1 Udder health

The review of literature on udder health was limited to the effect of udder health on lamb survivability and growth rates. Causes of udder defects and epidemiological determinants have not been researched unless there is a way of improving udder health outcomes within the scope of this project. Most of the information on udder health in ewes concerns acute mastitis in dairy ewes and how it impacts milk production and quality (e.g. Vasileiou *et al*, 2019).

3.1.2 Teeth, feet and reproductive performance

A broad electronic search was conducted using three bibliographic databases 'Cab Abstracts', 'Scopus' and 'Web of Science'. The data was screened first for relevance based on abstracts and then based on full text articles. Grey literature was also included in the search including industry funded project reports.

3.2 Case study methodology

Three case study producers were selected based on the following criteria:

- Minimum flock size of 7000 breeding ewes. About 6000 ewes, on average, were examined on each case study property (ewes 18 months old or less were not included in the case study work).
- Close proximity to Livestock Logic in Hamilton, Victoria (to comply with COVID travel restrictions).
- Diversity in management of ewes and ewe selection.
- One Merino flock, one composite flock, and one first-cross and composite flock.

The case study producer details are outlined in **Table *1***

Table 1 Case study producer details

	Farm 1 – Strathdownie, VIC	Farm 2 – Nareen, VIC	Farm 3 – Harrow, VIC
Ewe flock size	12,000	7000	10,000
Age of first joining	7 months	7 months	19 months
Length of joining	5 weeks	5 weeks	6 weeks
Typical feed regime	Pasture and minor levels of grain in late autumn	Pasture with supplementary feeding predominantly with silage and grain. Confinement feeding practices in late autumn with silage and grain.	Pasture with supplementary feeding predominantly with silage and grain to overcome energy deficits
Ewe breed/s	Purchased in first-cross ewe base with the younger generations bred on farm from composite rams	Composite	Merino
Lambing date/s	5 June to 10 July	20 June to 23 July	20 June to end of July

3.2.1 Pre-join ewe assessment

Between early December and early January the project veterinarians assessed each of the case study flocks for age, body condition score, udder health and teeth (factors identified in the literature review as key risk factors). Body condition score (BCS) was not assessed as an absolute (i.e. BCS 3 or 2.5) but as low (one BCS or greater difference) compared with the mob average. A classing system was developed to enable objective assessment of ewes (**Table *2***). Any animal that accumulated 5–9 points was classed as 'high risk' to join, or greater than nine points 'very high risk'.

Those ewes assessed as high or very high risk to join were identified using eID tags, with individual assessment information recorded for each animal. These ewes were also branded with marker on their backs to enable easy visual identification.

Following the pre-joining assessment (up until March/April, when mobs were pregnancy scanned) all ewes were run as normal (i.e. those classed as fit and unfit were still run in the same mobs as prior to assessment (e.g. age groups)). Average BCS of the ewe flock was assessed each month, and details on any supplementary feeding recorded.

Table 2 Ewe classing system

Teeth — Red marker	**Score**	**CODE**
Most teeth loose	5	TL5
Uneven wear of teeth	5	TU5
Teeth missing	0	
Sound mouth	0	
Lameness — Blue marker	**Score**	**CODE**
Non weight bearing	5	L5
Just weight bearing	4	L4
Severe lameness	3	L3
Moderate lameness	2	L2
Slight lameness	1	L1
Foot structural change — Purple marker	**Score**	**CODE**
Severe foot structural change	3	FM3
Moderate foot structural change	2	FM2
Slight foot structural change	1	FM1
Mammary glands — Green marker	**Score**	**CODE**
Firmness >50% of a half	5	M5
Teat missing	5	TM5
Teat scarring	5	TS5
Any lump over or within teat	5	NL5
Distinct palpable lump >squash ball in size	5	BL5
Distinct palpable lump <golf ball in size	3	SL3
Condition score — Orange marker	**Score**	**CODE**
1 CS or more below mob average	5	CS5
1/2 CS or more below mob average	3	CS3
Age — Orange marker on rump	**Score**	**CODE**
9 years at lambing	10	Purple
8 years at lambing	8	Yellow
7 years at lambing	5	Red
6 years at lambing	3	Blue
5 years at lambing	1	Black

To start the assessment, ewes were run up a race and any lame ewes were drafted off. This was done by setting up a long-range draft capability, which allowed ewes to walk naturally up the race and be drafted off. Normally when a person stands at the draft ewes will run quickly towards it, but by standing approximately 7m away and having a spring-loaded drafting gate with a rope on it, the ewes' movement could be thoroughly assessed, and any lame ewes were removed (Figure 1).

Figure 1 Long range drafting set up

The second step was to physically assess all ewes. This was initially tried in a race and a sheep handler. The race was found to be the preferred option as it was quicker to assess large numbers of sheep. Ewes were put firmly in a race and udders, mouths and body condition score were assessed on each ewe. Ewes under four years of age did not have their mouths assessed.

Conducting udder assessments more than four weeks after weaning meant udders were reduced in size and abnormalities that may arise in udders post weaning could be identified. The udder was felt from behind, with the whole udder palpated, including teats, for signs of abnormality.

Condition scoring focused on picking up the outliers. A mob average was determined from the first race and then any ewes half a condition score lower were classed as moderate risk and those a full condition score lower were high risk. Depending on other issues found in the ewe, this would determine if they were classed as 'fit' or 'unfit' for joining.

The lame ewes that had previously been drafted off were assessed on their own with attention to the cause of lameness. Ewes assessed as sound through walking up the race did not have an in-depth foot assessment.

Using this method it was possible to assess >1600 ewes per day. Some days >2300 ewes were assessed. This was done using two people and dogs. One person did the assessing and the other recorded any abnormalities in the ewes that had been determined unfit.

In a commercial setting it is likely unfit sheep would be identified with a spray mark rather than recording, which would make the process much quicker as both people could both be assessing the sheep.

3.2.2 Pregnancy scanning

During March/April the flocks were pregnancy scanned. Ewes were split into mobs of dries, singles, twins, triplets (if that was the farm practice), or multiples (where triplets and twins were scanned separately). For the dry ewes, the pregnancy status of fit and unfit ewes was recorded separately and the total number of dry ewes counted. This provided data on the proportion of fit vs unfit for dry ewes.

Following pregnancy scanning, up until April/May, when lambing mobs established, all ewes were run as normal (i.e. those classed as fit and unfit were run in mobs as normal for the case study business (e.g. age groups etc).

3.2.3 Lambing

At the time when ewes were split into their lambing mobs (May) the ‘unfit’ ewes were separated from ‘fit’ ewes to be lambed down separately. This was to enable easier tracking of ‘unfit’ ewe performance during lambing. Where appropriate ewes were also separated into mobs of similar pregnancy status (i.e. twins, singles, etc). Mob size for each ‘unfit’ parity group was the same as for ‘fit’ ewes, lambed down onto same feed on offer (FOO) and provided similar shelter. Depending on numbers on each farm, ewes with different problems within the unfit mob were split (e.g. the older ewes run as one mob and the ewes with unsound udders were run as one mob) to demonstrate the impact on performance these issues have. For each ‘unfit’ mob the following data was recorded: mob size, ewe age/s, pregnancy status, FOO, average BCS. For a representative sample of ‘fit’ mobs of differing parity the same information was also recorded.

During lambing mobs were checked as normal for each case study property.

3.2.4 Lamb marking

At lamb marking (late July to early August) the following information was collected for all ‘unfit’ mobs:

- count of number of ewes and lambs
- average ewe BCS.

For representative samples of fit mobs (single, twin and triplet) the following information was collected:

- count of number of ewes and lambs
- average ewe BCS.

Following lamb marking, ‘unfit’ mobs were kept on their own for at least one-month post lamb marking (boxed into larger groups of all ‘unfit’ ewes, if necessary). Data recording for dead and treated ewes continued.

3.2.5 Early/pre-weaning

At weaning (or just prior to, during September 2021), the following data was collected:

- weight of lambs and average ewe CS from ‘unfit’ mobs
- weight of representative sample of lambs and average ewe CS from fit mobs.

3.2.6 Production data analysis

On completion of lamb marking three datasets were collated in three excel spreadsheets:

1. Analysis 1: Ewe classing information before joining.
2. Analysis 2: Ewe scanning information from ewes classed as fit and unfit.
3. Analysis 3: Ewe and lamb mortality data for unfit and fit ewes in different litter categories.

Analyses on these data sets were performed using R statistical software. Univariable, multivariable and regression analyses were used.

The univariable association between input (explanatory) variables including:

- ewe fitness category (each category used where enough data was given, where there wasn't enough data ewes were grouped as either fit or unfit)
- litter size
- enterprise type (composite vs merino)
- farm

and output variables including:

- proportion of dry ewes at scanning
- ewe mortality at marking
- lamb mortality at marking
- lamb weight at marking

were assessed by fitting general linear mixed models with each input variable as a fixed effect and farm as a random effect.

Input variables with a P value of <0.25 were included in multivariable analyses using a forward stepwise approach. Where model assumptions were not met (by running residual diagnostics) generalised linear mixed models were used (negative binomial models). Significance was reported for these models where $P <0.05$.

3.2.7 Economic analysis

3.2.7.1 Background to economic analysis

A full farm financial analysis of the treatments was considered necessary due to the possibility that labour use efficiency and the investment in livestock may play a role in business profitability. This was likely to be increasingly true as the difference in the number of animals between treatments (fit and unfit) increased.

The base assumptions for the economic analysis were:

1. The pasture utilisation was held constant across all treatments for that farm. This is (through stocking rate) the single most important driver of profit on livestock farms. If the fitness of ewes to join has no impact on an ability to increase stocking rate that limits the return. Assuming a fixed level of feed production (management capability) means that only the impact of the fitness of ewes to join and the treatments implemented is being assessed.
2. The income and costs associated with the case studies are as close to the actual figures as possible since the relative price received for lambs and ewes (mutton) is a critical driver (i.e. the bigger the difference in favour of lamb price the better the profit response to classing ewes).

3. Based on the statistical analysis udder soundness is the key driver of the return from classing ewes. As such it is expected that classing out ewes on this criterion alone may have an increased benefit to profit.
4. The cost of assessing ewe fitness to join was assumed to be $0.40/ewe.

The replacement rate (i.e. the ewe lambs required to replace the ewes culled as unfit to join) is the main cost of classing out unfit ewes prior to joining. However, ewes that die must also be replaced. The replacement rate was assumed to be X + unfit ewes + ewe deaths + scanned dry ewes + ewes that did not rear a lamb (not measured). Where X is a baseline replacement rate of 10-15% for each individual case study farm.

