Final report

Increasing lambing percentages through better use of pregnancy scanning technology

Project code: L.LSM.0021

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Abstract

The project aimed to improve lamb survival and reproductive rate in Australian sheep through better adoption of pregnancy scanning, encouraging more producers to precision-manage flocks to better met the nutritional requirements of ewes of different litter sizes, including empty ewes. Currently 69% of sheep producers do not scan for litter size to enable this practice, so the project has directly addressed the key obstacle raised by non-adopting producers in that they believe that the business case for scanning is too weak to adopt the technology. This has involved an extensive benefit cost analysis on the value of scanning across a range of sheep producing regions and enterprise types, developing a detailed and strong business case for pregnancy scanning, and a study to better understand the accuracy of pregnancy scanning. Also included is work to improve the skills base of pregnancy scanners and to encourage the trialling and adoption of innovations in scanning technology, by creating a scanning image (video) library, training materials and information resources, running workshops and seeking scanner feedback to better understand their needs and views on scanning adoption. Key results are that the business case for pregnancy scanning for litter size is strong, being profitable across all regions in the winter and summer rainfall regions in southern Australia, across all genotypes and all times of lambing investigated, with an average a profit of $5.75 per ewe scanned, even after conservatively allowing for a discrepancy of 15% between scanning and lambing results for twin-bearing ewes. There are 166 pregnancy scanning operators active in Australia. With a return on investment of 400%, pregnancy scanning for multiples (litter size) can and should be a vital tool for improving reproductive rate and lamb (and ewe) survival rates.

Pregnancy scanning for litter size enables:

- the selling of empty ewes at scanning or at the following shearing,
- better allocation of feed according to ewe litter size,
- allocating multiple bearing ewes to the best lambing paddocks and/or reduce mob size,
- preparing the lambing feed budget in advance,
- earlier detection of any reproductive failure,
- more rapid re-mating of empty ewes, and
- more accurate selection of replacement ewes.

Key project highlights

- Pregnancy scanning to identify multiple-bearing, single-bearing and empty ewes and implementing optimal nutritional management and paddock allocation is profitable in all agricultural regions, lambing times and flock types.
- The average increase in profitability is $5.75/ewe scanned. The highest value is for flocks scanning just prior to the most significant feed deficit each year because decisions can be made to more effectively manage ewe nutrition during this feed shortage.
- Pregnancy scanning for pregnancy status only is generally about half as profitable as scanning for litter size. It is however a good introduction to the benefits and practicalities of scanning.
- Scanning at the correct time improves accuracy – scan for multiples (litter size) 80-90 days after the rams go in (based on the industry recommended 5-week joining period) and by correct ewe preparation – ewes should be off feed and water for a minimum of 6 hours before scanning.
- Scanning for pregnancy status is 97-98% accurate, whereas the agreement between fetal numbers identified at scanning and the number of lambs born is lower (85%-88%), partly due to unobserved lamb loss rather than scanning errors.

Executive summary

Background

Pregnancy scanning can be a vital tool for improving sheep reproductive performance. It enables identification of litter size early in pregnancy, so that ewes can be separately managed by litter size to meet recommended condition score targets to enhance lamb and ewe survival. However, an Australian survey found that 69% of respondents do not pregnancy-scan their ewe flocks for litter size (Howard and Beattie, 2018) and are thus not able to customise ewe nutrition during pregnancy and lactation specifically according to whether they are carrying singles, twins or more lambs.
This project aims to increase adoption of pregnancy scanning among Australian sheep producers (all regions) by 10% by 2032, with 15% more of the scanned flocks providing customised management to twin/multiple-bearing ewes by 2032 (by scanning for litter size). The project findings are being used to build a stronger business case for pregnancy scanning, directly addressing the most common reason for not adopting scanning, which was the perception that the business case is weak.

Objectives

1. Conduct the following activities with the aim of increasing adoption of pregnancy scanning by 10% (by 2032):
    a. Conduct an extensive benefit cost analysis on the value of scanning across a range of sheep producing regions and enterprise types
    b. Develop a detailed business case for pregnancy scanning, including information suitable for inclusion in MLA and AWI extension packages tailored to different production environments, producer skill levels and resource availability (e.g. livestock identification systems and labour availability)
    c. Conduct a series of case studies and surveys to create a better understanding of barrier to adoption of pregnancy scanning and develop solutions to overcome these barriers.

2. Design and implement strategies to improve the skills base of pregnancy scanners and encourage the trialling and adoption of innovations in scanning technology by:
    a. Creating a scanning image library (videos of real-time assessments) using 3 experienced pregnancy scanners and a human sonographer / radiologist as a tool for benchmarking
    b. Creating a series of training materials and information resources for pregnancy scanners, including content covering:
        i. Images and anatomical references to identify single and multiple pregnancies at different stages of the gestation
        ii. Ovine reproduction physiology
        iii. Fetal losses and causes of loss
    c. Conducted workshops for scanners, including use of benchmarking material, as part of a regular (bi-annual) conference'

Methodology

Scanning accuracy - accuracy of pregnancy scanning was examined, for pregnancy status and fetal numbers, using the MerinoSelect dataset maintained by Sheep Genetics. It compared consistency of scanning results with the number lambs born and also the range of scanning accuracy achieved by several different operators and accuracy at different fetal ages.

Engagement with pregnancy scanning contractors and a pilot benchmarking study – A demographic survey was conducted of 156 pregnancy scanning contractors identified as active in Australia. Due to the inability to run face-to-face meetings because of Covid-19-related restrictions, an on-line workshop for pregnancy scanners was conducted in early July 2021, with another conducted in late July 2022. Flocks at 3 sites have been double-scanned and ewe lambing results collected, with video imagery collected for training purposes.

Comprehensive economic analysis of pregnancy scanning – The Australian Farm Optimisation Model, which replaces the MIDAS model, was created and then used to model the profitability of pregnancy scanning for both pregnancy status and for litter size, across three different regions (long, medium and short growing seasons concentrated in the winter rainfall regions of southern Australia), three different genotypes (Merino, Merino x Terminal and a Maternal flock) and three different lambing times (autumn, winter and spring). The sensitivity of results to changes in prices of meat, wool and supplements, overall reproductive rates, wind chill and equation method used (GrazPlan or LifetimeWool project results) was also an. A further study, using a gross margin approach to estimate profitability from pregnancy scanning, was undertaken to study the effects of using the technology in the summer rainfall regions of Australia.

Creation of a detailed business case for pregnancy scanning – This drew on the experiences of three livestock consultants and feedback from the project team. It also incorporated the results from the updated economic analysis of pregnancy scanning.

Running of producer workshops, producer group & livestock consultant extension activities – in conjunction with MLA and AWI, 10 existing producer workshops or field days, 3 webinars, plus 5 livestock consultant updates were identified for project outputs to be extended to. Extension activities with producer groups included one honours project on-farm with the Barossa Improved Grazing Group, a workshop on 'Scanning and Survival in Sheep' organised in conjunction with the MacKillop Farm Management Group and a PDS project initiated with MerinoLink in NSW.

Results/key findings

- Pregnancy scanning for ewe litter size and implementing optimum nutritional management, optimal management of empty ewes and optimal paddock allocation is profitable in all agricultural regions for all genotypes and at all times of lambing. This includes the southern agricultural regions, as well as the spring-summer rainfall zone in NSW. The average increase in profitability is $5.75/ewe scanned, based on long-term prices for the period 2004 to 2020.
- Pregnancy scanning for pregnancy status only is generally about half as profitable as scanning for litter size (which also includes scanning for pregnancy status).
- The profitability of scanning is sensitive to sheep meat prices, but not very sensitive to wool and grain supplement prices, nor overall reproductive rate of the flock. At January 2022 lamb prices, the average profitability of pregnancy scanning is closer to $10/ewe scanned.
- The highest value from scanning is for flocks scanning just prior to the most significant feed deficit each year because decisions can be made to more effectively manage ewe nutrition during this feed shortage. This is 'winter' lambing in the long growing season environment and 'autumn' lambing in the medium and short growing season environments.
- In general scanning has the least impact on profit for spring lambing flocks.
- From a study of 68,000 Merino ewe records, scanning for pregnancy status is 97-98% accurate, whereas the agreement between scanning for fetal numbers and the number of lambs born is lower and more variable (85%-88%) on average. This lower accuracy is mainly from:
  - 10-12% singles observed as born to ewes previously scanned with twins, most likely as a consequence of unobserved lamb loss, rather than errors at scanning time
  - Some ewes giving birth to triplets were scanned as only bearing twins

- Accuracy of scanning can be improved by scanning at the correct time – scan for multiples (litter size) 80-90 days after the rams go in (based on the industry recommended 5-week joining period) and by correct preparation of the ewes on the day of scanning – ewes should be off feed and water for a minimum of 6 hours before scanning. There is also some potential to improve scanning accuracy, especially for higher litter sizes, such as triplets. Typically scan operators need additional training for detecting all multiples accurately and producers also need to request this service clearly at the time of scanning.

Benefits to industry

- Scanning for multiples (litter size), which enables precision management of lambing groups, as well as optimal management of dry ewes, is profitable in all winter and summer rainfall regions in southern Australia, in all genotypes and at all times of lambing investigated. The average profit was $5.75 per ewe scanned.
- Pregnancy scanning for multiples has a 400% return on investment and can and should be a vital tool for improving reproductive rate and lamb (and ewe) survival rates, via the following:
    - selling of empty ewes at scanning or at the following shearing
    - better allocation of feed in favour of multiple-bearing rather than single-bearing ewes and especially empty ewes
    - allocating multiple bearing ewes to the best lambing paddocks and/or reduce mob size to enhance lamb survival
    - ability to prepare the lambing feed budget in advance
    - earlier detection of any reproductive failure
    - ability to more rapidly re-mate empty ewes
    - more accurate selection of replacements by accounting for birth type

Future research and recommendations

- Extending the collation of pregnancy scanning data nationally, for benchmarking purposes, as already carried out on a regional basis in Western Australia, would add value to the current investment in pregnancy scanning technology.
- Projects addressing the logistical reasons given by some sheep producers for not scanning (especially for multiples), including not having enough paddocks and unwillingness to lamb down small mobs of twin or multiple-bearing ewes should be initiated.
- The feasibility of using machine learning (and/or deep learning) to aid in pregnancy scanning is worth investigation. This could help not only in ultimately increasing the capacity for scanning more sheep, but could potentially aid in further improving scanning accuracy, particularly for more fecund sheep and could aid in identification of fetal and uterine abnormalities.
- Extending the economic analysis and business case for pregnancy scanning to the pastoral/rangeland areas of Australia.
- Improvement of scanning accuracies for triplets and higher order litters and associated optimisation of management for ewes bearing triplets or more.
- Where the average flock litter size is 1.5 or more, sheep producers should be encouraged to request that scanning operators specifically look for and identify ewes carrying triplets, in addition to identifying twin and single bearing ewes and empty ewes.
- Video images of pregnancy scanning already collected during the L.LSM.0021 project, augmented by a number of additional scanning images, could be packaged in such a way as to provide an on-line learning package for novice scanners.
- A working group (to include pregnancy scanners, consultants and scientists) be established to:
    - provide recommendations on the future training needs for pregnancy scanners and how they can be best met.

    - plan conduct future workshops for scanners and provide a focus for interaction between scanners, scientists, consultants, producers, MLA and AWI and government.
- The best value in terms of extension is through support of small group learning activities, which have demonstrated their ability to achieve practice change. In particular, incorporating project findings in existing programs such as Lifetime Ewe Management and the newly-created Towards 90 Program, plus programs such as Lifting Lamb Survival and Profitable Grazing Systems, is strongly supported, which has been a priority during the current project.

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1. Background

Trans-abdominal ultrasonography of sheep can be used for visualisation of the following:

- Pregnancy (after day 35 or better after day 45 of gestation)
- The number of fetuses present and their size (fetal aging)
- Detection of non-pregnant ewes, based on lack of signs of pregnancy
- Some abnormalities of pregnancy and the uterus

Considerable early development of this technique for diagnosing pregnancy and litter size in sheep was conducted in Australia, with researchers concluding the technique to be an accurate, rapid and reliable method, suitable for commercial application (Fowler and Wilkins 1982, 1984; Wilkins and Fowler 1982).

Results from pregnancy scanning of sheep in mid-pregnancy can provide the following benefits for commercial sheep producers:

- selling of empty (non-pregnant) ewes at scanning or at the following shearing to improve overall flock reproduction rate
- better targeting/allocation of feed on offer or supplementary feed in favour of multiple-bearing ewes rather than single-bearing ewes and especially empty ewes, based on specific nutritional requirements reflecting litter size
- allocating multiple bearing ewes to the best lambing paddocks and/or reduce mob size for multiple bearing ewes to enhance lamb survival
- accounting for birth type effects when selecting replacements
- ability to be more proactive about animal welfare, through better understanding of both ewe and lamb losses
- provides a focus for improvement of reproductive management
- ability to prepare the lambing feed budget in advance
- earlier detection of any reproductive failure
- ability to more rapidly identify and re-mate empty ewes

Ewe culling and retention strategies can be practiced based on scanning and/or reproductive data recorded for individual ewes, with flock gains in net reproduction rate between 2% to 6% expected (Lee *et al.* 2014). Further, for ram breeders, litter size data from pregnancy scanning can also be used to aid in the genetic evaluation of reproductive traits, including all three component traits of conception, litter size and ewe rearing ability, as well as improving predictions for other traits where birth and rearing type affect phenotypes.

More generally, establishing (benchmarking) the reproductive potential of individual flocks is a critical step for sheep producers in their quest to lift lamb marking percentages. Most of this potential can be readily established by scanning ewes for litter size (fetuses/ewe) and pregnancy status. The reproductive potential of sheep flocks is commonly much higher than the lambing marking count and the difference between the two, described as reproductive wastage, averaged 42% in a large study reported by Kleemann and Walker (2005), varying widely between flocks, in agreement with a number of other studies (see review by Hinch and Brien 2014). Reducing reproductive wastage is a major opportunity for improvement across all sheep regions and breeds in Australia. Identifying and avoiding high levels of lamb losses is also an important welfare issue.

1.1 Industry adoption of pregnancy scanning

There are conflicting messages in industry about the profitability of pregnancy scanning in flocks, which was demonstrated by a survey of producers in Western Australia; producers were close to equally divided on its value (Elliot 2011). A part of this conflicting assessment of value has arisen from mixed messages from economic studies (see below).

In 2015/16, only 50% of Australian sheep producers had adopted pregnancy scanning, with only 31% indicating they scan for fetal numbers, according to a national survey (Howard and Beattie 2018). In contrast, adoption of pregnancy scanning in New Zealand is much higher, at 70.9%, with most scanning for fetal numbers (Corner-Thomas *et al.* 2015).

Therein lies the key industry problem being addressed in this project, in that 69% of Australian sheep producers can't customise ewe nutrition to litter size as they are not scanning ewe flocks for fetal numbers.

1.1.1 Economics of pregnancy scanning

Using 2014/15 prices, Young *et al.* (2016) reported that managing pregnant and lambing ewes based on the litter size they carry can provide a profit of $0.80 per ewe, based on data from a site in south-west Victoria that was lambing in spring. However, other reports have not been as supportive of the adoption of scanning technology. Earlier studies (e.g. Bowman *et al.* 1989) and Holmes and Sackett 2008) were conducted when the relative value of sheep to wool was considerably lower than in more recent times and likely impacted their conclusions. In addition, the benefits of pregnancy scanning were reported to be smaller for low fecundity flocks (Bowman *et al.* 1989) and for flocks lambing when feed is more plentiful (Bowman *et al.* 1989, Holmes and Sackett 2008). Holmes and Sackett (2008) went further, by concluding that "it was more profitable not to scan but ensure adequate nutrition for ewes in late pregnancy, managing them as if the whole flock were bearing a single lamb and were to lamb in the first cycle of lambing, rather than scanning and managing according to pregnancy status". Since that time, there have been measurable increases in litter size for ram breeding flocks actively selecting for higher reproductive output, which has flowed into commercial flocks (e.g. scanning % >150%). More recently, McGrath *et al.* (2016) reported a reduction in gross margin of $0.45/ewe from differential nutrition associated with scanning for a spring lambing flock with a relatively low scanning percentage of 124%.

With the existence of conflicting results from the available economic studies and the accompanying recommendations against scanning, it is therefore not surprising that industry adoption of pregnancy scanning in Australia has not been universal. In a final report to the Sheep CRC, Refshauge and Shands (2014) stated, in regard to pregnancy scanning "***What the sheep industry requires is a set of conditions that need to be met before a positive return on investment can be achieved, for a wide range of environments and business structures (i.e. location, dam breed, proportion of wethers and proportion of crossbreeding).***"

Although the study of Young *et al.* (2016) has satisfied part of that brief, the project team believe that the preparation of a comprehensive business case, including additional economic analysis across a range of environments (and seasons, management systems, flock sizes, prices for sheep, lambs and wool), will greatly assist in the uptake of pregnancy scanning by a larger number of sheep producers and convince more producers of the merits of scanning for litter size than just pregnancy status. The project team has based its views mainly on the answers by respondents to the Howard and Beattie (2018) survey, with the most common reason sheep producers gave for not pregnancy scanning were that they could 'see no benefit' (31% of respondents). Other common responses were that there was a lack of 'time / labour availability' (17%) and the technology was 'impractical in current system' (16%), which also suggest that respondents providing those answers were not convinced of the business case for pregnancy scanning their ewe flocks.

2. Objectives

As outlined in the contract – '*By the 31st of August 2022, the participant will:*

a. *Have conducted the following activities with the aim of increasing adoption of pregnancy scanning by 10% (by 2032):*
    a. *Conducted an extensive benefit cost analysis on the value of scanning across a range of sheep producing regions and enterprise types.*

    Response - This objective has been successfully met. A further request to extend the analysis to areas in NSW that experience different rainfall patterns than the winter rainfall areas of southern Australia has also now been met (see separate report by David Brown and John Young, Appendix 8.2).

    b. *Developed a detailed business case for pregnancy scanning, including information suitable for inclusion in MLA and AWI extension packages tailored to different production environments, producer skill levels and resource availability (e.g. livestock identification systems and labour availability).*

    Response - This objective has been successfully met.

    c. *Conducted a series of case studies and surveys to create a better understanding of barrier to adoption of pregnancy scanning and develop solutions to overcome these barriers.*

    Response - This objective has not been achieved as originally intended, partly due to funders not encouraging more surveys of sheep producers. Instead, reliance was placed on existing survey results (e.g. Howard and Beattie, 2018) and information from the pregnancy scanner survey and post workshop feedback and individual feedback from sheep producers and consultants.

b. *Have designed and implemented strategies to improve the skills base of pregnancy scanners and encouraged the trialling and adoption of innovations in scanning technology by:*
    a. *Creating a scanning image library (videos of real-time assessments) using 3 experienced pregnancy scanners and a human sonographer / radiologist as a tool for benchmarking.*

    Response - This objective has been achieved. Links to the library have been distributed to 166 Australian pregnancy scanners and to project funders and is listed as an associated resource (see Section 8.4).

b. *Created a series of training materials and information resources for pregnancy scanners, including content covering:*
    i. *Images and anatomical references to identify single and multiple pregnancies at different stages of the gestation*
    ii. *Ovine reproduction physiology*
    iii. *Fetal losses and causes of loss*

Response - This objective has been achieved. (See listed in Section 8.4).

c. *Conducted workshops for scanners, including use of benchmarking material, as part of a regular (bi-annual) conference'.*

Response - Due to the Covid-19 pandemic, no face-to-face workshops with scanners were feasible during the period from late 2020 to the end of 2021. Instead, an on-line workshop was conducted in early July 2021, following a survey of scanning contractors, details of which are incorporated later in this report. A second workshop for pregnancy scanner contractors, also on-line, was held on the 27th of July 2022. Recordings of both scanner workshops have been posted on U-Tube (See list of associated resources, Section 8.4).

3. Methodology

The methodology is described under each project output or groups of like outputs.

3.1 Study of pregnancy scanning accuracy

Records available in the Sheep Genetics (SG) database were used to investigate accuracy of scanning and more specifically, the level of agreement between scanning results and the number of lambs born that were observed at lambing time. Generally, data for individually identified lambs are submitted by ram breeders, with no specific requirement for pedigree or the recording of dead lambs. Additional data are therefore required to obtain correct reproductive phenotypes for ewes. At a minimum, this information includes the identification of dry (DRY) ewes recorded with no lambs and ewes which had lambs which died at birth or were not reared.

More recently, DRY ewes have also been identified by pregnancy scan results for maternal breed ewes, but the majority of lambs in that analysis were identified for birth type by observation at lambing (Bunter *et al.* 2019). For Merino breeders in particular, pregnancy scan results may become the primary source of identifying both conception and litter size (including the corresponding birth type attributed to recorded lambs).

The records used in this study were ewe phenotypes constructed for the reproductive traits referred to as conception (CON), litter size (LS) and the proportion of lambs born which survived (ERA). Only ewes which have conceived can have records for LS and ERA. The procedures to construct these phenotypes are described in detail elsewhere (Bunter *et al.* 2019), with some modification for Merino flocks. Pertinent to this study are the following features:

1. Each flock-year was assessed for the proportion of lambs with dams known and the consistency between the number of lambs recorded vs the birth type that was assigned to the litter. As the percentage of lambs without a known dam increases, we would expect greater error in the litter size assigned to dams reported, so lower limits for known dam pedigree are applied (>70% dams known required). Similarly, >80% of ewes with lambs recorded must have mean lamb birth type of lambs matching the count of lambs identified.
2. Each flock-year was assessed for mean litter size. Flock-years where all ewes had litter sizes of 1 were excluded, as this is a known recording error due to the use of 1 as a default value.
3. The pregnancy scan data are known to be either a count of fetuses or a WET/DRY scan only. WET/DRY scans cannot be used to establish litter sizes above 1, and are therefore only useful for identifying CON, whereas scan count can be used to assign both CON and LS. Some data submissions contain WET/DRY records within mobs of ewes scanned for multiples. This happens when the fetal age spread is large (i.e. older fetuses are present) and large fetal size constrains the determination of litter size.
4. The date at which joining commenced is either reported directly by breeders (joining starting date) or is inferred from lambing dates. Where both were provided, the consistency was checked.
5. The length of the joining period is reported directly by a smaller subset of breeders (start and end of joining dates) along with information on whether the joining was natural or by artificial insemination.
6. The scan data is submitted separately to the lambing data, but may previously have been used to assign lamb birth type (BT) by the breeder or data service provider (with or without subsequent correction). Perfect concordance of scan and BT for a large group of ewes identifies this problem.

The consistency of scanning to predict conception was evaluated using both scan wet-dry values as well as scan count. The consistency of scanning to predict lambs born was assessed using only scan count>0.

3.2 Regional workshops with pregnancy scanning contractors and pilot benchmarking study

The COVID-19 pandemic and associated restrictions on border movements and gatherings imposed by states over the last two years dramatically increased the risk of planning and hosting face-to-face events in 2020 and 2021. The project team therefore shifted focus to planning an online workshop, held on the 7th of July, 2021, to gather pregnancy scanners from across Australia. The workshop aimed to provide current and the latest information on aspects of pregnancy scanning and provide an opportunity to discuss issues of interest directly with pregnancy scanning contractors.

A list of pregnancy scanners was created using historical scanner contact lists (Sheep CRC online list), as well as existing lists shared from South Australia (c/o Dr Dave Kleemann of the South Australian Research and Development Institute), Western Australia (c/o Rebecca Butcher of the Department of Primary Industry and Regional Development), Victoria (c/o Kirstie Anderson of Agriculture Victoria), google, white pages and Facebook posts and Department of Regional NSW - Primary Industries' lists.

A total of 156 pregnancy scanners were identified at that time using these available lists and search engine results. Note that a demographic survey was conducted of pregnancy scanners in late 2020 and early 2021 and results collated prior to the conduct of the first workshop held on the 7th of July 2021.

It was noted that many pregnancy scanners do not use internet-based media, as only 53 scanners were detected via this means. Invitations were sent to all contacts via email and SMS, with a reminder message sent prior to the event.

The intention of the first workshop was to create awareness about the L.LSM.0021 project, but also to provide up-to-date information on matters important to pregnancy scanners, such as fetal imagery, pregnancy scanning rate database research, new data-collection technology, RFID technology systems to capture pregnancy scanning data real-time with Oviscan 6 machines. Other important topics included research into the accuracy of pregnancy scanning and the results of the pregnancy scanner demographics survey. At the time of the workshop, the results of the comprehensive economic analysis on the benefit costs of scanning were not available to share.

At the conclusion of the workshop presentations, the scanners were invited into break-out discussion groups to meet and greet with scanners from across Australia, as well as to discuss the issue of scanning adoption – how to get more producers scanning. The online workshop was recorded and posted to the YouTube website. Pregnancy scanner contact emails and SMS were utilised to distribute the link.

A second workshop for pregnancy scanner contractors, also on-line, was held on the 27th of July, 2022. The intention of the second workshop was to create further awareness of the outputs of the L.LSM.0021 project and to provide up-to-date information of importance to pregnancy scanners. This included the results of the comprehensive economic analysis of scanning benefits not available at the first scanner workshop, the business case for scanning, the creation and availability of a library of fetal imagery and the results of investigations into fetal losses in young sheep, including the detection of any abortion-causing diseases.

3.2.1 Pilot benchmark study

As a result of state border restrictions during 2020 and 2021 (due to the Covid-19 pandemic) especially affecting travel to and from the state of Victoria, flocks benchmarked were restricted to two states, New South Wales and South Australia.

Flocks on 3 properties were double-scanned and detailed lambing results obtained. Results from this work contributed to the overall assessment of the level of accuracy of scanning, especially for twins and multiples and the level of agreement between scanning rates and lambing rates, in addition to the study comparing scanning and lambing rates of MerinoSelect client flocks (described in this report). Video imagery of scanning was also collected at Eurongilly (see Property 2 below).

1. Cowra Ag. Research & Advisory Station (NSW DPI), COWRA, NSW, 2794

A total of 573 Merino ewes, mated to Merino rams were used in the study. Mating commenced 17 Jan, 2020 and lasted for 5 weeks. The first pregnancy scan was performed Day 39 after Rams Out or Day 74 after Rams In. A second scan was performed 24 days later (Day 63 after Rams Out or Day 98 after Rams In). Detailed lambing and pedigree records were collected at lambing time.

A general linear model (GLM) was fitted to the scan data. Agree1=scan1 data; agree2=scan2 data. Concordance (0/1) = ewe age class + lambing mob group + early/late (lambing mob group). Ewe age class was not significant and was removed from the model.

The cost of scanning and collection of lambing records was paid for by NSW DPI as an in-kind contribution.

2. Avondale, EURONGILLY, NSW, 2663

A total of 787 ewes (Karrawarra stud, based on the Focus Genetics bloodline from New Zealand – a maternal composite breed) were used in the study.

Ewes were mated from 28 February to 10 April, 2020 (42 day joining) and scanned for the first time on May 6, 2020 (68 days after Rams In date) and then scanned a second time on May 29, 2020 (91 days after Rams In date). Detailed lambing and pedigree records were collected from a paddock lambing. During the peak of lambing, so many lambs were born at the same time that some live lambs were not tagged and weighed at birth and a number of dead lambs were not recorded and associated with their dams. DNA sampling at lamb marking revealed the maternal pedigree for the lambs that were alive at marking, but DNA was not collected from the dead lambs, so some records are incomplete.

The property owners paid for the cost of the first pregnancy scan, with the L.LSM.0021 project paying for the cost of the second pregnancy scan, plus a contribution for extra labour at lambing time to record lambs born and pedigree information. Pregnancy scanning was undertaken by a professional contractor (Joe Scott, Coolac, NSW) using an Oviscan 6.

Statistical analysis was performed using R (R Core Team, 2020). Spearman Rho was used to test correlations between the fetal number identified at each pregnancy scan (Scan 1; Scan 2) and with the number of lambs born (NLB). Lin's concordance correlation coefficients (Lin's CCC) were calculated for the differences between each variable. For the correlation of Scan 1 and Scan2, Scan2 was assumed to be the "Gold standard" variable. For correlations with NLB, the gold standard was assumed to be NLB. To support the Lin's concordance analysis, Bland-Altmann charts were produced, with fitted trendlines and a coefficient of determination provided, using MS Excel. A Chi-square test was used to determine the proportions of errors due to fetal age because the first date of scanning included some very young fetuses, according to approximate gestational age.

3. 'Mernowie', MARRABEL, SA, 5413

This flock was of particular interest as the property has an intensive lambing system it uses for lambing down ewes in its AI program, so the lambing records, which are collected under pen conditions close to or at the time of birth are expected to be more accurate that those from paddock lambings.

Merino ewes (the last of 4 batches) were mated by artificial insemination on 16 January 2021 and were pregnancy-scanned for the first time on 22 March 2021 (Day 65 of pregnancy). Ewes scanned as pregnant (139) were pregnancy-scanned for a second time on 12 April 2021 (Day 86 of pregnancy). Ewes lambed in a shed, with detailed records of lambs born collected (date of birth, survival status at birth and days 3-5, litter size, birth weight, sex, cause of death).

The property owners paid for the cost of the first pregnancy scanning and the entire cost of recording at lambing time. The L.LSM.0021 project paid for the second pregnancy scanning.

3.3 Economic analysis of pregnancy scanning

The economic analysis described below is a comprehensive expansion of earlier work by Young et al. (2016). It examined the benefits and costs of scanning across a range of sheep production systems and different sheep regions in Australia. It also considered the impact of different sheep breeds and different levels of fecundity.

To complete this milestone required:

- Development of the conceptual model of all the components that contribute value when a flock is scanned. This involved brain storming within the project team, a literature search for previous analyses carried out and a theoretical assessment of the management changes possible when scanning.
- Improving the analysis framework to handle the extra detail required to value these components that had to date not been valued. This was done in conjunction with developing The Australian Farm Optimisation model (AFO) which is a major upgrade on MIDAS and will replace MIDAS as the main bioeconomic model used in Australia.
- Collating the relationships to be included in the modelling that predict production of the ewes and the progeny when following different nutrition profiles or being managed differently. The 2 main sources of data are the relationships developed in the Lifetime Wool Project and the relationships used in the GrazPlan suite of models.
- Carrying out the analysis and reporting.

To calculate the profitability of pregnancy scanning requires accounting for each of the benefits identified above together with the costs of pregnancy scanning. The complexity of the calculations required to represent the production impacts of pregnancy scanning suggest that a modelling framework is required and The Australian Farm Optimisation model was used for the winter growing season regions of southern Australia. However, a similar model does not exist for the summer rainfall regions and a gross margin analysis was carried out to represent the summer rainfall region.

The winter rainfall analysis was carried out with 3 regional versions of the Australian Farm Optimisation model (AFO). The AFO model calculates the profitability of the whole flock based on the productivity of each class of stock, commodity prices and the farm carrying capacity calculated in the detailed feed budget. As an optimizing model it calculates the optimum stocking rate, nutrition profile, pasture grazing intensity and rate of grain feeding that will maximize profitability and optimise productivity of the animals in the flock. The model accounts for changes in flock structure and the change in ewe energy requirements that result from increasing lamb survival or altering the number of ewes pregnant or lactating with singles or twins.

The capacity to optimise the feed allocation and optimise the nutrition profile for empty, single and twin bearing ewes was useful for this analysis, because a major driver of the profitability of pregnancy scanning is the differential management of the nutrition of the ewes based on pregnancy status and litter size.

The summer rainfall analysis was carried out using a gross margin approach. The important production drivers identified in the winter rainfall analysis were incorporated in the gross margin. It was necessary to estimate the impact of the alternative management on the amount of grain feeding required and the stocking rate of the ewes with different pregnancy outcomes. These assumptions were informed by a survey of producers in the region that were already pregnancy scanning their flocks.

Three genotype systems were examined in the analysis:

1. 'Merino-Merino' - Merino ewes mated to Merino rams. The production system is a self-replacing flock comprising a medium wool genotype. Surplus young ewes and all wethers are sold off shears after the hogget shearing at approximately 18 months of age. Young ewes are first mated to lamb at 2 years of age. Old ewes (culled for age) are sold off shears at 5.5 or 6.5 years of age (whichever is most profitable).
2. 'Merino-terminal' – A self-replacing flock based on the same ewe genotype as the 'Merino' flock. Ewes surplus to requirements for replacing the pure-bred Merino flock (culled for age at 5.5 yo or surplus young ewes) are mated to terminal sires to produce first cross prime lambs. Old ewes (culled for age) are sold off shears at 6.5 years of age.
3. 'Maternal' – a self-replacing flock based on a maternal composite genotype. Surplus young ewes and wethers are sold as lambs and young ewes that are retained are mated at between 7 and 8.5 months of age (depending on time of lambing). Old ewes (culled for age) are sold off shears at 5.5 or 6.5 years of age (whichever is most profitable).

Three times of lambing were examined in each of the 4 regions, although in the gross margin not all lambing times were investigated for all the flocks.

The regions included in the analysis were:

1. Winter rainfall South west Victoria. A 600 – 650 mm winter rainfall zone in the Hamilton region in SW Victoria with a 9-month growing season, with 100% pasture enterprises. The times of lambing evaluated in this region were 15-Apr, 1-Jun and 5-Aug.
2. Winter rainfall Great Southern in WA. A 500 - 600 mm winter rainfall zone in the Darkan region in WA with a 6-month growing season, typically 40-50% of the farm in crop. The times of lambing evaluated in this region were 15-May, 18-Jun and 23-Jul.

3. Winter rainfall Cereal Sheep zone. A 367 mm winter rainfall zone in the Cunderdin region in Western Australia with a 4.5 month growing season, typically 70-80% of the farm in crop. The times of lambing evaluated in this region were 15-May, 18-Jun and 23-Jul.
4. Summer rainfall Northern Tablelands. A region that is dominated by Merino fine wool production. The times of lambing evaluated in this region were 1-Aug, 1-Sep and 20-Sep which represents the spread in the producers that were surveyed.

These regions were selected based on there being existing models that cover a range of the growing season conditions of southern Australia and a typical summer rainfall region with which to compare the detailed winter rainfall modelling analysis.

3.3.1 Production assumptions

Where possible the assumptions made in the modelling analysis and the gross margin analysis were aligned, however, this was not always possible because of limitations in the gross margin framework. The important production assumptions to calculate the profitability of pregnancy scanning include the following and where there are differences it is mentioned:

1. The detailed modelling analysis was adjusted to align with the findings of another part of this project which demonstrated the agreement between scanning and the lambing outcome was approximately 85% (see Section 4.1). The adjustment for the gross margin analysis was the average reduction in the value of scanning ($/ewe) estimated in the detailed modelling.
2. Feed budgeting. For the detailed modelling this has been done using the equations from the Australian Feeding Standards (Freer *et al.* 2007 and as updated in Freer *et al.* 2012). For the gross margin analysis the feed budget is based on varying the DSE/hd for the different animal classes based on the estimated energy requirement of the ewes during the feed limiting period of the year.
3. Relationship describing lamb mortality and the connection with level of ewe nutrition and the chill index at lambing. The source of these relationships was the LifetimeWool project (Oldham *et al.* 2011) and the GrazPlan suite of models (Freer *et al.* 2012).
4. Ewe and lamb mortality due to dystocia. The source of these relationships was the GrazPlan suite of models (Freer *et al.* 2012). This was not included in the gross margin analysis.
5. Impact of nutrition on the fleece production of the ewes. This was based on the wool production relationships from the GrazPlan suite of models but only including the impact of energy intake and not including protein. Not included in the gross margin analysis.
6. Impact of BTRT (birth type/rearing type) and dam nutrition on the lifetime productivity of the progeny. The source of these relationships was the LifetimeWool (LTW) project (Thompson *et al.* 2011).
7. Peri-natal ewe mortality. Ewe mortality around the time of birth was estimated in the LTW project from CS of the ewe at the point of lambing and this has been used in this analysis. The GrazPlan models estimate mortality of twin bearing ewes from pregnancy toxaemia in the last 6 weeks of gestation from maternal live weight (LW) loss over this period and these relationships have been used in this analysis.
8. Weaning weight and weaner mortality. The weaner survival relationships used in AFO is a combination of the relationships derived by Campbell (2006) and those used in GrazPlan. This was not included in the gross margin analysis.

9. Response in subsequent flock reproductive rate from culling once or twice-empty ewes. The values used in the analysis were derived from the ‘Passenger vs performers’ research project (Hatcher *et al.* 2018) which had analysed Merino research flocks.
10. Paddock allocation at lambing. The effect of altering paddock allocation was based on calculations using the lamb survival equations in the GrazPlan models that include relationships for both ‘wool’ and ‘meat’ sheep and the effect of altering chill, and the mob size research of Lockwood *et al.* (2020).

3.3.2 Costs & Prices

The cost of scanning includes both the cost of the contractor and the labour cost associated with pushing the ewes through the scanning crate and the mustering that is required per mob. The contract cost for scanning was based on the current charge rate of a large industry contractor (Cousins Merino Services) being \$0.50/ewe if scanning for pregnancy status and \$0.75/ewe if scanning for multiples, both plus approximately \$0.02/ewe for travel. The cost of labour for mustering, yard work and R&M to infrastructure - if all labour is provided by casual labour - varies between \$0.31/ewe if scanning for pregnancy status, up to \$0.40/ewe if scanning for multiples.

Seven price scenarios were examined based on the percentiles of the output prices received over the period 2004 to 2020. The values varied were the 21µ MPG, the premium for fine wool (based on the price of other fibre diameters relative to 21µ), meat prices and grain prices. The scenarios were: wool prices 50^{th}, 70^{th} and 80^{th} percentile, Meat 50^{th}, 70^{th} and 90^{th} percentile and Grain 20^{th}, 50^{th} and 80^{th} percentiles.

The standard prices used in the reported results are the 70^{th} percentile prices for meat and wool, and the 50^{th} percentile prices for grain over the period 2004 to 2020. The higher percentile used for meat and wool is a reflection that those prices having been trending up over the period.

3.4 Business case for pregnancy scanning & precision management of lambing groups

The creation of a detailed business case for pregnancy scanning drew on the experiences of livestock consultants and their producer clients who have adopted the technology. It also drew on the results of the economic analysis and addressed aspects of the key reasons given by sheep producers who have not adopted pregnancy scanning technology.

The writing of business case documents on pregnancy scanning evolved considerably, to the extent that three separate sets of documents have been created. These are:

- Initial fact sheets drafted by Hamish Dickson (described below as *'3.4.1 Initial fact sheets on the business case for pregnancy scanning'*).
- A more detailed set of fact sheets drafted by Sue Hatcher (described below as *'3.4.2 Detailed set of fact sheets on the business case for pregnancy scanning'*).
- A single document drafted by Anne Collins (described below as *'3.4.3 Pregnancy Scanning Sheep – A guide for producers'*).

3.4.1 Initial fact sheets on the business case for pregnancy scanning

The business case for pregnancy scanning was completed to build on the comprehensive economic analysis work. These business case documents, drafted by Hamish Dickson, demonstrate scenarios where pregnancy scanning can be utilised, as well as key opportunities and challenges associated with its implementation.

Prior to development, a draft plan of the intended business case was written and circulated to the project leader and to Meat and Livestock Australia and Australian Wool Innovation for comment.

Four scenarios were initially developed to provide a range of sheep enterprises and levels of utilisation of pregnancy scanning. The four scenarios were:

1. Self-replacing Merino flock using pregnancy scanning for pregnancy status only (i.e. wet/dry)
2. Maternal composite flock using pregnancy scanning for litter size
3. Dual purpose type Merino flock using pregnancy scanning for litter size and fetal age
4. A non-specific sheep enterprise broadly using pregnancy scanning. This scenario was designed to be a general scenario that reviewed the broad use of pregnancy scanning and the peripheral benefits such as allowing lamb survival rates to be calculated

The above scenarios aligned closely with the enterprises used in the economic analysis work in Milestone 4, so that relevant cost benefit figures could be incorporated into the business case documents.

Following feedback from the L.LSM.0021 project team, as well as MLA and AWI staff, the number of scenarios were reduced to three, as follows:

1. A flock using pregnancy scanning for pregnancy status only (i.e. pregnant/empty). This could apply to either Merino, Merino-cross or non-Merino sheep enterprises.
2. A flock using pregnancy scanning for litter size. This could apply to either Merino, Merino-cross or non-Merino sheep enterprises.

3. A non-specific sheep enterprise broadly using pregnancy scanning. This scenario was designed to be a general scenario that reviewed the broad use of pregnancy scanning and the peripheral benefits such as allowing lamb survival rates to be calculated

Each business case document was written to provide a structure that producers could easily utilise and understand how pregnancy scanning could be incorporated into their business. Each business case includes background to the scenario, how pregnancy scanning would be conducted, how the pregnancy scanning data could be utilised in the business, cost benefit information and key considerations for implementing pregnancy scanning for the first time. These documents highlighted benefits that could gained through pregnancy scanning as well as challenges that should be considered prior to implementing pregnancy scanning.

3.4.2 Detailed set of fact sheets on the business case for pregnancy scanning

Following further feedback, it was decided to develop more detailed fact sheets, which could cater for the livestock consultant audience, as well as sheep producers.

There are two documents, one on scanning for pregnancy status only and the other on scanning for multiples (pregnancy status as well as litter size). These documents are considerably longer than the initial fact sheets described above. The structure of the documents includes a general section, then short sections on production systems in each of three rainfall zones, high (>600 mm), medium (500-600 mm) and low (<400 mm).

3.4.3 Pregnancy Scanning Sheep – A guide for producers

Following further discussion with MLA (and indirectly, AWI), it was decided to produce a further single document, similar in style and length to one recently produced for MLA and available from MLA's website ('*Managing breeding ewes in containment areas – A guide for producers*', written by Susan Robertson of Charles Sturt University).

3.5 Conduct producer workshops, producer group & livestock consultant extension activities

Where possible, the project aimed to provide talks, webinars and updates at events already organised by other parties, rather than create specific events. A total of 10 talks at producer workshops, 3 webinars and 2 presentations at consultant/advisor updates were targeted.

Covid-19 pandemic restrictions to interstate travel and the holding of large gatherings caused difficulty for industry and the project team alike in participating in producer workshops and field days, particularly in the first half of 2020 and again during the second half of 2021. Most face-to-face extension activity has therefore taken place in the first half of 2022, following the lifting of state border restrictions and limits on the size of gatherings.

In early 2022, the project team, together with MLA and AWI, developed a listing of planned industry events, webinars and update meetings with consultants/advisors. In all except one case, these industry events had already been planned/organised by others, with the project team negotiating with event organisers to become part of the program.

In terms of extension activities with producer groups, the following were undertaken:

- Barossa Improved Grazing Group (BIGG). An honours project was conducted during 2021 at Keyneton Station, Keyneton, SA. Results of this work was presented at a Focus Farm Field Day run at Keyneton Station on the 10th of June 2022.
- McKillop Farm Management Group (MFMG). Despite discussions since May 2020, it was not until early 2022 that an extension activity was successfully planned with MFMG. This was in the form of a workshop on Improving Sheep Reproduction and Lamb Survival for MFMG members, held on the 13th of April, 2022, featuring information generated by the L.LSM.0021 project. This workshop was used to help instigate a discussion group on improved sheep reproduction. Attendees were also encouraged to consider undertaking modules in the new Towards 90 Project, funded by MLA.
- MerinoLink (NSW). A successful PDS application (*L.PDS.2106* '*Pregnancy scanning in extensive sheep flocks'*) by MerinoLink & Sue Hatcher, based on a design similar to one discussed at a project meeting in Sept 2019, allowed for a more substantial study than feasible with funds from the L.LSM.0021 project alone. Work commenced in August 2021, aimed at increasing the net reproduction rate of sheep flocks in Western NSW & the Riverina. Four core producers each run a trial mob alongside a comparison mob, measured for key reproduction traits. There are also 7 sheep producers who observe the study. The trial includes condition scoring, pregnancy scanning for multiples, lambing single-bearing and twin-bearing ewes separately, wet and dry and key fitness indicator assessments of ewes.

3.6 Package of information for extension networks – workshops like 'Lifting Lamb Survival', Profitable Grazing Systems and 'Lifetime Ewe Management'

The first step chosen was to create a list of key extension messages from the project. This list was developed by the project team, in collaboration with MLA and AWI in early 2022 and was the basis of the material used in slides presented and points made during presentations, as outlined in Section 3.5 above.

In addition to the documents written on the business case for pregnancy scanning (listed as associated resources, see section 8.4), slides used in Powerpoint presentations have been curated into a collection for use by extension networks.

4. Results

4.1 Study on pregnancy scanning accuracy

Many Merino breeders report only lambs surviving at marking or weaning; therefore, there is no independent and accurate confirmation of true birth type for these lambs. This contributes to the perception of Merino producers that the mean scanning results are not reflected in the observed lambing percentage. This also means that, by definition, these flocks cannot be used to establish the relative accuracy of scanning for conception or lambs born.

The proportion of ewes with both scan and lamb records is <100% of ewes present for most flock-years. This highlights some limitations introduced by incomplete observation of all ewes at lambing (some due to ewe death) or at scanning (missed ewes), along with data entry errors and/or incomplete roll-calls. In most species, the time-period of most deaths for reproductive females typically coincides with parturition or immediately preceding or after parturition. Ewe death due to bearing multiples or large singles may also create bias in data reported.

Of the annual reproductive data available (N=568,024, April 27 2020), fewer ewes had data available regarding joining and scanning (N=338,807). In combination, there were many fewer ewes with both reproductive and pregnancy scanning data, recorded following a known joining interval allowed to be between 9-91 days (Table 1). The bulk of ewes retained in this subset of data were joined for close to either 35 or 65 days. Average conception based on scanning data (CON_scan) was identical to conception rate reported (CON) (Table 1), as most information on conception came from scanning records. However, mean litter sizes differed for litter size based on scanning (LS_scan) and LS based on lamb count, reflecting a combination of mothering up and scanning differences. Not all ewes had data retained for CON as data for producing breeding values are also filtered for contemporary group related errors. Nevertheless, the data available for investigation is substantial.

Table 1. Characteristics of the data (adult ewes only)

	N	mean	SD	min	max	5%	50%	95%
Joining interval	68360	40.0	9.37	9	91	28	39	60
CON_scan	68360	0.97	0.17	0	1			
CON	42978	0.97	0.17	0	1			
LS_scan	66433	1.49	0.52	1	4			
LS	66936	1.42	0.52	1	4			
ERA	38946	0.83	0.33	0	1			
Scan count	68360	1.45	0.57	0	4			
In to scan*	68360	83.7	14.0	18	182	63	84	104
Out to scan*	61111	46.1	15.0	-15	138	28	45	71
Scan to lamb*	68360	79.1	16.1	2	169	58	77	106

*Intervals between the start or end of joining dates and the scanning date are referred to as 'In to scan' and 'Out to scan', while the interval between scanning and lambing dates is 'Scan to lamb'

With respect to timing of scanning, the mean interval from the commencement of joining (ram in date) to scanning was 84 days, but the range was large (18-182 days). Where ram out dates were available, the average interval was 46 days after the removal of rams. In some cases, ewes were scanned before rams were completely removed from joining (eg -15 days, Table 1), demonstrating that some ewes remain with rams post-scanning. The 5%, 50% and 95% quantile values are provided to show the predominant ranges for intervals (in days).