3.2.7.2 Methodology for economic analysis

A full physical and financial model was constructed for each of the case study businesses for three treatments (current position, unfit ewes, fit ewes). The difference between the "current position and fit ewes" is the benefit of classing out unfit ewes. The "unfit" treatment describes the marginal cost of these animals. An example of the output is attached in Appendix 9.1. The model includes five sections:

1. **Stock numbers (livestock reconciliation)**

This section is basically a livestock reconciliation tracking all stock movements across the 12-month period and allowing the relative characteristics of the business with respect to animals and the assessed treatments to be tracked and verified.

2. **Feed budget (feed balance)**

It is important when assessing the impacts of systems changes at a business level that managerial competency is assumed to be a constant. If the new technology or technique does not promote the growth and utilisation of more home-grown feed, then this needs to be rigorously tracked because quite small changes in pasture utilisation can have large impacts on farm business profit. This is best tracked through a feed budget which in turn has stocking rate, through pasture utilisation as a limitation or cap.

3. **Capital (invested in the business)**

It is important that if there are changes in the capital invested in the business because of changes to the system or infrastructure this can be tracked. In this case there are significant differences in the number of sheep required to achieve the same stocking rate across the three treatments. As a result, the assessment of economic performance must incorporate changes in the capital base.

4. **Labour (standardised for total sheep numbers)**

Labour use efficiency is a key driver of farm profit. Where treatments may result in differing amounts of labour the impact on business performance must be incorporated into the analysis. In this instance the three treatments do have differences in labour requirements despite labour use efficiency (ewes per full time person) being held constant.

5. **Budget (scenario analysis of the treatments)**

A budget that incorporates variable costs and overhead costs can be used to assess the impact of the three treatments on gross margin, net profit, earnings before interest and tax (EBIT), return on capital and return on marginal capital.

It is necessary to use several economic indices to get an indication of the value of the proposed changes or treatments. Economic significance is subjective, so only the person or entity undertaking the investment can determine whether the expected return makes the investment worthwhile.

Three treatments were assessed:

1. **Current position (status quo)**

This is the base case and represents the current business performance and assumes that there is limited classing of ewes as unfit to join, with any selection pressure likely to be focused on age, but not assessing udder soundness.

2. **Unfit ewes**

This is what the business performance would look like if all ewes performed similarly to the unfit ewes. While this would never really be the case the purpose of this scenario it to get a feel for how expensive these ewes are at the margin (i.e. is the impact on the business large or small on a per ewe basis or is it due to the number of ewes afflicted or a combination of both).

3. **Fit ewes**

This is what the business performance would shift to if the ewes were assessed prior to joining and unfit ewes were culled.

Producer survey

To gauge whether the quantum of benefit was likely to encourage producers to change management practice 23 producers were asked to comment on whether they would consider the investment and associated practice change worthwhile. In each case they were asked the question:

"Would you undertake classing of ewes and the associated management and operational changes if it were to cost you $0.40/ewe and return you between $4.00 and $8.00 per ewe?"

It is important to describe both the magnitude of the benefit and what is involved in obtaining it since the monetary benefit alone may not always provide the necessary motivation.

3.3 Development of fit to join toolkit

The outcomes of the literature review and the case study phases of the project indicated a strong case to develop the ewe assessment (fit to join) tools, as outlined in the project proposal.

The literature review highlighted gaps in information, gaps in dissemination of existing resources and information, and mis-information guiding standard industry sheep management practices.

The case studies provided robust information on the production and economic benefits of assessing ewes pre-joining and refined an efficient methodology for classing ewes as unfit, which enabled large numbers of ewes (up to 2300) to be assessed per day. This process is likely to be even more effective and efficient in a commercial environment, compared with a research-focused process, used in the case studies.

With guidance from the MLA communications team and two-stage feedback from producers, the project team developed:

- a 43-page ute guide: *Fit to join: Improving ewe and lamb survival through pre-joining assessment*
- four step-by step, 'how to' videos:
    1. Ewe assessment overview.
    2. Udder assessment.
    3. Lameness assessment.
    4. Assessing older ewes.

Following the draft of the ute guide content and video storyboards, the project team sought feedback from 10 sheep producers. Producers were provided with the draft resources and a feedback form to complete (which also included opportunity for comments). The producers provided constructive feedback on the approach being taken in the ute guide and videos, including language. They were also able to provide comment on some of the technical elements of the project (such as the need to include clear images of abnormal udders) and guided the project team on easy-to-access formats for presenting project findings (i.e.an interactive PDF). MLA was also invited to provide feedback at this stage of the development process.

The project team also collated feedback from the same group of producers after the design phase of the ute guide and the first draft of the videos were produced. Feedback at this stage of the project was also sought from the technical members of the project team and the MLA communications team. All relevant feedback was incorporated to the resources to ensure information was accurate and the materials were engaging, practical and easy to use for producers and their advisors.

4. Results

4.1 Literature review

4.1.1 Udder health

4.1.1.1 Definitions

For the purposes of consistency, the following definitions are suggested.

Acute mastitis. Inflammation detected by clinical signs or clinical examination at the start of, or during a lactation. Most cases involve deeper structures of udder and have infectious causes including *Mannheimia spp, and Staphylococcus spp* (Omalecki, *et al*, 2009; Barber *et al*, 2011), but there may be inflammation of the skin and teat of the gland as a result of superficial infections (orf) or photosensitisation.

Sub-clinical mastitis. Inflammation of the mammary gland, mostly due infectious agents, which can affect milk quality and quantity, and may occasionally impact the success of future lactations or increase the risk of an acute episode. Sub-clinical mastitis is not apparent on routine examination and is detected by ancillary tests: somatic cell counts or culture. It is not of great relevance to this project.

Chronic mastitis*.* Inflammation or damage to the udder that persists between lactations, which has the potential to impact future lactations. While it can be detected by somatic cell counts at the end of lactation, or other means such as the rapid mastitis test (also known as the California mastitis test and culture), palpation of gland and observation of teat and skin and abnormalities as a predictor of future lactational performance are of most relevance to this project. Studies by Griffiths *et al* (2109a and b) strongly suggest that udder scoring systems have great utility for predicting udder health, and the productivity of ewes at future lactations.

Udder scoring systems fall into two types. Those designed to predict lactational capacity and milking ease (e.g. Casu *et al*, 2006); and those designed to detect pathological abnormalities by observation (e.g. Grant *et al*, 2016; Griffiths *et al*, 2019a and b). The two are not mutually exclusive, but most information will be taken from the latter group. An additional complication is that within the latter group there are categorical/descriptive systems and semi quantitative systems. The detailed system described by Griffith et al (2019a) could be used experimentally or, alternatively, aggregated into bigger categories for use by producers (as these Griffiths et al (2019a) did for the purposes of analysis).

There is a reasonable amount of literature on acute and sub-clinical mastitis as a cause of ewe and lamb death or reduced weaning weight (e.g. Arsenault, *et al*, 2008; Grant, *et al*, 2016; Holmoy, *et al*, 2014). These studies are mostly longitudinal — starting at the beginning of lactation combined with case-control matching to find determinants of mastitis. Moreover, while they relate to meat producing sheep, they often involve inapplicable production systems with small numbers of sheep and intensive husbandry of European or North American production methods (including housing). Methods used to determine chronic mastitis between lactations are often impractical for large, southern hemisphere flocks (e.g. individual somatic cell counts and the California Mastitis test).

4.1.1.2 Incidence and effects of acute and subclinical mastitis

Estimates of acute mastitis vary with country and production system. In Australia, Barber *et al* (2011), estimate clinical mastitis incidences of 1–4%, with some flocks experiencing incidences of mastitis up to 10% within one lactation. The issue is more pronounced in meat breeds, particularly Poll Dorsets (Barber *et al*, 2011). This may reflect the environment in which the sheep are run (high rainfall) or the fact that many merino flocks are less intensively supervised, meaning cases go unobserved. A large survey by Quinliven (1968) recorded an incidence of clinical mastitis of 1.5–2.2% in North Island (New Zealand) Romney studs.

Watson *et al* (1990) found a cross-sectional prevalence of 14% bacterial infection in a range of New England ewe flocks. While ‘infection’ does not equate with mastitis (as in pathological inflammation), these researchers found a strong correlation between infection and clinical abnormalities, particularly in meat sheep. Thus, their study may be an estimate of concomitant estimate of acute and subclinical mastitis.

A study in Quebec (Arsenault *et al*, 2008) reported an acute mastitis rate of 0–6.6%, with an average of 1.2%, while Grant *et al* (2016) reported an acute mastitis incidence of 2.1–3%, with one study mob having an incidence of 37% in central England.

The effects of acute and subclinical mastitis on ewe survival and lamb survival and growth is well researched in dairy sheep (e.g. Vasileiou *et al* 2019), but poorly understood in meat sheep, particularly in the southern hemisphere.

Barber and colleagues (2011) estimate ewe death rates of up to 50% of acute clinical mastitis cases, with most lambs also dying. The mortality rate is high with or without treatment, reflecting the fact that under extensive husbandry systems early intervention is unlikely. This is borne out by the study of Arsenault *et al* (2009), who recorded 12% case mortality rate in intensively studied and husbanded flocks in Quebec.

At least five studies report information on lamb survival and growth rates during and after acute mastitis. Grant *et al* (2016) found reduced growth rate (40g/day – 18%). Arsenault *et al* (2008) found significant lower weaning weights in lambs from ewes with acute mastitis if the ewes were older than four years (2.8kg), or if the ewes had more than two lambs (1.9kg). Using case-control matching these authors also found that ‘litters’ with mastitis had a 15.4% chance of losing at least one lamb, while those without mastitis had a 4.6% chance of losing one lamb. These mortality rates appear very low compared with Australian paddock-born lambs. Holmoy *et al* (2104) found a significantly increased odds ratio (1.6) of lamb death from ewes with clinical mastitis.

Of most relevance to this project is the study of Griffiths *et al* (2019a) who found ewes with clinical mastitis (visible udder inflammation or abnormal milk or pus at marking or weaning) had at 27% chance of losing at least one lamb while healthy ewes had a 9% chance of lamb mortality. This figure includes those lambs that perished before marking, so not all the mortality can be attributed to mastitis. Moreover, Griffiths and co-workers (2019b) found the lambs of ewes with clinical mastitis at weaning grew at 20g/day (9%) less than lambs of ewes without mastitis.

Therapeutic interventions for acute mastitis (antimicrobial and non-steroidal anti-inflammatories) are rarely practical under Australian conditions, reflecting flock size and a (relative) lack of supervision at lambing. When producers can treat clinical cases, long-acting, parenteral antibiotics (e.g. long acting oxytetracycline) and single-dose non-steroidal anti-inflammatories (NSAID) (e.g. meloxicam) have greatest utility (Batey and Nilon, 2019). Further, inter-lactational treatments (specifically, ‘dry-sheep’ intramammary treatments) are not given because there is no easy way to identify those animals requiring it and whole-flock treatment, apart from expense, is not in keeping with responsible antimicrobial stewardship.

Environmental determinants of acute mastitis are poorly researched for extensive sheep production systems (compared with housed sheep and dairy systems). Grant *et al* (2006) and Arsenault *et al* (2008) found age (greater than four years) increased the risk of mastitis in paddocked sheep. Age will be one focus of the case study work to be undertaken for this project. At this stage having more than two lambs is not a huge consideration in an Australian production system, but it may be in the future with improved genetics, maternal nutrition and better survival of multiples. Grant *et al* (2006) also found low protein pastures increased the risk of acute mastitis.

4.1.1.3 Incidence of chronic mastitis and udder abnormalities and their effect lamb productivity:

All udder imperfections found at or after weaning should be classed as cases of chronic mastitis. This includes damage to teats. The difficulty with this area is that many of the reports relating to the subject state that sheep are routinely culled for udder defects. Thus, researchers may be looking at biased samples.

Hayman *et al* (1955) found 6% of ewes had imperfect udders at weaning, and that lambs born to ewes with imperfect udders were lighter at weaning and had a higher risk of mortality. However, they also concluded that culling of ewes on udder imperfections is unlikely to result in increased survival or weaning weight. However, this was against a production system background of high lamb mortality and poor pre-weaning growth rates, and so may not be typical of current production systems

Three seminal, longitudinal studies (Grant *et al*, 2016 and Griffiths *et al* 2019 a and b) examined imperfect udders between lactations and followed the ewes through the subsequent lactation. Grant *et al* (2016) used intramammary masses (IMM) as a surrogate measure of chronic mastitis. They found a 12-fold increase in the odds ratio of a ewe having an IMM if the ewes had had acute mastitis, and a four-fold increase in the odds ratio if the ewe had an IMM at the previous lactation. Overall, they found 8.25% of ewes had IMM before starting lactation. Thus, IMM may be a reasonable measure of chronic mastitis. However, IMM had little effect on lamb growth rates (10g/day) unless they were also associated with an episode of acute mastitis.

Griffiths *et al* (2019a and b) have investigated lamb survival and weaning weights against ewe udder and teat scores. These papers not only provide information on production losses, but a useful udder scoring system by which to classify udder abnormalities. These authors used a complex scoring system to rate udders pre-joining, at lamb marking and weaning. In their analysis they aggregated the scoring system to presence of lumps, normal or abnormal teat palpation and a range of udder scores relating to preferred shape, depth and symmetry. Their complex analysis can be summarised as:

- 7% of ewes had udder lumps or were classified as hard
- 5% had abnormal teats
- 2.1% had asymmetrical udders.

These factors can be regarded, de-facto, as measures of chronic udder pathology. Importantly, all three measures were predictive of failure to rear all or part of their litter. Ewes with a lump or hard texture pre-joining had approximately a 70% chance of losing at least one lamb, compared with a normal ewe with a 12% chance of losing a lamb. Ewes with abnormal teats had a 55% chance of losing a lamb compared with normal ewes (12%). Ewes with asymmetric udders pre-lambing had a 26% chance of losing a lamb. These categories were not mutually exclusive. While the study uncovered interesting information on preferred udder morphology (shape, teat placement and udder separation) in line with the scoring system of Casu *et al* (2006), this is not of primary concern to this project (unless udder scoring maidens is deemed important for selecting maidens) and had little bearing on survival to weaning.

In their second paper (Griffiths *et al* 2019b) the authors assessed growth rates to weaning on the same criteria as given above. Lambs born to ewes classified as having hard udders pre-joining had growth rates 25g/day (10%) less than normal ewes. The lambs of ewes with palpable abnormalities had growth rates 19g/day (9%) less than normal ewes. Lambs of ewes with asymmetric udders at docking or weaning grew 36g/day (15%) slower than lambs of ewes with symmetric udders. Their conclusion was that lambs born to ewes with defective udders would have a weaning weight 2kg less than lambs of ewes with normal udders.

4.1.1.4 Currently available udder health resources

Udder health and morphology is cited as a reason to cull (West *et al*, 2009; Griffith *et al*, 2019a), and it's also stated that NZ producers inspect udders at least once per year. However, little is known about whether producers act on their inspection information, and if they do, what impact it has on prospective productivity (West *et al*, 2009).

AWI's manual *Keeping Productive Older Ewes* (Lee *et al*, 2012, Module 4) cites the work of Hayman *et al* (1955) and Jordan and Mayer (1989) showing increased udder pathology and decreased productivity in older ewes. However, this manual does not produce evidence of whether there is increased productivity from culling for udder defects. Moreover, this resource relates to retaining old Merino ewes, whereas this project aims to examine all ages and meat and wool breed.

As reproductive performance is a key profit driver of meat sheep flocks it could be reasonably expected that udder health will have a greater impact. Finally, the *Keeping Productive Older Ewes* resource (Lee *et al* 2012) does not use an udder scoring system on which to make culling decisions.

4.1.2 Teeth

4.1.2.1 Overview

The productive life of a sheep is largely dependent on its ability to graze (West *et a.l*, 2017). This can be affected by both dental abnormalities and lameness (among a multitude of other reasons). Dental abnormalities whether perceived or real are important to the sheep industry (West *et al*., 2017). It is common for farmers to examine incisors of ewes and make culling decisions based on these. A 'broken mouth' or the loosening and loss of permanent incisors in sheep is a common reason for culling (Spence *et al*., 1980) and may lead to premature culling at four or even three years of age, impairing production and increasing flock replacement costs (Spence *et al*., 1980). Premolars and molars (cheek teeth) are generally not looked at in live ewes due to difficulty in examination and so abnormalities in these teeth often go unnoticed but can have severe effects on production (West *et al*., 2017). The examination of the teeth of sheep is an essential part of any clinical investigation (Ganter, 2008; Farquharson, 2009). Ewe dentition is useful as an estimate of age (to a degree) or to determine the cause of poor production (e.g. low condition score).

4.1.2.2 Dental disease in sheep

Excessive incisor-tooth wear and periodontal disease are considered the two most important syndromes affecting sheep's teeth and their supporting structures; less commonly, problems of occlusion or bite, defective enamel formation, caries, fluorosis, and odontogenic cysts also occur (West, 2002).

4.1.2.3 Excessive incisor wear

Excessive wear of incisor teeth is common in grazing sheep flocks in Australia. In some areas, the incisor teeth are worn down to gum level before 3–4 years of age (Orr *et al*., 1979). The exact aetiology of excessive incisor wear has not been established (Spence *et al.*, 1980) however a number of factors have been implicated:

1. **Soil ingestion** (Healy *et al*., 1967; Healy & Ludwig, 1965; Ludwig *et al*., 1966).
   Healy *et al* (1967), and Ludwig *et al* (1965)) associated excessive wear of incisor teeth with soil ingestion when pasture length was low. They suggested that abrasions from the soil on the occlusal (biting) surface of the incisors resulted in excessive wear. Their studies identified that up to 70% of the wear occurred between July and October (southern

hemisphere), when soil content of faeces exceeded 40%, and that providing supplementary feed and rotational grazing reduced soil intake and also reduced incisor-tooth wear (Healy *et al.,* 1967). It has also been found that certain soil types are less readily ingested by ewes and therefore reduce the risk of wear

2. **Chemical attack**
   The clinical presentation of incisor wear is not always typical of shortening due to abrasion at the occlusal surface. Incisor teeth do not only shorten, but also dissolve and wear from the sides so that the incisors are eventually reduced to 'pebbles' (Barnicoat, 1957). It has been suggested that acidic soils may dissolve teeth (Mitchum & Bruere, 1984). However, this hypothesis has yet to be fully tested. Nevertheless, in conjunction with physical abrasion, solubilisation could account for the excessive rates of tooth wear observed on many Australian and New Zealand sheep farms (West *et al*., 2017).
3. **Defective tooth development** (West *et al*., 2017).
   Developmental defects of teeth have been reported experimentally with nutritional deficiencies as well as excessive parasitism and trauma. Anecdotally it has been reported that farms severely affected by drought have sheep which erupt permanent incisors with enamel defects and severely affected sheep have teeth that crumble away rapidly.
   Teeth contain approximately 90% calcium phosphate $(Ca_3PO_4)_2$ and thus calcium and phosphorous metabolism plays an important role in tooth development.
   Gastrointestinal parasitism alters the absorption of minerals and thus can affect calcium and phosphorous levels. The role of other minerals such as copper and molybdenum in sheep tooth wear is poorly understood and further research is needed in this area.
4. **Genetics**
   It has been demonstrated that there is a significant inherited component to the rate at which teeth wear. Border Leicester sheep and their crosses have incisors that wear faster than Romney sheep which in turn wear faster than Merino sheep (Meyer *et al.*, 1983). Further study and identifying genes involved in dental health would be valuable research objectives (Byun, 2012). For example, the transcription factor Ctip2 is a critical regulator of the enamel secreting cells during teeth development and growth (Golonzhka *et al.*, 2009).

The economic effects of premature tooth deterioration have been identified by West *et al.* (2017) and include:

- Overhead cost of maintaining flock increased as ewes are sold one to two years earlier and may have given two or three profitable lambing seasons otherwise. More ewe lambs are then kept for replacements and therefore fewer lambs are available for sale.
- Selection for genetic gain is affected if ewes that possess otherwise desirable characteristics are removed from flock before they have achieved their highest fertility.
- If premature culling occurs farmers may be forced to buy inferior stock or retain animals which would have otherwise been culled

A recent study by Richards *et al* (2018) found that the number of incisor teeth an older ewe possessed had no significant effect on their condition score (BCS). This conflicts with current production practices in Australia, in that broken or gummy-mouthed ewes are thought to be unable to maintain BCS and are therefore culled. However, this study did find that the condition score of sheep with no adjacent teeth being even was significantly ($P < 0.05$) lower than that of ewes with better teeth evenness. Further work in this area is warranted given the opposing evidence available in the literature compared to current practices. There is not enough evidence in the literature to suggest that culling of broken mouthed ewes should occur providing their body condition score is reflective of the nutrition and parasite control provided.