All values indicate that a percentage of ewes have been scanned outside the optimal timing (based on fetal age) for scanning. From previous research (eg Fowler and Wilkins, 1984) the general consensus is that conception and litter size are most accurately determined for an individual when the fetal age at scanning is between 35-42 and 110 days (Fowler, 2014), with some leeway related to scanning procedures. However, references for producers regarding timing of scanning typically refer to the mean interval between the ram in date and scan date only (eg scan 60-90 days after ram removal, or 80-100 days after the ram in date) and assume a joining interval of five weeks, resulting in some uncertainty regarding the minimum and maximum fetal ages which may occur due to the joining interval. More predictably, this fetal age range corresponds to a scanning date which occurs ≥ 35-42 days after rams are removed, combined with a joining interval of 58 days (or less) for ALL ewes to be within the target window at a single scanning event. Ram removal dates were less complete, and therefore the joining interval or minimum fetal age at scanning were not known for these ewes. The alternative is to use the interval from scanning to lambing to calculate fetal age at scanning, which shows that fetal age was more likely to be too high for accurate assessment of litter size for a proportion of ewes in this data.

4.1.1 Subgrouping

Data from adult ewes only (i.e. yearlings/hoggets excluded) were firstly summarised by site-year and used to estimate the regressions of mean litter size on mean scan count (when mean scan>0) and to investigate the average accuracy of scanning for conception. Data for mean litter size were limited to the range 1.1≤LS_scan≤1.85 to eliminate flock-year outliers.

Subgroups formed were:

1. The complete data (All flock-years)
2. Excluding ewes known to be artificially inseminated (No AI)
3. Joining interval was reported to be ≤42 days (Join≤42 days)
4. Where all ewes are within the target fetal age range (Optimal_age) or the interval from scanning to lambing corresponded to a fetal age between 42 and 100 days (Scan50-118)
5. Retain only data where the difference between flock-year means for LS – LS_scan was > -0.2. This data exclusion was based on the knowledge that flocks that do not observe lambs at birth report fewer lambs.
6. Only flock-year data from breeders who are ‘known’ to mother up

The percentages of ewes with concordant records were estimated for subgroups 1-4 above. Regressions of litter size on scanned litter size were subsequently estimated within each subgroup using flock-years where mean scanned litter size was ≤1.5 vs >1.5. Flock-years (N=12/162 flock-years) with a perfect match between LS and LS_scan were excluded from these regressions, as perfect concordance for litter size in large groups identifies breeders who use scan data to define lamb birth types, without observation of lambing outcomes. These data are therefore not independent observations and cannot be used to estimate regressions.

4.1.2 Percent concordance for individual records

The percentage of ewes with accurate scans for conception was above 98% in all data subsets, while the accuracy of assigning litter size correctly for individual ewes was approximately 86%, on average

(Table 2). Accuracy of scanning for conception before ram removal (<1% of scan records) reduced concordance to 93.3% for conception. The corresponding value for litter size was 69.3%. Reduced concordance supports the premise that accuracy of scanning is highest for individual ewes scanned at an appropriate stage of pregnancy (i.e. between 35-42 and 100 days of gestation). Therefore, the timing of a scanning event relative to the joining interval and ram out date is important to ensure all ewes within a flock-year are scanned within an appropriate gestational age range.

Assignment of litter size was more problematic for individual ewes than identifying conception and also more difficult to assess with respect to accuracy, because errors occur for both sources of information (scanning vs birth type assigned after lambing). In contrast to establishing litter size, lambed ewes can typically be identified to confirm conception, even if lambs cannot be found, providing observation of ewes is regular. Mean concordance for litter size increased to 88% (not tabulated) where lambing date could be used to confirm appropriate timing of scanning.

Table 2. Overall percentages of individual ewe records with perfect concordance for data subsets, excluding flock-years with perfect concordance

	N	CON_scan=CON	N	LS_scan=LS
All flock-years	42972	98.6%	66163	86.3
No AI	38008	98.6%	57634	87.0
Join<=42 days	33490	98.8%	57994	86.4
Optimum_age	26553	98.6%	49291	87.4

4.1.3 Concordance for flock-year means

Results for concordance of data sources by flock-year are shown in Table 3. Of the 162 flock-years available, only 43 did not have perfect concordance for conception outcomes and 149 did not have perfect concordance for litter size. This illustrates that scanning data was widely used to assign conception outcomes for ewes in the Merino reproductive analysis, and to a lesser extent litter size.

The median accuracy of scanning for conception was between 98-99%, but the worst 5% of flock-years in the complete data were below 80% concordance. It is unlikely that this result is due to scanner experience, even under adverse circumstances. A poor flock-year result may reflect different joining periods (i.e. the scan provided did not relate to the lambing outcome recorded – which can occur when breeders scan multiple times). When the data were restricted to flock-years for which the interval from scanning to lambing was between 50-118 days (Scan50-118: i.e. ewes were scanned from 42 to 100 days of gestation on average), the concordance for the worst 5% of flock-years was close to 90%. This again highlights the importance of optimising the timing of scanning. In more than 75% of flock-years, the accuracy of conception generally exceeded 95%, closer to 98% when timing was more accurate.

Results for litter size were more variable than for conception, but observed litter size can be plagued with significant error unless mothering up is performed with frequent lambing rounds. The median concordance for flock-years was approximately 86-87%, improving to 89.3% in the subset of flock-years identified with appropriate timing of scanning on average (based on scanning and lambing dates) and the exclusion of flock-years where the difference between lambs reported and scanned was larger than the average lamb losses expected between birth and weaning for singles. The latter exclusion identifies flocks where litter size is more likely to be identified by rear type rather than birth type. Breeders reporting rear type instead of birth type, due to lack of regular and accurate mothering up at lambing, is a known issue for Merino flocks. However, even with this exclusion litter size remained less accurate than conception for a significant proportion of flock-years.

Table 3. Quantiles for the average concordance between scanning and lambing outcomes reported, by flock-year (F-Y with perfect concordance for CON and LS excluded)

			Quantiles				
Data*	**N-FY***	**Trait**	**5%**	**25%**	**50%**	**75%**	**95%**
All	39	Conception	80.2%	95.7%	98.6%	99.4%	99.8%
	145	Litter size	62.3%	75.6%	86.5%	93.3%	97.5%
No AI	30	Conception	90.0%	97.0%	98.7%	99.5%	99.7%
	86	Litter size	60.9%	79.9%	88.0%	93.2%	97.8%
join<42/noAI	22	Conception	89.1%	97.0%	98.9%	99.5%	99.7%
	103	Litter size	60.3%	73.6%	86.8%	93.2%	97.3%
Target/noAI	21	Conception	82.3%	96.2%	98.8%	99.3%	99.7%
	95	Litter size	62.0%	74.7%	86.7%	92.9%	97.4%
Scan50-118	35	Conception	89.5%	98.2%	99.1%	99.5%	99.8%
	145	Litter size	62.3%	75.5%	86.5%	93.5%	97.5%
Scan50-118/noAI	26	Conception	95.7%	98.5%	99.1%	99.6%	99.8%
	135	Litter size	63.2%	77.9%	87.5%	93.6%	98.1%
Scan50-118/noAI	22	Conception	95.4%	98.4%	99.1%	99.5%	99.8%
+mean_diff>-0.2	113	Litter size	69.1%	82.9%	89.3%	94.7%	98.2%

*Subgroups as described above

4.1.4 Regressions of litter size on scanned litter size

Results above demonstrate that there are some significant discrepancies between scanning and lambing results for some flock-years, mostly observed with respect to litter size, which as noted above is also often reported with bias in Merinos. To further investigate scanning for litter size, regression coefficients were estimated using the averages of flock-years. Previous work has demonstrated that fewer lambs tend to be reported than scanned, although the reverse also can occur (e.g. Bunter *et al*. 2016). The pattern of discordance for litter size of individual ewes in this data is as shown below in Table 4. The primary source of discrepancy in Merinos was the reporting of singles born from twin-scanned ewes. This is in contrast to the historical observation by Fowler and Wilkins (1984) that the most common problem was failing to identify twins at scanning, which would result in more lambs reported than scanned. For flock-years with higher mean values, the percentages of triplets were typically under-reported, consistent with observations made by breeders with higher litter size. For ewes recorded with triplet lambs at birth, values for scanned litter size was almost equally assigned as values of 2 or 3, so 50% of triplet bearing ewes were scanned with a downwards bias.

Table 4. % concordance for litter size

		Scanned litter size			
		All records			
Reported litter size		1	2	3	4
	1	49.3	10.2	0.1	nr
	2	2.3	36.3	0.3	nr
	3	0.00	0.7	0.7	0.0
	4	nr	0.0	0.0	nr
		50 ≤ scan to lamb date ≤ 118			
Reported litter size		1	2	3	4
	1	49.1	10.1	0.1	nr
	2	2.3	36.6	0.3	nr
	3	0.00	0.7	0.7	0.0
	4	nr	0.0	0.0	nr
		Excluding perfect matches			
Reported litter size		1	2	3	4
	1	47.8	11.0	0.2	nr
	2	2.4	36.9	0.3	nr
	3	0.01	0.7	0.7	0.0
	4	nr	0.0	0.0	nr

nr: none reported

Regressions of litter size on scanned litter size are presented in Table 5. The expected regression coefficient for accurate scanning combined with accurate assignment of litter size from lambing is 1, and errors in either of these data sources will alter the value of this coefficient.

Table 5. Regression coefficients for litter size against scanned litter size, based on flock-year means

	N-flock-years	**N-ewes**	**LS all**	**scanLS≤1.5**	**scanLS>1.5**
All flock-Years	146	61337	0.87±0.06	0.80±0.10	0.67±0.18
No AI	138	52944	0.90±0.06	0.87±0.11	0.70±0.18
Exclude <-0.2	126	52743	0.99±0.05	0.97±0.09	0.98±0.18
Mother_up	17	7809	0.83±0.11	0.91±0.09	0.87±0.35
Join<=42 days	118	44762	0.81±0.08	0.67±0.16	0.52±0.22
No AI	105	39349	0.83±0.08	0.73±0.17	0.66±0.21
Exclude <-0.2	95	37000	0.96±0.07	0.98±0.11	0.75±0.21
Mother_up	16	6750	0.86±0.12	0.94±0.05	0.90±0.37
Optimum_age	146	58817	0.86±0.06	0.75±0.11	0.54±0.18
No AI	138	50882	0.90±0.06	0.85±0.11	0.66±0.18
Exclude <-0.2	123	49703	1.03±0.05	0.96±0.09	1.10±0.14
Mother_up	9	4490	0.88±0.10	0.93±0.09	1.14±0.32

All regressions were very high but generally <1, demonstrating that the number of lambs observed tended to be lower than the number of lambs scanned, on average (Table 1). However, when flock-years where large downward discrepancies between mean lamb and mean scan counts were excluded (Exclude<-0.2), all regression coefficients approached the expected value of 1. The threshold value of -0.20 was chosen because this value is above the average pre-weaning mortality expected for single born merinos. When mean litter size was >1.5, timing of scanning for individual ewes was optimal, and the data are filtered for a high probability of unreported lambs (Exclude <-0.2 or Mother_up) the underestimate of true litter size from inaccurate scanning for triplets becomes apparent as regression coefficients exceed 1.

Values for the difference between litter size reported and scanned at the 5%, 50% and 95% quantiles are shown in Table 6. The median difference averaged -0.05, and the 5% vs 95% quantiles demonstrate that fewer lambs were much more likely to be reported than more lambs (e.g. -0.277 vs 0.063) relative to scanned litter size. The distribution of values always improved with filters described above.

Table 6. Mean differences between lambs recorded and scans, excluding flock-years with perfect concordance

	Quantiles		
	5%	**50%**	**95%**
All flock_years	-0.277	-0.052	0.063
No AI	-0.283	-0.053	0.073
Exclude <-0.2	-0.172	-0.036	0.065
Mother_up	-0.142	-0.019	0.019
Join<42 days	-0.318	-0.058	0.120
No AI	-0.325	-0.048	0.108
Exclude <-0.2	-0.172	-0.036	0.126
Mother_up	-0.144	-0.018	0.025

The associations between flock-year means for scanned litter size (mean_sc), litter size reported (mean_ls), the difference between scanned litter size vs reported (mean_diff) and the proportion of matching records for litter size (mean_match) are shown in Figure 1. When the mean difference in litter size is <-0.2 lambs/litter, the mean match was below 0.8 and worsened with increasing litter size, regardless of whether that litter size was estimated from lambs or scans. High mean_ls was reported only as the difference observed between scan and lambs reduced, accompanied by the increased percentage of matching records. The pattern for mean_sc was similar to that for mean_ls, but of lower magnitude. Plots of residuals showed no distinct patterns (not shown) demonstrating that simple regressions were suitable for establishing the relationship between litter size reported and scanned litter size.

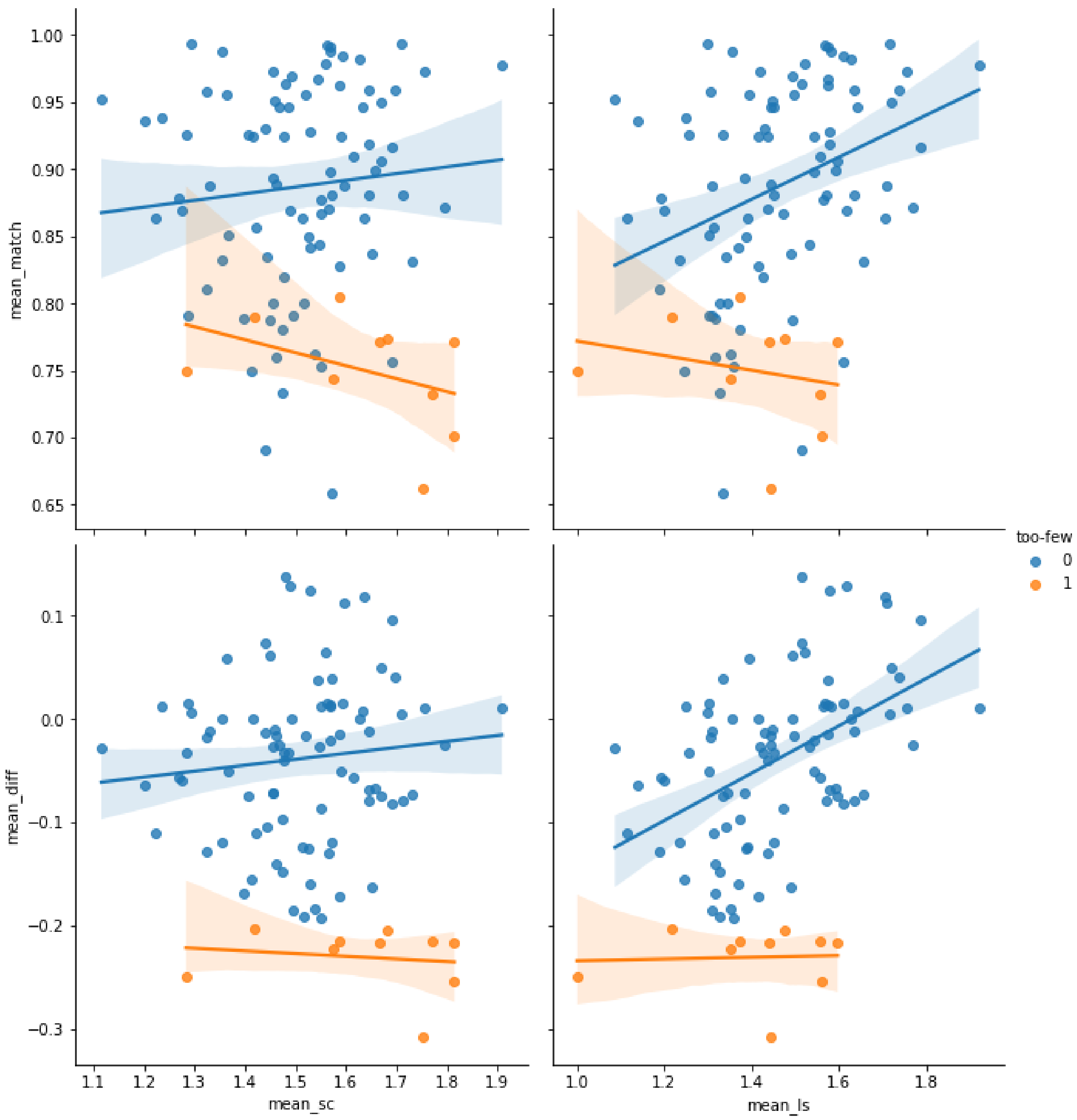

Figure 1. Associations between flock-year means for scanned litter size (mean_sc), litter size reported (mean_ls), the difference between litter size scanned vs reported (mean_diff) and the proportion of matching records for litter size (mean_match), discriminating between flock-years with a mean discrepancy of <-0.2lambs/litter (too-few=1) vs the rest (too-few=0).

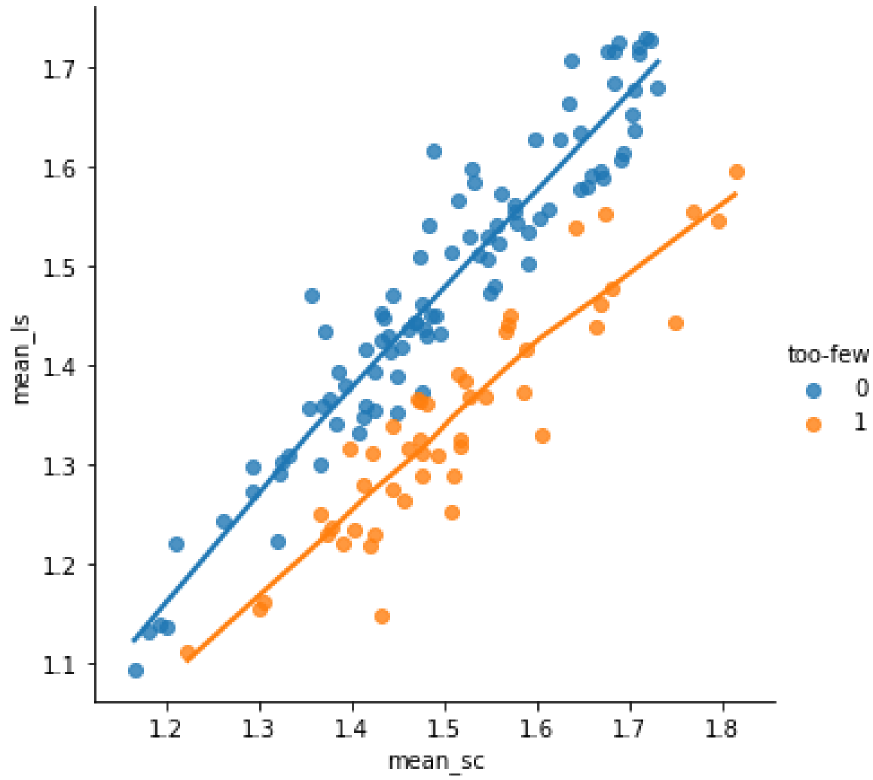

Figure 2. Regression of mean litter size on mean scanned litter size, discriminating between flock-years with ≤0.1 (blue) or > than 0.1 (orange) difference in means (b-values: 1.00±0.03 for blue, 0.80±0.05 for orange)

4.1.5 Discussion

When evaluating accuracy of individual records, the timing of scanning relative to the distribution of gestational age within a group of ewes is not considered. Therefore, examining flock-year means is more informative for how producers may observe results from this perspective, given that ewes are typically scanned as a group.

The overall distribution of singles, twins and triplets+ recorded in Merino data used for reproductive analyses in recent analyses was 64%, 34.5% and 1.5%, giving a mean litter size of 1.34 for adult ewes. This includes data derived from both mothering up and/or scanning. The mean percentage of lambs reared to weaning averaged 82% (N=170308), with survival rates of 85% for singles, 78% for twins and 60% for triplets. These are equivalent to 0.15, 0.56 and 1.2 lambs lost from each litter size. Producers who do not mother up immediately at lambing will observe therefore, on average, 18% fewer lambs by weaning (-0.3072 lambs, after accommodating proportions of ewes in each litter size class), assuming the above distribution of litter sizes and rearing rates. This may explain why many producers feel that the litter size scanned is not an accurate reflection of the litter size observed, unless they are carefully monitoring lamb losses and understand the true litter size distribution and lamb mortality rates for their flock. In the subset of data used to examine the accuracy of scanning in this study, the mean litter size reported was 5-11% higher than the industry average, which suggests a higher probability of scanning when litter size is higher.

These findings may be used to identify a threshold that identifies flock-years in the data where litter size (from scanning records) better reflects the count of surviving lambs, rather than lambs born. When flock-years where the difference between scan LS and LS was <-0.2 were excluded, the regression of LS observed on scan LS was close to the expected value of 1, regardless of mean litter size. This also supports the perception of inaccurate scanning for litter size is in part affected by failing to mother up close to lambing events, which is more relevant for larger litter sizes and very relevant for management practices in the Merino industry.

Removal of AI data tended to improve the concordance of conception and litter size traits. This may relate to the use of backup rams after AI, which introduces some uncertainty as to the alignment of scan records provided by breeders with the final lambing outcomes. The use of backup rams in AI programs may also lead to sub-optimal timing of scanning events for at least a proportion of ewes scanned. Artificial insemination also increases the ratio of ewes bearing multiples when compared to natural mating, for a given litter size (Loys *et al.* 2018).

Optimum timing of scanning itself created demonstrable improvements in the concordance for outcomes. However, ~25% of ewes were not scanned at the optimum time, based on lambing and scanning dates, assuming a target window for fetal age of 42-100 days. This is potentially because available descriptions for the correct timing of scanning can create some confusion. Lowering this percentage is expected to improve the average accuracy of scanning outcomes. This may be facilitated by providing a more robust tool which uses both ram in and out dates to determine the optimum time for scanning a group of ewes.

The proportions of adult ewes bearing singles, twins, triplets or higher order litter sizes can be predicted using mean litter size (Bodin and Elsen 1988). Below a flock average of 1.5 fetuses per ewe, the proportion of ewes bearing triplets is <2-3%; the proportion of twinning ewes peaks at a litter size of approximately 1.8, and the proportion of quadruplets remains negligible until means exceed 2 lambs/litter (Bodin and Elsen 1988). Therefore, failing to scan for triplets will have negligible impact on accuracy when the true flock litter size is below 1.5. However, the proportion of ewes bearing triplets will contribute to inaccuracy above 1.5. When flock litter size increases above 1.5, solutions need to be found to improve the accuracy of the scanning outcome, such as slowing the throughput of ewes per minute at scanning when seeking to identify triplet litters. Scan operators should be specifically requested to look for triplets above flock means of 1.5 to 1.6, if triplets are to be managed separately to twins, or the data are used for genetic evaluation.

Data used, sample sizes, limitations/robustness of analyses

A significant volume of data has been used for this analysis. Complicating factors for using industry data include: 1) lack of a consistent roll call for ewes across data sources (lambs vs scans), resulting in not all ewes having records for both lambs and scans; 2) automated use of scan results by some breeders to define lamb birth types, without change, vs ; 3) post-lambing correction of scan data once an anomaly has been observed (removing the difference); 4) bias in reporting both lambs and scans; 5) long joining periods and; 6) complicated or multiple scanning events, which means that the scanning data supplied may not be applicable to the joining event from which lambs were recorded. Unless all dates are available for checking, discordant data may not be identified with 100% success.

However, breeders can now upload to Sheep Genetics their scan data separately to their to lambing data, making it more feasible to identify what data source(s) breeders have used to submit their lambing data. In addition, data entry or observation errors can occur independently for both lambing and scanning data sources.

Reflection on acceptable accuracy rates

The scatter of flock-year means (Figure 2) provides visual support to producer's perceptions regarding lack of scanning accuracy. However, as stated previously, this lack of accuracy is due to errors in both assigning litter size at lambing combined with errors due to scanning. Smith et al (1988) previously showed that scanning errors were <5% for litter size in slaughtered ewes, but that concordance reduced to 86.9% in ewes mothered up twice daily. The results in this study, without control regarding the quality of mothering up were very similar (averaging 86%) but the spread of flock-years demonstrates additional sources of error and the expected value could be lower (i.e. all breeders do not mother up twice daily). Percentages of matching records below 80-85% could suggest poor matching of scans to ewes and/or poor accuracy of scanning or mothering up.

A lot of pregnancy scanning occurs within a few months of the year, with scanning businesses needing to juggle visits to numerous clients who may have similar joining dates and therefore clashes in the optimum timing for scanning. While scanning businesses attempt to optimise these visits, both with respect to timing for scanning and the logistics of travel, they may still be met with unfavourable weather conditions and poor pre-scanning management of ewes by clients. Further, excessive hours worked to complete scanning of large flocks may have a detrimental impact on accuracy of scanning, because of a tendency to minimise time per ewe. In addition, scanning for higher order multiples (eg triplets) is not routinely performed, and there is no scanning accreditation. Therefore, there is significant opportunity for error, perhaps reflected in very poor outcomes for a relatively small percentage of flock-years. Better attention to the timing of scanning and scanning procedures is expected to improve consistency of results and reduce the variability observed. Developing some tools to assist with identifying the optimum scanning date based on the joining interval would assist both breeders and scanners in this regard. For the majority of data, conception is very accurately assigned, but litter size is less so.

Breeders need to be educated on pre-scanning procedures and also relative sources of loss, given that many breeders do not actively perform activities which will enable accurate assessment of lamb losses. Considerable lamb losses may also occur without identification of these losses by breeders. In this circumstance, scan data would provide more useful data on litter size than would lamb counts. A scatter plot of residuals from the regression of means for litter size on scan count shows that most of the error observed is random, making scanned litter size suitable for genetic evaluation.

For genetic evaluation purposes, data errors reduce heritability from true values. Therefore, less emphasis is placed on the records to estimate breeding values. Lower heritability estimates were observed for litter size in Merinos relative to comparable data for maternal breeds based on use of broader industry data supplied to SG (Bunter et al, in preparation 2020). However, in both breeds some flocks exhibit higher heritability due to accurate recording and mothering up (eg see Bunter et al, 2016). Differences between these breeds include both mean litter size and the emphasis on accurate mothering up at lambing. However, non-zero heritability indicates the data are still of value for genetic evaluation purposes – particularly given the potential to use a higher volume of scan data, relative to data collected through mothering up, to define phenotypes for conception and litter size in Merinos. Scanning errors are very likely to be random across many families, with the exception of scanning high litter size ewes.

For management purposes, errors in predicting litter size at scanning may be more important than for genetic evaluation, as it affects management costs and the success of management interventions based on litter size (e.g. feeding for multiples). The key differences in observed vs predicted lambing outcomes for Merinos were ewes that were scanned with twins but reported with single lambs (10%

of records) and ewes which scanned with twins but reported to lamb triplets or quadruplets. These ewes generally come from higher litter size flocks, where scanning for triplets should be specifically requested. It needs to be investigated if the 10% discrepancy discussed above is due to unreported lamb losses or true scanning errors.

Accuracy of scanning is potentially affected by bias in comparisons reported. Ewes bearing multiples are less likely to obtain lambing data due to death of the ewe or her lambs.

4.2 Regional workshops with pregnancy scanning contractors and pilot benchmarking study

4.2.1 Agenda for first pregnancy scanner workshop

The agenda for the workshop is listed below in Figure 4.

Agenda:

Time	Item	Presenter
5:00pm	Welcome by workshop facilitator	Dr Gordon Refshauge (NSW DPI)
5:05pm	Lamb survival, reproduction and project overview	A/Prof Forbes Brien (University of Adelaide)
5:20pm	Industry update on foetal imagery	A/Prof Kiro Petrovski (University of Adelaide)
5:40pm	Pregnancy scanning data sets & GISmart	A/Prof Simon de Graaf (University of Sydney)
6:00pm	RFID tech update/refresh	Ms Elise Bowen (Sheep Data Management)
6:20pm	Report on pregnancy scanning accuracy	Dr Kim Bunter (Animal Breeding and Genetics Unit)
6:40pm	5 minutes break	
6:45pm	Results of pregnancy scanners survey	Dr Gordon Refshauge (NSW DPI)
7:00pm	Open discussion on training needs and industry adoption	Facilitators
7:30pm	Key comments from open discussion and Wrap-up	Principal Investigator A/Prof Forbes Brien
7:50pm	Close	Facilitator

Figure 4. The invitation pdf sent to the scanners. The banner at the top of the page was linked to the workshop registration webpage.

The online workshop was recorded and has been posted to the YouTube website. Pregnancy scanner contact emails and SMS were utilised to distribute the link.

4.2.2 Post-workshop feedback

A total of 36 pregnancy scanners attended the workshop online. The post-workshop feedback was provided by 23 people and is reported in Table 7 below.

Table 7. Overall rating of the workshop by attendees

Question	Excellent	Good	Fair	Poor	Very poor	N/A*
How would you rate the quality of the workshop?	13%	65%	13%	0%	0%	9%

* Scanner missed too much of the workshop to comment

Three-quarters of respondents rated the workshop as good or excellent, and 70% agreed or strongly agreed that the workshop was educational and helpful for their scanning (Table 8).

Table 8. Overall agreement about whether the workshop was educational and helpful

Question	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	N/A*
I found the workshop educational and helpful for my scanning	0%	4%	17%	61%	9%	9%

* Scanner missed too much of the workshop to comment

The opportunity was provided to attendees to make any other comments, with the responses given in Table 9.

Table 9. Responses to question: Do you have any other comments to make?

Need to cover health issues related to our industry, Breathing in spray can Fumes, dust in yards related health issues.
Wish there was a greater number of scanners present at
July is a very busy time for me so I missed a lot.
We need to have scanners bounce ideas and improvements from each other that is the best way to get improvement
Would love to be able to tap into these minds when I need them
Really interested in the abnormal pregnancy
Perhaps get a couple of the experienced pregnancy scanners involved. A couple of comments were made about pregnancy scanning equipment were quite inaccurate
More available training would be beneficial
Longer in discussion room or maybe another session with other different breakout group
A face to face meeting is still preferred to allow scanners to network
The ovi scan is not the only ultrasound on the market so future training might broaden its range of equipment used

Pregnancy Scanning data across SA - I don't think there is enough electronic tags taken up by farmers for this data to be accurate. Of the approx. 50,000 ewes we scan on the Eyre Peninsula there is only 3 or 4 farmers with electronic tags.
I found it valuable to attend the workshop, and it was as good as it could be online. Fingers crossed we can all be together for the next. Essential that we can come together as an industry on a regular basis. Many of us work alone in the industry, and therefore find it so beneficial to touch base and network with other scanners. That is where we learn then most, from our peers.
There were comments made that there was plenty of room for scanners to take on new work. I believe this to not be true. I feel that most new/learner scanners participated in the survey and a lot of the more experienced scanners with not a lot of time, would not have participated. I have been scanning for 16 years and every other operator I know, is maxed out. If we want more sheep scanned, we need more scanning operators. I can't speak for numerous operators to say that we have neither the space or capacity to take on new clients. Thanks
I think we needed a talk or contribution from well-known scanners e.g Andrew Naylor. Would have better if the pathology session had photos or videos utilising oviscan images which most scanners use
I don't think we us enough information around us to our advantage for instance, we are scanners and lamb marking contractors and we see first-hand from scanning to marking results we need to see more of this information
Maybe a workshop up at the Sunshine Coast in the "off-season"
I was away at the time of the workshop and ended up in poor mobile service. I haven't yet had a chance to view the recorded version.
Training new and old scanners or retraining

Would you recommend the workshop to others?
18 respondents replied *Yes* and 5 responded with *Maybe*

4.2.3 Breakout session – key take-home messages

At the conclusion of the presentations, all speakers and scanners were randomly allocated into break out rooms for a facilitated discussion on the adoption of pregnancy scanning and the requirements of training workshops for new entry and skilled operators. There were 7 facilitated break-out rooms, which resulted in between 2 and 5 pregnancy scanners placed within each room. This enabled sufficient opportunity and time for the discussion of each question.
The general view was that there is plenty of opportunity for more sheep to be scanned, that some non-adopters simply haven't seen the technology in practice, but once they do they are more likely to keep scanning. Generational change and the expansion of corporate agriculture is likely to increase adoption.

Lifetime Ewe Management course graduates and high-profile producers need to continue to be used as advocates for scanning, and case studies, but the language may need to change to "*Can you afford not to scan*" and the ROI / Cost/benefit needs to be clear and demonstrated. Case studies including reproductive disease investigations may be a useful way to contextualise the risk of not scanning.

A key take-home message includes the suggestion for a “Buddy” training scheme. This may support older scanners integrate technology better into their system, provide some relief on big jobs and greatly improve experience and confidence in new scanners.

The existing training workshops are considered to be very good but may need to be more widely promoted. The need for the training workshops to be week-long was suggested (if they aren’t already), but they should also include different types of equipment (RFID, probes, crates) as well as wellness and training in how to solve people problems. Scanning for fetal age, abnormalities, litter size are desirable at all workshops for all levels of experience, but more experienced scanners want more emphasis on abnormalities and technology, while novice scanners want exposure to every practical use of scanning. The wellness of pregnancy scanners is a very important matter, with issues for WH&S regarding poor working facilities and very long contact hours. Not only do these matters affect the welfare and longevity of scanners careers, but also affects accuracy within a job.

A “Community of Practice” might be possible to create through the Facebook group. There appears to be such a group, but it is hard to find.

4.2.4 Demographic survey of pregnancy scanners

From 156 surveyed people, 64 agreed to take part in the survey (41%). Two other people started the survey but did not complete, 1 was learning the skill as a new entrant, the other was busy and did not make an appointment to complete the survey. In total, 62 surveys were completed (39.7%).

Table 10 contains a summary or responses to questions on age, experience as a scanner and how much longer the person expects to scan, estimated number of sheep scanned annually the number of clients.

Table 10. Summary for all respondents (n=62)

Question	Average	Median	Min	Max
Age (years)	49.2	35-44	18-24	75+
No. of years operating as a pregnancy scanner	12.5	13.5	1	30
Expected number of years left with the sector	9.1	10	1	25
Estimated no. of sheep scanned annually in last 5 years	169,613	152,500	20,000	500,000
Number of clients	82.6	70	14	230

Most respondents were from NSW (46.8%), with the other respondents living in Victoria (27.4%) and South Australia (14.5%), Western Australia (8.1%), Queensland (1.6%) and Tasmania (1.6%). When asked which states they operate in, 38 worked in NSW, 31 in Victoria, 18 in South Australia, 7 in Queensland, 6 in Tasmania and 5 in Western Australia.

With the resources currently available, 61.3% of respondents felt they had the capacity to scan more ewes. When asked for how many more years they expected to be scanning sheep, 11 responded with *indefinitely*, and is not included in the summary. Taken from Table 10, the number of scanners (n=62) and the mean number of ewes pregnancy scanned annually (n=169,613) suggests these operators scan around 10,516,006 ewes, which may be 25-30% of the national ewe flock. If we accept that the survey by Howard and Beattie (2018) is correct in its estimation that 50% of ewes are pregnancy scanned in Australia (18-20 million ewes), then the respondents are scanning about half of all scanned ewes.

When asked if they had capacity to scan more sheep annually, there appeared to be no relationship with the number of years they expected to remain in the scanning sector of the industry (Table 11). Of the 15 respondents in the 45-54 age bracket (n=15), 66% did not have the capacity to scan more sheep and half (50%) of the scanners aged 35-44 indicated they could not scan more sheep.

Table 11. The relationship between the ability to scan more sheep and the number of years expected to continue to pregnancy scan sheep.

Years expected to continue scanning	Do you have the capacity with your current resources to scan more sheep?	
	Yes	*No*
0-5	67%	33%
6-10	50%	50%
11-15	63%	38%
16+	80%	20%

Responses to questions about confidence in performing scanning tasks are given in Table 12.

Table 12. Confidence in performing scanning tasks (% of respondents)

Task	Very confident	Confident	Somewhat confident	Not at all confident	N/A
Wet/Dry	98.4		1.6		
Singles	98.4		1.6		
Twins	83.9	6.5	8.1		1.6
Triplets	30.7	9.7	29.0	3.2	27.4
More than triplets	12.9	4.8	12.9	3.2	66.1
Fetal age	62.9		25.8	4.8	6.5
Abnormalities*	38.7		30.7	4.8	25.8
Gender determination	1.6			3.2	95.2

* Abnormalities were either fetal or uterine

As the number of fetuses increases, the scanners confidence declines, while the number of scanners not being asked to perform the task (N/A) increases. Confidence in the identification of fetal or uterine abnormalities is similar to that of scanning for triplets.

Responses to questions about the type of scanning equipment used and whether electronic identification technology is used is given in Table 13.

Table 13. Equipment and animal identification technology

Application of technology	Key finding
Type of scanning equipment	87.1% use Oviscan.
RFID equipment	53% of respondents have their own. 50% of respondents can capture RFID and pregnancy scan outcome. 29% of respondents have clients with RFID-tagged sheep. 32.3% of respondents have been trained how to incorporate RFID technology into their scanning operation. 24% of respondents never use their RFID technology when scanning sheep.

In total, 33 respondents had their own RFID tag reading equipment. Of these 31 scanners that had their own data capture equipment to record pregnancy scan outcome with the RFID ear tag, 45% (n=14) were based in NSW, but only half (50%) of NSW-based scanners had such equipment. Of the Victorian-based scanners, 64.7% (n=11) were able to match the pregnancy and RFID data, but 35.2% (n=6) were not. Scanners from South Australia were similar to NSW, with 44.4% of them not able to match pregnancy scanning data with RFID tag, but 55.6% were able to do so.

Of the 33 respondents with RFID tag reading equipment, 15 (45.4%) have been trained how to incorporate RFID ear tag reading technology into their scanning business and 27 (81.8%) use the equipment seldom or sometimes (Table 13).

Responses to questions about training needs and training workshops are given in Table 14.

Table 14. The need for training workshops and what a workshop needs to offer

Training requirements	Key finding
Training workshop	59.7% of respondents have attended a workshop. 14.5% of respondents had attended a training workshop more than once.
Should industry periodically organise workshops to improve scanner skills?	90% of respondents said yes, 25% suggest annual workshops 30% feel once every two years.
What skills should be taught at scanner training workshops:	
Wet/dry only	93.6% of respondents said no.
Scanning for twins	74.2% of respondents said no.
Scanning for triplets	46.8% of respondents said yes.
Fetal ageing	62.9% of respondents said yes.
Fetal reabsorption	54.8% of respondents said yes.
Uterine abnormalities	56.5% of respondents said yes.
Fetal gender assignment	46.8% of respondents said yes.
All types of electronic data capture & recording equipment	66.1% of respondents said yes.

When asked about attending a workshop to improve or refresh their skills, 4.8% felt they did not have time for training, 3.2% were not aware, 3.2% said they were self-taught and 29% said they would not attend the workshop. Responses to questions about ewe preparation for scanning and the role of the client are given in Table 15.

Table 15. Ewe preparation for scanning and the role of the client

Ewe preparation for scanning	Key finding
Do you tell your clients to keep ewes off feed and water before scanning?	79% of respondents always instruct this.
How many hours do you recommend the ewes need to be off *feed*?	The average is 10.9 ± 3.6 h, ranging between 0-24, median = 12 h.
Does this "off-feed" advice change with season and current conditions?	41.9% of respondents said yes, 54.8% said no.
How many hours do you recommend the ewes need to be off *water*?	The average is 9.1 ± 5.1 h, ranging between 0-24, median = 12 h.
Does this "off-water" advice change with season and current conditions?	72.0% of respondents do not change the advice.
Estimate for the number of ewes poorly prepared for scanning	The average number of sheep is 16.0 ± 15.8%, ranging between 0-80%, median = 10.
How many days after ram *introduction* do you prefer to scan?	84.5 ± 5.1 days, range 70-100.
How many days after ram *removal* do you prefer to scan?	40.9 ± 2.6 days, range 35-49.

When asked if the scanner tells their clients to keep ewes off feed and water before scanning, 4.8% said they never do, 6.5% say sometimes, 9.7% say often and 79% say always (n=62).

Using responses for the mean number of ewes scanned in the last 5 years and the respondent's estimate for the number of ewes that are poorly prepared for scanning shows that 25,973 ± 35,432 ewes are poorly prepared for scanning per respondent (n=58), the range for which was between 0 and 250,000 ewes.

When asked about the number of days passing after the rams were removed, 90.3% of respondents (n=60) preferred 42 days or less. When asking similarly, but about the number of days passing since the rams were introduced, 3.2% preferred 70 days, 56.5% preferred between 80 and 85 days, while 19.4% preferred 90-100 days.

Responses to questions about providing advice to the client are given in Table 16.

Table 16. Providing advice to the client.

Client-based questions	Key finding
How often do your clients ask you how to best manage pregnant sheep?	54.8% of respondents are often or almost always asked, 12.9% are seldom asked.
Do you feel confident in providing advice how to best manage pregnant sheep?	85.5% feel confident.
How often do you get feedback from your clients about the scanning results?	32.3% seldom or never receive feedback, 31.2% usually or always do.
How do you receive feedback from your clients?	3.2% of respondents receive the feedback formally, 91.9% receive it casually.
When do you receive feedback from your clients?	22.6% of respondents receive the feedback soon after lambing has finished, 37.1% at the next scanning.
Would you be interested in possibly attending a future training course in best practice ewe management so you can provide your clients with advice?	67.7% of respondents said yes, 30.7% said no and 1.6% were unsure.

Responses to questions about working in with client's facilities are given in Table 17.

Table 17. Working in with the client's facilities (%).

Issue	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	N/A
Sheep entry into your scanning crate & general sheep flow is a problem?	1.6	27.4	12.9	53.23	4.8	0
Fitting your scanning crate into the client's yards can be a problem.	1.6	35.5	4.8	51.6	6.5	0
Setting up drafting pens for the scanning task is often difficult.	0	37.1	8.1	54.8	0	0
How the client's staff handle the sheep can be problematic.	3.2	51.6	4.8	33.9	4.8	0
I'm generally pleased with my client's facilities and systems.	4.8	83.9	4.8	6.5	0	0

When asked about sheep entry into their scanning crate and general sheep flow 29% agreed or strongly agreed there was a problem, but 58.1% disagreed or strongly disagreed.

When asked if fitting their scanning crate into the client's yards can be a problem, 37.1% agreed or strongly agreed, while 58.1% disagreed or strongly disagreed and 58.4% agreed or strongly agreed that how the clients staff handled sheep can be problematic, but overall the majority (88.7%) were generally pleased with their clients' facilities and systems. When asked about their preferred yard designs, 51.6% indicated a bugle was a preferred feature.

Responses to questions about cost pricing for the type of scanning services offered are given in Table 18.

Table 18. Cost pricing for the range of scanning capabilities.

Type of scan	Cost ($/100 head)	Cost range
Wet/Dry only	60.15 ± 8.6	45-90
Multiples only	83.08 ± 12.53	65-150
Triplets	92.30 ± 14.60	65-150
Fetal ageing only	74.12 ± 14.58	45-150
Multiples + Early/Late fetal ageing	91.42 ± 14.53	65-150
Triplets + early/Late fetal ageing	96.97 ± 14.88	65-150

When asked if they offer scanning services for goats, 43.6% of respondents said they did, with approximately 239,000 goats scanned annually by these operators. The average number of goats scanned was 9192 ± 8500.

When asked if they offer scanning services for cattle, 43.6% of respondents said they did, with approximately 64,500 cattle scanned annually by these operators. The average number of cows scanned was 3225 ± 4567. Of the 27 respondents that indicated they scan for goats, 7 did not indicate how many they scan annually.

Of all respondents, 23 scan sheep only (37.1%). In addition to scanning sheep, 15 respondents (24.2%) scan both cattle and goats, 12 (19.4%) scan cattle and not goats and 12 (19.4%) scan goats and not cattle.

When asked if they offer ultrasound muscle scanning services, 4 respondents indicated they did (6.5%). Of these, two scan 500 animals, one scans 1500 and the fourth chose not to answer the question.

4.2.5 Agenda for second pregnancy scanner workshop

MEETING:	**2nd National sheep pregnancy scanners online workshop**
DATE/TIME:	Wednesday July 27th 2022
VENUE:	Online conference (Zoom)
TIME:	6:00pm to 8:00pm

Purpose:

- To provide Australian pregnancy scanners with new information regarding the practice of pregnancy scanning.

Objectives:

To provide up to date information on:

- the value proposition to pregnancy scan
- the development of business cases in favour of scanning
- the latest information on fetal reabsorption and to see examples of the video resources created for novice pregnancy scanners

Key Themes/topics:

- Increasing the adoption of pregnancy scanning of sheep

	Time	Item	Presenter
1.	6:00pm	Welcome, Sheep pregnancy scanning adoption project overview.	Forbes Brien (Uni of Adelaide)
2.	6:05pm	Can you afford not to scan? The economics of scanning and messages for adoption.	John Young (Farming Systems Analysis Service)
3.	6:45pm	Increasing the adoption of pregnancy scanning: The business cases.	Hamish Dickson (AgriPartner Consulting)
4.	7:15pm	Fetal losses – what's normal and what are the causes?	Caroline Jacobson (Murdoch University)
5.	7:45pm	New online video resources.	Gordon Refshauge (NSW DPI)
6.	8:00pm	Close	-

As part of an invitation to the workshop, the agenda was sent to the pregnancy scanners' mailing list that had been constructed by the project team (166 names were on the list as of July 2022). There were 70 pregnancy scanners registered prior to the workshop, although a number scanners indicated they would be travelling at the time. At the time of the workshop, a minimum of 55 people (and up to 60 people) were logged onto Zoom.

The online workshop was recorded and has been posted to the YouTube website. Links will be sent to pregnancy scanner contact emails and SMS once MLA and AWI had had an opportunity to view and approve the recording format.

4.2.5.1 Post-workshop Feedback

A post-workshop evaluation was conducted, with 17 people responding, with 16 providing ratings. They rated the workshop from Good (4), Very Good (6) to Excellent (6). So most respondents ranked the workshop as Very Good to Excellent.