4.1.2.4 Periodontal disease

Periodontal disease leading to premature tooth loss is recognised as a significant dental problem in sheep worldwide. The condition is characterised by inflammation of the gingivae, pocketing and food impaction around the tooth, and eventual tooth loss. Although cheek teeth are most commonly involved it has also been found that periodontal tissue of incisor teeth can be affected (Porter et al., 1970). Collagen loss due to periodontal disease results in disorganization of fibre groups within the incisor periodontal ligament and subsequent tooth loss (Spence *et al.*, 1980).

Historically periodontal disease is known as a condition that affected sheep on some farms and not others, and early investigators considered nutritional factors that could affect the supporting structures of the tooth, including the periodontal ligament and alveolar bone. Studies in New Zealand (Cutress & Schroeder, 1982; Suckling *et al*., 1974) failed to establish a causal role for calcium and phosphorus imbalances, low selenium, low vitamin D, high molybdenum, high oestrogen, or high vitamin A levels. Subsequently, it was established that periodontal disease in sheep began as a localised bacterial plaque-induced gingivitis which damaged the attachments of the periodontal ligament, leading to pocketing, tooth loosening, and eventually tooth loss. Although the basic pathogenesis of periodontal disease was recognised, the reasons for the variable incidence between flocks remained unclear (Frisken *et al.,* 1989). As a result, advice for the prevention of periodontal disease is largely empirical.

It is important to assess the real, rather than the perceived importance of tooth loss to the flock. Richards *et al*, 2018, found that older ewes with all incisor teeth being loose had a significant ($P < 0.05$) reduction in body condition score. However, as long as some teeth were firm there was little impact on the condition score. A possible reason for this is periodontal disease causes global tooth loosening however if some teeth are still firm periodontal disease is less likely the cause of tooth loosening.

4.1.2.5 Ewe dental examination

When dental disorders are suspected at a flock level, it is important to examine representative samples of sheep from the farm. This may include, for example, separating sheep of poor body condition score from those of adequate body condition score and examining the teeth of a selection of each. Different age groups should also be included. Evaluation should be made of the number, size and shape of the incisors and their occlusion with the dental pad (West et al., 2017). Evidence of gum inflammation or abnormalities of the enamel should be recorded. Incisors can be gently palpated to gauge looseness (Ridler & West, 2010) however 3 mm of movement is considered normal in sheep due to the large periodontal ligament (West et al., 2017). Cheek teeth in live sheep are not generally examined however, palpation through the cheek may detect grass impaction and spaces left by missing teeth, while palpation of the jaw may detect swellings such as those caused by odontogenic cysts. Careful examination of the cheek teeth should be included in any post-mortem examination of a sheep with a history of weight loss or cud-staining (Ridler & West, 2010).

4.1.3 Feet

The feet of ewes become a productivity issue when lameness occurs (West *et al*., 2017). Lameness is defined as a gait abnormality, caused by disease or injury in some part of limbs or trunk, usually accompanied by pain (Boden & Andrews, 2015). The underlying cause of lameness can be broadly classified as conformational abnormalities, trauma or infection (Coulon *et al.*, 1996; Gelasakis *et al.*, 2015; Green & George, 2008). Much like dental disease, lameness will affect a ewe's ability to graze, which will not only result in a loss of body condition score but can lead to diseases such as hypocalcaemia and pregnancy toxaemia (Stewart *et al*., 1984; West *et al.*, 2017).

4.1.3.1 Conformational anomalies

The structural soundness of the ewes' feet and legs plays an important role in lameness prevention ("Visual Sheep Scores," 2019). The Visual Sheep Scores booklet developed by AWI and MLA (2019) provides a useful visual reference to use when assessing the structural soundness of a ewe's legs and feet. These scores generally refer to genetic defects in ewe conformation. Ewes with scores in the higher end of this range should be culled from the breeding flock. In addition to conformation defects, other foot abnormalities can occur such as overlong toes.

4.1.3.2 Infectious causes of lameness

Lameness can be attributed to a variety of underlying pathogens which can cause conditions such as footrot and foot abscess. Both of these conditions have been listed as priority endemic diseases in the red meat industry (Lane *et al.*, 2015).

Footrot

Footrot is an endemic disease in Australia and one of the major causes of lameness in small ruminants such as sheep and goats (Lane *et al.*, 2015). It is caused by a complex mixed bacterial infection, of which the bacterium *Dichelobacter nodosus* is the necessary component (Allworth, 1995; Beveridge, 1941; Raadsma & Egerton, 2013). In Australia, footrot is estimated to cost the sheep industry $45 million per annum, "mainly due to production losses and the cost of controlling the disease" (Lane et al., 2015).

The disease is, at times, highly contagious (virulent footrot) and is characterised by infection of the interdigital skin, which may progress to separation between the hard and soft horn of the hoof matrix (known as underrunning) (Allworth, 1995). The mild (benign) forms of the disease are not economically significant (Raadsma & Egerton, 2013). The clinical expression of the disease is dependent on several important factors including the strain or strains of *D nodosus* present, the local environment (moisture, temperature and pasture conditions), the resistance of sheep to footrot and whether control is restricting the clinical expression of the disease (Lane et al., 2015). All these factors must be considered when making a diagnosis of the specific strain of footrot present (Lane et al., 2015). In most states virulent footrot is a notifiable disease (Buller & Eamens, 2014). Diagnosis is usually based on clinical expression although, depending on individual state regulations, additional laboratory tests may be used to classify the strain. However, there are serious limitations on the ability of laboratory tests to classify the strains (Allworth 2014).

Production losses associated with footrot depend on the strain of footrot, breed of sheep, local environment and control measures adopted (Allworth, 1995; Egerton et al., 2004; Raadsma and Egerton, 2013). In one trial, sheep with average footrot severity suffered weight losses of 0.5 to 2.5 kg liveweight (Nieuwhof et al., 2008). At a flock level the cost of eradication of virulent footrot has been estimated at $10 per sheep (Allworth, 1995).

Foot abscess

Foot abscess is primarily caused by the bacterium *Fusobacterium necrophorum* although other bacteria are considered to play a role (Egerton, 2007). The infection starts in the top layers of the skin, spreads to the deeper subcutaneous tissue and can extend to the foot joints in severe cases

(Egerton, 2007). Toe abscess can occur in all classes of sheep though typically in heavy sheep in wet conditions (Lane et al., 2015).

Foot abscess outbreaks vary from year to year with lush wet seasons resulting in outbreaks of over 10% of sheep affected (Lane et al., 2015). The economic impact of foot abscess can be significant. Affected sheep if pregnant are at risk of secondary pregnancy toxaemia and or hypocalcaemia and death (West et al., 2017). Affected sheep will usually develop a severe break in the wool resulting in lower fleece value and produce less wool (Lane et al., 2015). Affected sheep will often be culled prematurely due to chronic lameness and foot deformities caused by severe infections (West et al., 2017). The most effective treatment is parenteral antibiotics though response to treatment is often poor if infection is well established. Resolution usually occurs in about eight weeks (Lane et al., 2015). Prevention involves avoiding ewes in late pregnancy from being confined in wet, muddy yards or on wet country. If this is not possible consideration should be taken to institute treatment before infection develops such as pre-emptively foot bathing with 10% zinc sulphate (West et al., 2017). Vaccination against *F. necrophorum* has been trialled but the results have been disappointing in preventing foot abscess formation. Ewes, of any age, with uneven claw size or other signs of foot abscess damage should be culled according to the AWI booklet “Identifying and Keeping Productive Older Ewes in the Flock: A ‘How To’ Manual” (Lee et at., 2012) which is consistent with the literature.

4.1.4 Past reproductive performance

The ability to identify ewes that can outperform their counterparts, in terms of their lifetime productivity in the flock, will aid in improving flock efficiency and profitability (McLaren *et al.*, 2020). As stated previously; historically, Australian flocks have been run with a fixed age structure, ignoring individual merit and culling at a specific age. It is now accepted that producers should focus on keeping productive older ewes longer and culling less productive ewes earlier irrespective of age (Richards *et al.*, 2018). This point is impressed upon by Lee *et al* (2012); stating that “the objective should be to cull [ewes] with poor reproductive history from the breeding flock and to retain the ewes with the best reproductive record” using indicator traits such as fertility, fecundity and lambs weaned as a gauge.

Previous studies have also examined the effect of age on reproduction and the impact of reproduction status on productivity, but little research has been conducted on cumulative effects of reproductive performance on later productivity, reproduction and health. Selective breeding has been advocated as a means of improving lamb rearing ability and survival under pastoral conditions (Haughey, 1984). Haughey (1984) found that ewes that successfully reared lambs at two years of age (as maidens) were more likely to have superior rearing performance at subsequent lambings compared to ewes that did not. Subsequently, selective breeding for lamb rearing ability, defined as the ratio of lambs weaned to lambs born, has resulted in a reduction in lamb mortality (Cloete et al., 1998; Haughey, 1984). The repeatability of rearing performance has been estimated at 10% by Haughey (1984). Lamb rearing ability has been reported as a repeatable trait, in that the more lambs reared, the better the subsequent performance appears to be (Purser and Young, 1983). If the lamb was not reared from the ewe’s first lambing, lamb mortality at age three (second lambing) was 26.8%, but if the first lamb was reared, the mortality was 13.5% (Purser and Young, 1983).

4.1.5 Older ewes

The general consensus of authors is mortality rate increases exponentially in ewes older than 5 years and is considerably worse in drought years or with high stocking rates. In the papers reviewed, mortality rates differed slightly between flocks depending on breed and environmental conditions, but the general trend is as sheep get older their mortality rates increases (from an average of 3% at two years old to an average of 10% at seven years old) (Hickey *et al* 1960, Turner *et al* 1959). In the flocks considered in the articles reviewed, there was no selection pressure placed on ewes, so it is important to note that mortality rates may differ significantly in flocks where sheep are regularly classed out (Turner *et al*., 2020; Langlands *et al*., 1984; Hickey, 1960; Griffiths *et al.*, 2018). While litter size (fecundity) increases with age, and usually peaks around 6–7 years old, less lambs are weaned from ewes older than five years old compared with ewes less than five years old (Asutr *et al*., 2007).

Langlands *et al* (1984) compared ewes run at 10 ewes/ha and 20 ewes/ha, and showed that at higher stocking rates, reproductive performance decreases with age. This study found that lamb survival and fertility were 80% of ewes joined for all ages of Merino ewes, peaking between 4-5 years old. Likewise, Turner *et al* (1959) noted that in drought years, mortality rate of ewes older than seven years increased from 7.3% to 45%, while ewes less than six years old remained around 4%.

The extension package developed by AWI and NSW DPI *Identifying and Keeping Productive Older Ewes in the Flock* summarises the reproductive and economic effects of ewe age:

- Lamb survival declines with ewe age but is generally better in older ewes than maiden ewes.
- Age-related reproductive factors are influenced heavily by environment, most notably in dry/drought years.
- Overall reproductive rate doesn't decrease below that of maidens until ewes are more than seven years old

The studies reviewed for age-related reproductive factors are all older than 2007, and management of weaners and maiden ewes would be expected to have improved significantly during the past 13 years. More work in this area would be of value as this would provide contemporary data for reproductive factors of maiden and older ewes. This may have economic implications for age structure of flocks.

4.1.6 Young ewes

Maiden ewes have their own considerations pre-joining. Maiden ewes have been shown to have lower reproductive success than mature ewes, however this is not always the case. A study by Kleeman et al (2005) into the reproductive wastage of ewes found no difference between maiden and mature ewes (wastage was defined as fertility, fecundity and lamb survival). The key difference for maiden versus mature sheep is litter size. Maiden ewes have lower scanning percentages compared to mature ewes. In the studies mentioned, maiden ewes refer to two-year old sheep.

A study by Corner et al (2013) compared the reproductive performance (defined by lamb survival and growth rates of lambs) of ewe lambs (joined at nine months of age) and mature ewes. They found that lamb survival in ewe lambs was lower than that of mature ewes, due to lighter birthweights. However, in one of the study groups the lamb survival of single ewe lambs was equal to that of mature ewes' single lambs. They identified an opportunity for further research into increasing the liveweight of lambs born to ewe lambs to determine if this increased survival.

The key selection factor for joining ewe lambs is liveweight because this impacts fertility, as well as likely risk of dystocia at lambing time (Kenyon et al, 2014). Choice of sire breed for joining with ewe lambs may have an important role to play in minimising dystocia, as it has been shown that breeds selected for high muscling ASBVs are more likely to require intervention at lambing (Dwyer and Bünger, 2012).

4.1.7 Condition score

There have been substantial amounts of research into the impact of condition score on the reproductive performance of ewes. The Lifetime Wool project and subsequent Lifetime Ewe Management (LTEM) programs focused on the impact of condition score and liveweight on the reproductive performance of ewes, throughout the breeding cycle (Ferguson et al, 2007 and Trompf *et al,* 2012). The MLA-funded Lifetime Maternals Project built on this work, focusing on condition score targets and effects for meat and composite breeds (Thompson, 2017). Some differences in how condition score can be used as a target for reproductive performance were found between Merino and meat breeds, however in both breeds a higher condition score at joining results in higher fertility ewes and more lambs conceived (Thompson, 2017).

From the Lifetime Maternals Project, condition score at joining was shown to be potentially less important as an indicator of fertility compared to Merinos. Non-Merino ewes fed poorly during pregnancy and lambing down (less than CS3) had a reduced reproductive rate in the following joining, compared to what would be expected based on condition score alone at the subsequent joining (Thompson, 2017). This data was not specifically looked at in the Lifetime Wool project so cannot be commented on for Merinos.

4.2 Case study results

4.2.1 Production data

The proportion of fit to unfit ewes at the pre-join classing is described in Table 3 below. This proportion of unfit ewes (20% for farms 1 and 2 and 43% for farm 3) is substantial and was unexpected. Both case study farms 1 and 2 have sold cull ewes historically. Farm 2 has put the most selection pressure on ewes in recent years – there are limited ewes over six years of age and ewes that have failed to rear a lamb have been culled. However, udders of ewes that have raised lambs have not been assessed. Farm 1 has had limited pressure on ewes during recent years due to a goal of increasing ewe numbers, and culling has only been done via a visual assessment that a ewe wouldn't handle another 12 months in the production system. Farm 1 and 2 ewes were all older than two years. Only 40% of farm 3 total ewe flock are represented in the case study flock, which was cull Merino joined to a terminal ram (ewes that have failed to rear a lamb in previous years or older ewes). Therefore, this is not representative of the whole of Farm 3 flock or a Merino flock generally.

Table 3 Summary of the proportion of unfit ewes from each farm at classing

Farm	Fit	Unfit	% Unfit
1	6799	1573	19%
2	3700	913	20%
3	2656	1974	43%

Table 4 describes the reasons for ewes being classed as unfit on each farm. As there was often more than one reason that ewes could be classed as unfit, the total number of unfit ewes and the total number of ewes in all six categories are not equal.

This data is further summarised in Figures 1 to 3. There were differences across all case study farms, Farm 2 was a reasonably even spread with approximately 25% of ewes classed as unfit for age, udder and BCS, and the remaining 25% comprised of teeth and feet/lameness issues. Farms 1 and 3 the majority (over 50%) of ewes were classed as unfit based on age. For farm 1 the next highest category was udder (20%), followed by BCS (16%). For Farm 3 BCS 35% of ewes were classed as unfit based on BCS, and only 5% based on udder.

Figure 4 shows the number of issues per ewe represented as a percentage of ewes from each farm. Only two ewes on Farm 2 had five issues and so this does not feature on the graph. All three farms had a similar pattern with most ewes being categorised as having one issue only, followed by ewes with two issues and to a much lesser extent three issues or more.

Table 4 Number of unfit ewes in each category on each farm

Farm	Teeth		Lameness		Structural foot issues		Mammary		Body Condition Score		Age	
	Code	**n**	**Code**	**n**	**Code**	**n**	**Code**	**n**	**Code**	**n**	**Code**	**n**
1	TL5	13	L5	1	FM3	11	M5	210	CS5	207	A15	7
	TU5	4	L4	1	FM2	52	TM5	0	CS3	177	A10	96
	TM5	33	L3	59	FM1	27	TS5	15			A8	228
			L2	27			NL5	11			A5	17
			L1	20			BL5	207			A3	167
							SL3	24				
2	TL5	21	L5	0	FM3	7	M5	152	CS5	272	A15	0
	TU5	50	L4	0	FM2	58	TM5	8	CS3	79	A10	0
	TM5	77	L3	60	FM1	40	TS5	0			A8	1
			L2	25			NL5	12			A5	175
			L1	18			BL5	153			A3	163
							SL3	39				
3	TL5	0	L5	0	FM3	0	M5	32	CS5	474	A15	10
	TU5	4	L4	0	FM2	5	TM5	1	CS3	357	A10	77
	TM5	9	L3	3	FM1	1	TS5	0			A8	428
			L2	3			NL5	6			A5	709
			L1	0			BL5	45			A3	165
							SL3	28				

N = number of unfit ewes in each category.

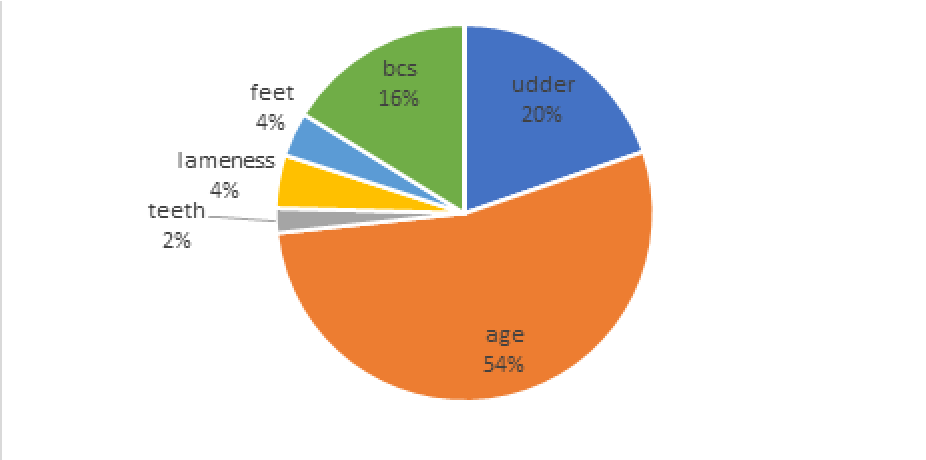

Figure 2 Proportion of unfit classes assigned on farm 1 calculated from the number of ewes in each class category divided by the total number of ewes

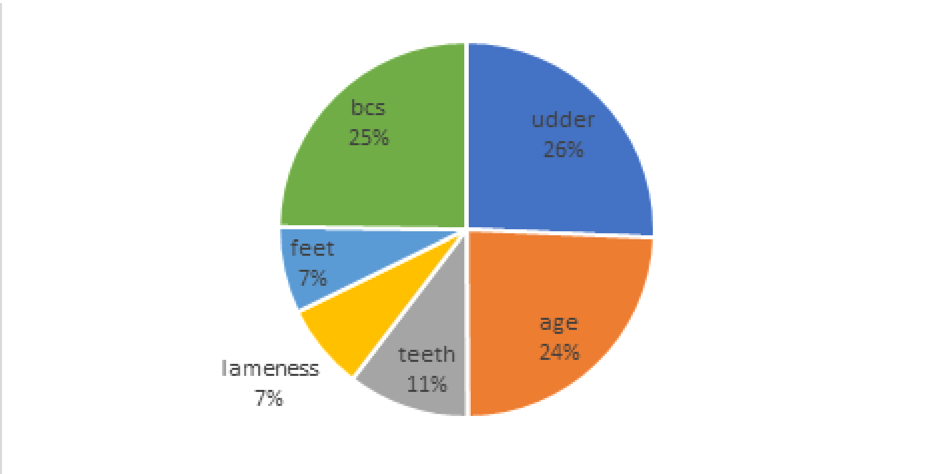

Figure 3 Proportion of unfit classes assigned on farm 2 calculated from the number of ewes in each class category divided by the total number of ewes