Some open-ended written responses were:

- *Had already heard a lot of what was delivered. A lot of it our clients needed to hear. Any information is of benefit.*
- *Next time give the scanner a chance to speak and ask questions. Most off the stuff you guys say we know. Be better to talk about losses stuff we don't know*
- *Can't get enough information about the economics and accuracy of scanning and its impact on animal welfare and farm management. Well done!*
- *As a Western Victorian scanner I found the concept of having to validate the need to scan very foreign. My clients comment that the information gained from scanning for multiple conceptions is possibly the single most important part of their management. I felt that most of the presentations was a farmer/producer focused workshop. The fetal absorption presentation was interesting.*
- *Great, keep it going each year. Would have like to have touched on the FMD issue and what it means for us as scanners. I think it was John quoting scanning rate for twins at 75c. That needs to be increased not many guys doing it for that rate anymore, makes us look silly outing a job with new scanning clients expecting that rate. some guys are closer to a $1- now - I was told to start off at 80c when I started 7 years ago!*
- *I found the area concerning fetal losses very educational. I will be accessing any info via MLA projects to keep in a folder for producers to view when questions arise. One trap as scanners we get is that producers think we are consultants / vets and we can solve all their animal health problems.*
- *Access to all of the presentations is really what I would like from here*

Feedback provided for future webinars on what respondents want to hear more about:

- *More on eid and software producers can use to make use of scanning information*
- *Scanning accuracy, & back up equipment*
- *Bio security protocols. Equipment.*
- *Losses in lamb before lambing. How feed can bring lamb % down or up.*
- *I'd like to learn more about scanning set ups and methods to improve sheep flow, restraint, safety and frustration free EID recording. Topics might include setting up EID and managing missing tags, pile ups etc; sheep flow, squeeze mechanisms to restrain boisterous sheep, preventing kneeling and lying down, tips on getting better pictures, managing mental and physical fatigue.*
- *More science.*

- *As scanners we need to have an accuracy focus. I would like to see a future presentation on what it costs producers if they experience an inaccurate scanning result because I believe inaccuracy is a bigger cost (in an intensive Victorian based system) than your presentation suggested. It is also an obvious issue for producers to dismiss the value of scanning.*
- *More on abortions.*
- *Lamb loss causes (very interesting as a farmer).*
- *OHS issues - Dust in yards, spray cans, chemical residue. Updates on any studies being conducted and results.*
- *Foetal loss. Any new developments in regards to equipment.*

4.2.6 Pilot Benchmark Study

4.2.6.1 Cowra Ag. Research & Advisory Station (NSW DPI)

Overall, there were 573 pregnant ewes, including 220 maiden ewes (2018 drop) and 353 mature ewes. The maiden ewes scanned 83% pregnant, with 127.8% fetuses present/ewe scanned pregnant. The mature ewes scanned 97% pregnant, with 154.1% fetuses present/ewe scanned pregnant.

- Ewes were mothered up at lambing. Seven lambs could not be assigned to dams.
- At the first scanning event, the fetal age range was 39-75 days; at the second scanning event, the fetal age range was 63-99 days. The scan count represents all fetuses seen, dead or alive. Dead fetuses were noted.
- Three pregnant ewes were recorded dry at scan 1 (N=1) or dry at scan 2 (N=2), representing a 0.5% error, and 7 ewes were not recorded at lambing (2 lambed, 5 not in lamb), with 0.7% loss of pregnancy or losing lambs.
- Based on scan data (without correction for the dead fetuses - which were noted for 6 ewes), the agreement in the scan count was 96.9% for N=573 ewes; increasing to 97.2% once fetal loss reported at the first scan was corrected for. The majority of ewes whose scans did not match (N=16) were ewes that conceived quickly and had the oldest fetus at the first scanning. Two of these ewes were recorded with a dead fetus at the second scan, but this was not accompanied by better consistency of scan count vs lambs born. This could suggest either a recording error (wrong ewes) or inaccurate observation of fetal death at the older fetal age.
- A total of 19/573 ewes died at or after lambing (3.3% of ewes expected to lamb) and therefore no marking details were recorded (all lambs effectively lost). Of the ewes that died, 12/19 (63%) were carrying twins/multiples; ewes carrying singles predominantly lambed late.
- 15.8% of ewes were assigned to a late lambing at scan 1, compared to 30.0% of ewes which would have been assigned to be late at scan 2. Assignment to early vs late was much more accurate at the first scanning event (82% of ewes correctly assigned to 'early' lambing - within 168 days from the ram in date - vs 68.8% based on the second scanning event). It is likely that the impact of increased litter size on lamb development contributed to smaller fetuses (presumed late) at the second scan event.

Ewes were moved to lambing paddocks based on scanned litter size as shown in Table 19 (LS values not adjusted for fetal loss, but assignment to litter size group generally did account for the expected litter size).

Accounting for ewe losses between scanning and lambing always improved the extent of agreement between scan and lamb counts. The consistency between the assignment of ewes to a litter size group and the lamb count was highest for single bearing ewes managed in a singles group (~95% or better agreement); agreement for ewes managed as twins ranged between 82-91.5% (appearing lower for larger mobs); ewes managed in mixed mobs ranged from 88.9 to 94.4%; ewes scanned with multiples had very low agreement (<50%).

Table 19. Distribution of ewes to lambing paddocks

Paddock	LS Group	No. ewes	Lambs with no dam (% ewes)	*Agree all (% ewes)	No. lambed	*Agree lambed (% ewes)
Campview	Singles	80		93.8-97.5	79	94.9-98.7
S3/4	Singles	55		96.4	54	98.1
Evans	Twins	92	2 (2.1%)	79.3-80.4	89	82.0-83.1
McLeods	Twins	47	1 (2.1%)	89.4-91.5	47	89.4-91.5
Orchard	Twins	41		87.8-90.2	41	87.8-90.2
R	Twins	63	1 (1.6%)	84.1-85.7	62	85.4-87.1
Btm Fore	Multiples	10		30.0-40.0%	9	33.3-44.4
Bald Hill	Mixed	76	1 (1.3%)	86.8-88.2	71	93.0-94.4
L	Mixed	109	2 (1.8%)	88.1	108	88.9

*Range for raw values at both scan events, and adjusted values (fetal loss) from first scan event

Table 20. Means by litter size group

Litter size group	N ewes (%)	*Mean scan1*	Ewes died	Mean lamb	% reduction in mean LS	% reduction in lambs*
Singles	135 (23.6%)	1.06	0.7%	1.00	-5.7%	-3.6%
Twins	243 (42.4%)	1.99	2.5%	1.87	-4.1%	-5.1%
Mixed	185 (32.3%)	1.52	5.4%	1.49	-2.0%	-1.8%
Multiples	10 (1.7%)	2.70	20%	2.67	-1.1%	0%

*Overall 3.7% reduction in lamb numbers for ewes both scanned and lambed

Results from the fitting of a linear mixed model (using GLM) to the scan data are shown below in Table 21:

Table 21. Least square means for concordance between the two scan results

Type of litter class	Fetal age classification	Least Square MEAN
Multiples	Early	0.191
Multiples	Late	0.902
Singles	Early	0.954
Mixed	Early	0.931
Mixed	Late	0.934
Twin	Early	0.850

There is poor concordance for twin/multiple lambs (but noting there are few multiple-bearing ewes) and twin lambing groups are the most likely groups to have unaccounted for lambs as well as ewes lost.

Discussion

- Repeatability of scans was very high (97.2%), but not 100%. Repeatability is reduced by error in pregnancy detection (0.5%), fetal loss (0.7%) and also 1.5-2% change in the number of fetuses observed between scan events.
- The concordance of scan with lamb counts is nearly always lower than the concordance of repeated scans, with the exception of ewes assigned to some singles mobs.
- Lambs observed at birth or marking is biased downwards by ewes lost (3.3%); these ewes are dominated (63%) by multiple pregnancies and therefore more lambs lost.
- Lambs were not counted at marking. Therefore, the known differential effect of litter size on lamb survival cannot be demonstrated with this data, but will further reduce concordance between scan counts and lambs marked.
- Assignment of ewes to early and late lambing groups is best done based on scanning with maximum fetal age <=75 days (scanning at 75 days after the ram in date). Later scanning was less accurate, presumably due to the change in fetal growth rates with increasing fetal age.
- Paddock differences in the extent of agreement between scans and lambs reflect subdivision of ewes into mobs as well as paddock specific effects (e.g. environment, predators etc).
- Ewe age was not a significant factor affecting concordance of scan with lamb counts. However, lambing mob group (singles, twins, multiples, mixed) significantly influenced concordance, as expected. The degree of concordance was highest for single bearing ewes (>95%), lowest for twins and especially multiples, and intermediate for mixed mobs. Mob size only approached significance, but increasing mob size tended to decrease concordance.

4.2.6.2 Avondale, EURONGILLY, NSW, 2663

The number of ewes correctly assigned to their litter size (using the number of lambs born - NLB records with date of birth - DOB as the 'correct record') was 66.4%. There 113 ewes that gave birth to more lambs than they were assigned at Scan 1. There were 81 ewes that gave birth to fewer lambs than they were scanned with at Scan 1 (8 ewes with 2 less lambs and 73 ewes with 1 less lamb). Table 22 provides the number of ewes identified according to litter size at each scanning event and includes the number of ewes that were identified with the same litter size (0-4) on both occasions. Table 23 reports the number of ewes correctly assigned to a litter size at each scan event that was the same at birth. Table 24 shows the allocation of ewes to litter size groups at both scans. Records above the diagonal are underestimates for fetal number and records below the diagonal are overestimates. Table 25 shows the number of fetuses identified at Scan 1 and lambs born. Table 26 shows the number of fetuses at Scan 2 and the number of lambs born.

Table 22. Counts for the number of lambs scanned at each scanning event and the number of ewes with the same outcome at both scans.

Litter status at first scan	Count Scan 1	Count Scan 2	Same litter both scans
0	135	131	125
1	77	61	58
2	300	304	267
3	63	79	46
4	3	3	3

Table 23. Counts for the number of lambs recorded at birth, the number of ewes correctly identified at Scan 1 and Scan 2.

Litter size at birth	Number of ewes	Correct at Scan 1	Correct at Scan 2
0	131	125	131
1	108	50	49
2	217	173	186
3	113	35	45
4	9	1	1

Table 24. The number of fetuses at each pregnancy scan.

	Scan 2					
Scan 1	**0**	**1**	**2**	**3**	**4**	**Grand Total**
0	**125**	2	5	3		135
1	2	**58**	15	2		77
2	4	1	**267**	28		300
3			17	**46**		63
4					**3**	3

Table 25. The number of fetuses at pregnancy Scan 1 compared to the number of lambs born (NLB)

	NLB					
Scan 1	**0**	**1**	**2**	**3**	**4**	**Grand Total**
0	**125**	4	5	1		135
1	2	**50**	20	5		77
2	4	50	**173**	70	3	300
3		4	19	**35**	5	63
4				2	**1**	3

Table 26. The number of fetuses at pregnancy Scan 2 compared to the number of lambs born (NLB)

	NLB						
Scan 2	**0**	**1**	**2**	**3**	**4**	**5**	**Grand Total**
0	**133**						133
1		**53**	11	1			65
2		50	**187**	67	3		307
3		9	20	**45**	5	1	80
4				2	**1**		3

Scan 1 compared to Scan 2

A Spearman Rho was calculated for the relationship between Scan 1 and Scan 2, indicating r = 0.86 ($P < 0.001$). Figure 3 shows the overestimates of dry and single ewes at Scan 1 and underestimates at higher order litters.

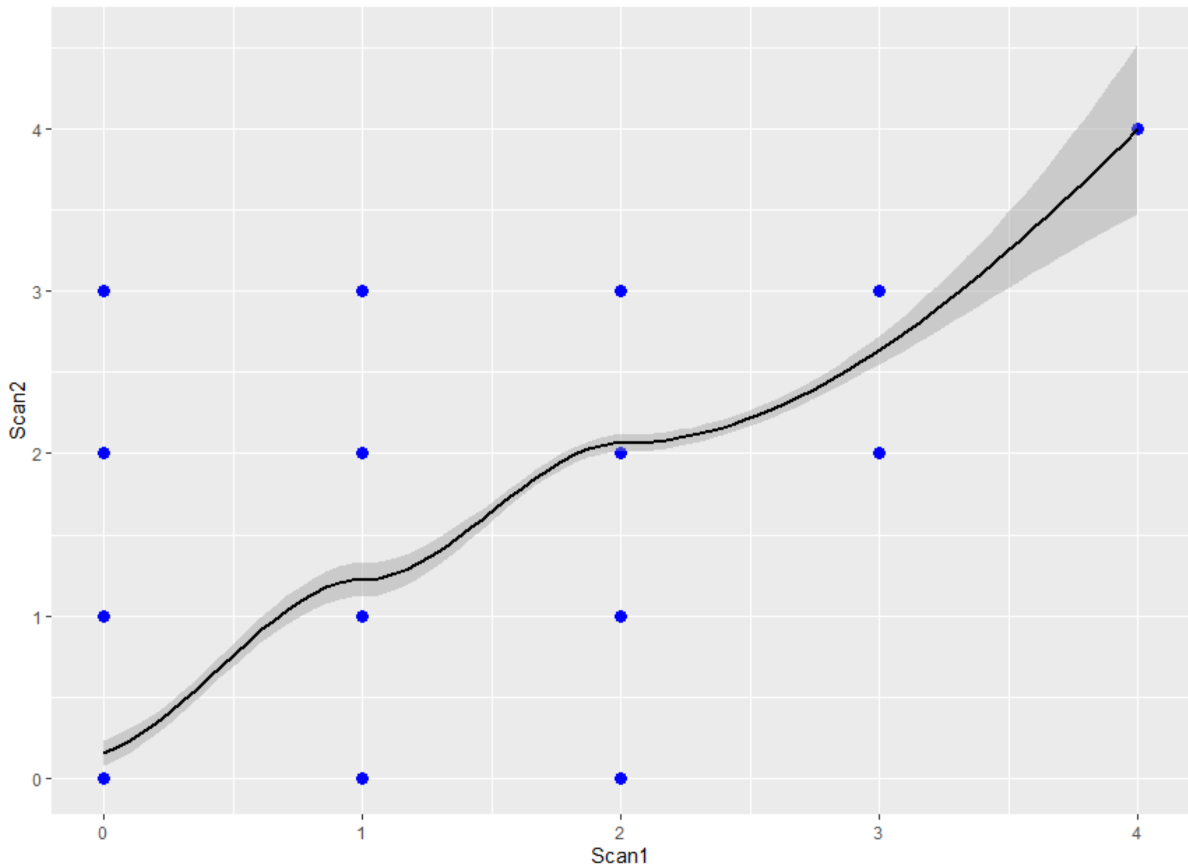

Figure 3. The correlation plot between fetal status at Scan 1 and Scan 2 with a loess regression fitted. Shading indicates standard error.

A Bland-Altmann plot supports these observations. In Figure 4, the differences are plotted against the “gold standard” Scan 2 results. The negative values on the y-axis occur when more fetuses were detected at Scan 2. The Lin’s CCC between Scan 1 and Scan 2 was 0.881 (Lower CI = 0.862, Upper CI = 0.898). The weak R^2 fitted to the scatterplot in the Bland-Altmann chart indicates a weak error associated with higher litter size at Scan 2.

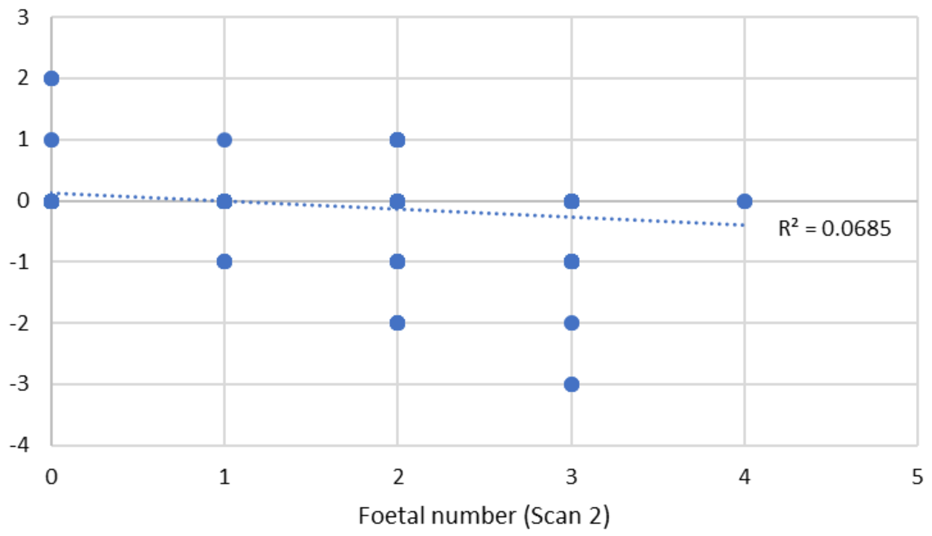

Figure 4. Bland-Altmann chart of the difference between Scan 1 and Scan 2, plotted against Scan 2.

Scan 1 compared to number of lambs born (NLB)

The number of ewes correctly assigned to their litter size (using NLB records with DOB as the 'correct record') was 71.3%. There were 85 ewes that gave birth to more lambs than they were identified with at Scan 2, and 81 ewes gave birth to fewer lambs than they were scanned with (9 ewes with 2 less lambs and 72 ewes with 1 less lamb).

The Spearman Rho correlation was r = 0.76 ($P < 0.001$). Figure 5 shows greater underestimates when the number of lambs born is evaluated. In this instance, some caution is advised as dead lambs were not DNA sampled and it remains a possibility that the underestimate of scan 1 fetal number (for those ewes scanned as twins, triplets and quadruplets) may be due to deaths.

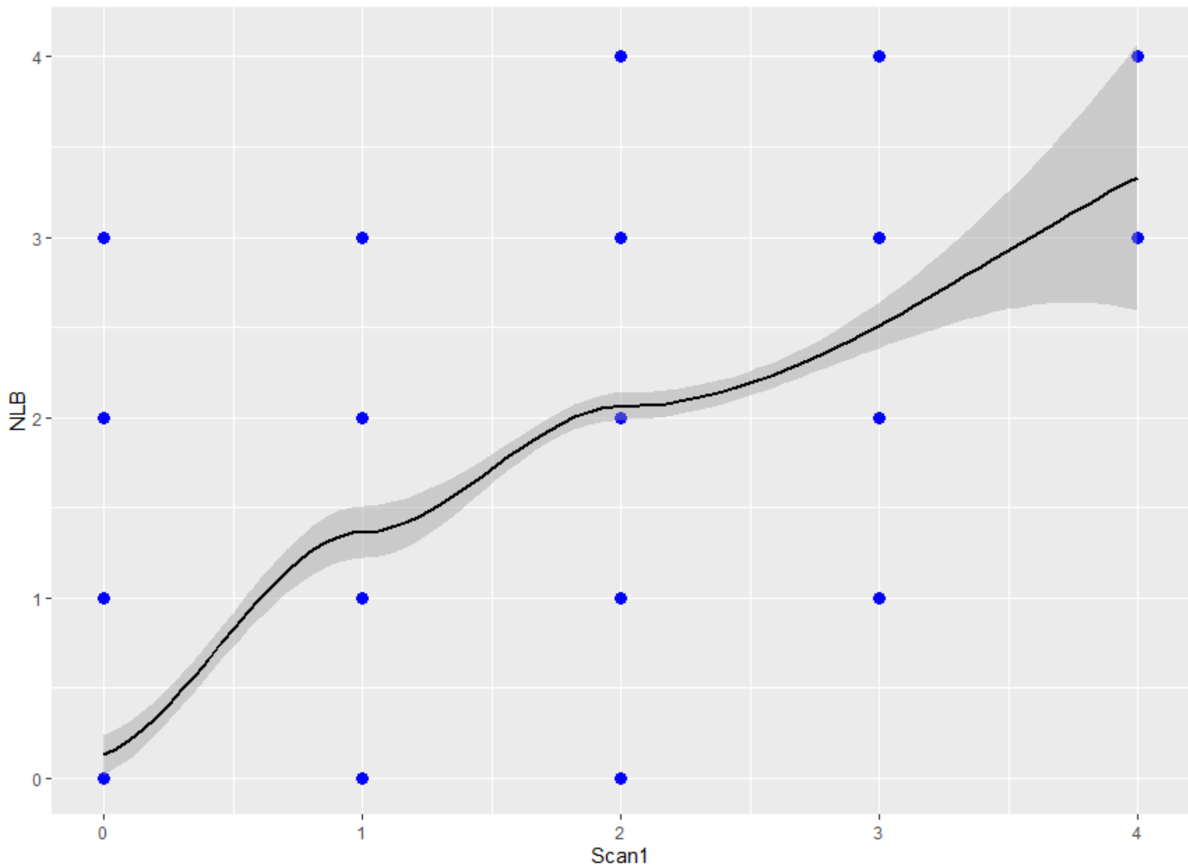

Figure 5. The correlation plot between fetal status at Scan 1 and number of lambs born (NLB) with a loess regression fitted. Shading indicates standard error.

The Bland-Altmann for the differences between Scan 1 and NLB is provided in Figure 6, which reports the differences plotted against the “gold standard” NLB results. The negative values on the y-axis occur when more lambs were born than were detected at Scan 1. The Lin’s CCC between Scan 1 and NLB was 0.786 (Lower CI = 0.754, Upper CI = 0.815). The low strength R^2 fitted to the scatterplot in the Bland-Altmann chart indicates the error associated with higher litter size at lambing.

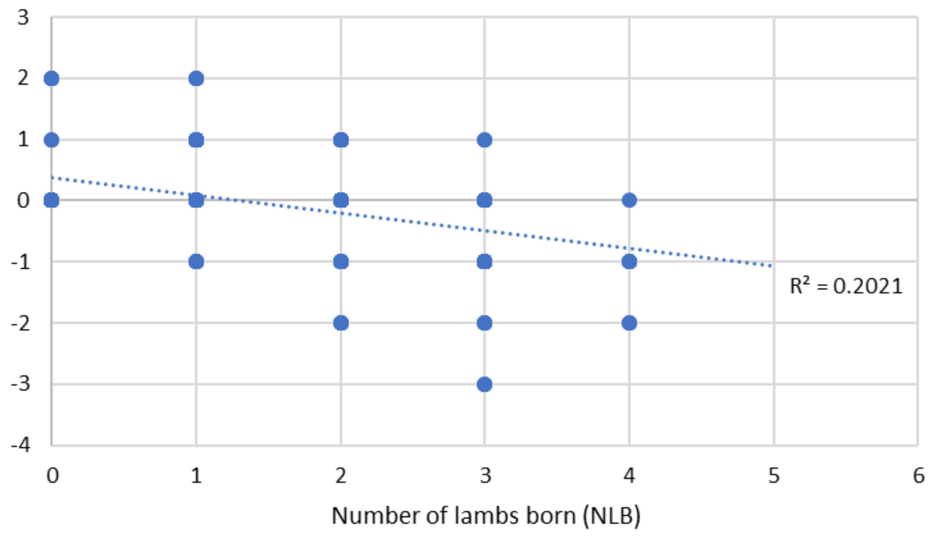

Figure 6. Bland-Altmann chart of the difference between Scan 1 and NLB, plotted against NLB.

Scan 2 compared to number of lambs born (NLB)

The Spearman Rho between Scan 2 and NLB was marginally higher, r = 0.801 ($P < 0.001$), than that observed for Scan 1 and NLB. The loess line fitted to the scatterplot (Figure 7) shows slightly more single-scanned ewes had twins, while twin numbers remained reasonably accurate, but divergences were occurring among the triplet and quadruplet scanned ewes.

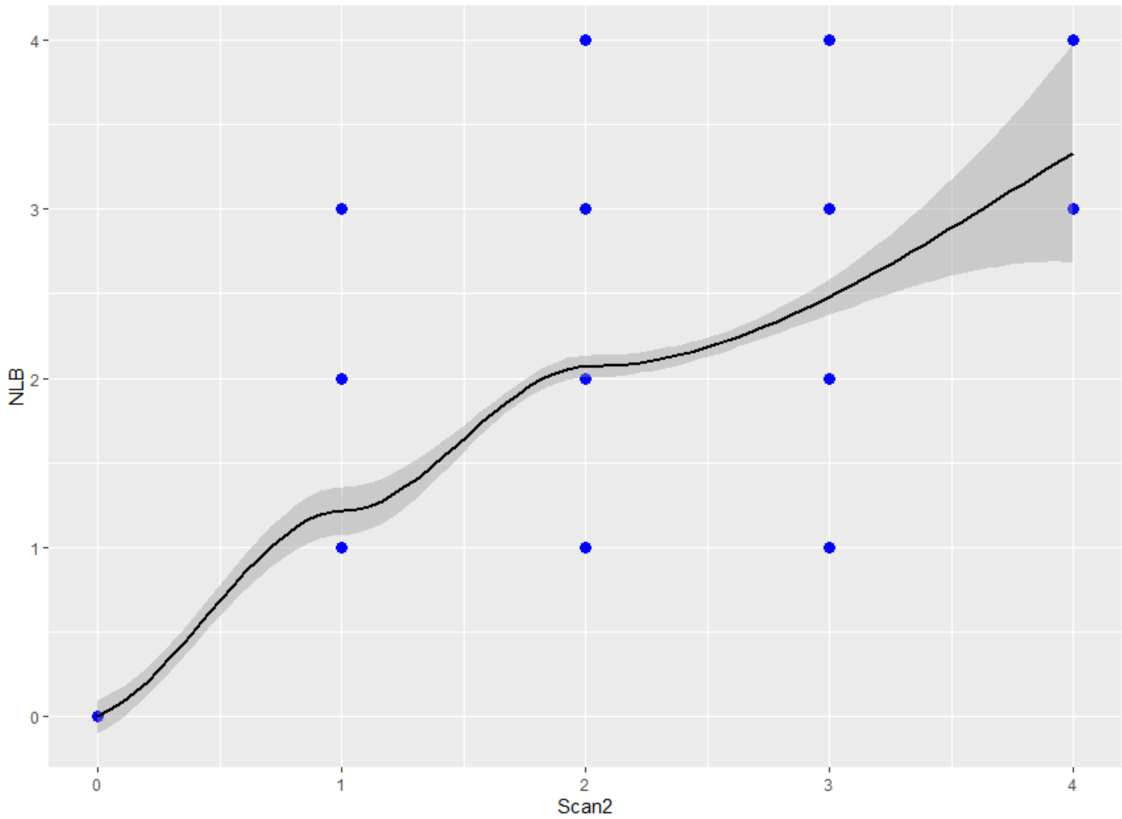

Figure 7. The correlation plot between fetal status at Scan 2 and number of lambs born (NLB). Shading indicates standard error.

The Bland-Altmann for the differences between Scan 2 and NLB is provided in Figure 8, which reports the differences plotted against the "gold standard" NLB results. The negative values on the y-axis occur when more lambs were born than were detected at Scan 2. The Lin's CCC between Scan 1 and NLB was 0.837 (Lower CI = 0.811, Upper CI = 0.859). The low strength R^2 fitted to the scatterplot in the Bland-Altmann chart indicates the error associated with higher litter size at lambing.

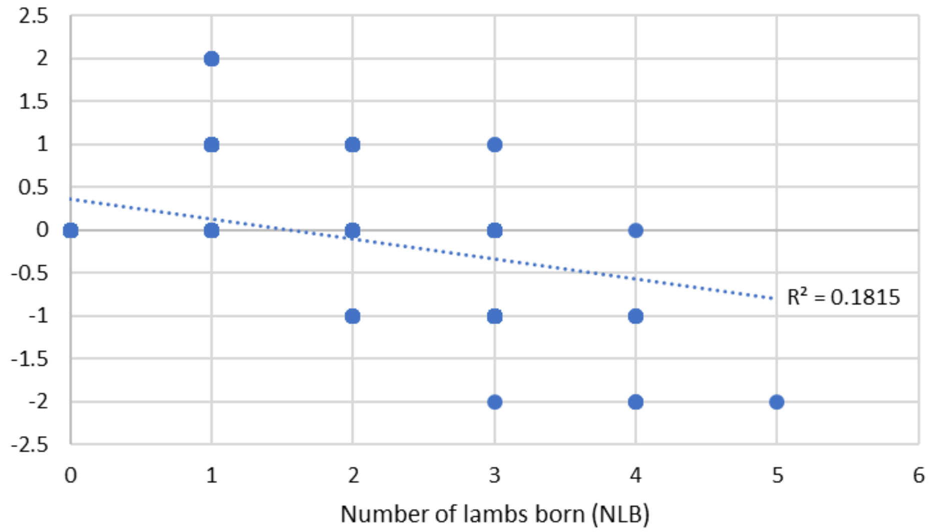

Figure 8. Bland-Altmann chart of the difference between Scan 2 and NLB, plotted against NLB.

Including fetal age estimates

The proportion of ewes that were assigned the same number of fetuses at Scans 1 and 2 and at NLB were classified for a Chi-square analysis as being "Exact", while all other data was classified as "Inexact". Of those ewes identified at Scan 1 with an early fetal age, 59.7% were "Exact", while 57.1% of Late ewes were exactly scanned. There was no disproportion of these values (χ^2 = 0.292, df = 1, P = 0.59), indicating that there was no greater scanning error rate due to mean fetal age when all ewes lie within an acceptable fetal age range at both scanning events.

Discussion

Overall, caution is advised when drawing conclusions from this data because lambs that died and were not seen with ewes were not assigned to dams. Further, tissue samples were not collected from these dead lambs that would have allowed pedigree matching via DNA analysis. It is possible that some of the error in the data arises from this situation, leading to greater discrepancies than might be expected between fetal number counts at scanning and the number of lambs recorded at birth. Further, some live lambs were missed being mothered up with their dams at lambing time, so tissue samples were taken at marking time for DNA analysis and further pedigree determination via DNA matching. It is possible that even after this process that some lambs could not be matched with their dams, further contributing to discrepancies between the counts of lambs born and counts of foetuses at scanning times.

Scan 1 compared to Scan 2

Differences between Scan 1 and Scan 2 values occurred across the range of litter size outcomes (0-4 fetuses). The loess line fitted to the plot (Figure 3) allows further interpretation of the density of data around the points and shows there are fewer errors than the scatterplot might otherwise imply, which is supported by the reasonable correlation coefficient. However, the strength of the correlation may be affected by the small number of quadruplets. The Bland-Altmann chart for the differences between the two scan events (Figure 4) indicates higher fetal numbers at Scan 1 than at Scan 2, suggestive of fetal loss. Of the 133 ewes scanned as non-pregnant at Scan 2, a total of 6 ewes had been scanned with 10 fetuses (2 single-bearing and 4 twin-bearing ewes). Of those ewes with higher fetal number at Scan 1, 17 ewes were scanned as triplets and by Scan 2 they were assigned twins. However, 9 of those ewes later lambed triplets and one had a set of quadruplets.

A strict interpretation of the Lin's CCC suggests Scan 1 has a poor correlation with Scan 2 (i.e. <0.9), but that is open to interpretation and others may regard the correlation having reasonable predictive relationship.

Scan 1 compared to number of lambs born

The lowest correlations were those between Scan 1 and NLB, in both Spearman Rho and Lin's CCC, with errors increasing with higher order litters. Much of the error at Scan 1 to NLB was ewes giving birth to triplet lambs that were from ewes scanned as twin-bearing. At the same time, 50 ewes were scanned as twins and gave birth to singles, although this could be partially explained if DNA data was available on all dead lambs (Table 6). The fitted loess line in Figure 5 shows that dry ewes and single ewes were underestimated for fetal number, while the accuracy of triplet and quadruplet ewes was also lower

Scan 2 compared to number of lambs born

The highest correlations among the variables was found between Scan 2 and NLB. Nevertheless, among the ewes that were pregnant and lambed, only 286 of 455 ewes were correctly assigned to their NLB, with 50 twin-scanned ewes having single lambs, 20 triplet-scanned ewes having twins and 67 twin ewes having triplets. The overestimates may be due to dead lambs not being DNA sampled. It is difficult to conclude whether the challenges faced during this lambing have affected the results of the study. The timing of Scan 2 was much more aligned with industry recommendations, which is encouraging because the correlation of 0.801 between Scan 2 and NLB is not far below that reported in the study of industry data, as outline in section 4.1.

4.2.6.3 'Mernowie', MARRABEL, SA, 5413

The owners of this property have in recent years chosen to lamb down their Merino stud ewes (which are mated by artificial insemination) in individual pens inside a covered shed, in an effort to improve lamb survival. This provided an opportunity to compare scanning records with a more reliable count of lambs born than could be achieved under paddock lambing conditions, where the influence of predation is likely to lead to underestimates of the actual number of lambs born, even when lambing rounds are carried out twice-daily (Smith *et al.* 1988).

In this study, 147 ewes were presented at the first pregnancy scan (65 days after AI). Of those, 139 ewes were determined to be pregnant. Only ewes determined as pregnant at first scan were scanned a second time at Day 86 of pregnancy, 21 days after the first scan. At first and second scans, there were 155.4% and 154.5% fetuses present/ewe pregnant, respectively. This relatively high rate of fetal numbers per ewe for Merinos likely reflects the AI synchronisation regime used.

The scanning contractor had difficulty identifying the litter size carried by 5 ewes at the second scan (the fetuses were too large and obscured by the large size of the placentomes), so the scan count for these ewes was recorded as ‘indeterminate’. Also, the scanning contractor did not attempt to distinguish any ewes carrying more than twins, so these were classified as carrying twins only.

Twelve out of 133 ewes (9%) did not have matching fetal numbers recorded between the two scans (Cohens Kappa correlation = 0.818, which is very good agreement).

16.9% of ewes do not match in lamb numbers between scan 1 and lambing (r=0.703).

12.9% of ewes do not match in lamb numbers between scan 2 and lambing, indicating a better result at scan 2 (r=0.732).

However, accounting for the fact that the scanning contractor reports only 2 fetuses even when there may be more than 2, ewes carrying singles can be compared to ewes giving birth to multiples at lambing instead. In that situation, the 16.9% of ewes that did not match in lamb numbers between scan 1 and lambing reduces to a 12.1% mismatch in identifying singles vs multiples (r= 0.757 = Cohens Kappa = 0.756 good agreement). Also, the 12.9% of ewes that did not match in lamb numbers between scan 2 and lambing reduces to 8.9% (r = 0.822 = Cohens Kappa = very good agreement).

The overall conclusion is that the statistical tests show very good agreement between scans, and good to very good agreement between identifying singles vs multiples litters, but of course a downwards bias if the scanner is not asked to identify and report triplets etc. Finally, the mismatch of assigning litter size is about 10% in a flock with a considerable number of multiple bearing ewes.

4.3 Economic analysis of pregnancy scanning

4.3.1 The value of scanning

Pregnancy scanning for multiples and implementing optimal management of the empty ewes, the optimal differential nutrition of the pregnant ewes and optimal allocation of the lambing paddocks based on litter size increased profitability in all the winter rainfall regions (Table 27) and the summer rainfall regions (Table 28) for all flocks for all times of lambing. The average value of the increase was $5.75/ewe scanned for the winter rainfall regions, this represents approximately a 400% return on the expenditure for contract costs and the extra on-farm labour associated with the scanning operation. Scanning ewes in the summer rainfall regions was similarly profitable at $4.44/ewe scanned.

Table 27: The increase in farm profit from scanning for multiples and implementing optimum management ($/ewe scanned) for each of the 3 regions and 3 flock types for 3 times of lambing in the winter rainfall analysis. Estimated for 85% agreement between scanning results & lambing outcome.

	Time of Lambing		
Region & Flock	Autumn ($/ewe)	Winter ($/ewe)	Spring ($/ewe)
Winter rainfall: Long Growing Season			
Merino	7.20	10.60	3.80
Mer-TS	6.40	8.80	6.00
Maternal	7.50	8.80	5.40
Winter rainfall: Medium growing season			
Merino	7.80	2.80	5.50
Mer-TS	9.80	5.20	3.70
Maternal	5.80	4.00*	4.20
Winter rainfall: Short growing season			
Merino	4.60	4.60	1.20
Mer-TS	5.20	4.70	1.90
Maternal	8.40	3.50	6.50
Average	7.00	6.10	4.25
Overall average	5.75		

* extrapolated from the value of scanning for multiples using the other scenarios

Table 28: The increase in farm profit from scanning for multiples and implementing optimum management ($/ewe scanned) for the summer rainfall region for the 3 flock types and 3 times of lambing. Estimated for 85% agreement between scanning results & lambing outcome.

	Time of Lambing		
Region & Flock	1-Aug ($/ewe)	1-Sep ($/ewe)	20-Sep ($/ewe)
Summer rainfall region			
Merino			3.85
Mer-TS		7.52	7.06
Maternal	2.01	1.74	
Overall average	4.44		

The variation in the value of scanning across regions aligns with the timing of the main feed shortage. The maximum value from scanning is achieved for flocks that are scanning just prior to the worst feed deficit. This is June lambing in the long growing season environment, May lambing in the medium and short growing environments, and early September lambing in the summer rainfall region. Scanning has less impact on the profitability of 'spring' or late lambing flocks which are scanning at the end of the main feed deficit in each region. Scanning later reduces the value that can be achieved from alternative management of the empty ewes and therefore the main benefit for spring lambing flocks is from differential management of the multiple-bearing ewes.

Note: Lower value of scanning associated with the later lambing doesn't equate to lower profit overall. Often the later lambing flocks are the most profitable, but there is less benefit from pregnancy scanning.

The benefit achieved from scanning for multiples is the combination of the benefit that can be achieved from identifying the empty ewes through scanning for pregnancy status and the extra value achieved by also identifying the multiple-bearing ewes. In most scenarios examined, scanning for pregnancy status only was also profitable (Table 29 and 30), however, it was almost always less profitable than scanning for multiples. Across the winter & summer rainfall regions scanning for pregnancy status was only half as valuable as scanning for multiples. These results suggest that scanning for pregnancy status only is a good starting point for farmers who are gaining experience with scanning, but that it should be used as a stepping stone to scanning for multiples.

Table 29: The increase in farm profit from scanning for pregnancy status only for each region in the winter rainfall analysis.

	Time of Lambing		
Region & Flock	Early ($/ewe)	Mid ($/ewe)	Late ($/ewe)
Winter rainfall: Long Growing Season			
Merino	6.30	5.70	1.30
Mer-TS	5.20	4.10	0.00
Maternal	7.10	7.70	2.90
Winter rainfall: Medium growing season			
Merino	4.10	-1.50	1.50
Mer-TS	4.60	0.90	-1.50
Maternal	4.80	3.00	0.90
Winter rainfall: Short growing season			
Merino	2.50	1.20	-0.30
Mer-TS	2.00	1.00	-0.90
Maternal	7.50	3.30	3.00
Average	4.90	2.82	0.77
Overall average	2.83		

Table 30: The increase in farm profit from scanning for pregnancy status only for the summer rainfall analysis.

	Time of Lambing		
Region & Flock	Early ($/ewe)	Mid ($/ewe)	Late ($/ewe)
Summer rainfall region			
Merino			1.16
Mer-TS		1.86	1.78
Maternal	1.64	1.57	
Overall average	1.60		

The modelling analysis carried out for the winter rainfall region was more rigorous than the gross margin analysis carried out for the summer rainfall region. In the modelling it was possible to include more production detail and better represent the feed budget. Therefore, we have greater confidence in the results from the modelling analysis than the gross margin analysis. However, the close agreement between the summer & winter analyses indicate that the detailed findings of the winter rainfall analysis are representative for the summer rainfall region. As a result, the focus of the reporting and extension have been on the results from the detailed modelling.

4.3.1.1 Rules of thumb

- Scanning for multiples and implementing optimum nutritional management, optimal management of emptys and optimal paddock allocation increased profit for all genotypes, in all regions at all times of lambing. The average increase in profit was $5.75 per ewe scanned.
- The maximum value from scanning is achieved for flocks that are scanning just prior to the worst feed deficit. This is 'winter' lambing in the long growing season environment and 'autumn' lambing in the medium and short growing environments.
- In general scanning has the least impact on profit for spring lambing flocks
- If scanning was 100% accurate in predicting the lambing outcome, then the value of scanning for multiples increase to $6.30/ewe scanned.

4.3.2 Optimum Nutrition Profiles

A major contributor to the value of scanning can be the ability to differentially feed empty, single- and multiple-bearing ewes. To value this appropriately requires identifying the optimum nutrition profiles for ewes carrying different numbers of foetuses. The following profiles were identified and used in the subsequent analysis.

If ewes are not scanned (e.g. Figure 9) then the empty ewes gain weight relative to the single bearing ewes and the twin bearing ewes lose weight. In the period prior to scanning the ewes with different numbers of foetuses are managed together and the weights diverge slightly due to differences in energy requirements. After scanning the ewe nutrition profiles are optimised for the groups that are identified by scanning. If the ewes are scanned for pregnancy status (e.g. Figure 10) then the nutrition level of the empty ewes is reduced at scanning. If the ewes are scanned for multiples, then the single- and multiple-bearing ewes can be differentially fed and the main adjustment is during the period from scanning to lambing (e.g. Figure 11). The ewes that conceived in different cycles were managed as a single mob and the value that could be achieved from foetal aging was not quantified in this analysis. Profiles for the other regions and each time of lambing are available in an Appendix.

The profiles developed in this project were done with a more rigorous process and an improved model compared with the profiles developed in the LifetimeWool project a decade ago and there are some differences. Although the profiles presented here were selected by comparing more than 2000 nutrition profiles, further improvement could be achieved with extra work.

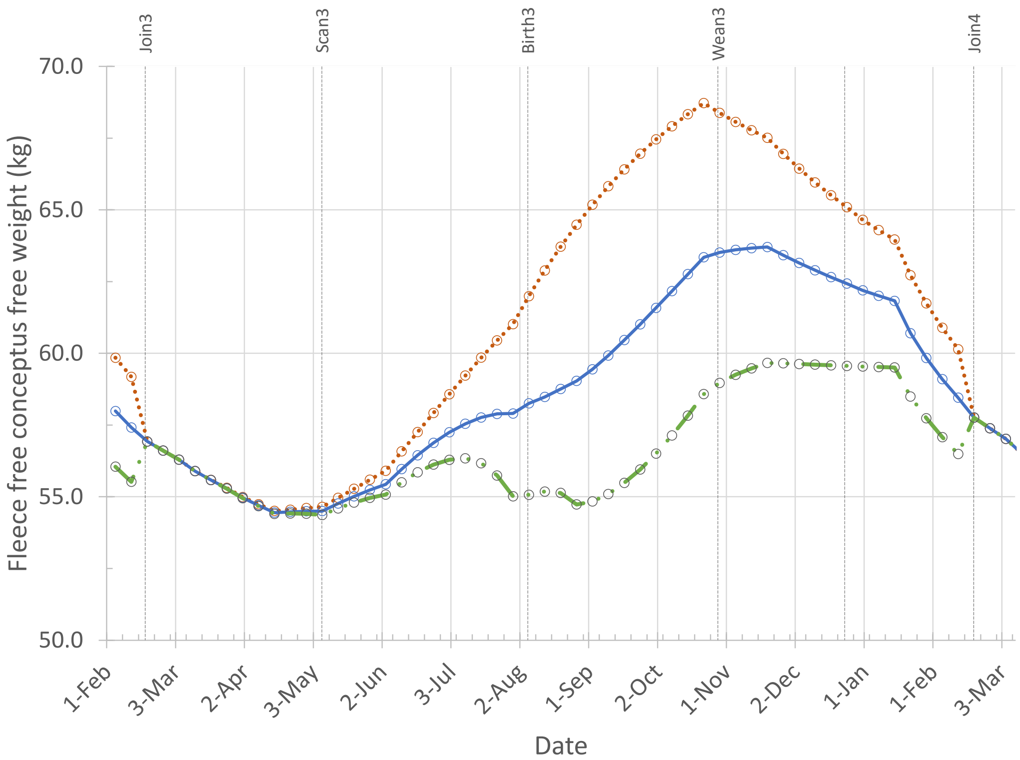

Figure 9: Example of optimum profile for empty (…), single-bearing (—) and twin-bearing ewes (– ··) from the medium rainfall region (GS of WA) with spring lambing if the flock is unscanned (○).

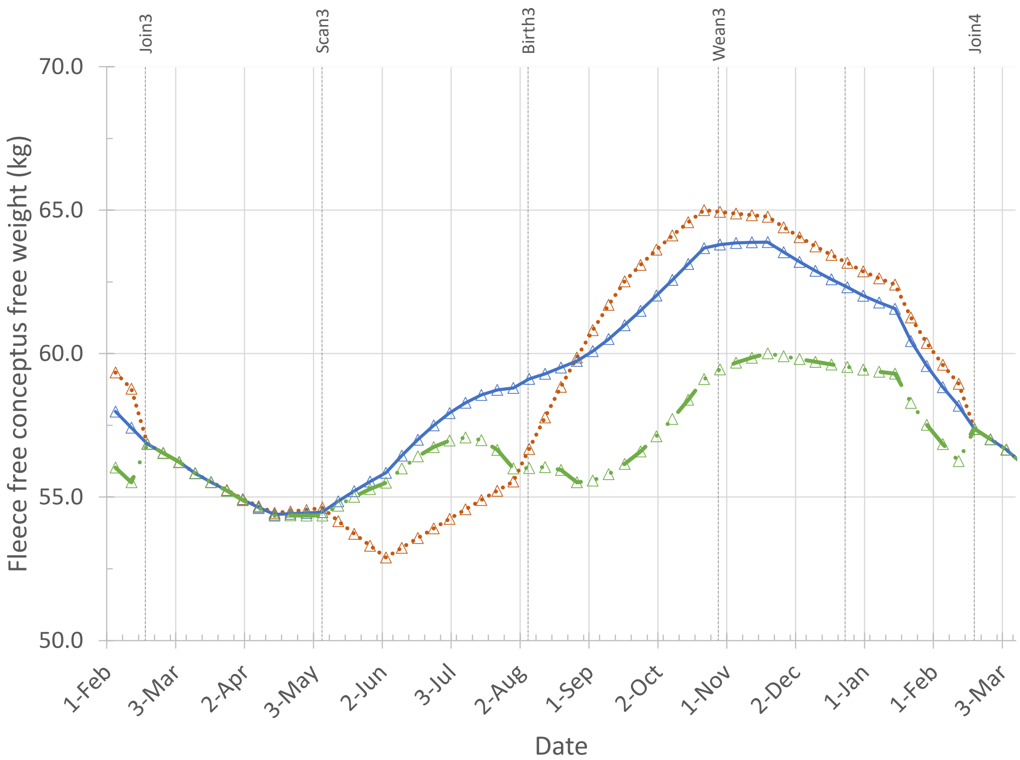

Figure 10: Example of optimum profile for for empty (…), single-bearing (—) and twin-bearing ewes (– ··) from the medium rainfall region (GS of WA) with spring lambing if the flock is scanned for pregnancy status (Δ) and the non-pregnant ewes are identified and differentially managed.

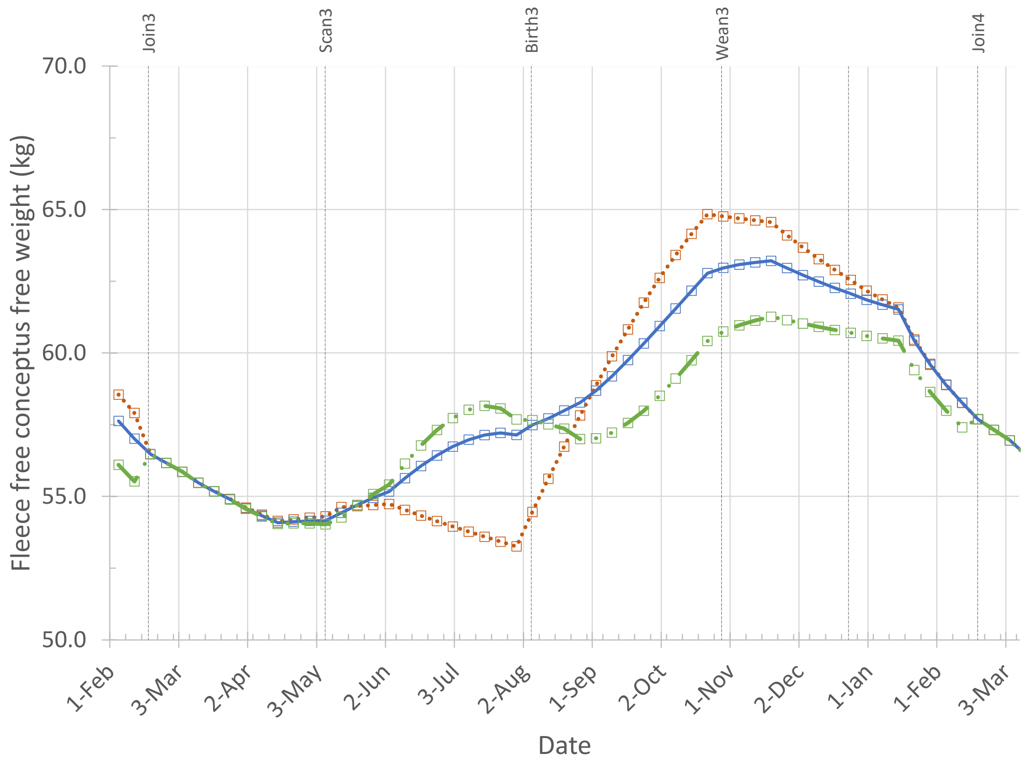

Figure 11: Example of optimum profile for empty (…), single-bearing (—) and twin-bearing ewes (– ··) from the medium rainfall region (GS of WA) with spring lambing if the flock is scanned for multiples (□) and the empty, sinlge- and multiple-bearing ewes are differententially managed.

4.3.2.1 Rules of Thumb

- If ewes are not differentially fed during pregnancy the empty ewes will be 3-5 kg heavier at birth than the single bearing ewes and the twin bearing ewes will be 3-5kg lighter.
- If empty ewes are identified and not sold then the optimal profile is for empty ewes to lose weight after scanning, the amount of weight loss depends on the severity of the feed shortage but can be up to 10kg lighter than the single bearing ewes at birth.
- If the multiple bearing ewes are also identified, the optimum nutritional management is to increase the feed supply and to be 2 to 3kg heavier than the single bearing ewes at birth.

4.3.3 Scanning for pregnancy status

Scanning for pregnancy status and altering the management of the empty ewes increases profit in all flocks that are scanning prior to the main feed deficit (Table 32). The increase in profit for flocks lambing prior to the feed deficit ranged from $2/ewe for Merinos in the short growing season environment up to $8.50/ewe for the maternal flock in the short growing season environment. Scanning for pregnancy status was not profitable in some regions/flocks if the scanning was occurring after the main feed deficit. In these cases, which were both merinos, the reproduction and feed benefits achieved were less than the cost outlay for scanning and the reduction in the wool production potential of the flock.

Selling the passengers to increase reproductive rate and reduce flock feed demand is the major contributor to the profitability of scanning for pregnancy status (Table 31). Altering the nutrition of the empty ewes that are retained is a minor contributor being half or a third of the value of managing the passengers when selling twice-empty ewes and much less when selling all the empty ewes (once-empty). The value identified as 'nutrition' when selling once-empty ewes at scanning is associated with the altering the nutrition of the pregnant ewes when the empty ewes have been removed.

It was optimal to sell once-empty ewes for the flocks that were scanning just prior to the main feed deficit provided that the weaning percentage was sufficient for the flock to be self-replacing. Flocks that could not be self-replacing or were scanning after the feed deficit sold twice-empty ewes. In the majority of the scenarios the empty ewes were sold at scanning (Table 32), although for the spring lambing flocks there was very little difference in profit with time of sale.

For maternals, identifying the empty ewes is a big contribution to the total value of scanning. This is driven by the gain in reproduction rate achieved from culling the once-empty ewes. However, the assumptions underpinning the analysis may not be correct, they are based on gains made in a Merino flock that had a higher proportion of empty ewes and hence a much higher selection pressure.

Table 31: Value of scanning for pregnancy status only ($/ewe) with the optimum management of the empty ewes and the contribution from each component that can be changed as a result of identifying the empty and pregnant ewes. Assuming 100% agreement between scanning and lambing.

	Value		Optimum	Contribution of the Component#	
	($/ewe)	($/empty)	management	Passengers	Nutrition
Long growing season – Merino					
Autumn	5.30	21.10	Twice-empty	4.30	1.80
Winter	4.40	33.20	Once-empty	3.80	1.20
Spring	0.90	8.90	Once-empty	1.30	0.00
*Long growing season – Maternals**					
Autumn	7.10	26.60	Twice-empty	13.00	0.20
Winter	7.20	67.10	Once-empty	11.40	0.40
Spring	2.80	30.60	Once-empty	8.40	0.40
Medium growing season – Merino					
Autumn	6.10	35.40	Once-empty	2.70	
Winter	-1.40	-10.10	Twice-empty	0.20	-0.70
Spring	1.50	11.30	Twice-empty	0.40	2.50
Medium growing season – Maternals					
Autumn	2.60	21.00	Once-empty	-2.40	
Winter			Once-empty	8.60	-7.60
Spring	0.40	3.90	Once-empty	4.80	-2.80
Short growing season – Merino					
Autumn	2.00	10.10	Once-empty	3.70	1.60
Winter	0.80	5.40	Twice-empty	0.30	-0.30
Spring	-0.20	-1.50	Twice-empty	0.60	-0.10
Short growing season – Maternals					
Autumn	8.50	62.40	Once-empty	11.70	-0.30
Winter	4.80	60.30	Once-empty	7.90	1.50
Spring	3.30	39.00	Once-empty	4.60	0.10
Overall average	3.30	25.00			

#The proportions don't sum to 100% because of interactions between the components and changes in the optimised management.

* The nutrition profile was not optimised for the Maternals in the long growing season environment.

Table 32: Management of the empty ewes that are identified by scanning for pregnancy status.

	Optimum Management	Proportion of emptys sold: At shearing	At scanning	Benefit of selling due to RR*
Long growing season – Merino				
Autumn	Twice-empty	0	59%	14%
Winter	Once-empty	0	100%	15%
Spring	Once-empty	0	100%	42%
Long growing season – Maternals				
Autumn	Twice-empty	0	51%	15%
Winter	Once-empty	0	100%	11%
Spring	Once-empty	0	100%	22%
Medium growing season – Merino				
Autumn	Once-empty	0	100%	34%
Winter	Twice-empty	0	21%	416%
Spring	Twice-empty	6%	15%	268%
Medium growing season – Maternals				
Autumn	Once-empty	0	100%	144%
Winter	Once-empty	0	100%	19%
Spring	Once-empty	0	100%	39%
Short growing season – Merino				
Autumn	Once-empty	0	100%	115%
Winter	Twice-empty	0	25%	373%
Spring	Twice-empty	6%	15%	176%
Short growing season – Maternals				
Autumn	Once-empty	0	100%	11%
Winter	Once-empty	0	100%	33%
Spring	Once-empty	0	100%	56%

* remainder of the benefit is due to removing the feed requirement of the empty ewe from scanning to shearing (if sold at scanning)

4.3.3.1 Rules of Thumb

- Scanning for pregnancy status increases profit for all flocks that are scanning prior to the main feed deficit and it is less valuable for flocks lambing in 'spring'.
- Selling once-empty ewes at scanning is most profitable for maternals provided the flock weaning percentage is sufficient to allow the flock to be self replacing.
- Selling once-empty ewes at scanning is most profitable for Merino-Merino flocks that are scanning prior to the main feed deficit (winter for long growing season and, autumn for medium and short growing season) and the flock weaning percentage is sufficient to allow the flock to be self replacing.
- Selling twice-empty ewes is generally the most profitable management for Merino flocks lambing in spring. Time of sale is less important for the flocks selling twice-empty ewes and the most profitable decision will likely depend on the amount of wool on the ewes back at scanning versus the value that would be realised for that wool.
- Selling empty ewes is not profitable for the Merino-terminal sire flocks because it reduces the number of surplus ewes that can be mated to the terminal sires. Retaining empty ewes was the most profitable management for these flocks.

4.3.4 Scanning for multiples

The increment in the value of scanning from identifying multiples was $4/ewe scanned and ranged from $0.30/ewe up to $10.80/ewe. For the earlier lambing flocks, scanning for pregnancy status is the major contributor to the total value of scanning and the increment due to scanning multiples is small (Table 33). The small contribution from scanning for multiples is because the value per multiple-bearing ewe tends to be smaller and the number of multiple-bearing ewes tends to be lower with earlier joining due to the seasonality of reproduction.

If presented as the value per ewe scanned with multiples the increment equates to $9.25/ewe scanned with multiples. This is an indication of the cost of errors associated with mis-identifying a multiple-bearing ewe as a single bearing ewe. If there is a 5% discrepancy between scanning and lambing then this reduces the total value of scanning by approximately $0.45 per multiple bearing ewe. A 15% discrepancy would reduce the value by approximately $1.40/multiple bearing ewe, which is about a 20% reduction in the total value of scanning (see Table 27).

Paddock allocation at lambing, differential nutrition of singles and multiples and improved management of replacement progeny contribute about equally to the extra benefit of scanning for multiples compared with scanning for pregnancy status only. The relative contribution does vary with the region, flock and time of lambing scenario and the maternals tend to have a lower benefit associated with paddock allocation.

Managing the performers adds very little to the value of identifying multiples based on the assumed benefits for reproductive rate and the costs of adjusting flock structure.

The benefits of differential nutrition of single- and multiple bearing ewes is a combination of increasing the nutrition of the multiple-bearing ewes and reducing the single-bearing ewes. Both contribute about equally to the profit outcome for both Merinos and maternals.

Differential nutrition of single- and multiple-bearing ewes improves lamb survival, progeny wool production (the Lifetime Wool effect), fleece value of the ewes and ewe mortality. On average, improved lamb survival accounts for 55% of the total value and progeny wool accounts for 40%. Ewe fleece value and ewe mortality are inconsistent in their effect and average close to zero. The small and inconsistent effect of dam mortality is not as expected particularly for the maternal flocks. The problem may be related to inaccurate relationships driving dam mortality due to pregnancy toxaemia and dystocia, because there is little information in this area. Improving these relationships may increase the value of scanning maternal flocks for multiples and may help sell the message to maternal producers.

Table 33: The increase in farm profit from scanning for multiples compared to scanning for pregnancy status ($/ewe scanned and $ per multiple bearing ewe identified) and the contribution of each lcomponent to the total value of scanning for pregnancy status for each growing season region, time of lambing and flock type examined.

Time of lambing	Increase in value $/ewe	$/multiple	Management of emptys and CFA ewes	Contribution of components* Pregnancy status	Performers	Progeny Management	Nutrition	Paddock allocation
Autumn	1.50	6.90	Twice-empty	5.30	-0.30	0.20	0.80	1.00
Winter	5.10	14.90	Once-empty	4.40	-0.10	2.80	3.50	1.80
Spring	2.70	7.10	Once-empty & performers	0.90	0.10	1.50	1.80	1.70
Autumn	0.30	1.50	Twice-empty	7.10	-1.00	-0.20	0.00	0.30
Winter	1.60	2.70	Once-empty & performers	7.20	0.30	0.00	0.10	1.60
Spring	3.00	4.10	Once-empty	2.80	-0.10	0.00	0.40	2.70
Autumn	3.10	8.90	Once-empty & performers	6.10	0.20	1.90	1.90	2.60
Winter	6.00	15.70	Twice-empty	-1.40	-0.40	1.70	1.80	2.50
Spring	4.30	11.20	Twice-empty	1.50	-0.10	0.80	4.50	2.00
Autumn	1.30	3.00	Once-empty	2.60	-1.80	0.70	1.00	3.10
Winter	10.80	16.90	Once-empty & performers	-4.80	1.10	5.50	6.90	1.70
Spring	10.00	16.50	Once-empty	0.40	-2.40	4.30	4.50	3.60
Autumn	2.80	8.90	Twice-empty & performers	2.00	0.40	-0.60	-0.20	1.50
Winter	4.90	13.70	Twice-empty	0.80	-0.10	2.40	2.30	1.80
Spring	2.30	6.70	Twice-empty & performers	-0.20	0.50	1.30	1.30	2.30
Autumn	1.90	5.70	Once-empty & performers	8.50	0.30	-0.70	-0.60	1.00
Winter			Once-empty & performers	4.80	0.20	-3.50	-2.80	1.30
Spring	6.10	12.60	Once-empty & performers	3.30	0.30	2.90	2.90	1.40
Average	4:00	9.25		2.75	-0.20	1.45	1.95	1.90

* the proportions don't sum to 100% because of interactions between the components and changes in the optimised management.

4.3.4.1 Rules of thumb

- The benefits associated with
    - improved allocation of paddocks at lambing
    - differential nutrition of singles and multiples
    - improved capacity to manage the replacement progeny from knowing birth type

  contribute equally to the extra value of scanning multiples.
- Identifying and managing the performers (by retaining 50% of the 5.5yo ewes with the highest net reproductive rate till 6.5 yo) had a low value, increasing profit in some scenarios and reducing it in others.
- Lamb survival and progeny wool production (LifetimeWool) are the main drivers of the value of differential nutrition.

4.4 Business case for pregnancy scanning & precision management of lambing groups

These are provided in a stand-alone document (see section 8.4).

4.5 Producer workshops, producer group and livestock consultant extension activities

The face-to-face events (producer workshops, field days or seminars) that the project team has participated in, as speakers on the program (in all bar one case, where a trade desk was manned), are listed in Table 34. By the end of June 2022, 9 events were held in which the project team participated. Unfortunately, the Best Wool/Best Lamb Annual Conference, which was scheduled to be held on the 16th of June, 2022 in Bendigo, has been delayed. A deferred event may still take place, in which Gordon Refshauge, NSW DPI (a project team member) plans to participate. Another member of the project team (Sue Hatcher), spoke at a later event (MeatUp, in Wagga in August, 2022), covering some content on pregnancy scanning generated from project outputs.

Table 34. Producer workshops, seminars and field days – talks given

Name of Event	Event No.	Location	Date	Deliverer / Topic	Number of Attendees	Ranking of Event
Sheep Connect SA, Prod. Advisory Group	1	SAGE Hotel, Adelaide, SA	28-Jan 21	Forbes Brien (FB) – Background & overview of project + progress	12	-
Mid-North High Rainfall Zone Technology Group	2	'Mernowie', Marrabel, SA	16-June 21	FB – Overview of project	12	-
MeatUp Forums	3	Gawler, SA	5-March 21	FB – '*Sheep Reproduction – getting the best out of your ewe flock*'. Included adoption & benefits of scanning	74	
	4	Longreach, QLD	25-March 21	Gordon Refshauge (GR) – '*How to improve sheep reproduction rates to increase productivity and profitability of your business*'. included scanning benefits	63	
AMSEA - Macquarie Site Field Day	5	Trangie Agric Res Centre	30 March 22	Sue Hatcher (SH) – *'Pregnancy scanning is profitable'*	75[2]	-
McKillop Farm Management Group – Workshop to establish a Discussion Group	6	Lucindale Football Club, SA	13 April 22	*'Scanning and survival in sheep'* Speakers - FB, Hamish Dickson (via Zoom), Alice Weaver, Josh Cousins & Andrew Kennedy (MLA funded Towards 90 Project	23	Mod to High Value to respondent's business[1]
AMSEA – SA site Field Day	7	Eckhert's, 'Mentara Park', Malinong, SA	3 June 22	FB – *Pregnancy scanning for genetic evaluation of sheep* Was a display/desk, rather than an oral presentation	130	
Barossa Improved Grazing Group – Focus Farm Field Day	8	Keyneton Station, Keyneton, SA	10 June 22	FB – *Pregnancy scanning* – key economic messages & results from honours project conducted at Keyneton Station	37[4]	Overall event value rating 8.6/10[2]
Best Wool Best Lamb – Annual Industry Conference		Bendigo, VIC	16th June 22	GR – to highlight video imagery of scanning and learnings as key feature *NB// Delayed due to Covid-19*	-	
WA Farmers Grains & Livestock Forum	9	Muresk Institute, Northam, WA	24 June 22	John Young presented: *Pregnancy scanning – can you afford not to scan?*	100	
MeatUp Forum		Northam, WA	5 Aug 22	No L.LSM.0021 project team members were involved, but Caroline Jacobson & Tom Clune from Murdoch University spoke on determining and managing scanning to weaning lamb loss, with some slides from the L.LSM.0021 project	76	
MeatUp Forum	10	Wagga Wagga, NSW	16 Aug 22	SH - Economics of pregnancy scanning and also the Sheep Reproduction Strategic Partnership	72	
MerinoLink	11	Bathhurst, NSW	12-Aug 22	GR - Improving lamb survival via the adoption of pregnancy scanning, understanding cause of death in lambs, and role of selection and management. *Included 11 slides on value of pregnancy scanning, and a 6 minute video sample of annotated pregnancy scanning videos*	30	-

Sources of Evaluation: [1]Sally Klose, McKillop Farm Management Group; [2]Department of Primary Industries and Regions, South Australia

Webinars given and consultant/advisor updates provided by the project team are listed in Table 35. Three webinars have been given by project team members. A total of 5 consultant/adviser updates have been given – 2 to the South Australian Livestock Consultants Group and 3 to Lifetime Ewe Management regional trainer forums.

A podcast recording was also made on the 13th of April, 2022 by the McKillop Farm Management Group on 'The business case for sheep scanning', with the speakers being Forbes Brien of the L.LSM.0021 Project and Charlie Crozier, a sheep producer from the South-East of South Australia. There have been 38 downloads of the podcast as of the 8th of September 2022.

Also of note, there has been 298 views of the recording of the first National Pregnancy Scanners on-line Workshop, organised by the L.LSM.0021 Project and held on the 6th of July 2021.

Whilst the Covid-19 pandemic and its restrictions have stymied face-to-face opportunities for extension of project messages during 2020 and 2021, the concentration of events during the first half of 2022, which has come towards the end of project has meant that all the key outputs and messages from the project were available to extend.

Table 35. Webinars and updates to consultant/advisor groups provided by the project team

Name of Event	Location	Date	Deliverer / Topic	No. of Attendees	Views of Recording
South Australian Livestock Consultants (SALC) – Livestock Advisor Update Conference	On-Line	29 July 21	Forbes B – *'Pregnancy Scanning and Flock Rebuilding'*. Background of preg scan project and progress to date	90	
SRSP Webinar Series	On-Line	5 April 22	*'How to Profit from pregnancy scanning':* John Young – Key Points of benefit cost study Josh Cousins – Pregnancy scanners perspective		512 (04/01/2023)
Sheep Connect SA	On-Line	18 May 22	Hamish D – Business case for pregnancy scanning.	41	29 (30/5/22)[1]
1. South Australian Livestock Consultants	University of Adelaide, Roseworthy, SA	11 Nov 20	Forbes B – *'Increasing lambing percentages through better use of pregnancy scanning technology'*. Background, project objectives, early results	25	
2. South Australian Livestock Consultants	Arkaba Hotel, Adelaide	4 May 22	Forbes B. *Benefit cost and business case for pregnancy scanning.*	18	
LTEM Regional Trainer Forums	McLaren Vale SA	3 May 22	Forbes B (in person) – overview & John Y (on-line) – economics of scanning	12 trainers[2]	
	Hamilton, Vic	18 May 22	Forbes B (in person) – overview & John Y (on-line) – economics of scanning	8 trainers[2]	
	Wagga, NSW	26 May 22	Sue H – overview & John Y – economics of scanning (both on-line presentations)	12 trainers[2]	

Information Sources: [1] Sheep Connect SA; [2] Bec Malseed, RIST, Hamilton, Victoria

In terms of producer group extension activities:

- *Barossa Improved Grazing Group (BIGG).* In early 2021, BIGG had a PDS project on containment feeding running at Keyneton Station, facilitated by a local livestock consultant, Deb Scammell (Talking Livestock) and ewes from that trial were deemed suitable candidates for a further study involving the utilisation of pregnancy scanning technology to better manage ewe nutrition for improving twin lamb survival and reproductive outcomes in general.

  The study was conducted during 2021 as part of an honours project for Alexander Turner, University of Adelaide, with the aims of using individual ewe management to control individual body condition scores (BCS) for increasing lamb survival rates and weaning weights from twin-bearing ewes. In particular, the study examined how body condition scores impacted the lambing and weaning rates of individual twin-bearing ewes via individual assessment, not mob averages.

  258 stud Merino ewes, joined with rams in December 2020 were scanned via trans-abdominal ultrasonography on the 29th of March 2021 to determine both pregnancy status and litter size. For the study, those ewes determined to be twin-bearing (129) were separated from the rest of the flock and run in a containment area for easier management and maintaining of body condition. Ewes were let out from containment (to adjust back to paddock conditions), three weeks before the beginning of lambing. BCS of the ewes was assessed on four occasions between pregnancy scanning and lambing. Ewes lambed under paddock conditions, with minimal supervision, except that dead lambs were collected each day for later necropsy. To assess parentage, two methods were used. Firstly, shepherd collars were placed on ewes for 48 hours prior to lamb marking for pedigree analysis by association and secondly, for DNA parentage analysis, tissue sampling unit (TSU) samples were taken from ewes and lambs at weaning and also from dead lambs at the time of necropsy. Twin-bearing ewes of BCS 2.0 had the lowest lamb marking of 50%, and the High BCS (>3.0) group of twin-bearing ewes had a 135% lamb marking, higher than the Low BCS (1.75 to 3.0) group at 123%. These preliminary results were impacted by 50 lambs not linked to ewes via DNA parentage analysis (out of 195 lambs sampled, including 22 dead lambs that were necropsied). After the student had completed the study, errors discovered in allocation of tag numbers on-farm were corrected and the DNA parentage analysis re-run, with 12 more lambs being linked by DNA to ewes. However, 38 lambs remained unmatched by DNA parentage analysis, due to some ewes being mis-drafted out of the twin-bearing mob prior to the time of DNA sampling (based on Shepherd Collar association results, rather than pregnancy scanning results). As aged ewes were sold off the property soon after their lambs were weaned, this error could not be corrected.

  A non-significant (P>0.05) Pearson correlation of -0.13 was calculated between the proportion of lambs reared to weaning per twin bearing ewe and ewe body condition score three weeks before lambing. This unexpected result was similar to findings of a recent study by Brougham *et al.* (2022). Despite the lack of correlation between lamb survival and ewe BCS, in the Brougham *et al.* (2022) study, lighter lambs were weaned from ewes in body condition scores of 2.5 and less compared lambs from ewes in a BCS range of 3.0 to 3.5. Notwithstanding, both trials were small in scale (93 and 96 twin-bearing Merino ewes respectively) and need to be repeated with larger studies before final conclusions are drawn, especially with regards to lamb survival.

  A field day at Keyneton Station on this work was originally planned for June 2021, with Gordon Refshauge, NSW DPI one of the speakers, along with Forbes Brien and Alex Turner.

However, due to COVID-19, restrictions, the day did not go ahead. Instead, a Focus-Farm field day was held at Keyneton Station on the 10th of June, 2022 and the preliminary results, plus key messages from the L.LSM.0021 project were presented by Forbes Brien. Approximately 40 people attended the Focus Farm field day.

- *MacKillop Farm Management Group.* The workshop 'Scanning and Survival in Sheep', was organised by MFMG, in conjunction with Forbes Brien and was successfully held on the 13th of April, 2022 at the Lucindale Football Club with approximately 25 attendees. The program for the workshop is pasted below:

In addition to the workshop, Forbes Brien recorded a Podcast on the 13th of April 2022 with the McKillop Farm Management Group, speaking about the key outputs of the L.LSM.0021 project.

- MerinoLink (NSW). Due to the recent commencement of the PDS project (in August 2021), apart from the 4 core and 7 observing sheep producers directly involved, there has not yet been any field day or seminar presentation on the results.

4.6 Package of information for extension networks – workshops like 'Lifting Lamb Survival', Profitable Grazing Systems and 'Lifetime Ewe Management'

These are provided as separate documents – see 'list of associated resources' (Section 8.4).

4.7 Monitoring and Evaluation activities

A limited amount of evaluation of extension events can be found in earlier sections, where a detailed description of the talks, webinars and consultant updates have already been provided, including talks given at the two national pregnancy scanner workshops.

5. Conclusion

Pregnancy scanning accuracy and agreement with lambing rates

On average, the error rate from scanning in the Merinoselect industry data studied as part of this project was very low for conception (eg average 2-3%) but higher and more variable for litter size (eg average 12-15%). For well managed flocks , the error rate for litter size could be reduced and the error in detecting dry ewes is frequently <1%.

Lack of agreement between scan and lambing records for litter size predominantly occurred for:

- 10-12% singles reported from twin scanned ewes (scan error, fetal loss or unreported lamb loss). Further, the expectation of fetal loss post-scanning is expected to <2% in healthy flocks (Anon, 2012). Therefore, this discrepancy is more likely the result of unreported lambs, which is a widespread issue for Merino flocks.
- Ewes lambing triplets were reported as scanning for twins or triplets (i.e. ~50% of triplet bearing ewes have an underestimate of litter size at scanning)

Therefore, scanners may need to apply more time to scanning for triplets as litter size rises above 1.5 (twinning ewes exceeds 50%).

The agreement of scan with lamb results for litter size is demonstrably improved with better timing of scanning with respect to fetal age at scanning. Assuming the most reliable scanning outcomes occur when the fetal age ranges between 35-42 and 100 days, breeders should aim to scan 42 days or more after the ram OUT date and maintain a short joining interval (<58 days) to ensure all ewes are within the target age range for fetal age at the time of scanning. Re-iterating clearer guidelines for the timing of scanning with respect to both ram in and out dates may assist producers to meet this target window for all ewes.

Poor results for some flocks are associated with a large difference between mean scan and lambing results. This is likely to result from delaying identification of lambs until marking or weaning, after the bulk of lamb deaths have already occurred. More divergent results suggest significant data error, either in lambing or scanning results.

Economic analysis of pregnancy scanning

Pregnancy scanning was shown to be profitable in all the scenarios of region (including the spring/summer rainfall region – see separate report by David Brown and John Young), flock and time of lambing that were examined provided the information, that can only be provided by scanning, was utilised to optimise management. This indicates that pregnancy scanning is an important strategy for improving profitability and improving lamb survival in the sheep meat and wool industries.

The profit that can be captured through scanning varied with time of lambing, the reproductive rate of the flock and the environment (chill at lambing). Therefore, effort will be required to package a message for industry that can accurately portray the variation within industry while still being understandable and demonstrating the overall benefit of scanning.

The sensitivity analysis carried out only tested a single factor at a time and did not show any factors that caused scanning to become unprofitable. However, there may be combination of factors that would identify scenarios in which scanning reduces profitability. When developing a general industry extension message the likelihood of these combinations should be considered and if the probability is low then they could be ignored.

This analysis has been more comprehensive than any prior analysis into the profitability of pregnancy scanning. It demonstrates that the benefit from pregnancy scanning accrues from a range of sources and the contribution of each varies with region, flock and time of lambing. Previous analyses have evaluated some but not all of the components that contribute to the profitability of scanning and this helps explain some of the variation in messages associated with the profitability of scanning. Because of the broad range of benefits, the profitability of pregnancy scanning is less sensitive to changes in any single factor.

5.1 Key findings

These are basically the same as the key and supporting list of extension messages discussed by the project team, together with MLA and AWI, with some further additions and refinements.

- Pregnancy scanning to identify multiple-bearing ewes, single-bearing ewes and empty ewes is profitable in all agricultural regions and flock types. This includes the southern agricultural regions that have a predominately winter rainfall pattern, as well as areas in the spring-summer rainfall zone in NSW in particular.

- The average increase in profitability is $5.75/ewe scanned, based on long-term prices for the period 2004 to 2020.

Table 36. The increase in farm profit ($/ewe scanned) from scanning for multiples and implementing optimum management for 3 regions, 3 flock types and 3 times of lambing.

	Time of Lambing		
	Autumn	**Winter**	**Spring**
	($/ewe)	*($/ewe)*	*($/ewe)*
Long Growing Season			
Merino	7.20	10.60	3.80
Merino – Terminal Sire	6.40	8.80	6.00
Maternal	7.50	8.80	5.40
Medium growing season			
Merino	7.80	2.80	5.50
Merino – Terminal Sire	9.80	5.20	3.70
Maternal	5.80	4.00*	4.20
Short growing season			
Merino	4.60	4.60	1.20
Merino – Terminal Sire	5.20	4.70	1.90
Maternal	8.40	3.50	6.50
Average	**7.00**	**6.10**	**4.25**
Overall average		**5.75**	

- For a 2,000 head ewe flock, this is a profit of $11,500.

- The return on investment for scanning averages 400%.

- Approximately half the value is from identifying pregnancy status (empty or scanned in lamb - SIL) and half the value is identifying single vs. multiple-bearing ewes.

- The value of identifying the single- and multiple-bearing ewes is equally spread between:
    - preferentially feeding multiple-bearing ewes to increase lamb survival and improve progeny lifetime wool production;

    - preferentially allocating the more sheltered paddocks to multiple-bearing ewes; and
    - improved selection of the replacement young ewes.

- Pregnancy scanning to identify pregnancy status only is generally profitable, but in most situations is less profitable than scanning for multiples.
    - Scanning for pregnancy status only can be a good introduction to the benefits and practicalities of scanning. It can be used as a stepping stone to scanning for multiples or fetal age.

- The accuracy of scanning can be improved by:
    - Scanning at the correct time – scan for multiples 80-90 days after the rams go in (based on the industry recommended 5 week joining period).
    - Correct preparation of the ewes on the day of scanning – ewes should be off feed and water for a minimum of 6 hours before scanning.

Supporting Extension Messages

1. Scanning for multiples is always more profitable than not scanning at all and mostly more profitable than scanning for pregnancy status only

2. Scanning has a larger impact on flock profitability for earlier lambing flocks that are scanning prior to the main feed deficit because of the increased value of identifying and altering the management of the empty ewes.

3. Scanning for multiples increases profitability more for Merino flocks than maternal flocks because preferential nutrition and preferential allocation of sheltered paddocks has a greater effect on the survival and production of multiple-born Merino lambs.

4. Actual reproductive rate does not have much effect on profitability when scanning for multiples because of the trade-off between reducing the number of empty ewes and increasing the number of multiple-bearing ewes as reproductive rate increases.

5. The return for Merino flocks is greatest in medium chill (average 1000 $kJ.m^{-2}.hr$) environments. For maternal flocks the benefits increase up to 1200 $kJ.m^{-2}.hr$. In either lower or higher chill environments the benefit from allocating twins to the low chill paddocks is reduced.

6. Scanning is profitable (as listed in Table 1) when calculated at current levels of agreement being achieved between scanning and lambing rates (when scanning for litter size), which is typically 85%. *Note: Profitability is higher ($6.30/ewe scanned), if calculated when assuming 100% agreement between scanning and lambing rates*

7. On average across regions, genotypes and time of lambing:
    - 65% of the value of identifying the empty ewes is from removing them from the flock and increasing the average future reproductive performance of the retained flock. The remaining 35% is from either reducing the feed demand from the flock because the ewes can be sold at scanning or from reducing the feed offered to the empty ewes during the pregnancy and lactation period.

    - Average profitability is $2.83/ewe from scanning only for pregnancy status. However, 50% of sheep producers do not scan at all, so are foregoing this profit opportunity, as well as the even larger opportunity if they scanned for multiples.

8. Some pastoralists are benefiting by adding in fetal ageing (in addition to scanning for pregnancy status), for better management of lambing groups (e.g. more appropriate timing of the lamb marking/weaning etc).

9. Scanning only for pregnancy status reduces profitability in some scenarios (Merino flocks with higher reproductive rates that are scanning after the main feed shortage – higher reproductive rate is associated with fewer empty ewes to be identified).

10. As the profitability of pregnancy scanning for multiples (average of $5.75/ewe scanned) has been estimated when the accuracy of scanning is conservatively set at 85%, a concern about scanning accuracy being less than 100% accurate is no excuse for lack of adoption. *'Do not let perfection be the enemy of the good'!*

11. Extra notes on improving the accuracy of scanning:
    - For joining periods longer than the 5-week industry recommendation, scanning can be undertaken across a wider window of time of 70-100 from rams in. However, accuracy is lower when scanning at 100 days, and at 70 days in flocks mating for 3 oestrous cycles. Further note. It is also useful to specify the timing of scanning relative to rams being taken out of the flock.

12. If you want to increase weaning percentages, scanning technology should be part of your annual management program. It provides vital information because it allows you to:
    - Understand how your flock is performing (and where to focus improvement) for each component of reproduction – fertility (pregnant vs non-pregnant at scanning), litter size (which ewes are carrying twins/multiples, versus those carrying singles), survival rates of lambs (calculated from combining scanning rate records with marking records)

    - Manage ewes according to their nutritional requirement, as you will know which ones are carrying twins/multiples, singles or are non-pregnant. In late pregnancy (last 6 weeks), single-bearing ewes need almost 40% more energy (and more protein) than non-pregnant ewes and over twice as much protein during lactation (see Figure 12). Twin-bearing ewes need even more in late pregnancy, 27% more energy than single-bearing ewes (and more protein) and 76% more than a non-pregnant ewe. In lactation, twin-bearing ewes need three times more protein than non-pregnant ewes.

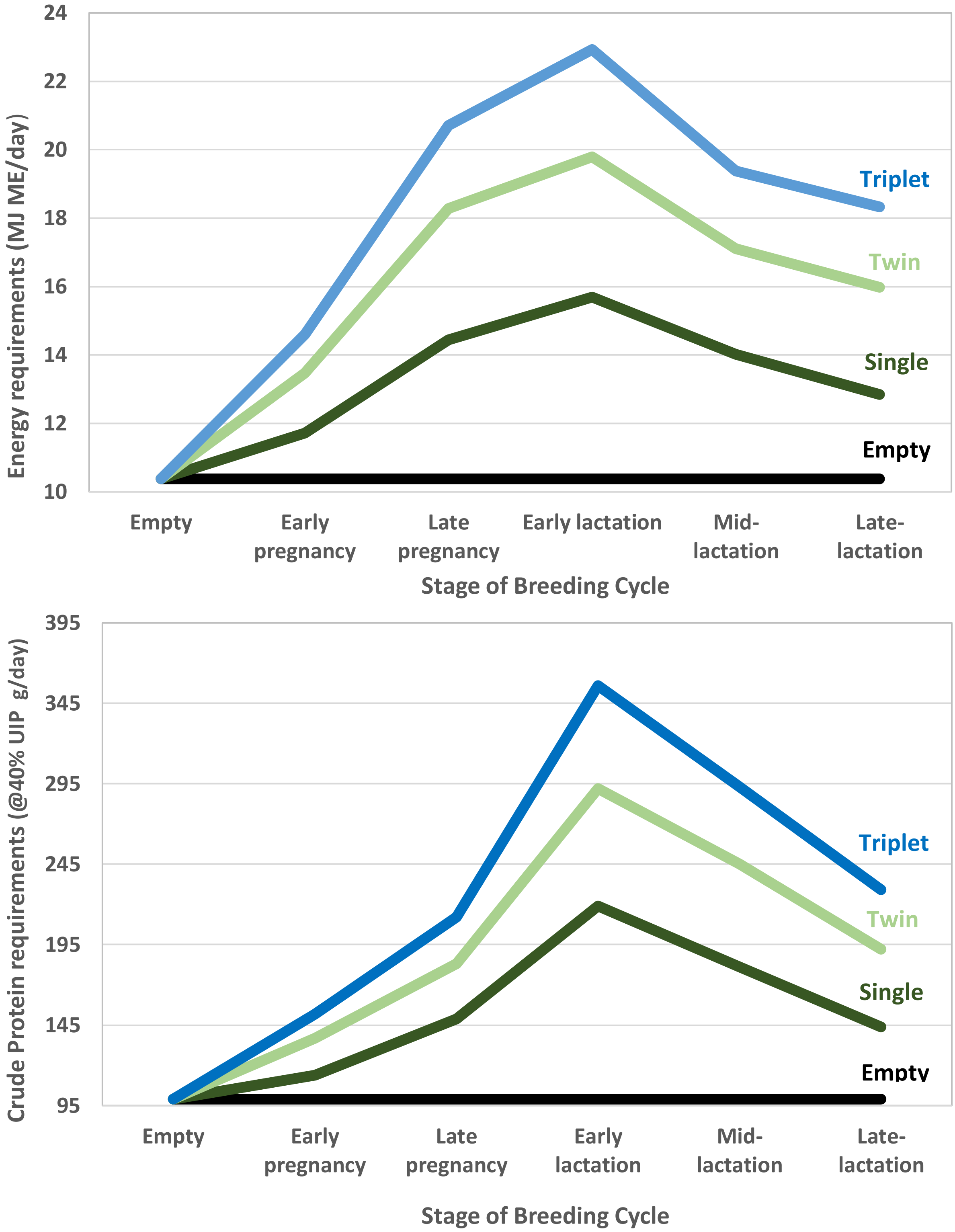

Fig. 12. Single, twin and triplet bearing ewes have greater energy and protein requirements than empty ewes. *Source: NRC (2007)*

13. Scanning allows you to be more proactive on enhancing animal welfare, especially when adopting the tailoring of ewe management according to the number of lambs they carry.

    a. This can improve survival of lambs and ewes (particularly twins/multiples*),* reduce difficult births and metabolic disease risk (pregnancy toxaemia and hypocalcaemia)

- Even if separately managing ewes of differing litter sizes at pasture is not practical, identified twin or multiple bearing ewes can be kept under containment feeding during late pregnancy or, under extreme conditions of drought (with little available supplementary feed), could be sold off the property

- It can also help satisfy Quality Assurance programs

14. Pregnancy scanning for litter size (even if just a portion of the flock – suggest a minimum of 200 ewes) is vital in helping to understand where the biggest opportunity is to reduce reproductive wastage e.g. be it improving lamb survival, improving pregnancy rates etc.

15. Capitalising on the information generated from scanning
    - Selling all empty ewes is most profitable if the flock weaning rate is high enough (>90%) to ensure the flock can remain self-replacing without altering the sale age of the cast for age ewes, if not, selling twice dry ewes is most profitable.

    - Selling empty ewes at scanning or at the following shearing depends on the time of scanning relative to the feed shortage and the value of the wool on the back at scanning. For maternal ewes with a low wool value, sale at scanning is most profitable.

    - If empty ewes are retained till shearing, reduce nutrition in late pregnancy and early lactation period and allocate the feed to the ewes pregnant with multiples. At lambing the empty ewes could be up to half a CS less than the pregnant ewes and by weaning the empty ewes should be a similar condition to the ewes that have raised twin lambs.

    - The multiple bearing ewes are the priority mob for better nutrition during pregnancy and lactation. The twin bearing ewes should be up to half a CS better than the single bearing ewes at the point of lambing but will lose more weight during lactation and be lighter at weaning.

    - Allocate the multiple bearing ewes to the better lambing paddocks – more sheltered, better aspect or fewer predators.

5.2 Benefits to industry

The take home messages from the project are:

- Scanning for multiples and implementing optimum nutritional management, optimal management of drys and optimal paddock allocation increased profit for all genotypes, in all regions at all times of lambing over the full range of reproductive rates examined in this analysis (scanning percentage range from 70% to 180%). The average increase in profit from scanning for multiples was $6.30 per ewe scanned, when 100% scanning accuracy is assumed.
- The highest value from scanning is achieved for flocks that are scanning just prior to the worst feed deficit because decisions can be made to more effectively manage the nutrition of the ewes during this feed shortage. This is ‘winter’ lambing in the long growing season environment and ‘autumn’ lambing in the medium and short growing environments.
- In general, scanning has the least impact on profit for spring lambing flocks.

- A discrepancy between scanning results and lambing outcome reduces the value of scanning. A 15% discrepancy reduces the value of scanning for multiples to $5.75/ewe scanned.

Nutrition profiles

- If ewes are not differentially fed during pregnancy, dry ewes will be 3-5 kg heavier than the single bearing ewes at lambing, and the twin bearing ewes will be 3-5kg lighter than the single-bearing ewes (maternal body weight).
- If dry ewes are identified and not sold, then the optimal management is for dry ewes to lose weight after scanning. The amount of weight loss depends on the severity of the feed shortage but the dry ewes can be up to 10kg lighter than the singles at birth (maternal body weight).
- If the multiples are also identified, the optimum nutritional management is to increase the feed supply and to be 2 to 3kg heavier than the singles at birth (maternal body weight).

Scanning for Pregnancy Status (wet/dry) only

- Scanning for pregnancy status increases profit for all flocks that are scanning prior to the main feed deficit and it is less valuable for flocks lambing in 'spring'.
- Selling once-dry at scanning is most profitable for maternal ewe flocks provided the flock weaning percentage is sufficient to allow the flock to be self-replacing.
- Selling once-dry at scanning is most profitable for merino flocks that are scanning prior to the main feed deficit (winter for long growing season and, autumn for medium and short growing season) provided the flock weaning percentage is sufficient.
- Selling twice-dry is generally the most profitable management for merino flocks lambing in spring. Time of sale is less important for the flocks selling twice-dry and the most profitable decision will likely depend on the amount of wool on the ewes back at scanning versus the value that would be realised for that wool if the ewe is sold.

Scan for multiples

- The benefits of scanning for multiples are associated with:
    - improved allocation of paddocks at lambing
    - differential nutrition of singles and multiples
    - improved capacity to manage the replacement progeny from knowing birth type

  These benefits contribute equally to the extra value of scanning for multiples.
- Based on data extrapolated from the 'passengers vs performers' empirical research project, identifying and managing the performers (by retaining 50% of the 5.5yo ewes with the highest net reproductive rate till 6.5 yo) had a low value, increasing profit in some scenarios and reducing it for others.
- Lamb survival and progeny wool production (LifetimeWool) are the main drivers of the value of differential nutrition. Models that don't include the progeny wool production benefits will miss this component of the benefits of scanning.

Paddock allocation

- The benefits from improving paddock allocation are an important contributor to the value of pregnancy scanning. Therefore, information about the benefits from differential allocation will be an important component of the extension message.
- If the only benefit from paddock allocation is due to optimising mob size at lambing the benefits of scanning are reduced by approximately $1.10/ewe on average. However, in all cases the total benefit remains positive because the scenarios that have low total benefits also have a lower reduction due to excluding the chill benefits.

Reproductive Rate

- The total value of scanning is not sensitive to the reproductive rate of the flock provided that the weaning percentage is sufficient that the flock can remain self-replacing when 'twice-drys' are sold.
- As reproductive rate increases the reduction in the value of managing the reduced number of dry ewes is offset by the increase in value of managing the extra multiple bearing ewes.
- The value of scanning for pregnancy status expressed per dry ewe is constant across a range of proportion of dry ewes, provided the flock can remain self-replacing.
- The increment in the value of scanning for multiples above that achieved from scanning for pregnancy status is constant across a range of proportion of multiple-bearing ewes.

Prices

- The value of scanning is sensitive to the price of meat and a 10% change in lamb price is associated with a 15% change in the value of scanning.
- The prices used in this analysis are below the current prices being received therefore the value predicted for scanning is an underestimate of what would be currently achieved. Extrapolating the results to the current meat prices indicates that the value of scanning would average about $10 per ewe.
- The value of scanning is not altered by the price of wool or the cost of grain because there is little change in the total quantity of wool produced or the amount of grain fed.

Equations and Chill

- Higher average chill increases the value of scanning for merinos and reduces the value for maternals. A ± 10% variation in the chill index altered profitability by about $1/ewe.
- Using the GrazPlan equations predicts about a $2/ewe lower benefit for pregnancy scanning of merinos, but a similar benefit for maternals. This is because the GrazPlan relationships for merinos show less difference between singles and twins in the response to survival due to their dams nutrition during pregnancy.

Accuracy of scanning

This can be improved by:

- Scanning at the correct time – scan for multiples 80-90 days after the rams go in (based on the industry recommended 5-week joining period).

- Correct preparation of the ewes on the day of scanning – ewes should be off feed and water for a minimum of 6 hours before scanning.
- For joining periods > 5-weeks, scanning can be undertaken across a wider window of time of 70-100 from rams in. However, accuracy is lower when scanning at 100 days, and at 70 days in flocks mating for 3 oestrous cycles. It is also useful to specify the timing of scanning relative to rams being taken out of the flock.

Improving animal welfare

- Scanning allows sheep producers to be more proactive on enhancing animal welfare, especially when adopting the tailoring of ewe management according to the number of lambs they carry.
  - This can improve survival of lambs and ewes (particularly twins/multiples*),* reduce difficult births and metabolic disease risk (pregnancy toxaemia and hypocalcaemia).
  - Even if separately managing ewes of differing litter sizes at pasture is not practical, identified twin or multiple bearing ewes can be kept under containment feeding during late pregnancy or, under extreme conditions of drought (with little available supplementary feed), could be sold off the property.
  - It can also help satisfy Quality Assurance programs.

Reducing reproductive wastage

- If a sheep producer is only pregnancy scanning for pregnancy status only, scanning even just a portion of the flock for litter size (recommend a minimum of 200 ewes be scanned for multiples) is vital in helping to understand where the biggest opportunity is to reduce reproductive wastage e.g. be it improving lamb survival, improving pregnancy rates etc. It also indicates flock potential.