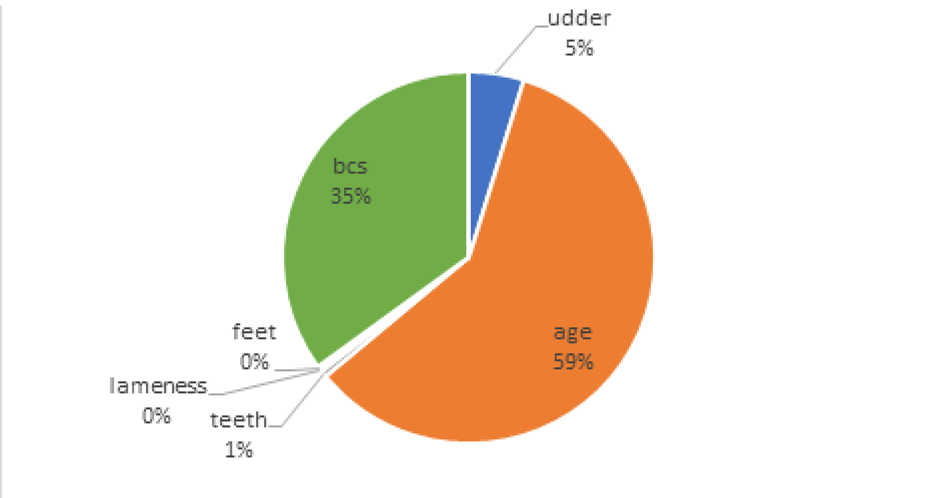

Figure 4 Proportion of unfit classes assigned on farm 3 calculated from the number of ewes in each class category divided by the total number of ewes

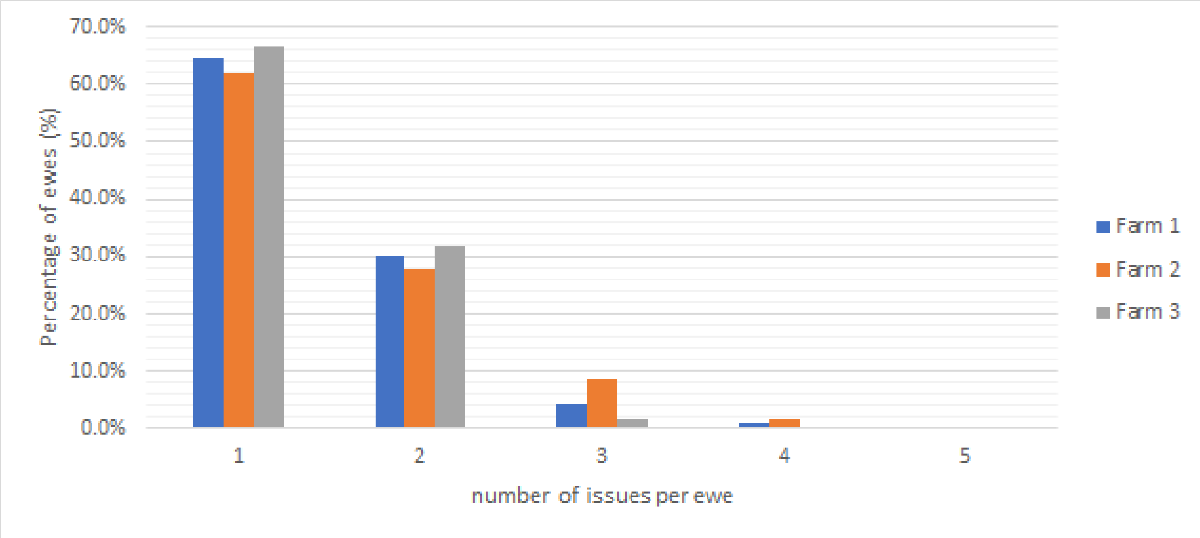

Figure 5 The number of issues per ewe represented as a percentage of ewes on each farm. Only two ewes on Farm 2 had five issues and so this does not show on the graph, given the scale.

The statistical analysis demonstrated that ewes are 4.4 times more likely to be scanned empty if they are classed as unfit compared to fit (Table 5**Table** , with summary of raw data presented in Table 6). On average 9.7% of ewes scanned empty in the fit ewes, while 19.7% scanned empty in the unfit ewes. This translated into differences for scanning percentage between fit and unfit ewes of 147% compared to 130%, however this was not a statistically significant difference. Farm 3 scanned more empty ewes and had a lower scanning percentage (lower fertility) as it was a Merino-based flock run at much lower flock condition score profile compared to the other cross bred/first cross flocks. The impact of type of unfit classification (age, feet, BCS) on ewe fertility was not able to be statistically determined, possibly due to the small sample size.

Table 5 Raw data summary of scanning results for all farms by ewe class (fit vs unfit)

Farm	Ewe class	Ewes in	Scanned empty	Dry %	Scanned %
1	**fit**	6799	112	2	160
2	**fit**	3700	32	1	180
3	**fit**	2656	686	26	100
Average	**fit**	**-**		**9.7**	**146.7**
1	**unfit**	1573	220	14	141
2	**unfit**	913	38	4	171
3	**unfit**	1974	808	41	79
Average	**unfit**	**-**		**19.7**	**130.3**

The statistical analysis demonstrated that unfit ewes were three times more likely to die between joining and marking compared to fit ewes (Table 7 and Table 8, with summary of raw data presented in Table 6). Lamb marking percentage was also lower in unfit ewes compared to fit ewes (123% compared to 137%, (Table summary of raw data). There was a statistical difference between unfit and fit ewes in terms of lamb deaths. Lambs had a 21% (CI:7-37%) higher risk of death from scanning through to marking if their mother had been classed with an unsound udder. Lambs from unfit triplet ewes were at even higher risk, with a 25% higher risk of death (CI:5%-48%) compared with fit triplet ewes (Table 6**Table**).

Table 6 Raw data summary of marking results for all farms by ewe class (fit vs unfit)

Farm	Ewe class	Litter type	Unfit reason	Unfit reason 2	Ewes in	Ewe deaths	Ewe mortality (%)	Foetus' scanned	Lambs marked	Marking %
farm1	**fit**	twin	fit	fit	4172	63	1.5	8344	6989	168
farm1	**fit**	single	fit	fit	2515	30	1.2	2515	2267	90
farm2	**fit**	single	fit	fit	972	3	0.3	972	962	99
farm2	**fit**	twin	fit	fit	2443	32	1.3	4886	3950	162
farm2	**fit**	triplet	fit	fit	277	12	4.3	831	625	226
farm3	**fit**	single	fit	fit	1239	37	3.0	1239	1088	88
farm3	**fit**	twin	fit	fit	646	24	3.7	1292	807	125
farm1	**unfit**	twin	old	unfit	180	3	1.7	360	281	156
farm1	**unfit**	twin	udder	udder	266	10	3.8	532	356	134
farm1	**unfit**	twin	other	unfit	415	9	2.2	830	653	157
farm1	**unfit**	single	NA	unfit	492	2	0.4	492	467	95
farm2	**unfit**	single	skinny/lame	unfit	92	0	0.0	92	82	89
farm2	**unfit**	single	udder	udder	75	2	2.7	75	58	77
farm2	**unfit**	single	other	unfit	72	1	1.4	72	65	90
farm2	**unfit**	twin	skinny/lame	unfit	135	0	0.0	279	228	169
farm2	**unfit**	twin	udder	udder	220	0	0.0	440	274	125
farm2	**unfit**	twin	other	unfit	188	5	2.7	376	275	146
farm2	**unfit**	triplet	NA	unfit	69	7	10.1	207	104	151
farm3	**unfit**	single	NA	unfit	780	27	3.5	780	684	88
farm3	**unfit**	twin	NA	unfit	417	26	6.2	834	492	118

Table 7 Average ewe mortality and marking results by ewe class

	Average ewe mortality	Average marking %*
fit	2.2	137
unfit	2.7	123

** marking percentage is calculated as lambs marked from ewes joined*

Table 8: Significant results from statistical modelling to determine association of risk factors (output variables) for various input variables

Area of interest	Model used	Input variables	Output variables	Risk ratio	95% CI for RR
Ewes scanned empty[a]	Generalized linear mixed model (negative binomial)	Number of ewes scanned "empty"	Ewe type + Enterprise Type	4.37	1.83-10.45
Ewes not making it to scanning[b]	Generalized linear mixed model (negative binomial)	Total of ewes joined – ewes at marking	Ewe type + Enterprise Type	2.95	3.57-13.76
Lamb death[c]	General linear model	Proportion of lambs dead (from scanning to marking)	reason * litter + enterprise	1.21 (bad udder cf fit)	1.07-1.37
				1.25 (unfit, triplet cf fit, triplet)	1.05-1.48

There was no statistical difference in lamb weights between lambs from fit and unfit ewes (although only data from farm 1 was available for this analysis). The small sample size of unfit ewes on each farm and the need to keep them separate within normal farm practices meant that stocking rate and feed levels despite the best efforts of the project team were not consistent. This meant some mobs had higher feed quality and quantity from marking to weaning, greatly affecting weight gain. Therefore the data captured on the weight of lambs at weaning is not a good reflection of the ewe performance.

In summary, the key results from statistical analysis of the three case study farms are:

- Ewes are 4.4 times more likely to be scanned empty if they are classed as unfit compared to fit. The impact of type of unfit classification (age, feet, BCS) on ewe fertility was not able to be statistically determined, possibly due to the small sample size.
- Unfit ewes were 3 times more likely to die between joining and marking compared to fit ewes. However, it wasn't possible to separate out which of the causes of 'unfitness' are the greatest contributors to ewe mortality (again due to small sample size).
- There was a statistical difference between unfit and fit ewes in terms of lamb deaths. Lambs had a 21% (CI:7-37%) higher risk of death from scanning through to marking if their mother had been classed with a bad udder. Lambs from unfit triplet ewes had a 25% higher risk of death (CI:5%-48%) compared to fit triplet ewes.

4.2.2 Economic (cost-benefit) analysis results

There were three farms 1, 2, and 3 involved in the study. The first two farms are prime lamb businesses and the third a wool business. The results for each of the business are summarised in Table . It should be noted that in the case of Farm 3 it was assumed to only run a ewe flock (i.e no wether enterprise was included in the analysis in Table 9).

Table 9 Summary of results

	Farm 1			**Farm 2**			**Farm 3**		
	All	Unfit	Fit	All	Unfit	Fit	All	Unfit	Fit
Replacement rate	18%	21%	17%	26%	27%	26%	24	25	23
Net profit ($m)	1.043	0.745	1.094	1.827	1.518	1.874	0.493	0.436	0.518
ROC	4.2%	3%	4.4%	4.4%	3.7%	4.5%	4.4	3.9	4.6

The marginal return to each farm is outlined in Table 10. The marginal return is simply the cost of assessing the ewes and the return from culling them and running the higher replacement rate. In this case it was assumed that the cost of classing the ewes was $0.40/ewe. The return is described on a per ewe and a return on marginal capital basis.