6. Future research and recommendations

Future R&D

- Extending the collation of pregnancy scanning data nationally, for benchmarking purposes, as already carried out on a regional basis in Western Australia, is a fairly obvious way of adding value to the current investment in pregnancy scanning technology.
- Projects addressing the logistical reasons given by some sheep producers for not scanning (especially for multiples), including not having enough paddocks and unwillingness to lamb down small mobs of twin or multiple-bearing ewes should be initiated. These could include investigating whether single-bearing and twin/multiple-bearing ewes that have been separated during late pregnancy to better meet condition score targets for lambing and have met them successfully could be boxed back together just before lambing, without reducing overall lamb survival compared to maintaining separate single and twin/multiple-bearing flocks through lactation. This would create less and slighter larger mobs for lambing, more closely matching available lambing paddocks.
- Although originally planned as part of the L.LSM-0021 project, the feasibility of using features of scanning imagery as predictors of later fetal and lamb health and survival is still worth investigating, especially with the greater availability of suitable video equipment to directly attached to scanning equipment and the absence of Covid-19 travel restrictions. A similar

recommendation is made for investigating the feasibility of remote diagnosis, where video imagery of scanning can be sent to a sonographer specialist.
- Also, originally proposed but rejected as part of the L.LSM.0021 project, the feasibility of using machine learning (and/or deep learning) to aid in pregnancy scanning is still worth investigation. This could help not only in ultimately increasing the capacity for scanning more sheep, but could potentially aid in further improving scanning accuracy, particularly for more fecund sheep and could aid in identification of fetal and uterine abnormalities.
- Extending the economic analysis and business case for pregnancy scanning to the pastoral/rangeland areas of Australia.
- Improvement of scanning accuracies for triplets and higher order litters and associated optimisation of management for ewes bearing triplets or more.
- Video images of pregnancy scanning already collected during the L.LSM.0021 project, augmented by a number of additional scanning images, could be packaged in such a way as to provide an on-line learning package for novice scanners.
- A working group (to include pregnancy scanners, consultants and scientists) be established to:
    - provide recommendations on the future training needs for pregnancy scanners and how they can be best met.
    - plan conduct future workshops for scanners and provide a focus for interaction between scanners, scientists, consultants, producers, MLA and AWI and government.

Development and adoption activities which would ensure the red meat industry achieves full value from the project's findings
- The project team strongly believes that best value would be obtained through support of small group learning activities, which have demonstrated their ability to achieve practice change. In particular, incorporating project findings in existing programs such as Lifetime Ewe Management and the newly-created Towards 90 program, plus programs such as Lifting Lamb Survival and Profitable Grazing Systems, is strongly supported.

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8. Appendix: Economic analysis of the benefits and costs of pregnancy scanning in sheep

8.1 The winter rainfall regions

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Abstract

Reducing reproductive wastage is a major opportunity for improvement across all sheep regions and breeds in Australia. Scanning ewes to establish reproductive potential and then managing to that potential is a critical step to lift lamb marking percentages and profitability. However, 69% of all sheep producers do not scan for fetal numbers and are therefore not fully aware of the potential within their flocks. Furthermore, there are conflicting messages in industry about the profitability of pregnancy scanning flocks. Therefore, achieving some clarity on scenarios where scanning is likely to increase profit would help industry.

The analysis in this project was carried out with the Australian Farm Optimisation model representing 3 regions with varying length growing season across southern Australia. For each region three flock types and three times of lambing were evaluated. The flock types were based on a merino mated to merino, merino mated to a terminal sire and a maternal composite genotype. This provided 27 different scenarios that were tested.

The results demonstrate that pregnancy scanning is an important strategy for improving profitability and improving lamb survival in the sheep meat and wool industries. Farm profit was increased in all the scenarios of region, flock and time of lambing that were examined. The benefit ranged from $1.20 up to $10.60 per ewe scanned. The benefits accrue from a range of sources and because of this broad range the profitability of pregnancy scanning is robust to changes in any single factor.

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Introduction

There are conflicting messages in industry about the profitability of pregnancy scanning flocks which was demonstrated by a survey of producers in Western Australia that found that producers were close to equally divided on its value (Elliot 2011). Young *et al*. (2016), using prevailing prices in 2014-15 and production responses from the Lifetime Wool research project (Oldham *et al.* 2011; Paganoni *et al.* 2014), estimated that targeting ewe nutrition according to litter size increased profit by $0.80 per ewe for a flock with 124 foetuses per 100 ewes scanned. This value was increased if farmers could target other management to the twin ewes, beyond targeted nutrition, to further increase twin lamb survival. This aligns with an earlier study of Bowman *et al.* (1989) that showed an increase in cash operating surplus of about $0.10/ewe if the reproductive rate was 97% but contrasts with "the take-home message from Holmes and Sackett (2008) that it was more profitable not to scan but ensure adequate nutrition for ewes in late pregnancy, managing them as if the whole flock were bearing a single lamb and were to lamb in the first cycle of lambing, rather than scanning and managing according to pregnancy status" quoted from Refshauge & Shands (2014). McGrath et al. (2016) showed an approximately $0.45/ewe reduction in gross margin from differential nutrition associated with scanning for a spring lambing flock with a scanning percentage of 124%. They also tested a flock scanning 144% and the gross margin of the scanned flock was "at least as high as not scanning", demonstrating that reproductive rate influences the profitability of scanning. Bowman *et al.* (1989) also demonstrated that the value of scanning increased with higher reproductive rate.

A component of the mixed messages is that each author mentioned above showed some scenarios in which scanning increased profit and some scenarios where it reduced profitability. Therefore, achieving some clarity on scenarios where scanning is likely to increase profit would help industry. This view was articulated in a final report to the Sheep CRC, where Refshauge and Shands (2014) stated, in regard to pregnancy scanning "What the sheep industry requires is a set of conditions that need to be met before a positive return on investment can be achieved, for a wide range of environments and business structures (i.e. location, dam breed, proportion of wethers and proportion of crossbreeding)."

To achieve this goal requires identifying and quantifying the benefits of pregnancy scanning, which can accrue from:

1) separation of multiple-bearers from single bearing and empty ewes and better allocation of pasture or supplementary feed based on specific nutritional requirements reflecting litter size. This can include
   a) preferential nutrition of ewes during pregnancy based on litter size to increase total lamb survival by targeting the animals that have the greatest survival response from altering nutrition. Either
      i) increasing nutrition for ewes to reduce mortality of lambs due to starvation and mis-mothering or
      ii) reducing nutrition to dams that are having difficult births due to over large lambs.
   b) preferential nutrition of multiple bearing ewes to maximise the lifetime wool production benefits achieved from improved pregnancy nutrition. The lifetime effect of improved nutrition is similar for both single and twin bearing ewes but the twin bearing ewe has more progeny to express the benefit.
   c) preferential feeding of ewes during lactation based on litter size, to either
      i) increase total weaner survival by targeting the animals that have the greatest survival response from improved nutrition.

   ii) increase prime lamb sale value by targeting nutrition to the animals that will generate the most income from the extra weight.
  d) limiting nutrition of single bearing ewes to reduce mortality due to dystocia while maintaining nutrition levels to multiple bearing ewes to reduce mortality due to pregnancy toxaemia. This is a likely strategy for the maternal breeds.
  e) reducing nutrition to empty ewes to reduce total flock feed demand
  f) selling the scanned empty ewes to reduce total flock feed demand.
2) selling empty ewes as a premium price product during winter, being a period of low supply.
3) Culling the ‘passengers’, culling empty ewes to remove the low performing ewes from the flock so the feed can be utilised by more productive animals.
4) Retain the ‘performers’, retain older ewes that have a proven track record of high reproductive performance for an extra year.
   Culling and retention strategies (passengers versus performers) can be practiced based on scanning records of individual ewes, with flock gains in net reproduction rate between 2% and 6% expected (Lee et al. 2014).
5) improve allocation of dams to paddocks based on litter size
  a) better allocation of limited shelter resources and better lambing paddocks to the ewes that will generate the biggest response, which is likely to be those with multiple foetuses
  b) optimising the mob size at lambing based on litter size, because survival of twins is more responsive to smaller mob size than singles.
6) better allocation of feed and shelter based on predicted lambing dates from foetal aging, so that ewes giving birth (and their progeny) early or late in the lambing period can be more appropriately managed during the high-risk period around the point of lambing.
7) identify conception failure that may allow remating of the empty ewes or identification of an emerging issue that can be more appropriately managed either through having more lead time or being able to be more specific about the time of the reproductive failure.
8) it enables producers to calculate lamb losses between scanning and marking and also measure the reproductive potential of their ewe flock. Both of these may highlight other management changes that could increase flock reproduction levels and provide motivation to the manager to implement changes to improve lamb survival and flock reproduction.

To calculate the profitability of pregnancy scanning requires accounting for each of these benefits together with the costs of pregnancy scanning. Excluding any of the benefits will lead to an underestimate of ‘true’ profitability.

Review of previous studies

Previous analyses that have been carried out include Bowman *et al.* (1989), Holmes and Sackett (2008), McGrath *et al.* (2016) and Young *et al.* (2016). Each of these analyses have valued some of the above components but not all.

Bowman *et al.* (1989) using the Breeding Ewe model evaluated:

‘1a’ Preferential feeding during pregnancy “to maintain maternal bodyweight” this would reduce ewe & lamb mortality at birth.
‘1c’ Preferential feeding during lactation to improve lamb growth rates and weaning weight
‘1f’ Selling the empty ewes at scanning to reduce flock feed demand
‘2’ Including a 20% premium on the sale price of the empty ewes sold at scanning
‘4’ Selectively breeding from the twin bearing ewes to increase subsequent flock reproductive rate.

Holmes & Sackett (2008) using partial budgeting evaluated:

- ‘1a’ the preferential nutrition of ewes during pregnancy to increase lamb survival. This was achieved more by implication than being specifically quantified because the authors looked at the cost of supplying feed to meet the energy demands of the ewe in late pregnancy. They assessed the difference in feed requirement of single and twin bearing ewes and the benefit of being able to meet the demand of twin bearing ewes. Although no cost was quantified, the conclusion was that the best outcome was to feed all ewes as if they were single bearing and lambing in the first cycle. This approach, while representing the feed demands of the majority of ewes does not put a value on the benefit that could be achieved by increasing the feed to the twin bearing ewes while reducing the feed provided to the single bearing ewes. However, that question would have been very hard to address in a partial budget framework as used by these authors.
- ‘1f’ Selling empty ewes to reduce the feed demand of the flock
- ‘3’ Culling empty ewes to increase subsequent reproduction of the current flock is mentioned but they conclude that “there is no benefit to the subsequent productivity of the commercial flock”.
- ‘5’ better allocation of dams to paddocks based on litter size. They assumed an 8% improvement in twin lamb survival in the better paddocks compared to the average.

McGrath *et al.* (2016) using the AusFarm wholefarm simulation model evaluated:

- ‘1a’ preferential nutrition to increase lamb survival
- ‘1e’ reducing the nutrition of empty ewes to reduce total flock demand

Young *et al.* (2016) using the MIDAS whole-farm bioeconomic model concentrated on the differential nutrition of the ewes during pregnancy based on the LifetimeWool research findings. They evaluated:

- ‘1ai’ preferential nutrition to increase lamb survival
- ‘1b’ preferential nutrition to optimise lifetime wool production
- ‘1e’ reducing the nutrition of empty ewes to reduce total flock demand
- ‘1f’ selling the scanned empty ewes to reduce total flock feed demand
- ‘2’ selling empty ewes as a premium priced product in winter
- ‘3’ selling empty ewes to increase subsequent reproduction
- ‘5’ better allocation of dams to paddocks based on litter size, however, this was not based on valuing a particular strategy simply as a sensitivity analysis.

Modelling

The complexity of the calculations required to represent the production impacts of pregnancy scanning suggest that a modelling framework is used rather than the partial budget analysis of Holmes & Sackett (2008). The 2 whole farm models that are capable of this type of analysis are AusFarm & AFO (the MIDAS replacement). Each model has advantages and disadvantages.

AFO (MIDAS replacement)

The advantage of AFO is optimising management, particularly optimising stocking rate, pasture utilisation, grain feeding and the nutrition profile for ewes with different litter size. This ensures that the comparison is not controlled by the users selection of the flock management of either of the scanning scenarios. The impact of the user selection of the flock management was demonstrated by the comment in the paper of McGrath *et al.* (2016) that they allocated the twin bearing ewes “approximately 25% more area per head than the single bearing ewes”. In the optimisation models the allocation of feed to singles and twins is optimised based on the rules included in the model rather than being an arbitrary decision of the user.

The main limitation of AFO is not explicitly representing seasonal variation. This could be important because it is expected that in a poor year that feed will have a higher opportunity cost, and therefore practices such as allocating the scarce feed to the priority mobs or selling empty ewes will be more valuable. Due to this shortcoming the static equilibrium optimisation models will under-estimate the value of scanning, however, for this analysis the shortcomings due to not representing seasonal variation are outweighed by the benefits of being able to efficiently represent the other factors that are impacted by pregnancy scanning.

AusFarm

Advantages: AusFarm explicitly represents between year variation in pasture growth and animal production, and therefore the value of pregnancy scanning in the range of season types could be quantified. However, it is important to also include other tactics that could be employed in poor seasons that mitigate the feed shortage, otherwise the AusFarm analysis would overestimate the value of pregnancy scanning by overestimating the opportunity cost of the pasture.

Disadvantages: Optimising management in AusFarm is a user intensive process, especially considering that to benefit from the representation of seasonal variation requires that the management would need to be optimised for each season individually. This is an important limitation because optimum allocation of feed to ewes with different litter size is one of the main benefits of pregnancy scanning and poor feed allocation decisions in the analysis would under-estimate the value of scanning.

Further differences that would be noticed if analyses from the two models were compared is the different production relationships that link ewe nutrition profile to ewe production, lamb birth weights and lamb survival & progeny production. Young *et al.* (2011) concluded that differences in lamb mortality was a major driver of the profitability of different nutrition profiles. The MIDAS model used the relationships developed in the Lifetime Wool project to estimate birthweight from ewe LW profile and then lamb mortality at birth to lamb birth weight (Oldham *et al.* 2011; Paganoni *et al.* 2014) and as subsequently updated to include FOO at birth and chill index (Thompson *pers comm.*). In contrast AusFarm estimates lamb mortality due to exposure at birth from dam body condition at birth and chill index as explained in the LambsAlive DST (Donnelly *et al.* 1997). The relationships used in AusFarm generally predict a higher mortality than the LTW relationships, especially for the single bearing ewes. Furthermore, the AusFarm predictions of the change in lamb mortality with changing ewe nutrition is more responsive to change in nutrition for single born lambs but less responsive for twin born lambs. This difference is likely to reduce the estimated profitability of scanning ewes and providing differential nutrition.

The AFO model includes both relationships so the optimum nutrition profiles and profitability can be compared using the 2 different equation systems. Furthermore, the AFO & MIDAS models include the impact of ewe nutrition during pregnancy on progeny lifetime production from the Lifetime Ewe Management program, whereas these are not included in the AusFarm model and were not included in the Breeding Ewe model used by Bowman *et al.* (1989).

Aims

The aim of this report is to identify the necessary conditions that make scanning profitable, this will be the background for preparation of a comprehensive business case across a range of environments, seasons, management systems, flock sizes and prices for sheep, lambs and wool. The Australian Farm Optimisation model (AFO) has been used for the analysis, this model is a development from MIDAS and includes more detail in most components of the farm; the feed budget and flock management are especially relevant to this analysis. Focus has been applied in the analysis to examine the impact of seasonal variation on the value of scanning. A subsequent version of AFO will directly address seasonality however that functionality is still under development.

Method

Production assumptions

Estimated profit from pregnancy scanning is likely to be sensitive to the expected change in productivity when nutritional management of the empty, single or twin bearing ewe is altered. Therefore, alternative estimates have been compared to determine if this alters the recommendations about profitability and whether this is an area that needs further assessment prior to robust messages being available for industry. Two sources of information have been compared:

1. The Lifetime Wool research project (LTW) offered a range of nutrition during pregnancy to ewes in small plots and also in paddock scale trials. A range of relationships were developed from the small plot trials and the survival responses were scaled based on the paddock scale results. The relationship used in this analysis are from the Lifetime Ewe Management manual upgrade carried out in 2020 (Thompson *pers. comm.*)
2. The relationships in the GrazPlan series of models that have been developed by CSIRO and documented in Freer *et al.* (2012).

Scanning accuracy

The modelling analysis was carried out assuming that the agreement between the scanning result and the lambing outcome was 100% which is consistent with the findings of Fowler & Wilkins (1984) and Smith *et al.* (1988) in a research setting. However, a review by Bunter (2021) using farm data showed only an 85% agreement between the scanning result and the number of lambs born. The discrepancy is explained partly by foetal loss from scanning through lambing and partly by scanning difficulty due to less-than-ideal timing in commercial flocks. The predominant discrepancy was between ewes identified with twins and lambing as a single. As a result of this discrepancy the modelling results were subsequently adjusted to align with the findings of Bunter *et al.* (2021).

Identifying a multiple as a single, results in the multiple bearing ewe being managed as a single. The impact of this on profit can be approximated from the results presented in the economic analysis by:

1. Scaling the increase in profit from scanning multiples compared with just scanning for pregnancy status. This will represent the reduction in profit from managing 15% of the multiple bearing ewes as if they had only been scanned for pregnancy status. It will be a slight over-estimate because a component of the value of scanning for multiples is associated with altering the nutrition of the single bearing ewes, not just changing the management of the multiple bearing ewes.
2. Making a further allowance for the multiple bearing ewe being managed as a ‘single’ rather than ‘only scanned for pregnancy status’. This is the effect of reducing the nutrition of the

multiple bearing ewes from the level that is optimal if the ewes are not scanned to that which is optimal for singles if they are scanned.
The main results (**Table 19**) indicated that the value of altering the nutrition of the multiple bearing ewes from the unscanned optimum to the optimum when scanned for multiples was \$1.95/multiple bearing ewe. It has been assumed that the reduction in profit if managed as single would be half this value (\$1/multiple bearing ewe).

The average reduction in profit estimated for scanning with 85% agreement compared with 100% is \$0.55/ewe. The magnitude of the difference is higher for spring lambing than autumn and winter lambing because of the higher scanning percentage expected for the later joining.

Lamb Mortality due to exposure and mis-mothering

The method for estimating lamb survival developed in the LTW project was a 2-step process. Firstly, calculating lamb birthweight from the ewe LW profile, sex of the lamb and birth type (BT). Then calculating transformed lamb survival from birth weight, birth type (BT), sex, chill index & FOO at lambing, which is then back transformed. These back transformed values were then scaled by the paddock level scalar.

The relationships are:

$$Birth\ weight\ (BW) = 3.57 + 0.028LW_{joining} + 0.034LWC_{early\ preg} + 0.046LWC_{late\ preg} - 1.03(twin) - 0.2(female)$$

$$tSurvival = 1.295 + 3.708BW - 0.3417BW^2 - 0.4827(twin) - 2.521(female) - 0.01017chill + 0.00293chill(female) + 1.592FOO - 0.37FOO^2$$

$$Survival = 1/(1 + e^{-tSurvival})$$

$$Scaled\ survival = Survival_{base} + PaddockLevelScalar(Survival - Survival_{base})$$

BW (kg) is estimated from ewe LW at joining & LW change during pregnancy (kg).
Chill ($kJm^{-2}.d$) is calculated using relationship from Nixon-Smith (1972).
The paddock level scalar, estimated from the paddock scale monitoring in the LTW project, was 8.5 for single lamb survival and 2.0 for twin lamb survival. These estimates were made prior to the analysis of the 'plot level' chill index data and chill data was not available for the paddock scale trial. As such these paddock scale adjustments have not been tested over a range of chill levels (see also Figure 5).

Note: The relationship between birthweight and survival of single born lambs begins to reduce if birth weight is above 5.5kg (Figure 1). This is consistent with difficult births and increased mortality due to over large lambs (which is one component of dystocia) and mortality due to dystocia is not included specifically as it is in the GrazPlan equations.

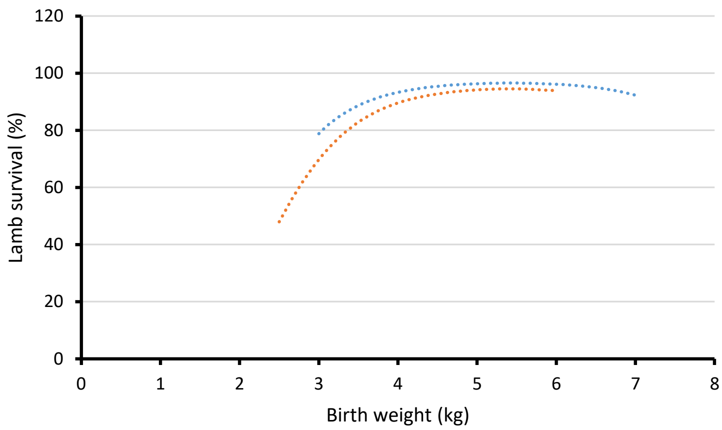

Figure 1: Relationship predicted by the LTW equations between birth weight and survival of single (blue dots) and twin born lambs (red dots).

The relationship used in the GrazPlan models calculates a transformed mortality index from ewe body condition at birth (BC), birth type (BT) & chill index. The mortality index is back transformed to mortality.

$$tMortalityIndex\ Wool\ sheep = -9.95 - 1.71BC + 0.0098chill + 1.1(twin)$$

$$tMortalityIndex\ Meat\ sheep = -8.90 - 1.49BC + 0.0081chill + 0.82(twin)$$

$$Mortality = 1/(1 + e^{-tMortality})$$

$$Survival = 1 - Mortality$$

Body condition (BC) is defined as ewe LW divided by normal weight (where normal weight is the weight of a well grown animal of the same age). A BC of 1.0 is similar to a CS of 3.

The LTW equations and GrazPlan equations generate different predictions for lamb survival with varying ewe condition score at lambing and different chill index at birth. The LTW plot scale equations predict higher survival at all ewe CS (Figure 3) and the paddock scale equation predict higher if ewe CS at lambing is greater than 2.5 (Figure 2). The LTW predictions are higher for all levels of chill (Figure 4), although both sources predict high survival of both singles and twins if the chill index is less than 800.

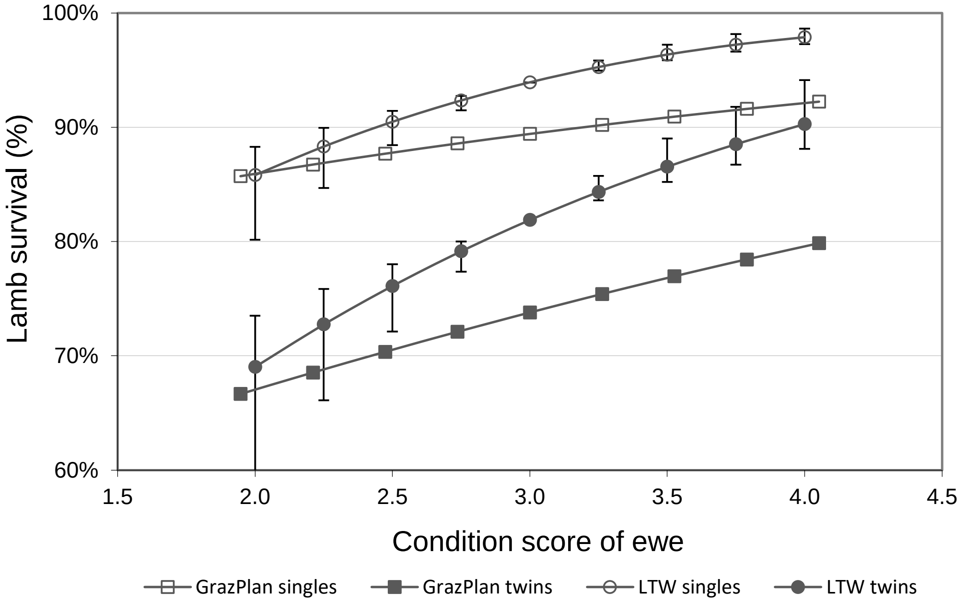

Figure 2: Lamb mortality of single and twin born lambs from ewes with different CS at lambing estimated using the LTW equations and the GrazPlan equations. Paddock scalar included for LTW, FOO 1000kg/ha, Chill Index 1000. The error bars on the LTW estimate are based on the timing of the LWC.

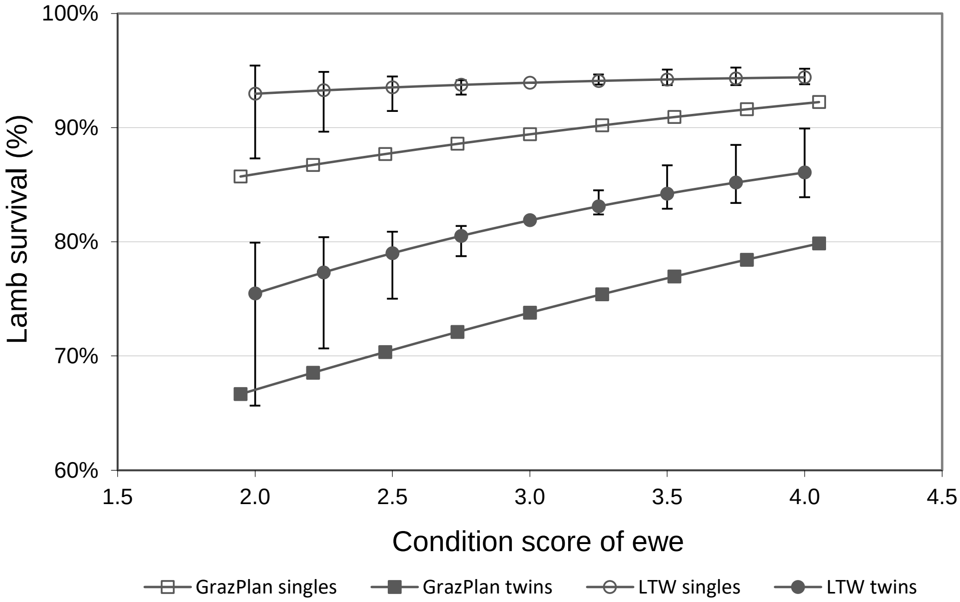

Figure 3: Lamb mortality of single and twin born lambs from ewes with different CS at lambing estimated using the LTW equations and the GrazPlan equations. Plot scale relationship for LTW, FOO 1000kg/ha, Chill Index 1000.

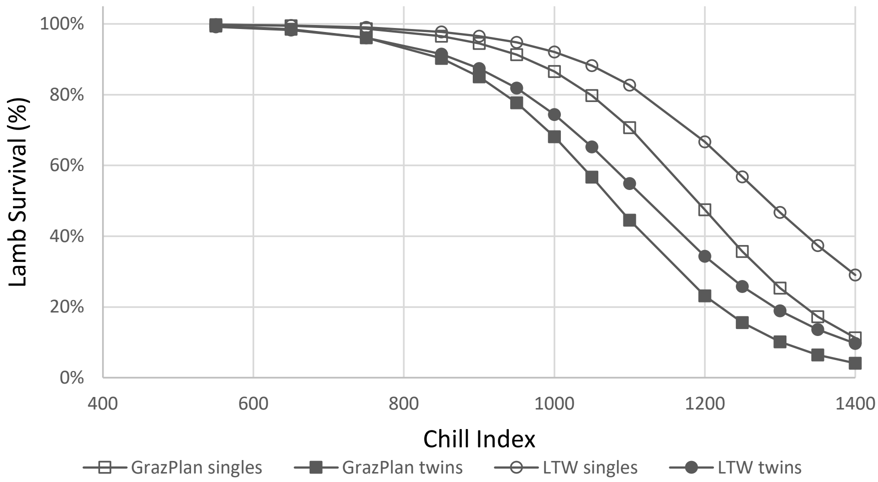

Figure 4: Impact of chill index on survival of single and twin born lambs, estimated using the GrazPlan relationships and the Lifetime Wool relationships for a ewe that is condition score 3 (body condition 1) at birth. FOO 1000kg/ha, Chill Index 1000. Note: there is no effect of plot scale/paddock scale for the chill index at CS 3 because the paddock level scalar is only related to change in nutrition relative to CS3.

An important driver of the profitability of different nutrition of single and twin bearing ewes is the difference in the predicted change in mortality of singles and twins if the nutrition of the ewes is improved and the ewes are in better condition at birth. If twin lamb survival is more responsive to improved dam nutrition, then differential feeding in favour of twins is likely to increase profit, whereas if the responses are similar, then differential feeding will have little impact and if the single survival is more responsive then differential feeding in favour of singles is likely to increase profit. The response in lamb survival from increasing dam condition score varies between the 3 sets of prediction equations and also with the chill index (Figure 5).

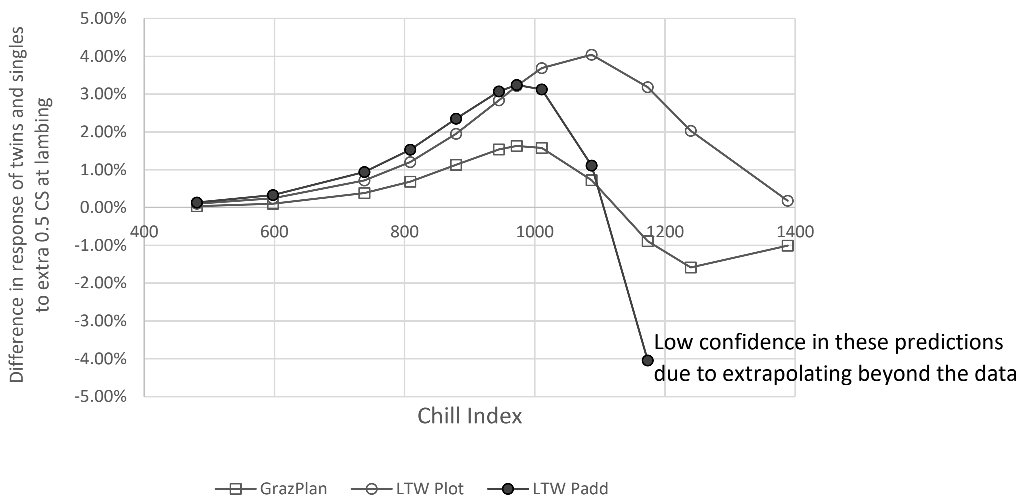

Figure 5: The difference in response to improved nutrition for twin bearing ewes versus single bearing ewes with different levels of chill index, estimated using the GrazPlan relationships and the Lifetime Wool paddock scale and plot scale results. A positive value indicates twin lamb survival is more responsive and a negative value indicates singles are more responsive.

The single and twin lamb survival are both more responsive to ewe CS change when the paddock level scalar is included but the 'difference in response' is very similar when the chill index is below 1000 (Figure 5). Because the paddock scalar has not been tested over a range of chill levels the paddock level adjustment has not been used in this analysis that includes a sensitivity analysis on chill level for regions that vary in chill level.

The GrazPlan equations predict a similar response to improving condition score for singles and twins across the entire range of chill index, the maximum difference is between ± 1.6% from the 0.5 CS change and is in favour of the twins below a Chill index of 1100 and in favour of the singles if above 1100. In contrast the LTW equations are both above 3% difference in favour of the twins when the chill index is about 1000. The predictions from the paddock scale are also in favour of single lamb survival if the chill index increases above 1100 however the magnitude of the differences is much greater than the GrazPlan predictions. The LTW plot scale predictions show a 4% difference in favour of twins with a chill index of 1100 and above that chill index the differential reduces to be almost 0 at 1400.

These differences in response are likely to alter the profitability of scanning for multiples however extra data may be required to decide which are the more accurate prediction.

Ewe & Lamb Mortality due to dystocia

The GrazPlan equations include a relationship to predict the proportion of lambs lost from dystocia depending on foetal weight at term in relation to expect birth weight and greater than average condition of the mother. This is a sigmoid function of an index of dystocia, the 5% & 95% mortality correspond with an index of 1.1 and 1.7

$$Dystocia\ Index = \frac{foetal\ weight}{normal\ BW} * \max\ (1, body\ condition)$$

Impact of BTRT and dam nutrition on progeny lifetime productivity

Birth type and rear type alter the productivity of an animal during its lifetime. The LTW project estimated the impact of BTRT on progeny CFW & FD and showed the impact through to shearing at 51 mo when the trial terminated (Thompson *et al.* 2011). The reduction in CFW averaged 0.27 kg for BTRT 22 and 0.12 for BTRT 21 compared with BTRT 11. The increase in FD average 0.29 µ for BTRT 22 and 0.22 for BTRT 21 compared with BTRT 11. The LTW project also quantified the impact of dam LW and LW change during pregnancy on the progeny lifetime wool production. A higher CS at lambing increase progeny CFW and reduced progeny FD over their lifetime. The coefficients determined in the trial are in Table 1.

Table 1: Impact of ewe liveweight profile during pregnancy on the progeny clean fleece weight and fibre diameter. Source: Thompson *et al.* 2011

	CFW	Fibre diameter
LW at joining	0.012	0
LW change early pregnancy	0.022	-0.019
LW change late pregnancy	0.021	-0.031

The GrazPlan documentation doesn't include an impact of BTRT or dam nutrition on the progeny fleece growth in later life. Therefore, there is uncertainty whether this is included in analyses carried out with the AusFarm model.

Peri-natal ewe mortality

Ewe mortality around the time of birth was estimated in the LTW project from CS of the ewe at the point of lambing. Transformed mortality was calculated from CS at lambing, this was back transformed and an adjustment made for twin bearing ewes.

$$tMortality = -0.4045 - 1.4535 Ewe\ CS_{lambing}$$

$$Mortality_{singles} = 1/(1 + e^{-tMortality})$$

$$Mortality_{twins} = Mortality_{singles} + 0.0225$$

Single and twin bearing ewes are estimated to be equally responsive to improved CS at lambing if starting at the same CS. However, if ewes are fed the same during gestation, the twins will be lower CS at lambing and hence slightly more responsive to improved nutrition than the singles. Twins at CS2.5 would generate 0.4% better improvement in ewe survival from feeding to gain 0.5CS than single bearing ewes at CS2.75. In the GrazPlan models, there is not an equivalent measure of ewe mortality that is dependent on ewe weight at lambing.

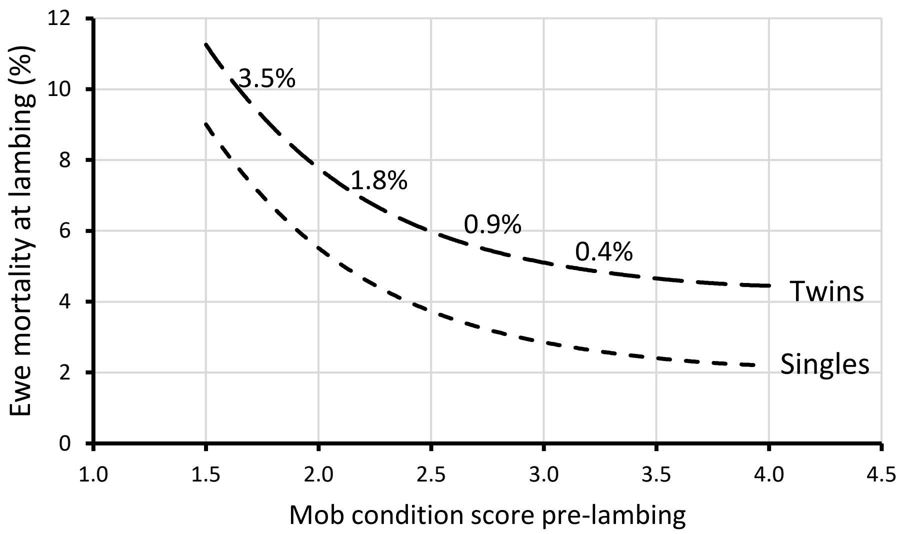

Figure 6: Ewe mortality at lambing based on information in the Lifetime Ewe management program.

The GrazPlan models estimate mortality of twin bearing ewes from pregnancy toxaemia in the last 6 weeks of gestation from maternal LW loss over this period using a sigmoid function. 5% & 95% mortality correspond with losing 5% & 35% of normal weight over the 6 week period prior to lambing (which equates to 60 g/hd/d & 400 g/hd/d for a 50 kg SRW ewe). In AFO this 'Preg Tox' function is used together with the LTW ewe mortality function due to CS at lambing (described above).

Weaning weight & Weaner mortality

If ewes are scanned for litter size and lambed in separate mobs, the nutrition during lactation can be differentiated to alter lamb growth rate and weaning weight. Whether differential management increases profit depends on the different response of singles and twins to nutrition. There are 2 main effects of altering weaning weight

1. Heavier weaners will reach sale weigh targets sooner and with less post weaning feeding. This benefit will be similar for singles and twins and may depend on the target sale weight and the management of the animals that do not reach the target.
2. Heavier weaners with the same post weaning growth rate have higher survival and are less sensitive to improved nutrition during pregnancy and lactation (**Figure 7** derived from relationships from Campbell 2006). Therefore, differential feeding of the twin born progeny at the expense of the single born progeny would increase overall weaner survival because the increase in survival of the lighter twin born lambs would be greater than the reduction in survival of the heavier single born lambs.

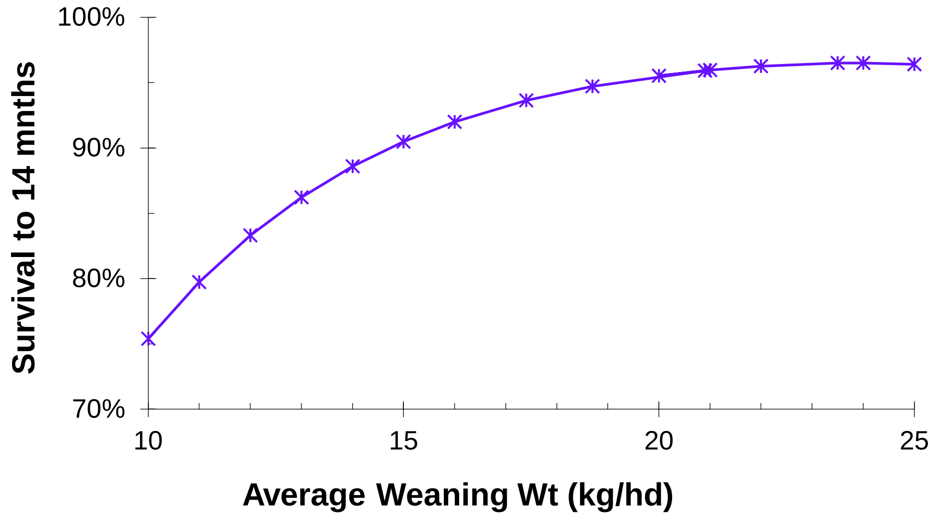

Figure 7: Survival of weaners to 14 months of age for different weaning weights with a post weaning growth rate of 50g/d. Source: Angus Campbell pers comm.

The method developed in the LTW project for estimating weaning weight was similar to estimating birth weight but also included FOO during the lactation period and the impact of birth type & rear type (BTRT).

$$Weaning\ weight\ (WWt) = 4.56 + 0.18LW_{joining} + 0.21LWC_{early\ preg} + 0.14LWC_{late\ preg} - 1.85(BTRT\ 21) - 4.94(BTRT\ 22) - 0.72(female) + 7.9FOO - 1.5FOO^2$$

The GrazPlan relationships simulate lamb growth rate based on milk production of the ewe and the intake of pasture of the progeny. LWG is a function of MEI above the requirements for maintenance, the efficiency of utilisation of energy for growth and the energy density of the tissue gained. Ewe potential intake is affected by the relative condition (condition score) of the ewe at parturition, the nutrition of the ewe while lactating and the suckling demand of the of the progeny. Lamb growth rate is determined by:

i. The milk production of the ewe
ii. BTRT, which affects the competition for milk
iii. Pasture quality and FOO, which alters progeny pasture intake once the rumen has developed sufficiently to consume solid feed. The rate of rumen development is assumed to be the same for both singles and twins so progeny intake is not a further source of motivation for differential allocation of the pasture resource.

The weaner survival relationships used in AFO is a combination of the relationships derived by Angus Campbell and those used in GrazPlan. Each set of relationships individually did not include sufficient detail to be used in an optimisation model. The relationships from Campbell combined LW change for the entire period from weaning to 14 months of age and indicated that maintenance or losing weight during this period led to 100% mortality. To be useful the prediction is required for smaller timesteps. However, the relationship does provide a continuous response function that is capable of being optimised.

The relationship in GrazPlan is a step function with an increase in mortality triggered if the animal is growing more slowly than 20% of the normal growth rate and either it is less than 365 days of age or body condition is less than 0.6 (CS ~1.0). The time step function is not amenable to optimisation because the optimum would likely be liveweight gain of 21% of normal growth which would be predicted to achieve 100% survival.

A hybrid function was developed that is a continuous function that incorporates liveweight change (LWC) relative to normal growth rate and body condition relative to a threshold value. The threshold for increased mortality due to slow growth is relative to normal growth rate, so the absolute level of growth varies with age. As a young animal (normal growth rate ~250g/hd/d) the growth rate must be greater than 100 g/hd/d for mortality not to increase, whereas for an adult (normal growth = 0g/hd/d) mortality only increases if losing greater than 150 g/hd/d. If LWC is above the threshold relative to normal weight change then mortality doesn't increase above the non-reducible base mortality value. However, if below the threshold, mortality increases in a quadratic function. There is a similar function for relative condition (condition score) and the results from LWC and RC are multiplied together. The quadratic functions are parameterised (Table 2) so that mortality equals the 'indicative' mortality input value if both LWC and RC are at their 'indicative' values (Figure 8). Following both Campbell and GrazPlan, the same parameters are used for both single and twin born animals. Twin born animals are lighter at birth and have a lower growth potential therefore they are on a more responsive part of the curve.

Table 2: Parameters used in the AFO mortality function that adjusts mortality by rate of liveweight change (LWC scalar) and relative condition (RC scalar). When LWC & RC are at indicative values then mortality is at the indicative value.

	Threshold	Indicative value
LWC scalar	-0.03	-0.10
RC scalar	0.9	0.8
Annual Mortality		10%

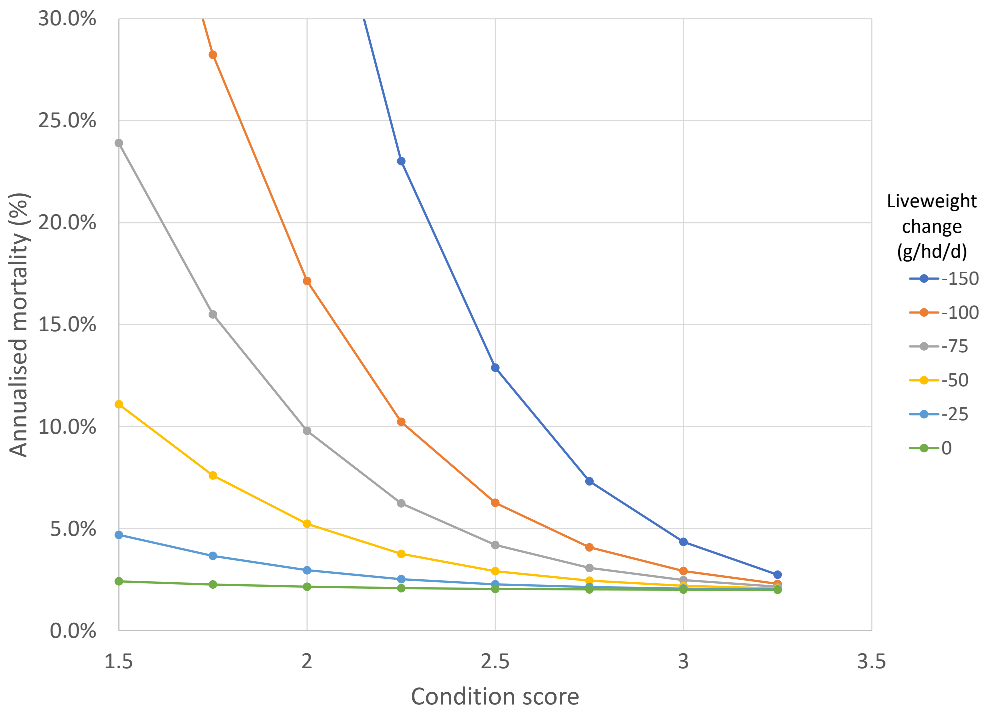

Figure 8: Predictions of mortality rate for a range of liveweight change and condition score, generated from the mortality function used in the Australian Farm Optimsation model.

Response due to culling once or twice-empty ewes

Work carried out by the NSW DPI (Lee *et al.* 2009) has shown that there is large variation in the lifetime reproductive performance of individuals in a flock. They analysed the D-Flock, C-Flock and QPlu$ flocks and the top 50% of ewes produced between 0.62 and 0.75 more lambs each year than the bottom 50%. Other work by NSW DPI quantified the gains of adopting a system of culling the "passengers" at 3.5yo if they hadn't raised a lamb after 2 lambing opportunities, and retaining the "performers" being the top 50% of the 5.5yo ewes. That work showed a net benefit of approximately 11% on total flock weaning percentage and this was comprised of a 4% gain due to culling the passengers and a 7% gain due to retaining performers. Scanning and identifying the empty ewes allows culling the 'passengers', scanning to also identify the multiples allows retaining the 'performers'. A subsequent empirical analysis (Hatcher *et al*. 2018) that examined a wider range of industry datasets did not demonstrate such large gains and showed gains in total flock number of lambs weaned of between 0 and 2.5% from culling twice-empty ewes. This second analysis covered a shorter duration than the first and as such captured less of the genetic effects of culling on scanning performance.

The results from both these analyses are not well suited to providing inputs for this economic analysis because they calculated the benefit over the whole flock rather than generating data by age group that is necessary for the AFO model which optimises flock age structure based on individual age group data. Using the data is made more difficult because culling the 'passengers' increases the proportion of young ewes in the flock and these animals have a lower reproductive performance, so the impact on the reproductive performance of the older ewes is greater than indicated by the above numbers. Estimations based on differences between age groups and typical age structures indicate that culling twice-empty ewes in the above datasets increased the subsequent scanning rate of the retained animals by 5%. This benefit was applied in this analysis if ewes were scanned and the empty ewes were sold, either at scanning or at the subsequent shearing. A further 1% genetic improvement over the whole flock was included extra to the benefit in the current generation.

The NSW D flock had an extra year of data and allowed a comparison of retaining all animals for the 5th joining relative to selecting 50% of the ewes based on net reproductive rate. The top 50% of the ewes had a scanning percentage an extra 8.5% higher. This was achieved through both identifying the scanning performance of the ewes as well as the rearing ability, for this analysis the potential improvement in scanning percentage of the 6yo age cohort from retaining 50% of the 'performers' was estimated at 6% and was applied if ewes were scanned for litter size and a maximum of 50% of the old ewes were retained to 6 years of age. A genetic effect of a further 1% improvement in RR was assumed if the 'performers' were retained.

The SA component of the PvP project analysis included the impacts of selling empty maidens (once-empty) or selling twice-empty after the second lambing opportunity. Culling twice-empty increased flock NLW by 1.2% and culling once-empty increased by 2.1%, an improvement of 70% over culling twice-empty (it was associated with selling 4 times the number of ewes). Part of the extra benefit associated with culling once-empty is the extra year for which the passengers have been removed. Calculations done using a flock structure similar to the SA research flock retaining the ewes for 4 matings and accounting for the number of joinings that will be improved as a result of culling once or twice-empty showed that a 25% higher response was required to replicate the flock level response. In this analysis the 25% scalar of the benefit of culling once-empty relative to twice-empty was included and evaluated.

It is expected that the response to culling empty ewes would vary with the selection pressure and the proportion of animals being culled, however, this has not been included in the analysis because of a lack of data. This could be important for the maternal flocks that have a lower proportion of emptys and therefore may not respond to culling as the merino flocks measured in the research reviewed. This uncertainty about the gains that can be made in reproductive rate from selection using scanning data means the results of this analysis are only indicative values of the potential on offer from scanning.

Improved paddock allocation at lambing

Lambing paddock has an impact on lamb survival which may be due to exposure or aspect or other as yet unidentified factors. Although the reasons have not all been elucidated farmers know which are their better lambing paddocks and can allocate the multiple bearing ewes to these paddocks. It is likely that the survival of the multiple bearing lambs will be more responsive to the better conditions and there will be more lambs born in the better paddocks if the multiples are identified and allocated to the better paddocks.

Mob size at Lambing

Another aspect of paddock allocation is mob size at lambing. Lockwood *et al.* (2020) demonstrated the financial benefit of differentially allocating multiple bearing ewes to the smaller paddocks and and single bearing ewes to larger paddocks. This was without re-fencing, just reallocation among existing paddocks. They showed that lamb mortality at birth could be reduced if mob size at lambing was reduced and the effect was greater for twins (2.25% increase in survival for a 100hd reduction in mob size at lambing) than for singles (0.85% per 100 hd). This difference in response between twins and singles means that overall survival can be improved by reducing the mob size of twins and increasing the mob size of singles using existing paddocks. The optimum estimated by Lockwood *et al.* (2020) was that twin mob size is half that of singles.

For this analysis it was assumed that the mob size if ewes are not scanned is 200 ewes per mob and that merinos have 35% twins and maternals have 50% twins.

Exposure & chill index

Paddocks on-farm vary in the level of exposure and this alters the level of chill experienced by the lambs at birth. Differential allocation of ewes to paddocks based on level of exposure could increase average lamb survival if the less exposed paddocks are allocated to the ewes whose progeny are most responsive.

At low chill levels twin lamb survival is more responsive whereas at high chill levels (>=1200 for ‘wool’ genotypes and >=1300 for ‘meat’ genotypes) the single lamb survival is more responsive.

The GrazPlan relationships were used to calculate the net benefit in lamb mortality if the ewes are differentially allocated to lambing paddocks for birth. GrazPlan rather than LTW relationships were used because they predict different values for wool and meat genotypes. The net overall flock benefit (Table 3) is the accumulation of:

- the improvement in the mortality of the twins that would have been born in the ‘poor’ paddock that are now born in the ‘good’ paddock. The values are derived from Figure 9 and the benefit ranges from 4.9% to 21.0% between the scenarios. The standard scenario (average chill of 850 kJ/m^2/hr, Merinos 8.8% & Maternals 4.9%) aligns with the values assumed by Holmes and Sackett (2008) of an 8% reduction in twin lamb mortality.
- the increase in mortality of the singles that would have been born in the good paddock that are now born in the ‘poor’ paddock. The increase varied from 2.3% up to 24% with the standard scenario being Merinos 3.4% and Maternals 2.3%.
- the number of lambs born per ewe allocated to the different paddocks
- the proportion of ‘good’ versus ‘poor’ paddocks, which is assumed to be 50% based on working on average chill level.
- the proportion of singles and twins. These proportions affect the number of ewes that can be reallocated from their respective undifferentiated paddocks.
- The relative stocking density of singles and twins during the lambing period. The calculations have been carried out assuming that when allocating the ewe to lambing paddocks that the relative stocking density of singles is 120% of twins, which is the ratio of 1.5DSE/hd for singles and 1.8 DSE/hd for twins.
- The number of ewes that can be reallocated. This is determined by the lesser of the number of DSE of single-bearing ewes in the sheltered paddocks that can be moved to exposed paddocks or the number of DES of twin-bearing ewes in the exposed paddocks that can be moved to the sheltered paddocks.

For this analysis 3 exposure scenarios have been tested to demonstrate the magnitude of the potential benefits of paddock allocation to reduce exposure for twin-born lambs. The benefit of allocating the less exposed paddocks to the multiple bearing ewes at the expense of the single bearing ewes lambing in the more exposed paddocks was estimated assuming a differential in chill index between sheltered and exposed paddocks of 100 kJ/m^2/hr. The net benefit in reduced lamb mortality averaged over all the lambs born was between 0.8% and 3.6% (Table 3) with the standard value for the analysis being 1.8% for merinos and 1.0% for maternals.

Table 3: Calculation of the benefit associated with altering paddock allocation to reduce the net flock lamb mortality. The mortality is based on calculations using the GrazPlan relationships for Wool & Meat sheep with chill index ranging plus and minus 50 units either side of 850 (Low), 1000 (Medium) and 1200 (High).

Flock	Scenario	% twins	Change in Mortality*		Proportion of ewes that are re-allocated		Net benefit
			Singles	Twins	Singles	Twins	
Merino	Low chill	35	+3.4	-8.8	32	50	-1.8
	Medium chill		+11.6	-21.0			-3.6
	High chill		+24.0	-17.4			-0.8
Maternal	Low chill	50	+2.3	-4.9	50	42	-1.0
	Medium chill		+6.9	-12.3			-2.3
	High chill		+18.0	-19.9			-2.5

* change in mortality of twins that move from exposed to sheltered paddocks (percentage points)
of singles that move from sheltered to exposed paddocks (percentage points)

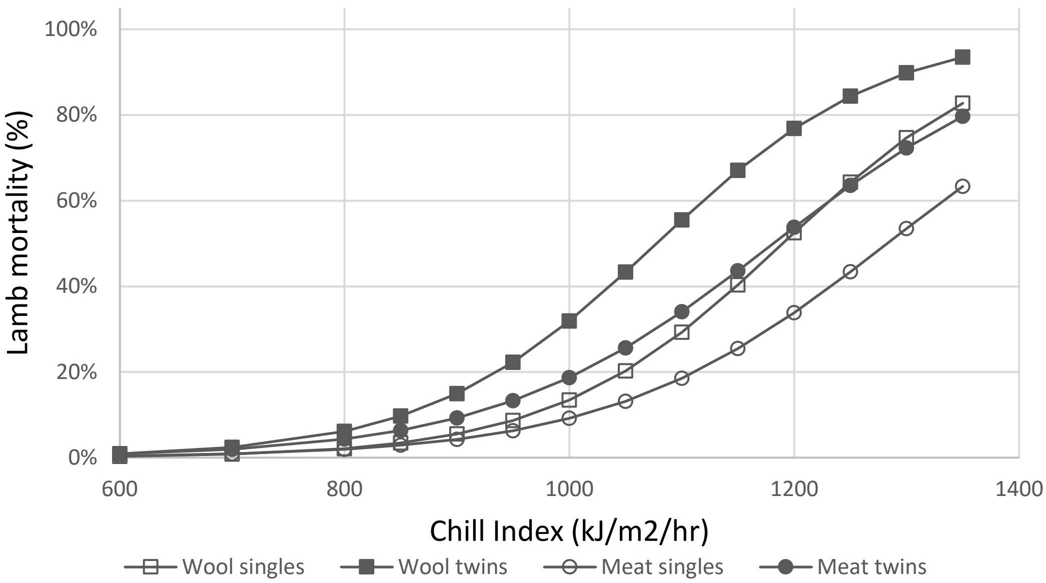

Figure 9: Predicted mortality at birth of single and twin born lambs from 'wool' sheep and 'meat' sheep for a range of chill index. Predictions based on the GrazPlan equations.

Cost assumptions

The cost of scanning includes both the cost of the contractor and the labour cost associated with pushing the ewes through the scanning crate and the mustering that is required per mob. If all labour is provided by casual labour the labour cost varies between \$0.31/ewe if scanning wet & empty up to \$0.40/ewe if scanning for multiples.

The cost of casual labour is assumed to be \$256 per day (\$32/hr all-inclusive for an 8 hour day). The amount of casual labour that has to be hired depends on the timing of scanning relative to other jobs on the farm, especially cropping related jobs. Whether there is a clash will depend on the time of scanning relative to the break of season. For the later lambing times for GSM & CWM scanning is occurring after the break of season and there is a clash, whereas with earlier lambing scanning is happening prior to the break. 'Dry seeding' may be occurring at this time but it is less time critical than seeding after the break of the season.

Table 4: The assumptions used for the cost of contracting. Source of contract cost: Cousins Merino Services if more than 2000ewes to scan. Less than 2000ewes add $0.10/hd.

	Pregnancy Status	Multiples
The contractor#		
Contract cost ($/hd)	$0.50	$0.75
Throughput (hd/day)	3000	2000
Travel	$1.30/km	$1.30/km
Farmer provided labour		
Yard work – labour units	2	2
Cost per hd*	$0.17	$0.26
Mustering*	$0.06	$0.06
Other costs		
R&M on infrastructure & Fuel	$0.08	$0.08
Total cost	$0.83	$1.17

based on contract cost if greater than 2000 ewes being scanned (source: Cousins Merino Services)
* assuming that all labour is hired.

Price scenarios

Seven price scenarios were examined based on the percentiles of the output prices received over the period 2004 to 2020. The values varied were the 21µ MPG, the premium for fine wool (based on the price of other fibre diameters relative to 21µ), meat prices and grain prices. The scenarios (**Table 5** & **Table 6**) were:

Table 5: The price scenarios examined in the analysis. For each scenario prices of wool, meat and grain were based on a percentile level during the period 2004 - 2020.

	Commodity			
	Wool		Meat	Grain
	21µ MPG	FD Premium		
Standard	70th	50th	70th	50th
Wool High	80th	80th		
Low	50th	50th		
Meat High			90th	
Low			50th	
Grain High				80th
Low				20th

The prices per unit for the standard scenario are outlined in **Table 6**.

Table 6: Standard prices and the range examined in this analysis.

Commodity		Units	Standard price	Low	High
Wool	18µ	c/kg clean (fleece)	1515	1280	1875
	20µ	c/kg clean (fleece)	1290	1090	1425
	22µ	c/kg clean (fleece)	1235	1050	1305
Meat	Lamb[1]	c/kg DW	565	465	670
	Mutton[2]	c/kg DW	385	285	490
	Breeders[3]	$/hd	120	100	140
	Export wether4	$/hd	102	85	120

[1] Price for top of the prime lamb grid: 18.1 – 28kg fat score 2 – 4.
[2]. Price for top of the mutton grid: 18.1 – 35kg fat score 2 - 4
[3]. Price for breeding ewes CS 3 at 5½ years old.
[4]. Price for export wethers 60kg CS 3+

Ewes that are 5½ years old or younger can be sold into the breeding market for a premium price above the mutton price provided they are a minimum of CS 2.5. Ewes of 18 months old receive a 10% premium over CFA ewes.

There are differences in price during the year associated with selling emptys at scanning for a premium price relative to sale at next shearing. The variation in price during the year is based on historical monthly price movements for mutton and calculating the price each month relative to the annual low in Sept/Oct (Table 7). The price premium received for selling at scanning compared with selling at shearing depends on both the time of shearing and scanning which varies with region and the time of lambing scenario, however, the premium averages about 10%.

Table 7: Price variation of mutton for each month of the year. Source: NLIS price reports collated by Kate Pritchett DPIRD.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
15%	17%	19%	21%	23%	25%	27%	29%	0%	0%	5%	10%

Model description

The analysis was carried out with the Australian Farm Optimisation model (AFO). It is a whole-farm profit optimisation model that is a major upgrade on the MIDAS model. As with the MIDAS model it calculates the farm profitability for a fixed farm size for the whole flock based on the productivity of each class of stock, commodity prices and the farm carrying capacity calculated in a detailed feed budget.

- It optimises stocking rate (and therefore flock size) and grain feeding to maximise profit for each scanning scenario for each genotype.
- It accounts for the different feed requirements of empty, pregnant or lactating ewes with single or multiple lambs and the variation in the proportion between genotypes
- It accounts for the difference in wool production and value per kilogram between genotypes and the impact of gestation and lactation on wool value.
- It optimises flock structures for each genotype and accounts for different feed requirement profiles of ewes, young sheep and wethers during the year.

The improvements of AFO over MIDAS that are relevant for this analysis are:

1. the inclusion of automatic optimisation of the feed supply profile for the different classes of stock on the farm. In MIDAS the optimisation of feed supply had to be carried out by the user and required a long hand process that was difficult to carry out for the number of scenarios involved in this analysis.
2. Improved representation of the impact of feed quality on growth rates and production.
3. Easier evaluation of alternative equation systems for predicting animal performance from feed supply. This capacity allowed the comparison of the LTW & GrazPlan equations.
4. Improved representation of lamb and weaner growth rates and the ewe energy requirements for milk production.

Three regional versions of the Australian Farm Optimisation model (AFO) were used in the analysis. AFO calculates the profitability of the whole flock based on the productivity of each class of stock and commodity prices and the farm carrying capacity calculated in the detailed feed budget. As an optimizing model it calculates the optimum stocking rate, nutrition profile, pasture grazing intensity and rate of grain feeding that will maximize profitability and optimise productivity of the animals in the flock. The model accounts for changes in flock structure and the change in ewe energy requirements that result from increasing lamb survival or altering the number of ewes pregnant or lactating with singles or twins. The capacity to optimise the feed allocation and optimise the nutrition profile for empty, single and twin bearing ewes is important for this analysis, because a major driver of the profitability of pregnancy scanning is the differential management of the nutrition of the ewes based on pregnancy status and litter size.

The feed budgeting module in AFO is based on the energy requirement and intake capacity equations of the Australian Feeding Standards (Freer *et al.* 2007, 2012), these are also the basis of the GrazFeed model. The feed year is divided into 10 periods and the feed budget is calculated for each period. With different targets for ewe nutrition the metabolisable energy (ME) requirement for the ewes can vary for each of the 10 periods. The model then calculates whether the most profitable way to achieve the required nutrition for the flock is by adjusting stocking rate, adjusting grain feeding or adjusting the grazing management of pastures and varying the severity of grazing at different times of the year to alter the pasture production profile.

AFO is a steady state model, so an implicit assumption is that any management change has been applied for sufficient time for the impact to have permeated the entire flock. This is important in this analysis because altering the ewe nutrition strategy will take a number of years before the impacts on progeny wool production will have worked through the entire flock. A full investment analysis would account for the time cost of money and discount the future benefits achieved from altering ewe nutrition now, however, this is not possible within the AFO framework and hasn't been included in this analysis. The AFO results could therefore be an overestimate of the value achieved on farm, however, this over-estimation is only affecting the benefits associated with the progeny lifetime fleece value and will be relatively minor when expressed in $/ewe.

Model details

The sheep and pasture sub-model in the optimisation model represents the whole flock and includes a powerful feed budgeting module that optimises animal and pasture management across the whole farm over the whole year. It describes the biological relationships of a representative farm and calculates the profitability of the whole flock based on the productivity of each class of stock, the commodity prices and the farm carrying capacity calculated in the detailed feed budget. The profit maximisation accounts for the cost of supplementary feeding & the value of production per animal. This structure ensures that all calculations of profitability for each genotype are done with optimum management for that genotype.

AFO evaluates the trade-off between increasing stocking rate and reducing the nutrition of the flock (with concomitant reduction in per head production), adjusting grain feeding or adjusting the grazing management of pastures (through adjusting the severity of grazing at different times of the year - which alters feed consumption and quality, and the future pasture production profile). The preceding is all achieved while achieving minimum ground cover constraints during summer and autumn. This mimics that farmers (through experience over time) optimise the nutrition of their livestock classes by altering grazing management, stocking rate and level of supplementary feeding.

The feed budget is based on dividing the year into 10 periods. The periods are shorter at pasture senescence and the break of season and longer in the middle of the growing season and mid-summer (Table 8). For each period, the energy requirement and the intake capacity for each livestock class is calculated based on liveweight and liveweight change using the equations of the Australian Feeding Standards (Freer *et al.* 2007). The feed requirement of the animals can be met from pasture, crop residues or grain feeding subject to a constraint on the minimum quality and availability of the feed offered related to the intake capacity of the sheep. If there is insufficient feed available or it is more profitable to defer grazing of the green pasture then grain can be used as a supplement or a substitute to paddock feed.

Table 8: The beginning of each of the 10 feed periods in the three regional versions of the AFO model used in this analysis (break of season is represented by the 1st date of the growing season).

Season	Long growing season SW Victoria	Medium growing season Great Southern WA	Short growing season Cereal Sheep Zone
Green	25 Mar	24 Apr	7 May
	15 Apr	15 May	21 May
	1 Jun	12 Jun	11 Jun
	5 Aug	7 Aug	16 Jul
	9 Sep	25 Sep	10 Sep
	7 Oct		
	18 Nov		
Empty (predominantly)	23 Dec	30 Oct	8 Oct
	25 Jan	27 Nov	29 Oct
	25 Feb	22 Jan	3 Dec
		12 Mar	25 Mar
		9 Apr	22 Apr

At the beginning of the growing season the density of annual pastures is affected by the paddock land use history (rotation). During the periods of the growing season, pasture growth is a function of the quantity of feed on offer at the beginning of the period and the grazing intensity during the period. The growth function varies with the land management unit and the period during the year. Grazing intensity in each period is optimised through valuing the trade-offs between pasture utilisation rate, sward digestibility, capacity of animals to selectively graze and, subsequent FOO and pasture growth rates. During the period when pastures are not actively growing (in summer and autumn) any feed that is not required to meet the energy demands of the livestock on hand can be deferred to be utilised in a later period, subject to a decline in the quantity and quality.

Livestock management

Three genotype systems were examined in the analysis:

1. 'Merino-Merino' - Merino ewes mated to Merino rams. The production system is a self-replacing flock comprising a medium wool genotype. Surplus young ewes and all wethers are sold off shears after the hogget shearing at approximately 18 months of age. Young ewes are first mated to lamb at 2 years of age. Old ewes (culled for age) are sold off shears at 5.5 or 6.5 years of age (whichever is most profitable).
2. 'Merino-terminal' – A self-replacing flock based on the same ewe genotype as the 'Merino' flock. Ewe surplus to requirements for replacing the pure bred merino flock (culled for age at 5.5 yo or surplus young ewes) are mated to terminal sires to produce first cross prime lambs. Old ewes (culled for age) are sold off shears at 6.5 years of age.
3. 'Maternal' – a self-replacing flock based on a maternal composite genotype. Surplus young ewes and wethers are sold as lambs and young ewes that are retained are mated at between 7 and 8.5 months of age (depending on time of lambing). Old ewes (culled for age) are sold off shears at 5.5 or 6.5 years of age (whichever is most profitable).

Three times of lambing were examined in each of the 3 regions for each of the three flocks. The management timing was similar for the medium and short season environments and slightly different for the long growing season environment (Table 9).

Table 9: Summary of the management regime implemented in the three regions for each time of lambing.

	Long growing season			Medium & Short growing season		
	Autumn	Winter	Spring	Autumn	Winter	Spring
Rams in date*	15-Nov	1-Jan	8-Mar	16-Dec	19-Jan	23-Feb
Lambing date (Start)	15-Apr	1-Jun	5-Aug	15-May	18-Jun	23-Jul
Shearing time	15-Oct	1-Dec	15-Jan	15-Oct	1-Dec	15-Jan
Weaning date	15-Jul	31-Aug	4-Nov	14-Aug	17-Sep	22-Oct

* for adult ewes. Maternal ewe lambs are mated 3 Jan, 21 Feb & 8 Mar for the long growing season environment, and 2 Feb, 21 Feb & 23 Feb for the medium and short growing season environments.

Best practice animal husbandry was applied for all ewes and lambs in each system and tasks such as crutching and shearing were undertaken using contract labour. Additional details on the production characteristics (CFW, FD, reproductive rate and lamb survival) are provided in the regional summary in the next section.

The regions

The regions included in the analysis were:

1. South west Victoria. A 600 – 650 mm winter rainfall zone in the Hamilton region in SW Victoria with a 9 month growing season with 100% pasture.
2. Great Southern in WA. A 500 - 600 mm winter rainfall zone in the Darkan region in WA with a 6 month growing season, typically 40-50% of the farm in crop.
3. Cereal Sheep zone. A 400mm winter rainfall zone in the Cunderdin region in Western Australia with a 4.5 month growing season, typically 70-80% of the farm in crop.

Long growing season - South west Victoria

Land management units

The model represents a 'typical' farm in the Hamilton region in south west Victoria. The total area of the farm is 1000ha and is comprised of 3 land management units (LMUs; Table 10).

Table 10: Description and area of each LMU on the model farm for SW Victoria.

Land Management Unit	Area (ha)	Description
Ridges	200	Well drained gravely soils at tops of hills.
Mid slopes	600	Moderately drained loams in the mid slopes
Flats	200	Clay soils in lower slopes that are often waterlogged.

Pasture production

The pasture production in the Hamilton model is based on a highly productive perennial ryegrass and sub-clover stand typical of pastures on farms in the top 20% of the monitor farm project. This pasture is grown on all land management units. The growth rate of the pasture has been based on simulations using the GrassGro model with climate data from the Hamilton weather station (Steve Clark *pers comm.*).

Farm summary

Table 11: Summary of farm productivity if ewes aren't scanned in the long growing season environment (SW Victoria) for each flock type for each time of lambing.

		Merino-Merino			Merino-Terminal			Maternal		
		Aut	Win	Spr	Aut	Win	Spr	Aut	Win	Spr
Farm Profit	$/ha	154	174	341	158	193	413	-27	60	345
Wool income	$/DSE	33.20	32.30	29.90	32.90	31.60	28.70	7.00	6.60	7.20
Sales income	$/DSE	26.40	30.20	33.10	30.30	34.40	37.60	44.10	47.50	61.80
Farm area	ha	1000	1000	1000	1000	1000	1000	1000	1000	1000
Area of pasture	%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Stocking rate	DSE/ha	12.5	11.9	16.5	11.7	12.2	17.0	8.1	10.2	15.8
Number of ewes	hd	4950	5130	6440	5260	6040	7700	3860	4760	7440
Supplement fed	t	220	150	360	190	190	290	10	40	490
	kg/DSE	17.8	12.3	21.8	16.5	15.4	17.3	1.5	4.4	31.2
Reproductive rate	Ave %	96%	121%	128%	97%	121%	130%	94%	149%	165%
	4yo %	96%	125%	133%	97%	125%	133%	86%	162%	189%
Lamb survival	Singles%	83%	76%	81%	84%	77%	81%	89%	84%	88%
	Twins%	61%	50%	56%	63%	53%	59%	72%	66%	72%
NLW (flock ave.)	%	67%	71%	81%	68%	74%	84%	72%	98%	117%
CFW (adult ewes)	kg/hd	3.5	3.5	3.4	3.5	3.5	3.5	3.0	3.0	3.1
FD (adult ewes)	µ	17.5	17.7	17.6	17.5	17.7	17.6	33.7	34.0	34.2

Medium growing season - The Great Southern

The AFO model for the Great Southern region of Western Australia was used in this analysis. The model was calibrated to represent a typical 2130 ha property in the 500 – 600 mm winter rainfall zone surrounding Darkan in the Great Southern region based on farm benchmarking from ICON Agriculture (Andrew Ritchie pers. comm.). This zone is characterised by winter rainfall and a six-month growing season with a mix of annual grasses and subterranean clover and a total pasture production of 8t DM/ha.

Land management units

The total area of the farm is 2130ha and is comprised of 3 LMUs (Table 12).

Table 12: Description and area of each land management unit on the Great Southern model farm.

Land Management Unit	Area (ha)	Description
Deep sands	150	Deep sand not often waterlogged
Gravelly sands	1230	Duplex soil with gravelly sand over clay at 30 – 40cm. Ironstone ridges prevalent in the landscape
Loamy sands	750	Duplex soil with loamy sand over clay at 30 – 40cm. Granite outcropping is prevalent in the landscape

Pasture production

The pasture production in the Great Southern model is based on a mixed sward of sub-clover and volunteer annual grasses with capeweed. The profile of growth rates during the season has been based on measured pasture growth (DPIRD unpub trials). The total pasture production has been calibrated from the Icon Agriculture farm benchmarking database so that farm stocking rate and level of supplementary feeding are consistent with client average production.

Farm summary

Table 13: Summary of farm productivity if ewes aren't scanned in the medium growing season environment (Great Southern of WA) for each flock type for each time of lambing.

		Merino-Merino			Merino-Terminal			Maternal		
		Aut	Win	Spr	Aur	Win	Spr	Aut	Win	Spr
Financial										
Farm Profit	$/ha	228	275	324	231	281	354	193	205	239
Wool income	$/DSE	31.90	31.50	32.90	29.20	29.40	30.10	8.00	8.60	8.70
Sales income	$/DSE	28.10	33.10	39.00	33.10	36.00	41.50	46.10	50.60	58.30
Land use										
Farm area	ha	2130	2130	2130	2130	2130	2130	2130	2130	2130
Area of pasture	%	45%	56%	56%	48%	55%	60%	29%	36%	47%
Stock management										
Stocking rate	DSE/ha	10.0	10.8	11.2	9.7	10.8	12.3	8.3	8.9	9.5
Number of ewes	hd	3450	5230	5270	4170	5390	7020	1740	2300	3530
Supplement fed	t	140	150	150	150	140	140	110	170	240
	kg/DSE	14.6	11.5	11.0	15.5	11.3	9.0	21.2	24.6	25.0
Production										
Reproductive rate	Ave %	117%	125%	125%	115%	126%	125%	132%	159%	151%
	4yo %	117%	128%	127%	116%	128%	127%	141%	174%	177%
Lamb survival	Singles%	84%	79%	88%	84%	79%	88%	86%	83%	90%
	Twins%	58%	52%	68%	59%	54%	70%	66%	62%	75%
NLW (flock ave.)	%	77%	75%	93%	77%	77%	94%	92%	101%	115%
CFW (adult ewes)	kg/hd	3.6	3.6	3.6	3.6	3.6	3.6	3.2	3.2	3.2
FD (adult ewes)	μ	19.3	19.3	19.0	19.3	19.3	19.0	34.0	34.9	33.8

Short growing season - Cereal Sheep zone

Land management units

The model represents a ‘typical’ farm in the Cunderdin region in the wheatbelt of WA. The total area of the farm is 3750ha and is comprised of 8 land management units (LMUs; Table 14).

Table 14: Description and area of each LMU on the model farm for the cereal-sheep zone.

Land Management Unit	Area (ha)	Description
Poor sands	260	The sandplain soils occur within the Ulva soil landscape. Loose, white and pale yellow sands which are commonly over 2 m deep and have a grey topsoil. Poor moisture and nutrient availability of these soils result in very poor crop and pasture growth.
Average sandplain	400	Yellow sandy soils that are commonly over 2 m deep. They have a brown topsoil. Cereal yields are limited by poor moisture and nutrient availability
Good sandplain	650	Often contains large percentages of ironstone gravel. It produces high to very high cereal, lupin and pasture yields in most years. It does not become waterlogged in wet years
Shallow duplex	400	The Booraan unit occurs downslope from the Ulva sandplain and extends towards the valley floor. Slopes

		are in the order of 2 to 8%. Hardsetting, heavier, grey to brownish soils that occur on the upper and mid slopes. Topsoil is about 10cm deep . The clay subsoil occurs at 10 at 30cm. Good moisture and nutrient availability. Problems with soil structural decline and water erosion may be encountered.
Medium heavy	375	The Danberrin unit contains soils derived from fresh rock and is commonly found around rock outcrops and in minor .drainage lines. Slope gradients vary from 2 to 8%. Above average quality soil suitable for cereals, lupins and pasture. These soils may suffer from limited moisture availability in dry periods , waterlogging in seepage areas and shallow rock areas which limit root growth result in reduced yields.
Heavy valley floors	375	The Merredin unit contains the heavy red and grey soils which characteristically support salmon gum and gimlet. Can produce good cereal and field pea crops and good medic based pastures. Production may be reduced due to soil structural decline and salinity.
Sandy surfaced clays	565	The pale, sandy surfaced Belka unit has a sandy topsoil that ranges from about 10 cm to over 100 cm. The shallow soil is a good quality soil suitable for cereal and pasture production, and the deep soil is an average to good quality soil suitable for cereals, pastures and lupins. Problems with salinity, waterlogging and wind erosion may be encountered.
Deep duplex	725	This is included in the Booraan unit. Generally a productive soil with good moisture and nutrient availability. Waterlogging problems can occur in some years in areas of this soil on lower slopes. Traffic compaction pans, water and wind erosion may present some problems.

Pasture production

The pasture production in the Hamilton model is based on a highly productive perennial ryegrass and sub-clover stand typical of pastures on farms in the top 20% of the monitor farm project. This pasture is grown on all land management units. The growth rate of the pasture has been based on simulations using the GrassGro model with climate data from the Hamilton weather station (Steve Clark *pers comm.*).

Farm summary

Table 15: Summary of farm productivity if ewes aren't scanned in the short growing season environment (Cereal sheep zone) for each flock type for each time of lambing.

		Merino-Merino			Merino-Terminal			Maternal		
		Aut	Win	Spr	Aut	Win	Spr	Aut	Win	Spr
Farm Profit	$/ha	147	158	167	152	168	176	161	141	150
Wool income	$/DSE	34.40	35.80	35.90	32.80	32.90	32.80	6.50	8.90	8.50
Sales income	$/DSE	30.10	36.00	40.30	37.20	41.00	43.10	54.50	55.60	64.30
Farm area	ha	3750	3750	3750	3750	3750	3750	3750	3750	3750
Area of pasture	%	28%	30%	30%	28%	32%	32%	32%	29%	28%
Stocking rate	DSE/ha	7.1	6.9	7.1	7.2	7.3	7.7	6.1	6.1	6.2
Number of ewes	hd	2820	2930	3260	3550	4040	4340	3480	2610	3070
Supplement fed	t	60	70	100	90	90	130	40	20	50
	kg/DSE	7.4	9.1	11.8	11.5	10.0	13.5	5.1	3.2	7.7
Reproductive rate	Ave %	111%	120%	118%	108%	118%	118%	124%	145%	142%
	4yo %	112%	123%	121%	112%	123%	121%	132%	162%	162%
Lamb survival	Singles%	90%	89%	94%	90%	89%	94%	92%	89%	95%
	Twins%	69%	71%	81%	70%	72%	82%	75%	73%	84%
NLW (flock ave.)	%	84%	92%	99%	83%	91%	100%	97%	109%	121%
CFW (adult ewes)	kg/hd	4.0	4.0	4.0	4.0	4.0	3.9	3.1	3.1	3.1
FD (adult ewes)	µ	20.1	20.2	19.8	20.2	20.2	19.8	34.0	34.5	33.7

The Analysis

Optimum Nutrition Profiles

A major component of the value of pregnancy scanning is the differential nutritional management that is possible when pregnancy status or litter size has been identified. Differential nutritional management can begin at scanning and is associated with different feed requirements and different production levels for:

- Liveweight and the effects on reproduction rate and value at sale
- ewe mortality
- fleece weight and fibre diameter of the ewe
- progeny birth weight and lamb survival & progeny fleece production

All of the production outcomes above and the feed requirements of the flock are combined in the feed budget, and the optimum feed profile for the ewes are optimised from a selection of 2000 options for each class of animal. The classes of ewes optimised for each level of scanning are:

Don't scan
- All ewes are optimised together by age group

Scan for pregnancy status
- Empty ewes by age group
- Pregnant ewes by age group

Scan for multiples
- Empty ewes by age group
- Single bearing ewes by age group
- Multiple bearing ewes by age group

Contribution of the components

The component analysis was only carried out for the Merino and the maternal flocks. It was not possible for the Merino-terminal flock because controlling the nutritional management of the 2 flocks of ewes that are represented in the model was difficult.

Each component was removed from the model calculations individually to assess the value of that component. There are interactions between the components and the optimum management can vary when some components are removed therefore the sum of the individual components does not equal the sum of the components combined. Therefore, these results are only indicative of the contribution of each component to the final result. Some of the components were also further broken down in to sub-components. The components and sub-components examined were:

Scanning for pregnancy status

- Culling the passengers
  - Increase in reproduction
- Nutrition and production
  - Empty ewes
  - Pregnant ewes

Scanning for multiples

- Pregnancy status
- Managing the performers
  - Increase in reproduction of the animals retained
- Nutrition and production
  - Empty ewes
  - Single-bearing ewes
  - Twin-bearing ewes
- Paddock allocation

The components of production when scanning for multiples was also valued using a similar process

- Ewe & hogget mortality
- Ewe fleece value
- Progeny birth weight and survival
- Progeny Fleece value (Lifetime Wool effects)

Sensitivity Analysis

Sensitivity was carried out to provide more detail on the contribution of some of the important components that contribute to the profitability of scanning. For each of the 27 region, flock & time of lambing scenarios a number of levels were examined for each of

- Paddock allocation benefits, 4 levels: One level was the standard which was based on an average chill of 850 kJ m^{-2}.hr and the difference for sheltered and exposed of 100 kJ m^{-2}.hr. Another level was using the benefits expected from allocating ewe based on optimum mob size and the other levels where higher at 1000 and 1200 average chill levels.
- Flock reproductive rate, 5 levels: One was the standard level as predicted by the GrazPlan relationships, the others were scaled ± 15% and 30% from the expected value.

- Reproduction rate increase expected from culling the passengers, 5 levels: One level was the standard as outlined in an earlier section '*Response due to culling once or twice-empty ewes*' on page 100. The other 4 levels were scaled ±25 & 50% from the standard.
- Prices, 7 levels: The scenarios were standard prices, low & high wool prices, low & high meat prices and low & high grain prices.

Equation system

The main analysis used the lamb survival relationship developed from the plot scale information in the LifetimeWool project and the predictions were based on the range of chill expected at lambing based on historical weather records. For this sensitivity analysis the calculated chill index was varied ± 10% and the calculation f lamb survival was compared for the paddock scale LTW relationship and the GrazPlan relationship.

Results & Discussion

Value of scanning

Pregnancy scanning for multiples and implementing optimal management of the empty ewes, the optimal differential nutrition of the pregnant ewes and optimal allocation of the lambing paddocks based on litter size increased profitability in all regions for all flocks for all times of lambing (Table 16). The value per ewe scanned varied from $1.20/ewe for Merinos lambing in spring in the short growing season environment up to $10.60/ewe for Merinos lambing in winter in the long growing season environment. The average value of the increase was $5.75/ewe scanned and represents a 500% return on expenditure after covering contract costs and the requirement for extra on-farm labour associated with the scanning operation.

Table 16: The increase in farm profit from scanning for multiples and implementing optimum management ($/ewe scanned) for each of the 3 regions and 3 flock types for 3 times of lambing. Estimated for 85% agreement between scanning results & lambing outcome.

	Time of Lambing		
Region & Flock	Autumn ($/ewe)	Winter ($/ewe)	Spring ($/ewe)
Long Growing Season			
Merino	7.20	10.60	3.80
Mer-TS	6.40	8.80	6.00
Maternal	7.50	8.80	5.40
Medium growing season			
Merino	7.80	2.80	5.50
Mer-TS	9.80	5.20	3.70
Maternal	5.80	4.00*	4.20
Short growing season			
Merino	4.60	4.60	1.20
Mer-TS	5.20	4.70	1.90
Maternal	8.40	3.50	6.50
Average	7.00	6.10	4.25
Overall average	5.75		

* extrapolated from the value of scanning for multiples using the other scenarios

The benefit achieved from scanning for multiples is the combination of the benefit that can be achieved from identifying the empty ewes through scanning for pregnancy status and the extra value achieved by also identifying the multiple-bearing ewes. These two components are discussed in more detail in subsequent sections.

The variation in the value of scanning across regions aligns with the timing of the main feed shortage. The maximum value from scanning is achieved for flocks that are scanning just prior to the worst feed deficit. This is ‘winter’ lambing in the long growing season environment and ‘autumn’ lambing in the medium and short growing environments. Scanning has the least impact on the profitability of ‘spring’ lambing flocks that are scanning at the end of the autumn/winter feed deficit in all regions because this reduces the value that can be achieved from alternative management of the empty ewes which means the main benefit is from differential management of the multiple-bearing ewes.

Rules of thumb

- scanning for multiples and implementing optimum nutritional management, optimal management of emptys and optimal paddock allocation increased profit for all genotypes, in all regions at all times of lambing. The average increase in profit was $5.75 per ewe scanned.
- The maximum value from scanning is achieved for flocks that are scanning just prior to the worst feed deficit. This is ‘winter’ lambing in the long growing season environment and ‘autumn’ lambing in the medium and short growing environments.
- In general scanning has the least impact on profit for spring lambing flocks
- If scanning was 100% accurate in predicting the lambing outcome then the value of scanning for multiples increase to $6.30/ewe scanned.

Optimum Nutrition Profiles

A major contributor to the value of scanning can be the ability to differentially feed empty, single- and multiple-bearing ewes. To value this appropriately requires identifying the optimum nutrition profiles for ewes carrying different numbers of foetuses. The following profiles were identified and used in the subsequent analysis.

If ewes are not scanned (eg. Figure 10) then the empty ewes gain weight relative to the single bearing ewes and the twin bearing ewes lose weight. In the period prior to scanning the ewes with different numbers of foetuses are managed together and the weights diverge slightly due to differences in energy requirements. After scanning the ewe nutrition profiles are optimised for the groups that are identified by scanning. If the ewes are scanned for pregnancy status (e.g. Figure 11) then the nutrition level of the empty ewes is reduced at scanning. If the ewes are scanned for multiples, then the single- and multiple-bearing ewes can be differentially fed and the main adjustment is during the period from scanning to lambing (eg. Figure 12). The ewes that conceived in different cycles were managed as a single mob and the value that could be achieved from foetal aging was not quantified in this analysis. Profiles for the other regions and each time of lambing are presented in Sub-Appendix 1.

The profiles developed in this project were done with a more rigorous process and an improved model compared with the profiles developed in the LifetimeWool project a decade ago and there are some differences. Although the profiles presented here were selected by comparing more than 2000 nutrition profiles, further improvement could be achieved with extra work.

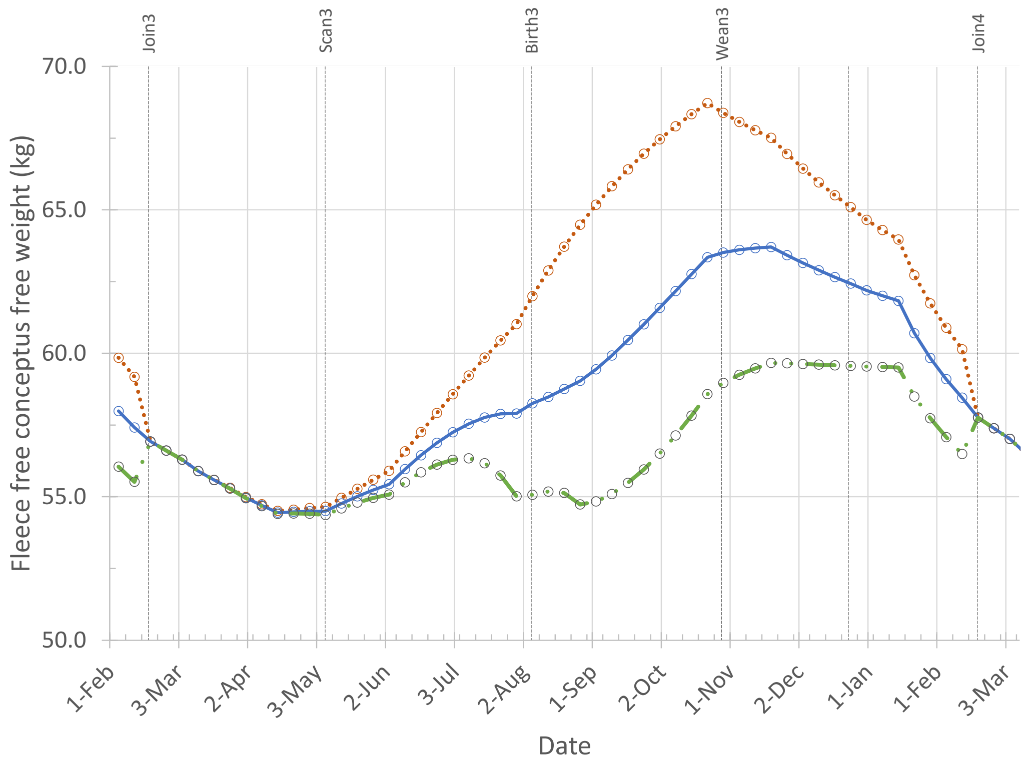

Figure 10: Example of optimum profile for empty (...), single-bearing (—) and twin-bearing ewes (– ··) from the medium rainfall region (GS of WA) with spring lambing if the flock is unscanned (○).

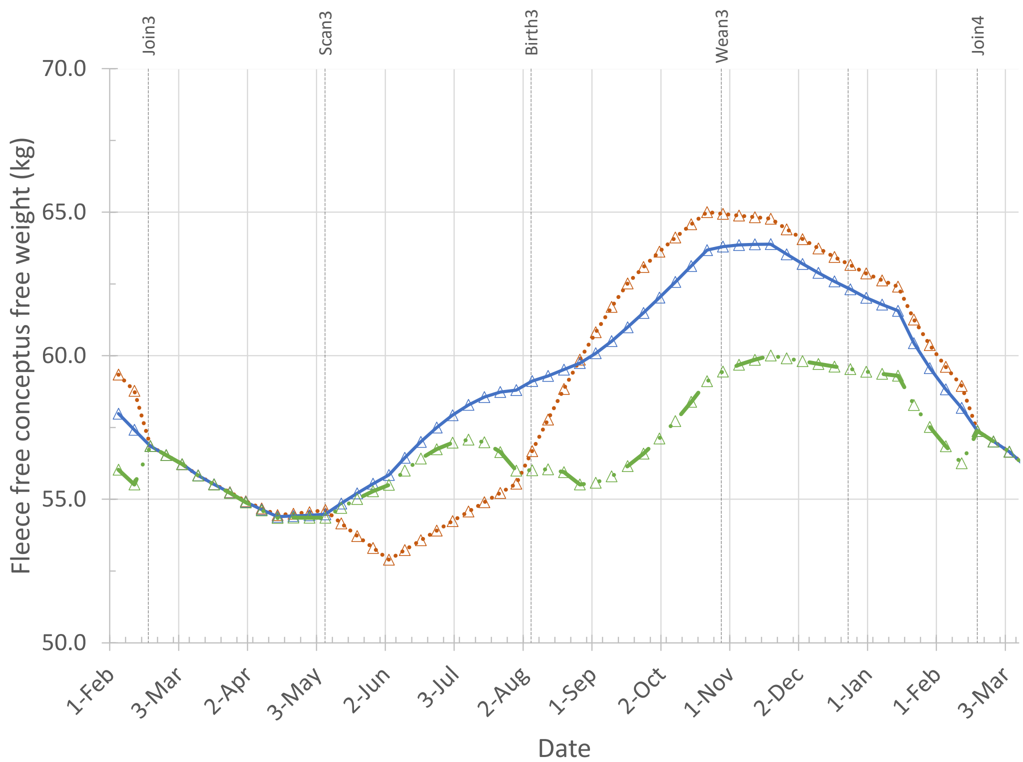

Figure 11: Example of optimum profile for for empty (...), single-bearing (—) and twin-bearing ewes (– ··) from the medium rainfall region (GS of WA) with spring lambing if the flock is scanned for pregnancy status (Δ) and the non-pregnant ewes are identified and differentially managed.

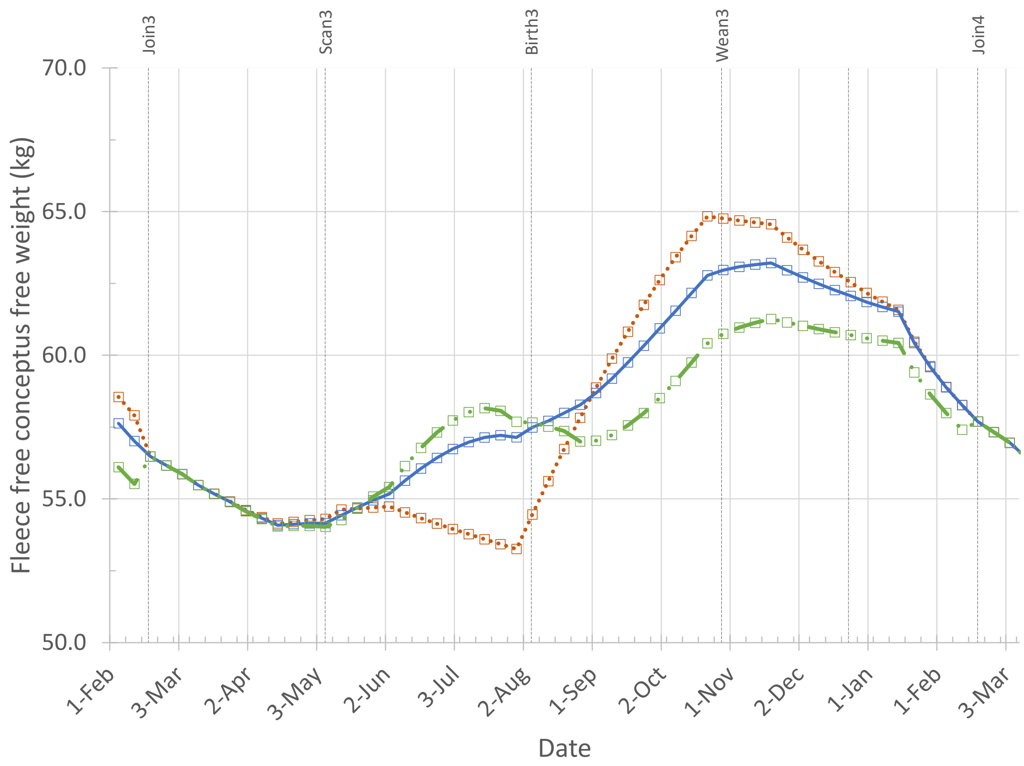

Figure 12: **Example of optimum profile for empty (…), single-bearing (—) and twin-bearing ewes (– ··) from the medium rainfall region (GS of WA) with spring lambing if the flock is scanned for multiples (□) and the empty, sinlge- and multiple-bearing ewes are differententially managed.**

Rules of Thumb

- If ewes are not differentially fed during pregnancy the empty ewes will be 3-5 kg heavier at birth than the single bearing ewes and the twin bearing ewes will be 3-5kg lighter.
- If empty ewes are identified and not sold then the optimal profile is for the empty ewess to lose weight after scanning, the amount of weight loss depends on the severity of the feed shortage but can be up to 10kg lighter than the singles at birth.
- If the multiples are also identified, the optimum nutritional management is to increase the feed supply and to be 2 to 3kg heavier than the singles at birth.