Table 10 Marginal return on capital invested in classing ewes fit or unfit

	Farm 1	**Farm 2**	**Farm 3**
Gross return	$51,600	$47,413	$24,970
Return per ewe	$8.32	$4.31	$4.09
Return on Marginal Capital	2081% (20x)	1078% (10X)	1023% (10x)

The survey results are summarised in Table 11. As a rough rule of thumb producers have historically implemented managerial or operational changes when the return is a doubling of their money (i.e. they will generally invest $1 to make $2). The results in Table 10 are therefore not surprising however it is safe to say that with record profits at play that this threshold might increase.

Table 11 Survey of producers to determine threshold for economic significance of classing ewes for fitness to join

Producer type	**Number**	**Response**	
		Yes	**No**
Wool	7	5 (70%)	2 (30%)
Prime lamb	16	12 (75%)	4 (25%)

Of the variables associated with ewes being classed as unfit, udder function was the only one found to be statistically significant. The impact of classing out just for udder function was assessed for Farm 1 and resulted in a much larger return. The comparative results are summarised in Table 12.

Table 123 A comparison of the returns associated with culling based on udder soundness alone versus udder soundness plus condition score, age and feet

	Farm 1 (Unfit all)	Farm 1 (Unfit udder)
Gross return	$51,600	$67,086
Return per ewe	$8.32	$10.82
Return on Marginal Capital	2081% (21x)	2705% (27x)

The impact of adding wethers to the wool business was also assessed since initially it was hypothesized that limiting the benefit to the maternal flock would increase the size of the benefit. This relationship is summarized in Table 13.

Table 43 Comparison of a flock comprising of ewes only against ewes and wethers

	Farm 3 (ewes only)	Farm 3 (plus wethers)
Gross return	$24,970	$27,836
Return per ewe	$4.09	$5.20
Return on Marginal Capital	1023% (10x)	1301%

4.2.3 Interpretation of economic (cost-benefit) analysis results

The economic return from classing out unfit ewes aligned with the statistical analysis. Most producers, whether wool or prime lamb focused, would implement the changes required to class out unfit ewes for the modelled return. The difference in economic performance is primarily associated with proactively culling ewes for being unfit to join rather than joining them and having higher ewe and lamb mortality. For a fixed level of resource (pasture or energy) this results in improved business performance. It is worth noting that in the current market the difference between lamb price and mutton price (the money received for cull ewes) is quite small. This reduces the economic benefit of proactive culling, as modelled at this time.

The magnitude of the return is dependent on each individual business and relative performance in several areas (e.g. the higher the scanning rate or fertility of the flock the more you stand to lose by not culling). However, despite the range of potential returns from the three businesses the lowest return was still acceptable to the producers surveyed. The lowest response came from Farm 3, the farm with the worst fertility but more importantly the least dependency on fertility to drive profit. In this wool business empty ewes can still be run as a profitable unit and so the marginal benefit of fertility once you exceed replacement rate is quite low. This is especially true if we hold the stocking rate constant across treatments.

In the case of the wool business (Farm 3) adding a percentage of the total flock (25% in this case) as wethers was expected to reduce the return. What it actually did was to increase the proportion of the flock retained as replacements out of fewer ewes. If the same carrying capacity and stocking rate are assumed, then this increases the importance of fertility and the return from improving it.

It would appear (although unable to be statistically supported by the case study analysis) that businesses that have had some selection pressure in place on the fitness of ewes to join have a smaller predicted benefit. This is to be expected since some of that benefit has already been realized (annually). Additionally, it is positive that implementing the change across all businesses, regardless of enterprise, inherent fertility or economic performance resulted in a positive benefit. In addition to this the strategy is unlikely to have major cashflow implications since the ewes are culled prior to mating (and therefore don't bear any costs).

It appears that the higher the inherent fertility of the flock the higher the potential return since any ewe mortality will generally result in a disproportionately higher rate of lamb loss.

4.2.4 Producer survey

The results from the producer survey *"Would you undertake classing of ewes and the associated management and operational changes if it were to cost you $0.40/ewe and return you between $4.00 and $8.00 per ewe?"* is summarised in Table 14. It is important to note that this survey was conducted as part of phase 2 of the project (case study economic analysis), so producers who responded were doing so purely on the basis of the financial cost-benefit data, without any exposure to the extension resources and associated key messages. Given the positive response to the fit to join toolkit from producers who reviewed it (section 4.3), it would be expected that the reported willingness to adopt would be the minimum.

Table 54 Summary of producer survey to gauge likely adoption of fit to join resources.

Enterprise type	N	Yes	No
Wool	7	70%	30%
Prime Lamb	16	75%	25%

4.3 Development of fit to join toolkit

The results from the literature review and the case studies were used to inform the content and approach to developing the fit to join - ewe assessment resources. The project team also reviewed existing sheep reproduction extension programs and resources to ensure the fit to join resources would add value to and complement, rather than duplicate, existing resource. For example, condition score, from a nutritional perspective, and its impact on reproductive fitness of ewes at joining has already been incorporated into extension products for producers (e.g. LTEM, Bred Well Fed Well (BWFW), Lifting Lamb Survival (LLS)). For this reason, condition scoring was not included in detail in the fit to join guide (i.e. a condition score video was not developed). Similarly, there are already excellent industry resources for footrot, so detailed information on footrot was not included. In these instances, where a factor was important for fitness to join, but was already adequately covered in existing resources, they were signposted in the ute guide with interactive links used to link resources with users. Relevant extension programs are also signposted in the fit to join guide (e.g. BWFW, LTEM Picking Performer Ewes).

As part of developing the Fit to Join guide, an extension and adoption integration plan was developed so the fit to join resources can be 'bolted on' to existing programs where appropriate (T90), or they can be sign-posted to from an existing extension program (e.g. LTEM, BWFW). This has resulted in the production of two PowerPoint slide decks (short and long) and a Fit to Join factsheet, which will be made available to the deliverers of relevant extension programs.

The producers who provided feedback on the development of the toolkit were overwhelmingly positive in their feedback relating to all components of the Fit to join toolkit. In particular, they commented on the practical nature of the material and believed the resources would help take them to the next level of productivity and address animal welfare concerns, particularly around the number of lambs born, but not surviving.

Meetings held with developers of existing sheep reproduction extension packages have also been positive, with developers/package owners committing to build the fit to join toolkit into existing packages where appropriate or to highlight the availability of the resources. The project team has already had the opportunity to share with industry the project findings via a Sheep Reproductive Strategic Partnership webinar (*https://www.mla.com.au/research-and-development/livestock-production/reproductive-efficiency/sheep-reproduction-strategic-partnership-srsp/#:~:text=The%20Sheep%20Reproduction%20Strategic%20Partnership,weaning%20rates%20and%20decreasing%20mortality*).

Presentation of the project is also locked in at upcoming industry events, including Livestock Advisor Updates and the Australian Sheep Vets conference.

An article on the project has already been written for the MLA *Feedback* magazine (scheduled for publication in the December issue).

5. Conclusion

Often sheep producers get frustrated they cannot achieve the high marking percentages others do, even though they're implementing industry best practice for the ewes they join in the lead up to and during lambing. An underlying reason for this may be because they're joining ewes that aren't fit to rear a lamb (and up to 20% of the flock could fall into this category). Improved lamb marking and ewe mortality outcomes can be achieved if the flock is 'fit to join'.

By taking action early (pre-joining) to assess ewes there can be substantial productivity, welfare and economic benefits through a combination of strategic, targeted management and culling. Once a business has adopted the process and it becomes standard practice then the numbers of ewes likely to be culled in a pre-joining assessment each year would be expected to reduce. However, this reduction may depend on how strict and on what variables ewes have been culled at weaning, historically.

The combination of literature review and the case study work presented here provide a strong justification that assessing ewes for fitness to join results in improved animal welfare, productivity and financial outcomes for commercial sheep enterprises.

The literature review highlighted gaps in information, dissemination of existing resources and information, and mis-information that is guiding standard industry sheep management practices. The case studies provided robust information on the production and economic benefits of assessing ewes pre-joining.

Through the development of the fit to join ute toolkit, supporting resources such as PowerPoint slides and factsheet, and proactive engagement with the owners and developers of relevant sheep reproduction extension programs, this project provides a real opportunity to fill information gaps and extend information to improve industry practice in ewe assessment pre-joining. The potential benefits from uptake of these resources for ewe and lamb survival across industry are significant.

The important point is by taking action early (pre-joining) to assess ewes there can be substantial productivity, welfare and economic benefits through a combination of strategic, targeted management and culling. Once a business has adopted the process and it becomes standard practice then the numbers of ewes likely to be culled in a pre-joining assessment each year would be expected to reduce. However, this reduction may depend on how strict and on what variables ewes have been culled at weaning.

6. Key findings

- An opportunity exists to improve lamb and ewe survival outcomes through a simple, yet effective, ewe assessment and selection process pre-joining.
- The key risk factors that impact on ewe and lamb survival include: udder health and structure, body condition, lameness, teeth and age.
- Ewes assessed as 'fit to join' are more likely to rear healthy lambs, increasing marking percentages, enterprise profitability and animal welfare outcomes.
- Analysis on three commercial sheep operations indicates unfit ewes are four times more likely to scan empty and three times more likely to die between joining and scanning. Lambs from unfit ewes had a 21% higher risk of dying.
- The economic benefit for classing and culling ewes as unfit to join was modelled at between $4 and $8 per ewe.

7. Benefits to industry

The sheep and wool industry can achieve substantial productivity, welfare and economic benefits if producers take action early (pre-joining) to assess their ewes (through a combination of strategic, targeted management and culling) for their fitness to join.

The fit to join project and the associated outcomes (ute guide, videos, MLA factsheet and PowerPoint slide decks, proactive engagement with developers and owners of relevant sheep reproduction extension packages) provide an opportunity to fill information gaps and extend information to improve industry practice in ewe assessment pre-joining.

8. Future research and recommendations

- Further research into repeatability of reproductive performance for both maidens and mature ewes is required. This is currently an area of conjecture and would benefit from on-farm trials to determine how repeatable ewe performance actually is and the financial implications.
- To determine the uptake of the fit to join toolkit, track number of copies of the guide printed and disseminated, and monitor downloads or views of the videos.
- Continue to implement the project adoption integration plan, to ensure that the resources developed are widely shared and available to industry.