Scanning for pregnancy status

Scanning for pregnancy status and altering the management of the empty ewes increases profit in all flocks that are scanning prior to the main feed deficit (**Table 17**). The increase in profit for flocks lambing prior to the feed deficit ranged from $2/ewe for Merinos in the short growing season environment up to $7.20/ewe for the maternal flock in the long growing season environment. Scanning for pregnancy status was not profitable in some regions/flocks if the scanning was occurring after the main feed deficit. In these cases, which were both merinos, the reproduction and feed benefits achieved were less than the cost outlay for scanning and the reduction in the wool production potential of the flock.

Selling the passengers to increase reproductive rate and reduce flock feed demand is the major contributor to the profitability of scanning for pregnancy status (Table 17). Altering the nutrition of the emptys that are retained is a minor contributor being half or a third of the value of managing the passengers when selling twice-empty ewes and much less when selling all the empty ewes (once-empty). The value identified as ‘nutrition’ when selling once-empty ewes at scanning is associated with the altering the nutrition of the pregnant ewes when the emptys have been removed.

It was optimal to sell once-empty ewes for the flocks that were scanning just prior to the main feed deficit provided that the weaning percentage was sufficient for the flock to be self-replacing. Flocks that could not be self-replacing or were scanning after the feed deficit sold twice-empty ewes. In the majority of the scenarios the empty ewes were sold at scanning (Table 18), although for the spring lambing flocks there was very little difference in profit with time of sale.

For maternals, identifying the emptys is a big contribution to the total value of scanning. This is driven by the gain in reproduction rate achieved from culling the once-empty. However, the assumptions underpinning the analysis may not be correct, they are based on gains made in a merino flock that had a higher proportion of emptys and hence a much higher selection pressure.

Table 17: Value of scanning for pregnancy status only ($/ewe) with the optimum management of the empty ewes and the contribution from each component that can be changed as a result of identifying the empty and pregnant ewes. Assuming 100% agreement between scanning and lambing.

	Value		Optimum	Contribution of the Component[#]	
	($/ewe)	($/empty)	management	Passengers	Nutrition
Long growing season – Merino					
Autumn	5.30	21.10	Twice-empty	4.30	1.80
Winter	4.40	33.20	Once-empty	3.80	1.20
Spring	0.90	8.90	Once-empty	1.30	0.00
*Long growing season – Maternals**					
Autumn	7.10	26.60	Twice-empty	13.00	0.20
Winter	7.20	67.10	Once-empty	11.40	0.40
Spring	2.80	30.60	Once-empty	8.40	0.40
Medium growing season – Merino					
Autumn	6.10	35.40	Once-empty	2.70	
Winter	-1.40	-10.10	Twice-empty	0.20	-0.70
Spring	1.50	11.30	Twice-empty	0.40	2.50
Medium growing season – Maternals					
Autumn	2.60	21.00	Once-empty	-2.40	
Winter			Once-empty	8.60	-7.60
Spring	0.40	3.90	Once-empty	4.80	-2.80
Short growing season – Merino					
Autumn	2.00	10.10	Once-empty	3.70	1.60
Winter	0.80	5.40	Twice-empty	0.30	-0.30
Spring	-0.20	-1.50	Twice-empty	0.60	-0.10
Short growing season – Maternals					
Autumn	8.50	62.40	Once-empty	11.70	-0.30
Winter	4.80	60.30	Once-empty	7.90	1.50
Spring	3.30	39.00	Once-empty	4.60	0.10
Overall average	3.30	25.00			

[#]The proportions don’t sum to 100% because of interactions between the components and changes in the optimised management.

* The nutrition profile was not optimised for the Maternals in the long growing season environment.

Table 18: Management of the empty ewes that are identified by scanning for pregnancy status.

	Optimum Management	Proportion of emptys sold: At shearing	At scanning	Benefit of selling due to RR*
Long growing season – Merino				
Autumn	Twice-empty	0	59%	14%
Winter	Once-empty	0	100%	15%
Spring	Once-empty	0	101%	42%
Long growing season – Maternals				
Autumn	Twice-empty	0	51%	15%
Winter	Once-empty	0	100%	11%
Spring	Once-empty	0	100%	22%
Medium growing season – Merino				
Autumn	Once-empty	0	100%	34%
Winter	Twice-empty	0	21%	416%
Spring	Twice-empty	6%	15%	268%
Medium growing season – Maternals				
Autumn	Once-empty	0	100%	144%
Winter	Once-empty	0	100%	19%
Spring	Once-empty	0	100%	39%
Short growing season – Merino				
Autumn	Once-empty	0	100%	115%
Winter	Twice-empty	0	25%	373%
Spring	Twice-empty	6%	15%	176%
Short growing season – Maternals				
Autumn	Once-empty	0	100%	11%
Winter	Once-empty	0	100%	33%
Spring	Once-empty	0	100%	56%

* remainder of the benefit is due to removing the feed requirement of the empty ewe from scanning to shearing (if sold at scanning)

Rules of Thumb

- Scanning for pregnancy status increases profit for all flocks that are scanning prior to the main feed deficit and it is less valuable for flocks lambing in ‘spring’.
- Selling once-empty at scanning is most profitable for maternals provided the flock weaning percentage is sufficient to allow the flock to be self replacing.
- Selling once-empty at scanning is most profitable for merino flocks that are scanning prior to the main feed deficit (winter for long growing season and, autumn for medium and short growing season) and the flock weaning percentage is sufficient to allow the flock to be self replacing.
- Selling twice-empty is generally the most profitable management for merino flocks lambing in spring. Time of sale is less important for the flocks selling twice-empty and the most profitable decision will likely depend on the amount of wool on the ewes back at scanning versus the value that would be realised for that wool.

Scanning for multiples

The increment in the value of scanning from identifying multiples was $4/ewe scanned and ranged from $0.30/ewe up to $10.80/ewe. For the earlier lambing flocks, scanning for pregnancy status is the major contributor to the total value of scanning and the increment due to scanning multiples is small (Table 19). The small contribution from scanning for multiples is because the value per multiple-bearing ewe tends to be smaller and the number of multiple-bearing ewes tends to be lower with earlier joining due to the seasonality of reproduction.

If presented as the value per ewe scanned with multiples the increment equates to $9.25/ewe scanned with multiples. This is an indication of the cost of errors associated with mis-identifying a multiple-bearing ewe as a single bearing ewe. If there is a 5% discrepancy between scanning and lambing then this reduces the total value of scanning by approximately $0.45 per multiple bearing ewe. A 15% discrepancy would reduce the value by approximately $1.40/multiple bearing ewe, which is about a 20% reduction in the total value of scanning (see Table 16).

Paddock allocation at lambing, differential nutrition of singles and multiples and improved management of replacement progeny contribute about equally to the extra benefit of scanning for multiples compared with scanning for pregnancy status only. The relative contribution does vary with the region, flock and time of lambing scenario and the maternals tend to have a lower benefit associated with paddock allocation.

Managing the performers adds very little to the value of identifying multiples based on the assumed benefits for reproductive rate and the costs of adjusting flock structure.

The benefits of differential nutrition of single- and multiple bearing ewes is a combination of increasing the nutrition of the multiple-bearing ewes and reducing the single-bearing ewes. Both contribute about equally to the profit outcome for both Merinos and maternals.

Differential nutrition of single- and multiple-bearing ewes improves lamb survival, progeny wool production (the LTW effect), fleece value of the ewes and ewe mortality. On average, improved lamb survival accounts for 55% of the total value and progeny wool accounts for 40%. Ewe fleece value and ewe mortality are inconsistent in their effect and average close to zero. The small and inconsistent effect of dam mortality is not as expected particularly for the maternal flocks. The problem may be related to inaccurate relationships driving dam mortality due to pregnancy toxaemia and dystocia, because there is little information in this area. Improving these relationships may increase the value of scanning maternal flocks for multiples and may help sell the message to maternal producers.

Table 19: The increase in farm profit from scanning for multiples compared to scanning for pregnancy status ($/ewe scanned and $ per multiple bearing ewe identified) and the contribution of each component to the total value of scanning for pregnancy status for each growing season region, time of lambing and flock type examined.

	Increase in value		Management of emptys and CFA ewes	Contribution of components*				
	$/ewe	$/multiple		Pregnancy status	Performers	Progeny Management	Nutrition	Paddock allocation
Autumn	1.50	6.90	Twice-empty	5.30	-0.30	0.20	0.80	1.00
Winter	5.10	14.90	Once-empty	4.40	-0.10	2.80	3.50	1.80
Spring	2.70	7.10	Once-empty & performers	0.90	0.10	1.50	1.80	1.70
Autumn	0.30	1.50	Twice-empty	7.10	-1.00	-0.20	0.00	0.30
Winter	1.60	2.70	Once-empty & performers	7.20	0.30	0.00	0.10	1.60
Spring	3.00	4.10	Once-empty	2.80	-0.10	0.00	0.40	2.70
Autumn	3.10	8.90	Once-empty & performers	6.10	0.20	1.90	1.90	2.60
Winter	6.00	15.70	Twice-empty	-1.40	-0.40	1.70	1.80	2.50
Spring	4.30	11.20	Twice-empty	1.50	-0.10	0.80	4.50	2.00
Autumn	1.30	3.00	Once-empty	2.60	-1.80	0.70	1.00	3.10
Winter	10.80	16.90	Once-empty & performers	-4.80	1.10	5.50	6.90	1.70
Spring	10.00	16.50	Once-empty	0.40	-2.40	4.30	4.50	3.60
Autumn	2.80	8.90	Twice-empty & performers	2.00	0.40	-0.60	-0.20	1.50
Winter	4.90	13.70	Twice-empty	0.80	-0.10	2.40	2.30	1.80
Spring	2.30	6.70	Twice-empty & performers	-0.20	0.50	1.30	1.30	2.30
Autumn	1.90	5.70	Once-empty & performers	8.50	0.30	-0.70	-0.60	1.00
Winter			Once-empty & performers	4.80	0.20	-3.50	-2.80	1.30
Spring	6.10	12.60	Once-empty & performers	3.30	0.30	2.90	2.90	1.40
Average	4:00	9.25		2.75	-0.20	1.45	1.95	1.90

* the proportions don't sum to 100% because of interactions between the components and changes in the optimised management.

Rules of thumb

- The benefits associated with
  - improved allocation of paddocks at lambing
  - differential nutrition of singles and multiples
  - improved capacity to manage the replacement progeny from knowing birth type

  contribute equally to the extra value of scanning multiples.
- Identifying and managing the performers (by retaining 50% of the 5.5yo ewes with the highest net reproductive rate till 6.5 yo) had a low value, increasing profit in some scenarios and reducing it in others.
- Lamb survival and progeny wool production (LifetimeWool) are the main drivers of the value of differential nutrition.

Sensitivity Analysis

Paddock Allocation

The value of scanning is sensitive to the lamb survival benefit achieved from allocating the lambing paddocks that increase survival to the multiple bearing ewes. There are likely to be a range of paddock factors that affect lamb survival, but for this analysis in general and this sensitivity specifically, level of exposure has been evaluated because relationships exist in the literature to quantify the effect. The aim of this sensitivity was to determine the importance of paddock allocation, and the calculations quantified the benefits associated with mob size and allocation of shelter.

In this analysis the standard is paddock allocation based on shelter with an average chill index of 850 and a differential of 100 index units between the sheltered paddocks and the exposed paddocks with an reduction in overall lamb mortality of 1.8% for merino lambs and 1.0% for maternal lambs (see section 0). The range tested was a minimum of 0.8% associated with allocating paddocks based on optimum mob size up to a maximum of 3.6% for Merinos with an average chill index of 1000 $kJ/m^2/hr$.

If the potential benefit is reduced and the only benefit from improved paddock allocation is due to optimising mob size for single- versus multiple-bearing ewes, then the value of scanning is reduced by about $1.10 per ewe. The variation is greater for the Merino based flocks with a reduction in average value of $1.50/ewe and less for the maternal flocks $0.30/ewe. This is a medium reduction and indicates the importance of paddock allocation as an important driver of the profitability of pregnancy scanning. However, even if the only benefit achieved from paddock allocation is to optimise the mob size at lambing all the scenarios remain positive for the value of scanning.

If the potential benefit is related to allocation of shelter to the multiple-bearing ewes then as chill index increases from a minimal value the benefits of improved paddock allocation increase (Figure 13 & Figure 14). For merino based flocks the maximum value is achieved if the chill index averages about 1000. If the chill index is above 1000 then the relative advantage of providing the more sheltered paddocks to the multiple-bearing ewes rather than to the single-bearing ewes begins to diminish, beyond a chill of about 1250 it would be optimal to allocate the sheltered paddocks to the single-bearing ewes because survival of the single born lambs will be more responsive. For maternal based flocks the benefit of allocating the more sheltered paddocks to the twin-bearing ewes continues to increase with higher chill index up to 1200 $kJ\ m^{-2}.hr$ (Figure 14), although total benefits would begin to reduce above a chill of 1200.

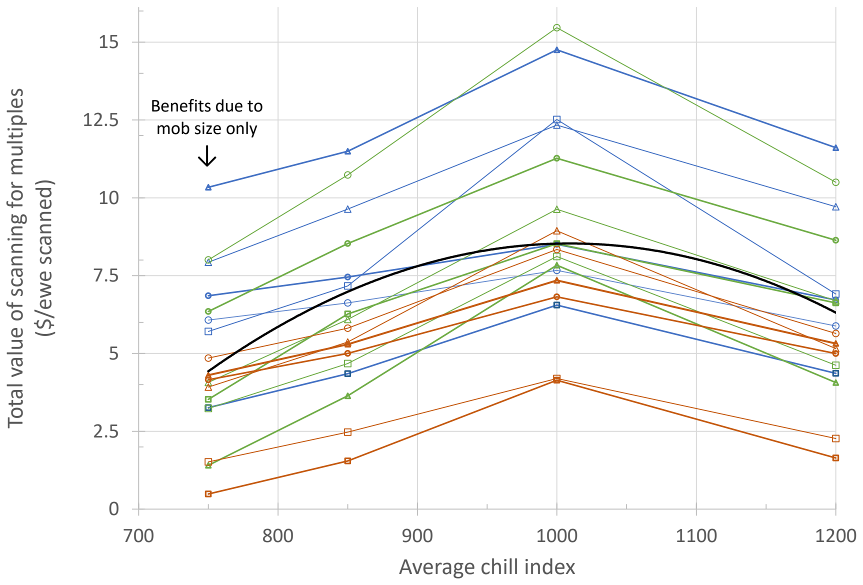

Figure 13: Impact of varying the average chill at lambing on the value of pregnancy scanning Merino flocks as affected by the gains in lamb survival due to allocation of the lambing paddocks. With a chill index of 750 the benefits are associated with allocating paddocks to optimise mob size rather than to reduce the chill experienced by the twin born lambs. Across the 18 Merino scenarios examined for the 3 regions (Long growing season - blue, medium growing season - green and short growing season - Red), the 2 Merino flocks (Merino-Merino – open symbol heavy line, Merino-terminal sire – open symbol thin line) and the 3 times of lambing (autumn – circle, winter – triangle, spring – square). The solid black line is the average across all scenarios

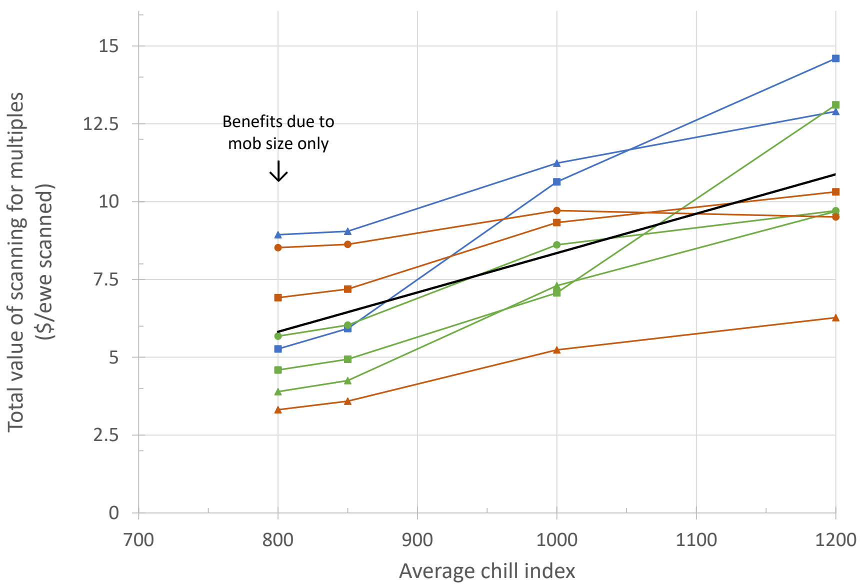

Figure 14: Impact of varying the average chill at lambing on the value of pregnancy scanning maternal flocks as affected by the gains in lamb survival due to allocation of the lambing paddocks. With a chill index of 800 the benefits are associated with allocating paddocks to optimise mob size rather than to reduce the chill experienced by the twin born lambs. Across the 9 maternal scenarios examined (legend as described in Figure 13).

Rules of Thumb

- The benefits from improving paddock allocation are an important contributor to the value of pregnancy scanning. Therefore, information about the benefits from differential allocation will be an important component of the extension message.
- If the only benefit from scanning is due to optimising mob size at lambing the benefits of scanning are reduced by approximately $2.20/ewe, however, the total benefit remains positive for all the scenarios.

Flock Reproductive Rate

The total value of scanning for multiples was greater than zero for all the scenarios over the complete range of reproductive rates examined (Figure 15) and there was not a strong or consistent trend in the value of scanning with varying reproductive rate. For some scenarios the total value of scanning increased with higher reproductive rate and for some scenarios the value reduced and for some there was little change. However, there was slight trend at very low reproductive rate for scanning to be less valuable. When reproductive rate is very low the scope to cull the emptys is reduced because the flock is unable to replace and this removes one option for benefiting from scanning.

The total value of scanning is a combination of the value achieved from scanning for pregnancy status (and improving the management of the empty ewes) and the increment from scanning for multiples (and improving the management of the multiple bearing ewes). The value of scanning for pregnancy status tends to reduce as reproductive rate increases and the number of empty ewes in the flock decreases (Figure 16). The increment in the value of scanning multiples increases as reproductive rate and the number of multiple bearing ewes in the flock increases (Figure 17).

Further detail for each region is presented in Sub-Appendix 1.

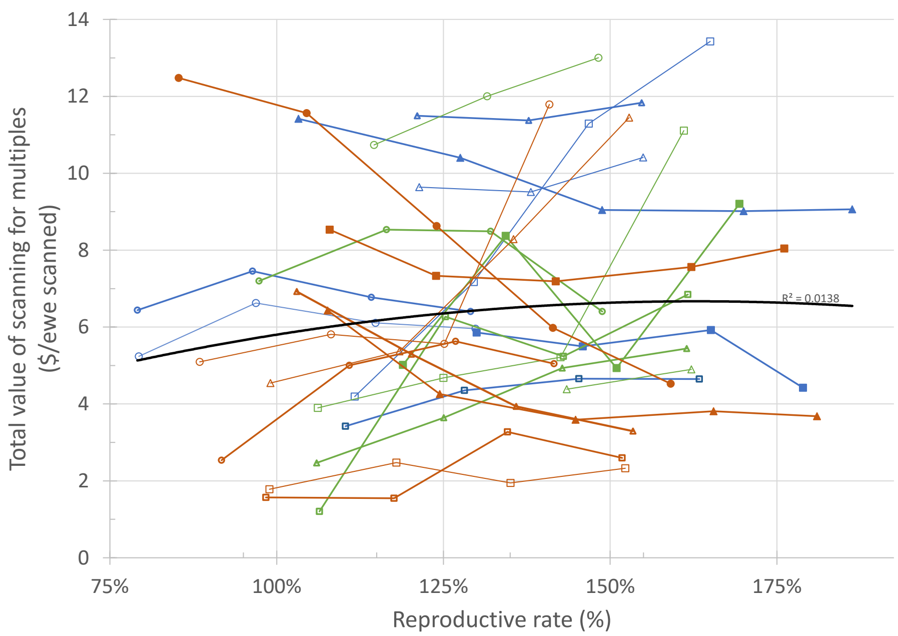

Figure 15: The increase in profit from scanning for multiples compared to not scanning ($/ewe scanned) if implementing optimal nutritional management, optimal management of the empty ewes and optimal allocation to lambing paddocks. Across the 27 scenarios examined for the 3 regions (Long growing season - blue, medium growing season - green and short growing season - Red), the 3 flocks (Merino-Merino – open symbol heavy line, Merino-terminal sire – open symbol thin line, maternals – solid symbol) and the 3 times of lambing (autumn – circle, winter – triangle, spring – square). The solid black line is the average across all scenarios

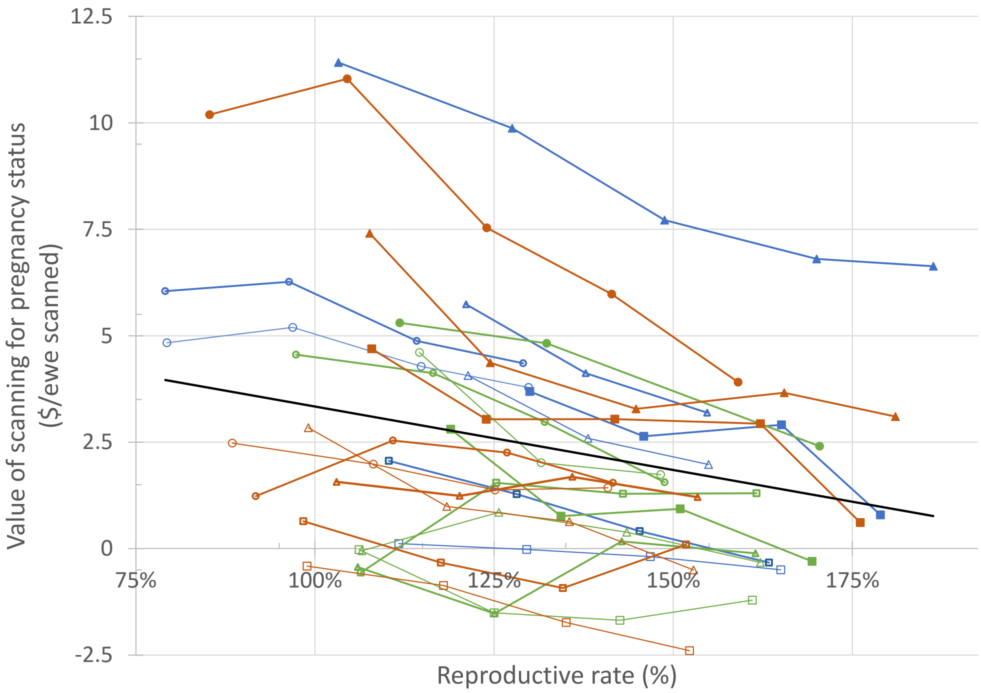

Figure 16: The change in profit from scanning for pregnancy status with optimum management of nutrition and the empty ewes, and the impact of varying the reproductive rate of the flock. Legend as described in Figure 15.

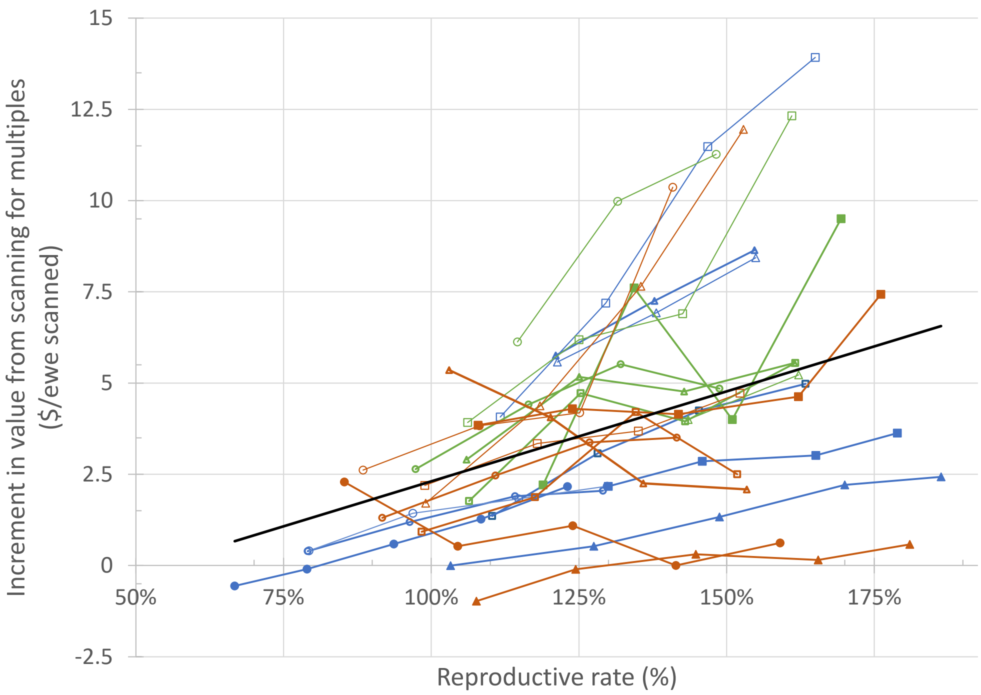

Figure 17: The change in profit from scanning for multiples above that from scanning for pregnancy status ($/ewe scanned) and the impact of varying the reproductive rate of the flock. Legend as described in Figure 15.

Rules of Thumb

- The total value of scanning is not affected by the reproductive rate of the flock provided that the weaning percentage is sufficient that the flock can remain self-replacing when 'twice-emptys' are sold.
- As reproductive rate increases the reduction in the value of managing the reduced number of empty ewes is offset by the increase in value of managing the extra multiple bearing ewes.
- The value of scanning for pregnancy status expressed per empty ewe is constant across a range of proportion of empty ewes, provided the flock can remain self-replacing (Figure 72, Figure 74 & Figure 76).
- The increment in the value of scanning for multiples above that achieved from scanning for pregnancy status is constant across a range of proportion of multiple-bearing ewes when expressed as $/multiple-bearing ewe (Figure 73, Figure 75 & Figure 77).

Selling Empty

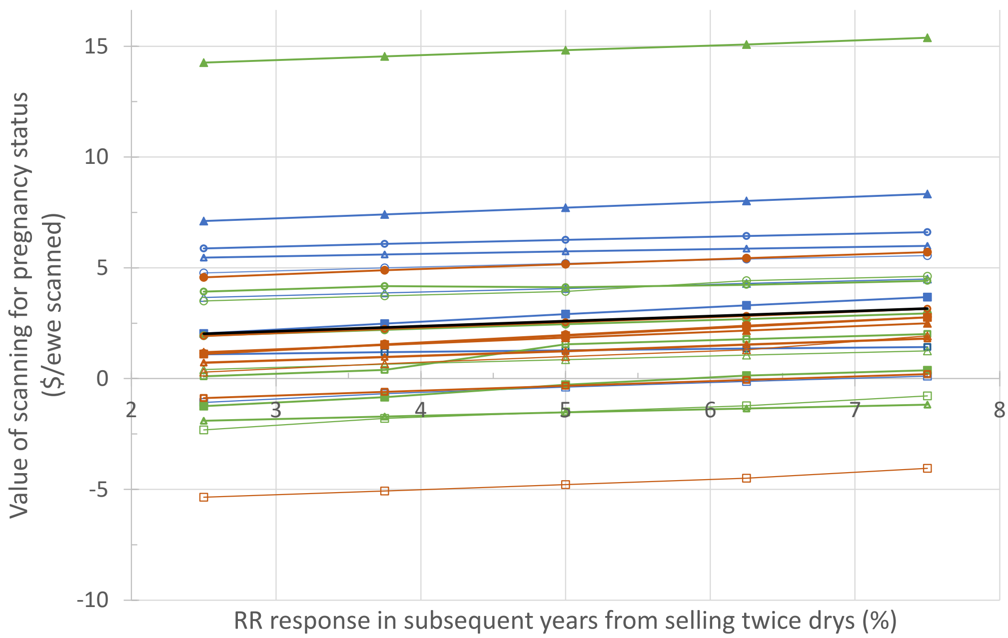

Figure 18:The impact of the increase in reproductive rate due to culling passengers on the value of scanning for pregnancy status. Note: The x axis is expressed as the benefit of selling 'twice-empty', for the flocks that are selling 'once-empty' the benefit is 25% greater than 'twice-empty'. Results for the 27 scenarios examined for the 3 regions (Long growing season - blue, medium growing season - green and short growing season - Red), the 3 flocks (Merino-Merino – open symbol heavy line, Merino-terminal – open symbol thin line, maternals – solid symbol) and the 3 times of lambing (autumn – circle, winter – triangle, spring – square). The solid black line is the average across all scenarios

The increase in reproductive rate achieved from selling the 'passengers' is an important contributor to the value of identifying pregnancy status. The assumptions in this analysis were based on values from industry research flocks examined in the "Passengers vs Performers" project. The sensitivity tested in this analysis covered a range of 50% lower to 50% higher than the 'best estimate' values. Within this range the value of pregnancy scanning changed by $1.15 per ewe scanned (**Figure 18**). A reduction of this magnitude is less than the total value of scanning for all the flocks and indicates that even if there were no future benefits from culling emptys that all flocks would still benefit from pregnancy scanning.

Prices

Changing wool prices and grain prices across the range of price scenarios examined had no consistent effect on the value of scanning and the average effect was no change (Figure 20 & Figure 21). This is because adopting scanning has little effect on the total quantity of wool produced and there is not a consistent effect on the total quantity of supplement fed. In contrast varying the meat price did alter the value of scanning (Figure 19) because the quantity of lamb produced is increased. Altering the meat price scenario down to the 50th percentile and up to the 90th percentile altered the value of scanning by plus or minus 30% on average. The range of lamb price that is associated with the percentile change is plus and minus 18% so the value of scanning changes by a greater proportion than the lamb price.

Extrapolating the results of this analysis would indicate that lamb price would have to drop by 60% to $2.50/kg for the average profitability of scanning to drop to zero. So, although the profitability of scanning is sensitive to meat price the likelihood of scanning becoming unprofitable is very low.

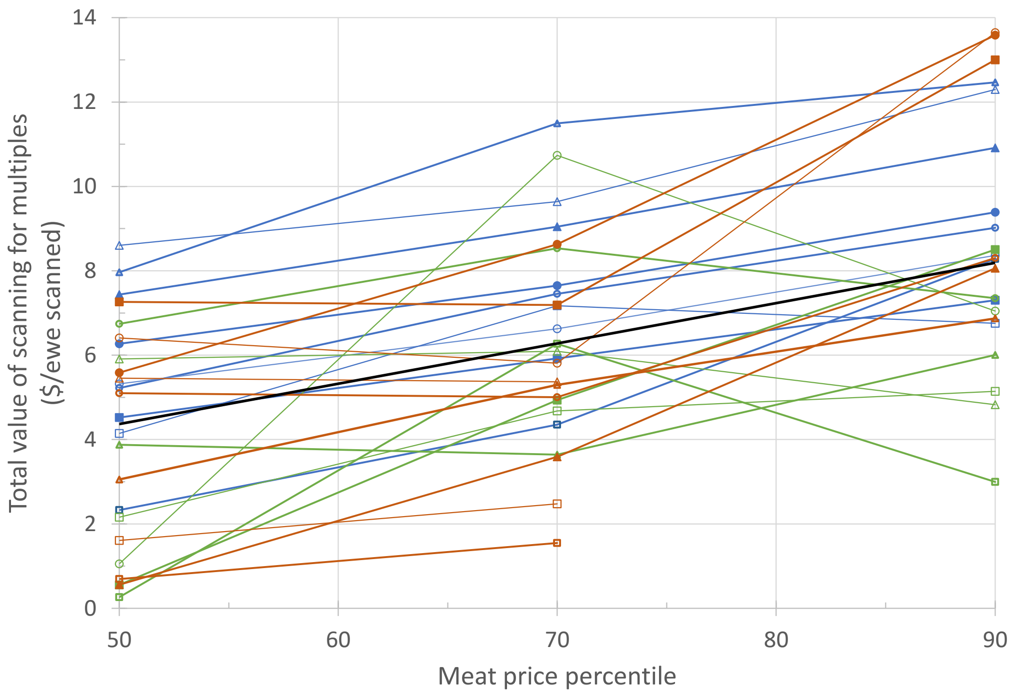

Figure 19: Impact of altering meat price on the value of scanning for multiples for all 27 scenarios of region, flock and time of lambing. A change from the 50th percentile to the 90th percentile represents a change in the lamb price from 465c/kg up to 670c/kg. (Long growing season - blue, medium growing season - green and short growing season – Red. Merino-Merino – open symbol heavy line, Merino-terminal sire – open symbol thin line, maternals – solid symbol). Lambing in Autumn – circle, winter – triangle, spring – square). The solid black line is the average across all scenarios

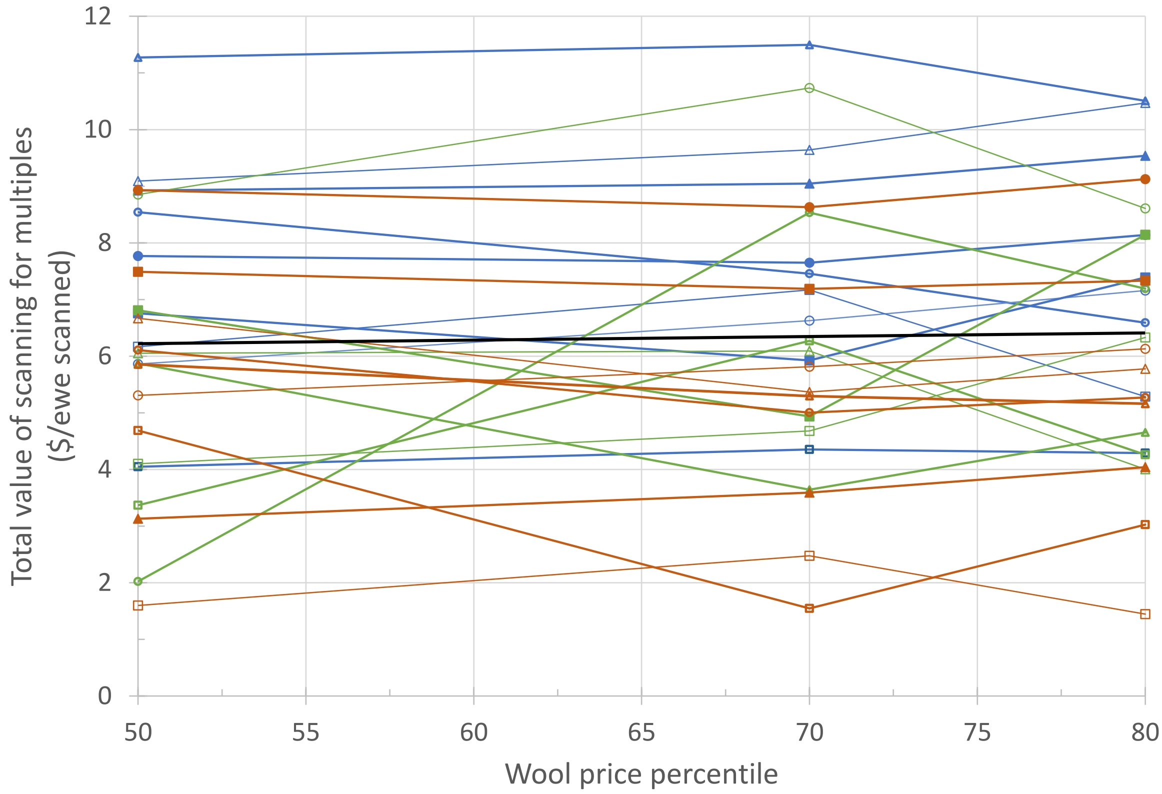

Figure 20: Altering the wool price scenario did not have a consistent effect on the value of scanning for multiples and the net effect across all the scenarios of region, flock and time of lambing was zero.

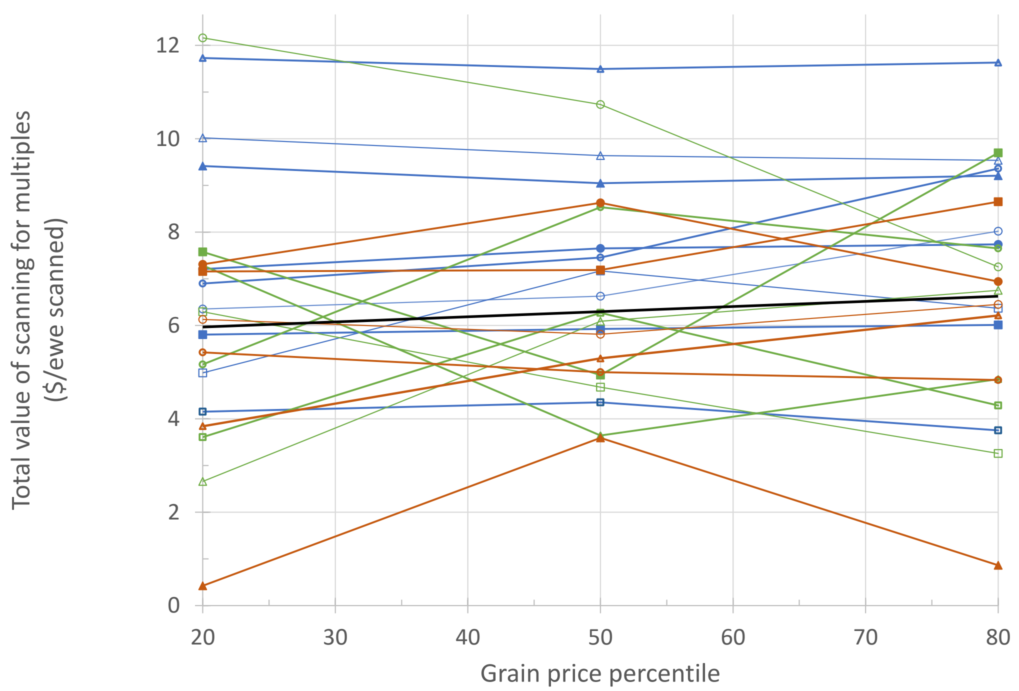

Figure 21: Altering the grain price scenario did not have a consistent effect on the value of scanning for multiples and the net effect across all the scenarios of region, flock and time of lambing was almost zero.

Rules of thumb

- The value of scanning is sensitive to the price of meat and a 10% change in lamb price is associated with a 15% change in the value of scanning.
- The prices used in this analysis are below the current the prices being received therefore the value predicted for scanning is an underestimate of what would be currently achieved. Extrapolating the results to the current meat prices indicates that the value of scanning would average about $10 per ewe.
- The value of scanning is not altered by the price of wool or the cost of grain because there is little change in the total quantity of wool produced or the amount of grain fed.

Equation system for lamb survival

The impact of differential nutrition on lamb mortality is an important driver of the profitability of pregnancy scanning to identify the multiple bearing ewes (Table 19). In the standard analysis the increase in survival has been estimated using the LTW plot scale equations that relate ewe LW profile during pregnancy to birth weight and then relate birth weight to lamb survival (Figure 1 & Figure 2). The level of lamb mortality in each region was based on the likely range of weather conditions during the lambing period. In this sensitivity the estimated chill index was scaled up and down and the LTW relationships were compared with the GrazPlan relationships.

The value of scanning Merino ewes estimated using the GrazPlan relationships is about $2.20/ewe lower than the value using the Lifetime Wool relationships. This reduction leads to some scenarios being close to 0 for the value of scanning which highlights that for some scenarios the choice of the relationships can be important.

The comparison hasn't been presented for the Merino mated to a terminal sire because the results are very similar to the pure-bred Merino. Similarly, the comparison between LifetimeWool and GrazPlan has not been presented for the maternal flock because for this genotype the survival relationships are very similar. For maternals, the GrazPlan equations estimate a slightly higher ($1/ewe) profitability for scanning and both sets of equations suggest that the average value of scanning is reduced slightly in the higher chill scenario, although the reduction is only $1/ewe over the range -10% to +10% in the chill index.

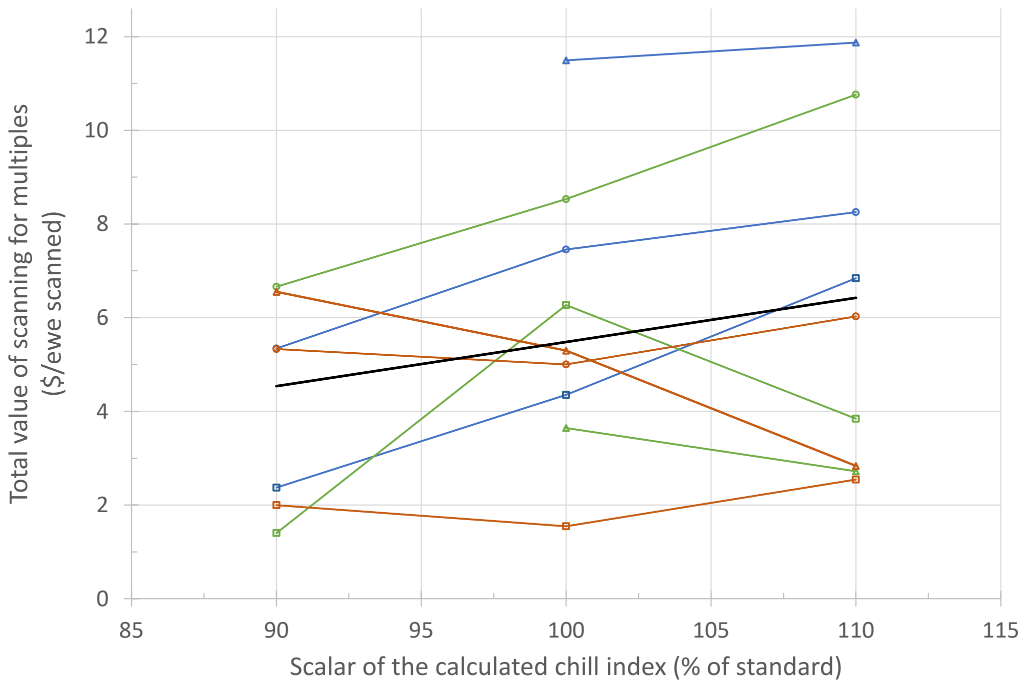

Figure 22: The total value of scanning to identify multiples for Merino flocks with lamb survival estimated using the LTW plot scale equations. For the 3 regions (Long growing season - blue, medium growing season - green and short growing season – Red) and 3 times of lambing (Autumn – circle, winter – triangle, spring – square). The solid black line is the average across all scenarios.

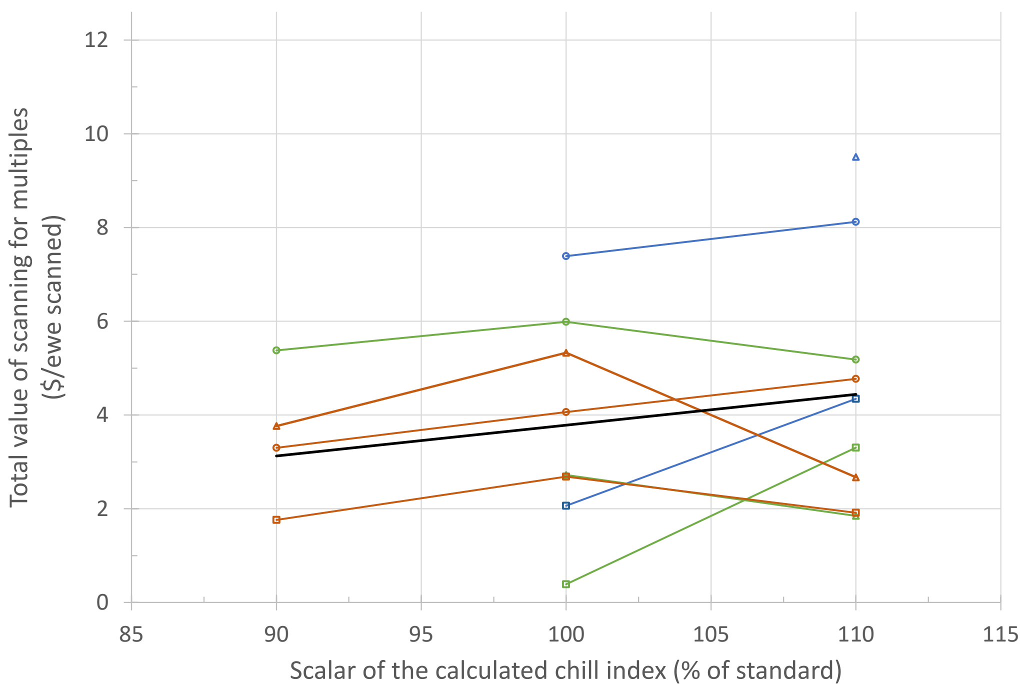

Figure 23: The total value of scanning to identify multiples for Merino flocks with lamb survival estimated using the GrazPlan lamb survival equations. (Legend as described in Figure 22).

Rules of Thumb

- Higher average chill increases the value of scanning for merinos and reduces the estimated value for maternals. Plus and minus 10% variation of the expected chill index altered profitability by about $1/ewe.
- Using the GrazPlan equations predicts about a $2/ewe lower benefit for pregnancy scanning of merinos, but a similar benefit for maternals. This is because the GrazPlan relationships for merinos show less difference between singles and twins in the response to survival due to their dams nutrition during pregnancy.

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Sub-Appendix 1

Value of scanning for multiples if 100% agreement between scanning and lambing

Table 20: The increase in farm profit from scanning for multiples and implementing optimum management ($/ewe scanned) for each of the 3 regions and 3 flock types for 3 times of lambing.