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10. Appendix

10.1 Example of the economic assessment tool

Business analysis - Grazing

2020-21	Farm 1 All	Farm 1 unfit	Farm 1 fit
Lamb price	$3.90 /kgLwt	$3.90 /kgLwt	$3.90 /kgLwt
Wool - Micron AVG	30	30	30
Wool price (GFWT)	$5.00 /kg greasy	$5.00 /kg greasy	$5.00 /kg greasy
Cattle price	$3.10 /kgLwt	$3.10 /kgLwt	$3.10 /kgLwt
Rainfall	550 mm	550 mm	550 mm
DM yield/ha	5.6 t DM/ha	5.7 t DM/ha	5.6 t DM/ha
DM yield/ha/100mm	1,023 kg DM/ha	1,033 kg DM/ha	1,022 kg DM/ha

1. STOCK NUMBERS

Item	Comment	Farm 1 All	Farm 1 unfit	Farm 1 fit
Stocking rate (DSE/ha)		18.8 DSE/ha	18.9 DSE/ha	18.7 DSE/ha
Ewes lambed		11,100	11,650	11,000
Wethers		0	0	0
Cows calved		0	0	0
Stock On Hand at Start		(no.)	(no.)	(no.)
Sheep	Ewe mortality	1.4%	1.6%	1.4%
	Scanned dry (not pregnant)	0.0%	0.0%	0.0%
	Dry (did not rear a lamb)	0.0%	0.0%	0.0%
Ewes Joined		11,258	11,839	11,156
	Marking rate	132%	112%	136%
Lambs marked		14,652	13,048	14,960
	Replacement rate	26%	27%	26%
Replacement ewe lambs		2,972	3,149	2,945
Lambs sold		11,680	9,899	12,015

2. FEED BALANCE

		Farm 1 All	Farm 1 unfit	Farm 1 fit
Dryland Area (Grazing)		**1,948**	**1,948**	**1,948**
Dryland Pasture				
Home		1,948	1,948	1,948
Cropping		0	0	0
		1,948	**1,948**	**1,948**
Total Pasture (Grazing)		**1,948**	**1,948**	**1,948**
		4,870	4,870	4,870
Pasture Utilisation per Hectare Upside potential for both these key variabl		(tDM/ha)	(tDM/ha)	(tDM/ha)
Dryland Pasture		5.7	5.7	5.7
Total Pasture Utilised		(tDM)	(tDM)	(tDM)
Dryland Pasture		11,104	11,104	11,104
		11,104	**11,104**	**11,104**
Purchased Feed		(tDM)	(tDM)	(tDM)
Hay (tDM)		0	0	0
Grain/Pellets per ewe		0.000 t/ewe	0.000 t/ewe	0.000 t/ewe
Grain/Pellets		0	0	0
		0	**0**	**0**
Total Feed Supply		**11,104**	**11,104**	**11,104**
Sheep flock		(No.)	(No.)	(No.)
Ewes joined		11,258	11,839	11,156
Ewes to lamb		11,100	11,650	11,000
Ewe hoggets		2,972	3,149	2,945
Rams	1.5%	169	178	167
Lambs sold		11,680	9,899	12,015
Ewe replacements		2,972	3,149	2,945
Wethers		0	0	0
Liveweight sold		(kg)	(kg)	(kg)
Average lamb weight (sale)		45	45	45
Total Kg Lwt (lamb)		525,600	445,442	540,665
Feed Requirements per Head		(tDM/hd)	(tDM/hd)	(tDM/hd)
Ewes to lamb		0.55	0.55	0.55
Ewe hoggets		0.30	0.30	0.30
Rams		0.40	0.40	0.40
Lambs sold	4.0 kgDM/kgLwt)	0.20	0.20	0.20
Ewe replacements		0.55	0.55	0.55
Wethers		0.30	0.30	0.30
Cows calved		4.40	4.40	4.40
Bulls		2.80	2.80	2.80
Calves sold	4.0 kgDM/kgLwt)	1.72	1.72	1.72
Heifers retained		2.07	2.07	2.07
Total Feed Requirements		(tDM)	(tDM)	(tDM)
Ewes to lamb		6,105	6,408	6,050
Ewe hoggets		892	945	884
Rams		68	71	67
Lambs sold		2,278	1,930	2,343
Ewe replacements		1,620	1,716	1,605
Wethers		0	0	0
Cows calved		0	0	0
Bulls		0	0	0
Calves sold		0	0	0
Heifers retained		0	0	0
Total Feed Requirements		**10,961**	**11,070**	**10,949**
Feed Surplus/Deficit		**142**	**34**	**155**
		1%	0%	1%

3. INVESTMENT

		Farm 1 All	Farm 1 unfit	Farm 1 fit
Land & Improvements		$m	$m	$m
Home farm Dryland		35.80	35.80	35.80
Capex		0.00	0.00	0.00
Total Land and Improvements		**35.80**	**35.80**	**35.80**
Stock				
Ewes to lamb		$250/hd	$250/hd	$250/hd
Ewe hoggets		$180/hd	$180/hd	$180/hd
Rams		$2,400/hd	$2,400/hd	$2,400/hd
Ewes		2.81	2.96	2.79
Ewe hoggets		2.64	2.35	2.69
Rams		0.41	0.43	0.40
Ewe replacements	$200/hd	0.59	0.63	0.59
		6.45	**6.36**	**6.47**
Plant & Machinery		**0.50**	**0.50**	**0.50**
Other Assets	eg Cash/Hay/Silage	**0.00**	**0.00**	**0.00**
Total Assets		**42.75**	**42.66**	**42.77**
Liabilities				
Mortgage 1 (land)		0.00	0.00	0.00
Mortgage 2		0.00	0.00	0.00
Machinery purchase		0.00	0.00	0.00
Total Liabilities		**0.00**	**0.00**	**0.00**
Net Worth (Equity)		**42.75**	**42.66**	**42.77**

4. LABOUR EMPLOYED

	Farm 1 All	Farm 1 unfit	Farm 1 fit
Labour Units	(No.)	(No.)	(No.)
Owner/Manager	1.00	1.00	1.00
Other/Casual	1.50	1.60	1.45
Total Labour Units	**2.50**	**2.60**	**2.45**
DSE per FTE	7,770	7,841	7,857

4. LABOUR EMPLOYED

	Farm 1 All	Farm 1 unfit	Farm 1 fit
Labour Units	(No.)	(No.)	(No.)
Owner/Manager	1.00	1.00	1.00
Other/Casual	1.50	1.60	1.45
Total Labour Units	**2.50**	**2.60**	**2.45**
DSE per FTE	7,770	7,841	7,857

5. BUDGET

			Farm 1 All	Farm 1 unfit	Farm 1 fit
Wool sales					
Adult fleece		3.5/kg	249,215	262,095	246,970
Lambs		0.5/kg	36,630	32,620	37,400
			285,845	**294,715**	**284,370**
Stock Sales					
Sheep					
Lambs			2,050,000	1,738,000	2,109,000
Ewes		$154/hd	433,418	455,818	429,513
Cull rams	25%	$70/hd	3,000	3,200	3,000
Wethers	50%	$100/hd	0	0	0
			2,486,418	**2,197,018**	**2,541,513**
Crops					
Canola	0.0/t	$700/t	**0**	**0**	**0**
Cereal	1.5/t	$300/t			
Total Income			**2,772,263**	**2,491,733**	**2,825,883**
Sheep Stock Purchases					
Rams	25%	$2,400/hd	101,400	106,600	100,500
Bulls		$4,000/hd	0	0	0
			101,400	**106,600**	**100,500**
Animal costs					
Sheep			$0.40	$0.40	$0.40
An. Health/Vet		$11/ewe	123,900	130,300	122,800
Fitness check			0	0	13,387
Shearing		$7.5/ewe	84,500	88,800	83,700
Electricity		$3/ewe	33,800	35,600	33,500
Stock Cartage		$2/ewe	22,600	23,700	22,400
Wool selling costs		$4/ewe	45,100	47,400	44,700
Other		$1/ewe	11,300	11,900	11,200
		$29/ewe	**321,200**	**337,700**	**331,687**
Pasture Costs					
Seed	10%	$60 /ha	11,688	11,688	11,688
Fertiliser		$50 /ha	97,400	97,400	97,400
Sprays		$20 /ha	25,000	25,000	25,000
Cropping		$300 /ha	0	0	0
Contract Work		$5 /ha	9,800	9,800	9,800
Hay/Silage Making		$2 /ha	3,900	3,900	3,900
			147,788	**147,788**	**147,788**
Purchased Feed					
Silage/hay/straw		$300/t	0	0	0
Agistment Costs (sheep)		$0/hd	0	0	0
Agistment Costs (cattle)		$0/hd	0	0	0
Grain/Pellets		$350/t	0	0	0
			0	**0**	**0**
Tractor, Plant & Vehicle Operating					
Registrations		$3,000	3,000	3,000	3,000
Fuel & Oil		$20 /ha	39,000	39,000	39,000
Repairs		$10 /ha	19,500	19,500	19,500
			61,500	**61,500**	**61,500**
Repairs to Structures & Improvements					
Home farm		$30,000	30,000	30,000	30,000
Run Off		$0	0	0	0
			30,000	**30,000**	**30,000**
Wages/Drawings		Including Superannuation			
Owner/Manager		$90,000	90,000	90,000	90,000
Other Wages		$65,000	97,500	104,000	94,250
			187,500	**194,000**	**184,250**
Insurance			0	0	0
General		$15,000	15,000	15,000	15,000
Workers Compensation		4%	7,500	7,760	7,370
			22,500	**22,760**	**22,370**
Admin & General Overheads					
Acctg/Advisory		$7,500	7,500	7,500	7,500
Bank Charges/Fees		$300	300	300	300
Electricity General		$3,000	3,000	3,000	3,000
Lease		$0	0	0	0
Rates & Land Tax		$5 /ha	9,740	9,740	9,740
Telephone		$2,200	2,200	2,200	2,200
Other		$1,000	1,000	1,000	1,000
			23,740	**23,740**	**23,740**
Finance Costs					
Mortgage 1	$0	4.5%	0	0	0
Stamp Duty	$0	4.5%	0	0	0
Machinery Purchase		25.0%	0	0	0
Overdraughts	$0	4.50%	0	0	0
			0	**0**	**0**
Depreciation/Capital ReplacementCapital Purchases					
Plant & Machinery depreciation		10%	50,000	50,000	50,000
Bank funding			0	0	0
Other			0	0	0
			50,000	**50,000**	**50,000**
Total Expenses			**945,628**	**974,088**	**951,835**
Net Profit			**1,826,635**	**1,517,645**	**1,874,048**
		Percent of income	65.9%	60.9%	66.3%
		Return on Capital	4.4%	3.7%	4.5%
		ROE (NP/Equity)	4.3%	3.6%	4.4%