	Time of Lambing		
Region & Flock	Autumn ($/ewe)	Winter ($/ewe)	Spring ($/ewe)
Long Growing Season			
Merino	7.50	11.50	4.40
Mer-TS	6.60	9.60	7.20
Maternal	7.70	9.00	5.90
Medium growing season			
Merino	8.50	3.60	6.30
Mer-TS	10.7	6.10	4.70
Maternal	6.00	4.20	4.90
Short growing season			
Merino	5.00	5.30	1.50
Mer-TS	5.80	5.40	2.50
Maternal	8.60	3.60	7.20
Average	7.40	6.50	5.00
Overall average	6.30		

Optimum nutrition profiles

Long growing season

Autumn lambing

Merino ewes

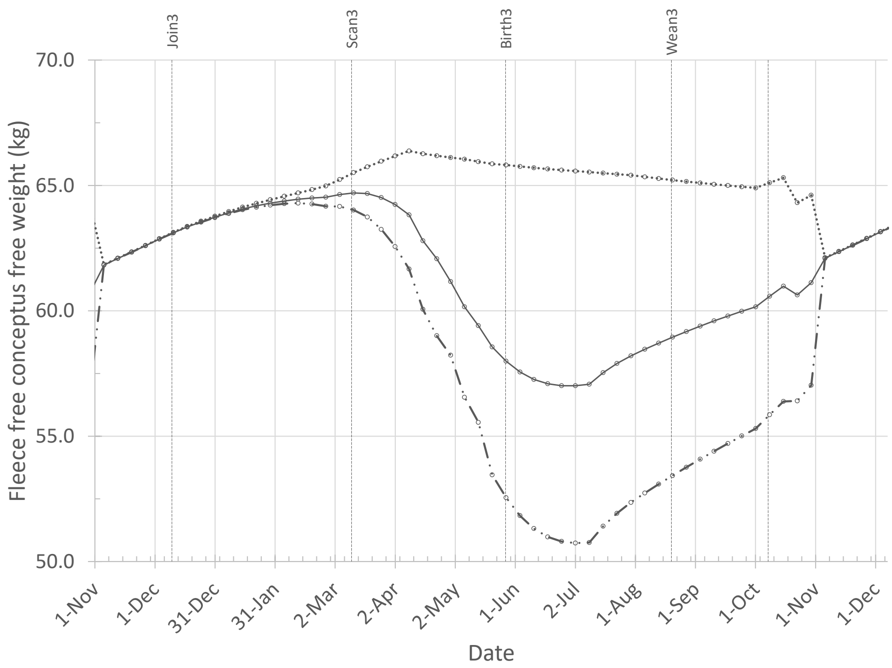

Figure 24: Optimised profile for empty (··), single- (—) and twin-bearing (-··) Merino ewes that have not been scanned.

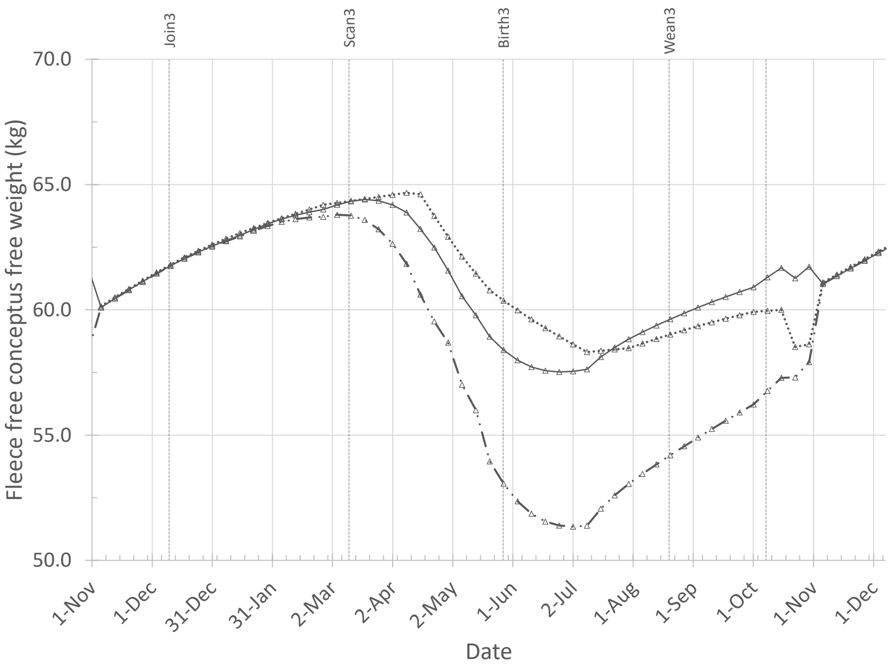

Figure 25: Optimised profile for empty (⋯), single- (—) and twin-bearing (-⋅⋅) Merino ewes that have been scanned for pregnancy status

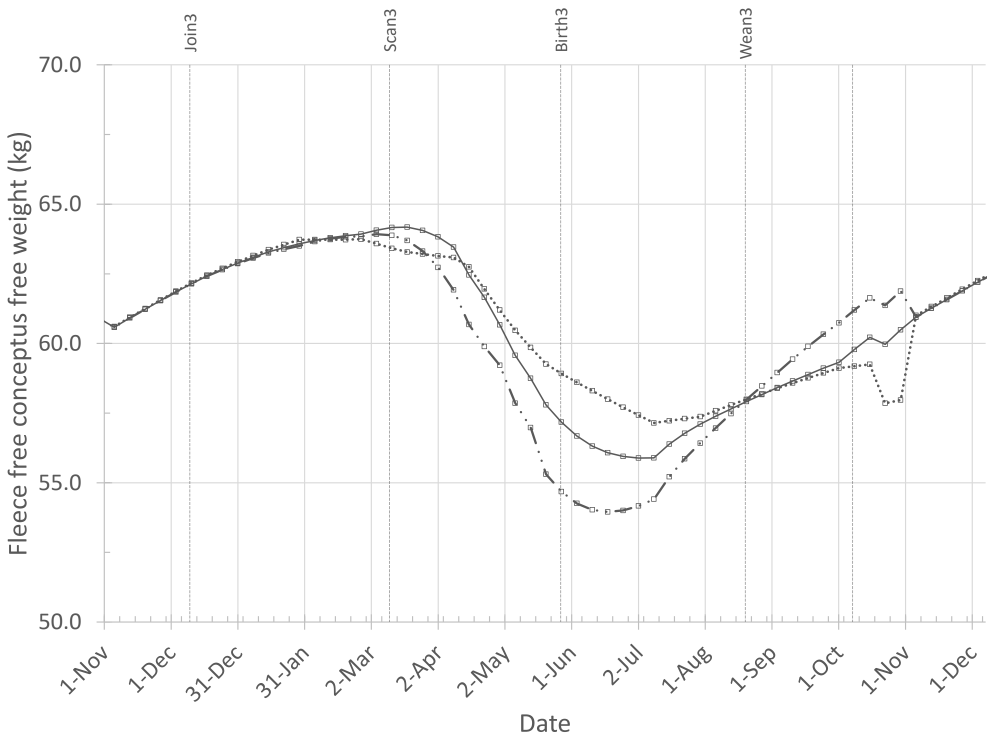

Figure 26: Optimised profile for empty(⋯), single- (—) and twin-bearing (-⋅⋅) Merino ewes that have been scanned for multiples

Maternal ewes

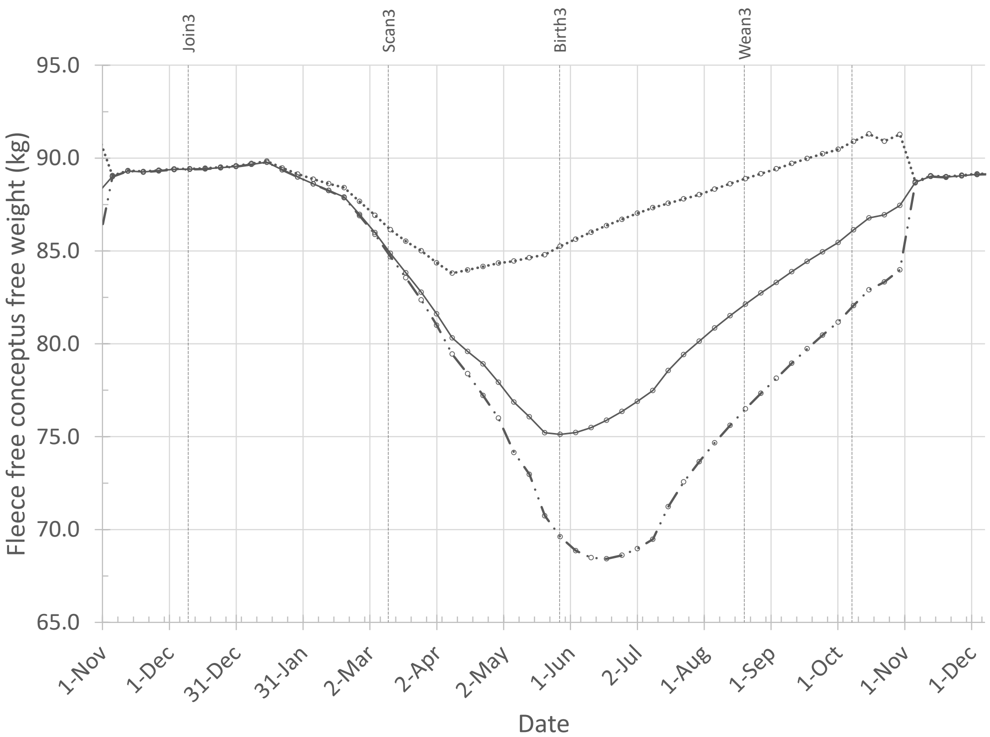

Figure 27: Optimised profile for empty (¨), single- (—) and twin-bearing (-¨) Merino ewes that have not been scanned.

Nutrition profile optimisation didn't produce different feed supply profiles for the autumn lambing Maternal ewes in the long growing season environment.

Winter lambing

Merino ewes

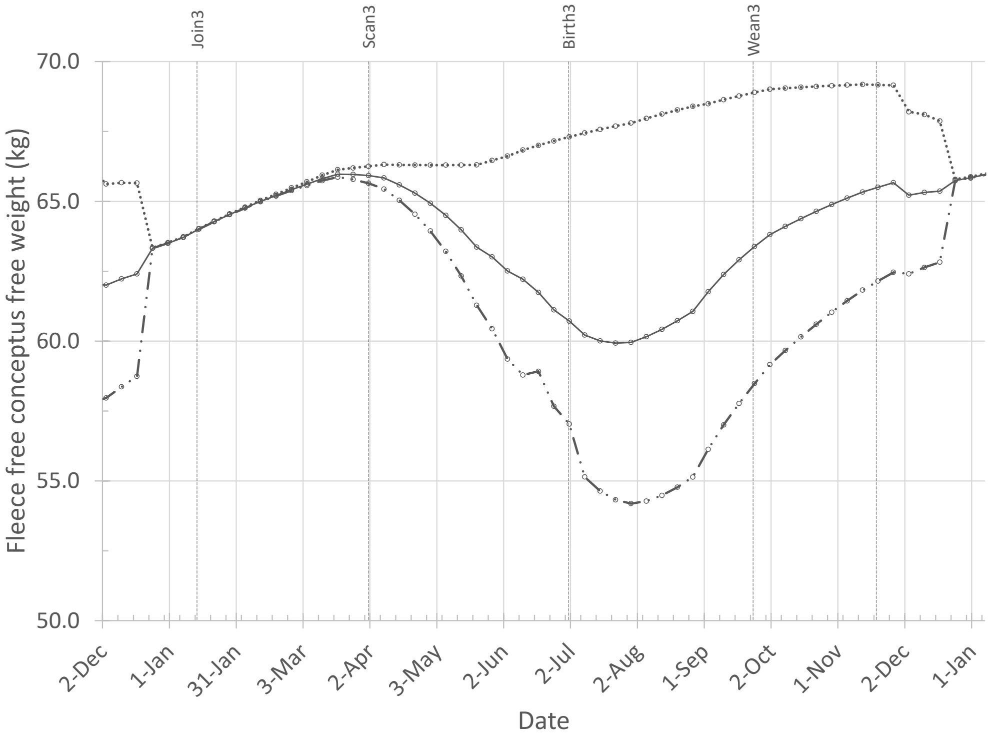

Figure 28: Optimised profile for empty(··), single- (–) and twin-bearing (-··) Merino ewes that have not been scanned

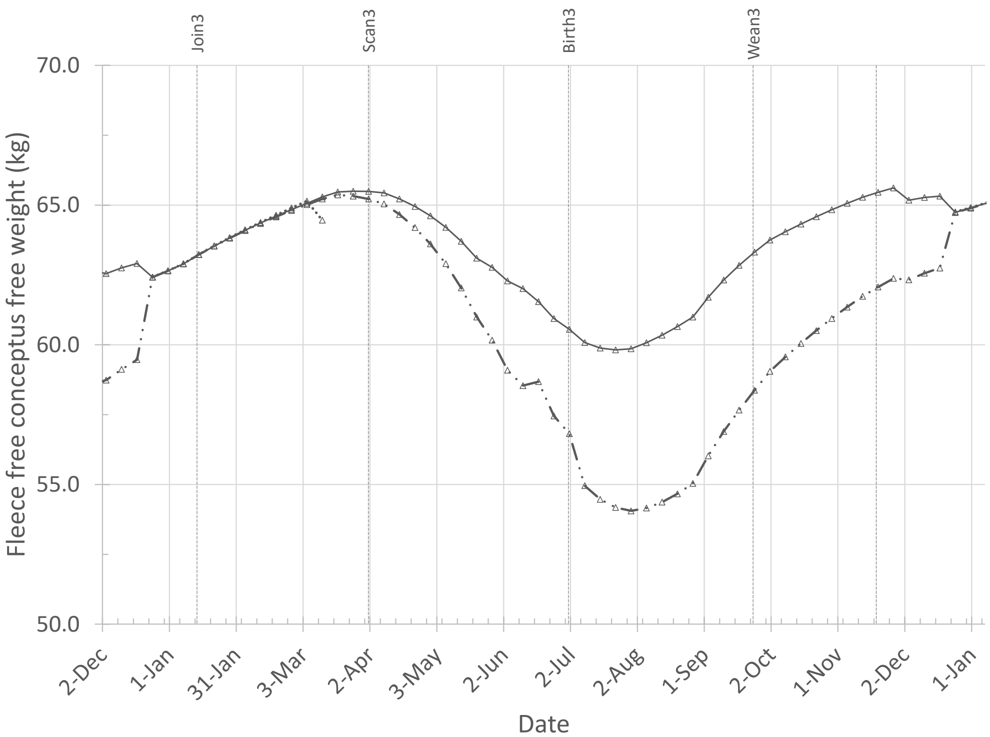

Figure 29: Optimised profile for empty(··), single- (–) and twin-bearing (-··) Merino ewes that have been scanned for pregnancy status

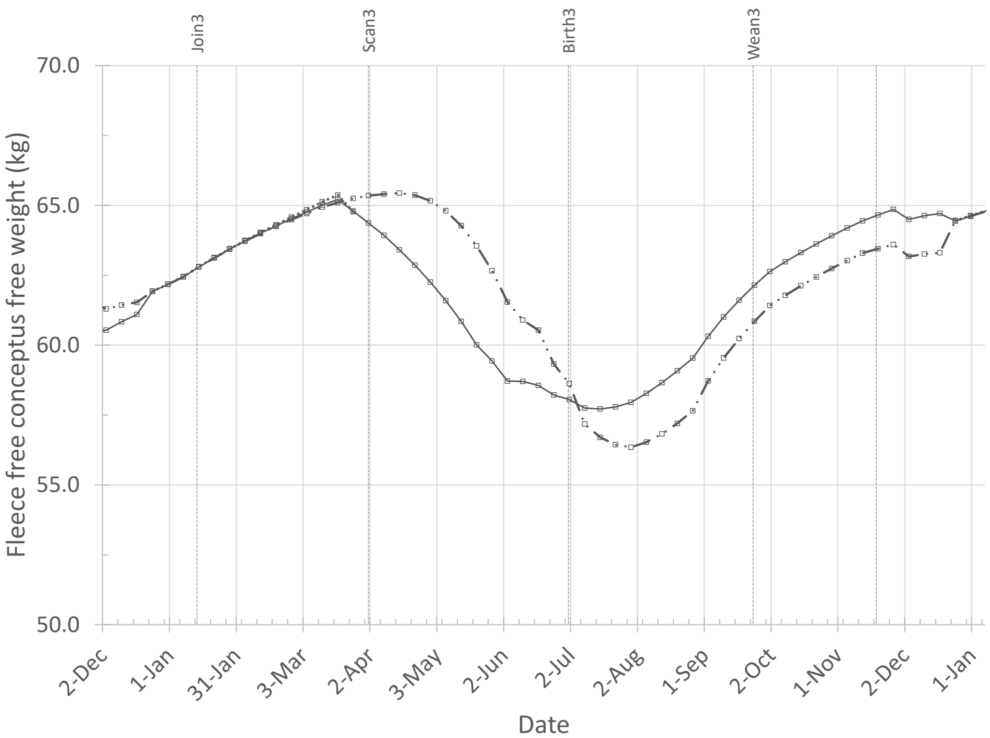

Figure 30: Optimised profile for empty(⋯), single- (—) and twin-bearing (-⋯) Merino ewes that have been scanned for multiples

Maternal ewes

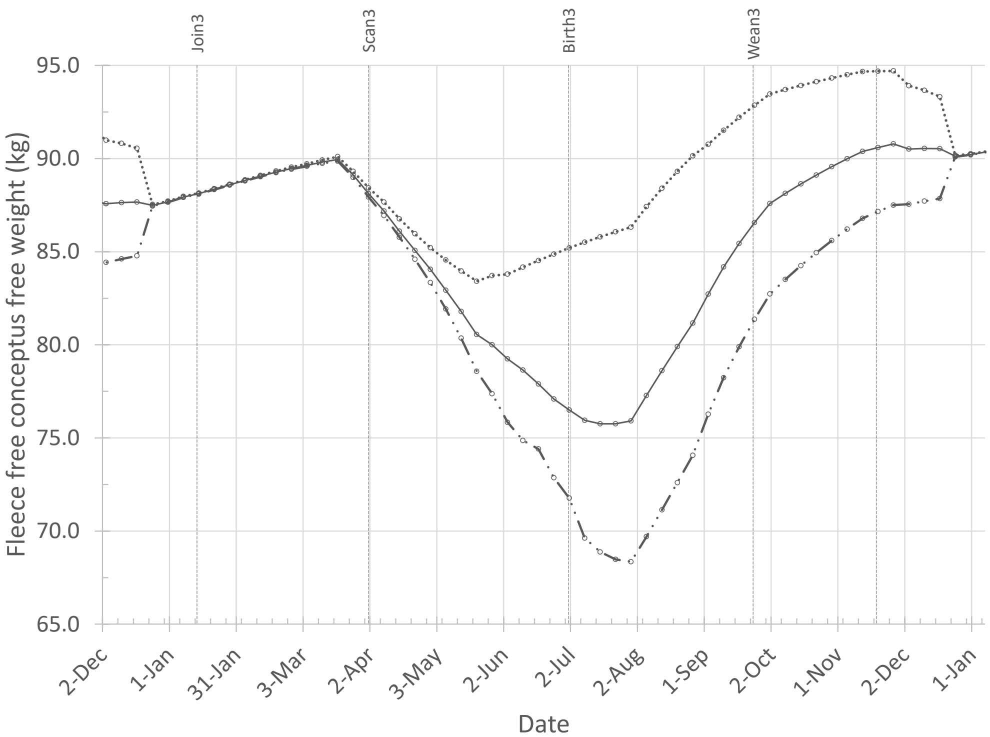

Figure 31: Optimised profile for empty(⋯), single- (—) and twin-bearing (-⋯) Maternal ewes that have not been scanned

Nutrition profile optimisation didn't produce different feed supply profiles for the winter lambing Maternal ewes in the long growing season environment.

Spring Lambing

Merino ewes

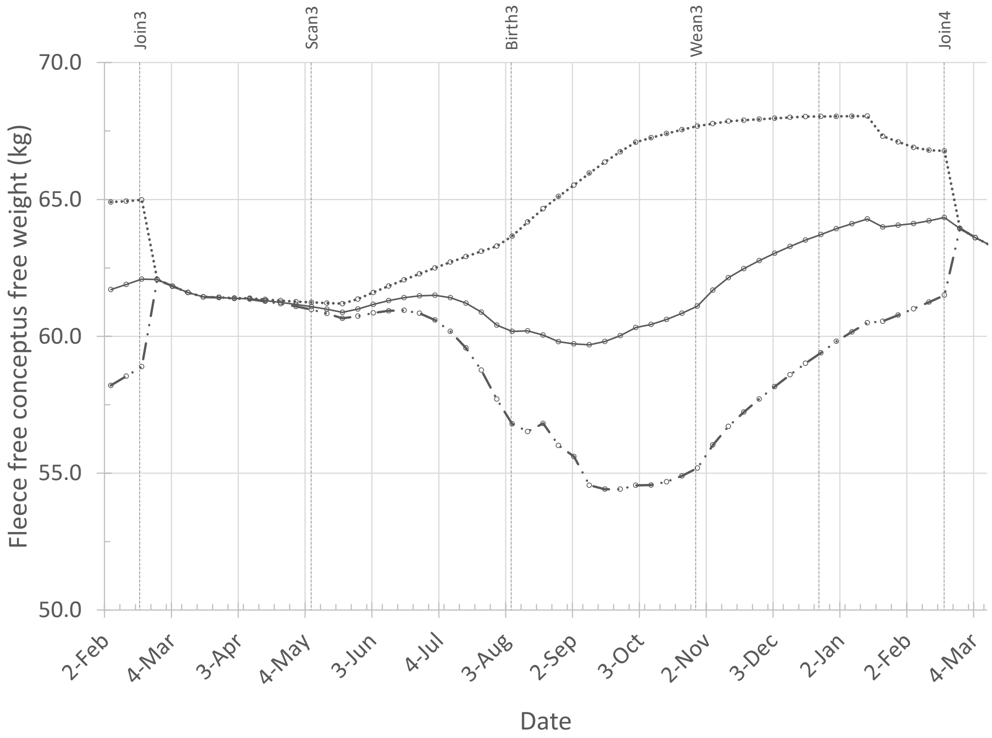

Figure 32: Optimised profile for empty(··), single- (–) and twin-bearing (-··) Merino ewes that have not been scanned

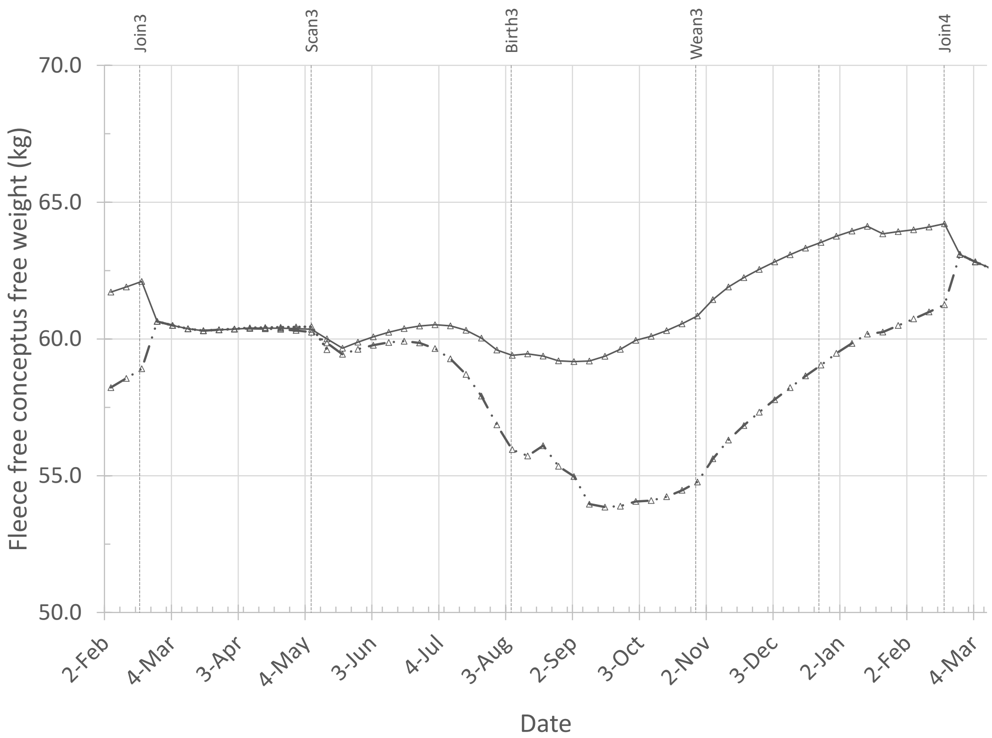

Figure 33: Optimised profile for empty(··), single- (–) and twin-bearing (-··) Merino ewes that have been scanned for pregnancy status

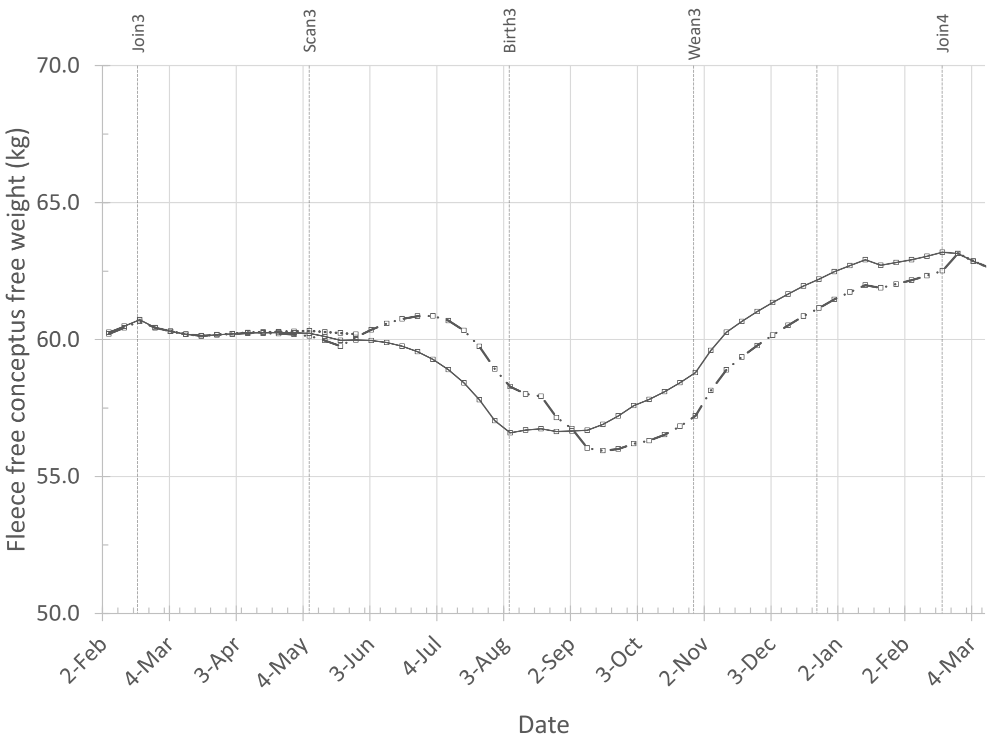

Figure 34: Optimised profile for empty(···), single- (—) and twin-bearing (-··) Merino ewes that have been scanned for multiples

Maternal ewes

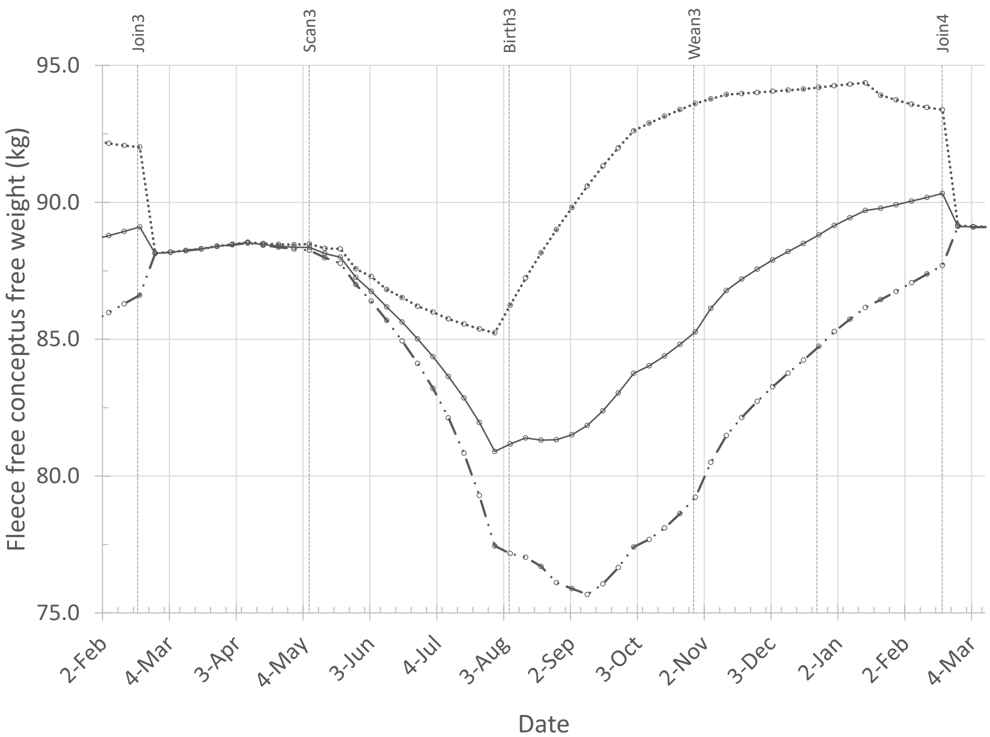

Figure 35: Optimised profile for empty(···), single- (—) and twin-bearing (-··) Maternal ewes that have not been scanned

Nutrition profile optimisation didn't produce different feed supply profiles for the spring lambing Maternal ewes in the long growing season environment.

Medium growing season

Autumn lambing

Merino ewes

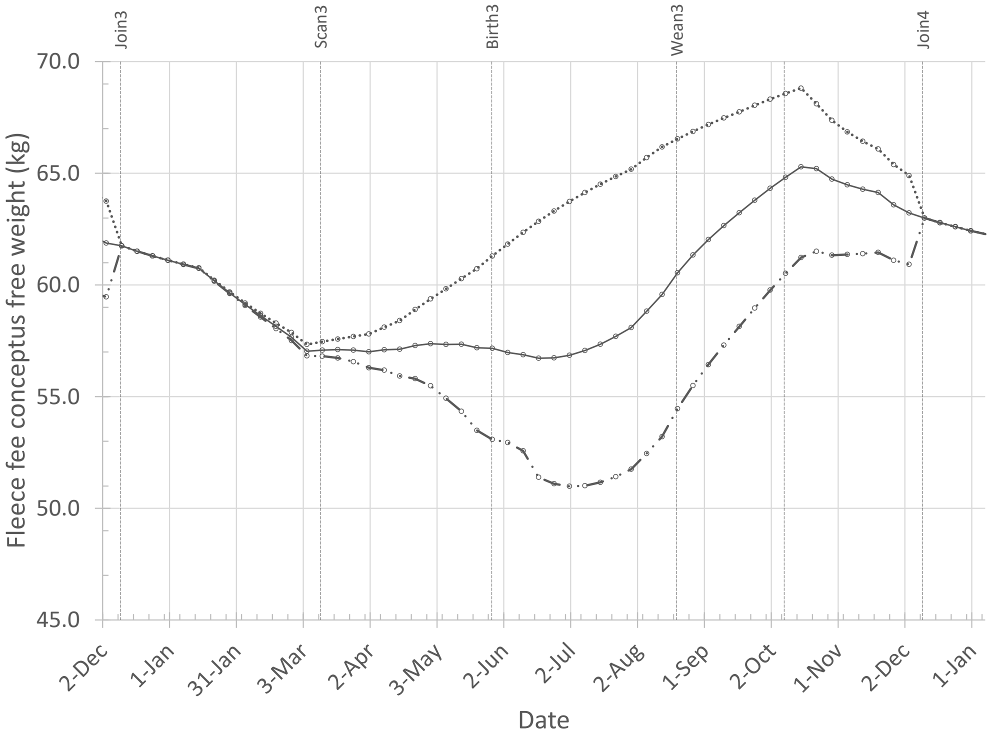

Figure 36: Optimised profile for empty (¨), single- (–) and twin-bearing (-¨) Merino ewes that have not been scanned.

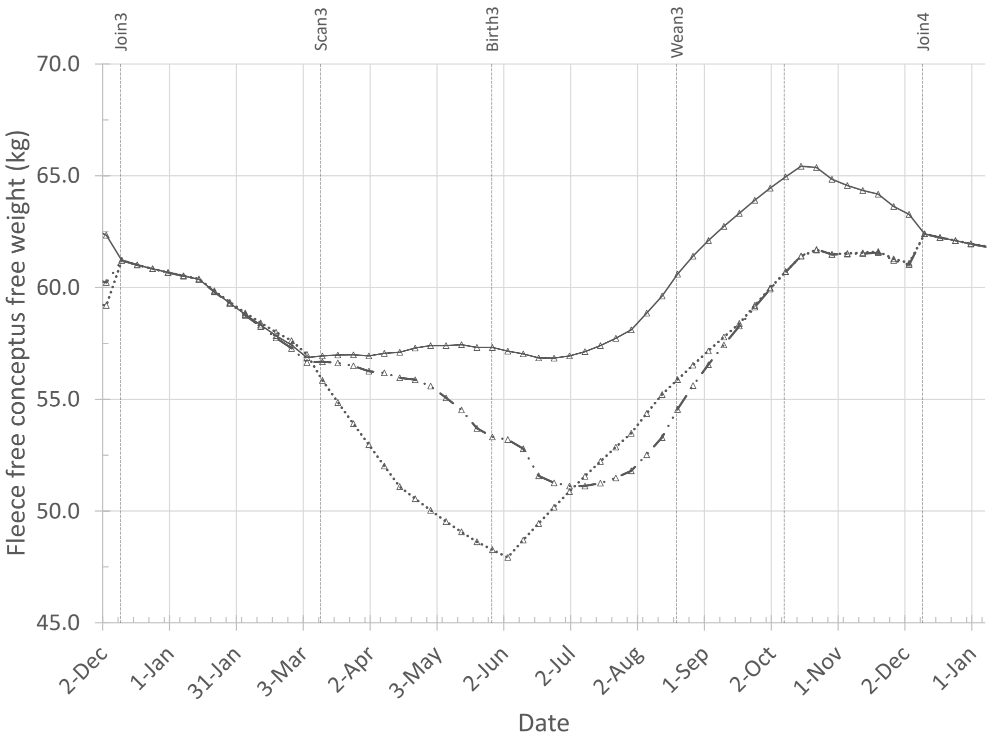

Figure 37: Optimised profile for empty (¨), single- (–) and twin-bearing (-¨) Merino ewes that have been scanned for pregnancy status

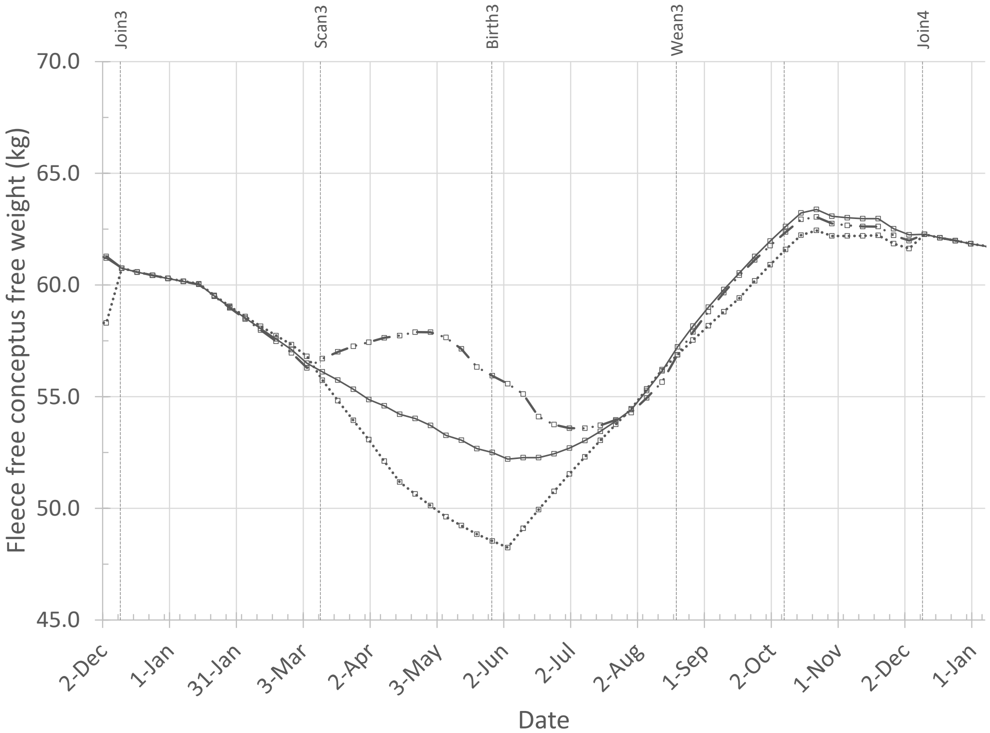

Figure 38: Optimised profile for empty(⋯), single- (—) and twin-bearing (-⋅⋅) Merino ewes that have been scanned for multiples

Maternal ewes

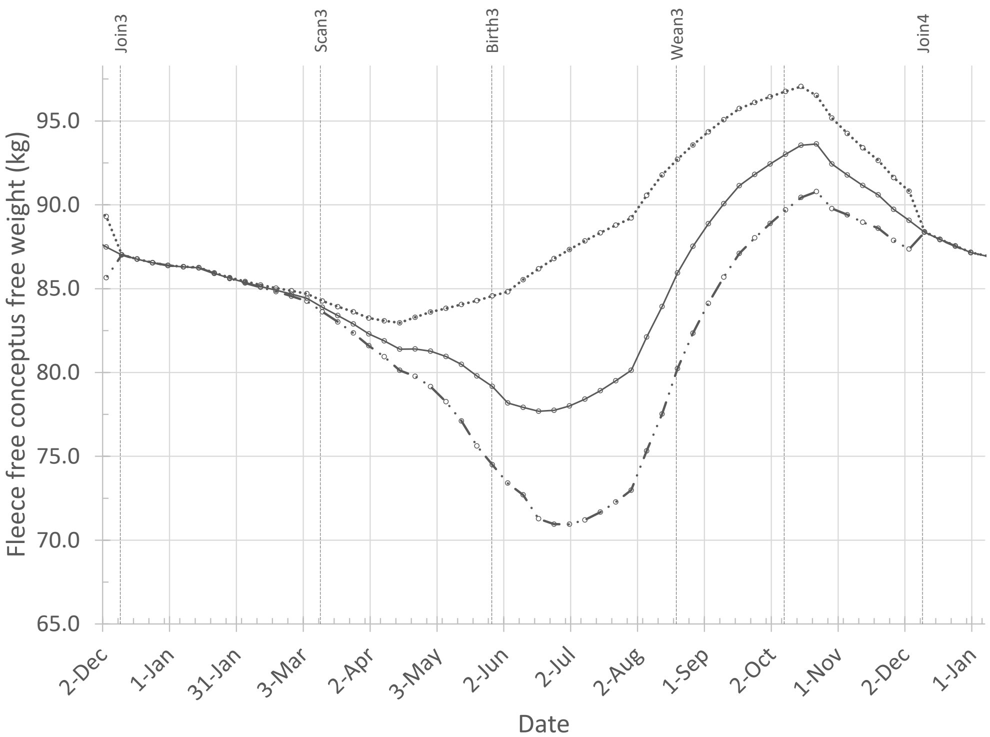

Figure 39: Optimised profile for empty(⋯), single- (—) and twin-bearing (-⋅⋅) Maternal ewes that have not been scanned

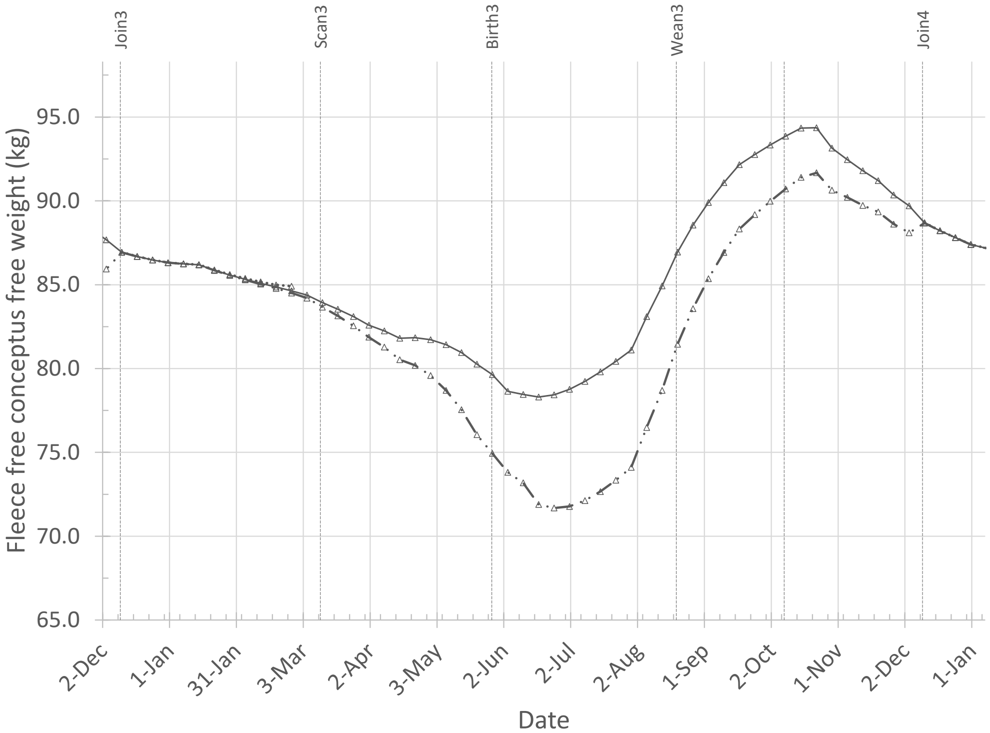

Figure 40: Optimised profile for empty (··), single- (—) and twin-bearing (-··) Maternal ewes that have been scanned for pregnancy status

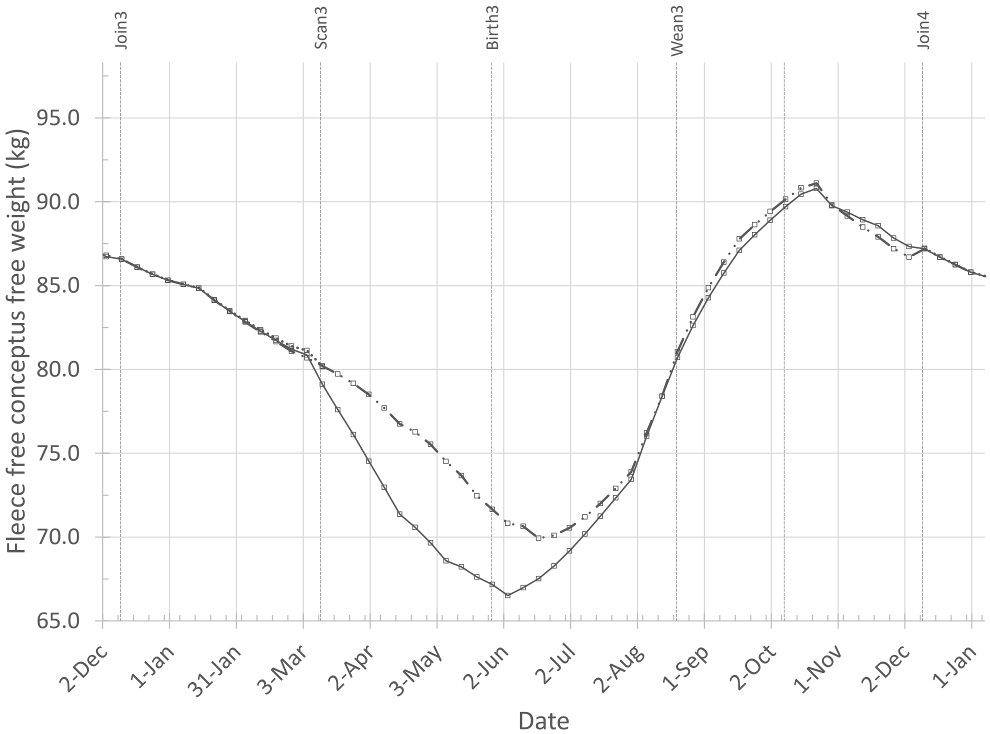

Figure 41: Optimised profile for empty(··), single- (—) and twin-bearing (-··) Maternal ewes that have been scanned for multiples

Winter lambing

Merino ewes

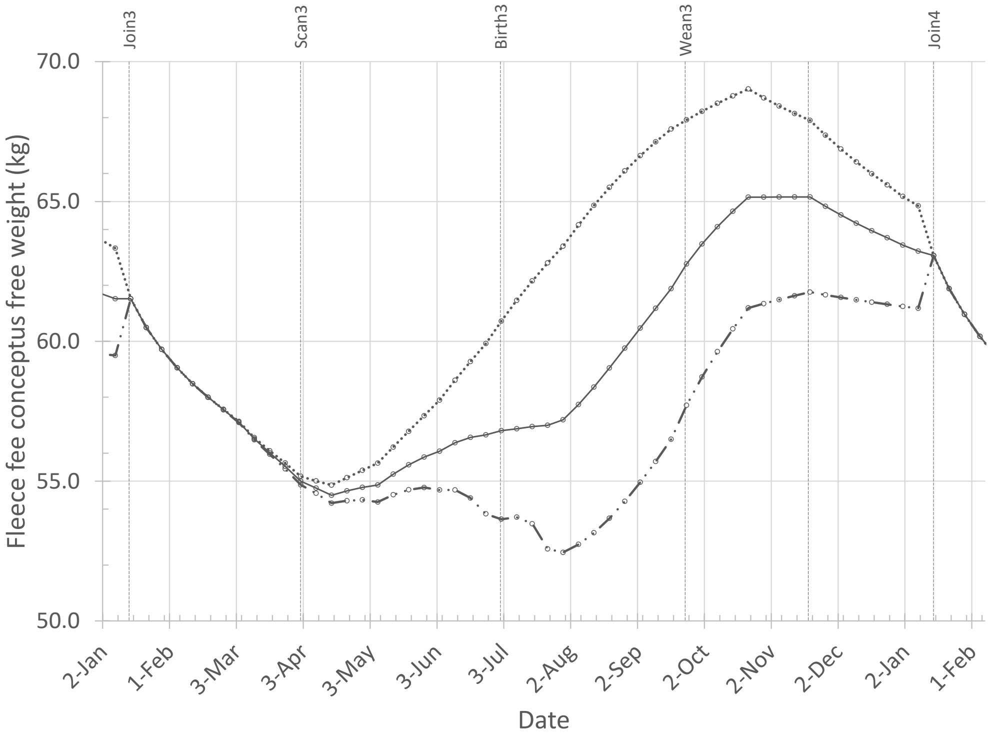

Figure 42: Optimised profile for empty(··), single- (—) and twin-bearing (-··) Merino ewes that have not been scanned

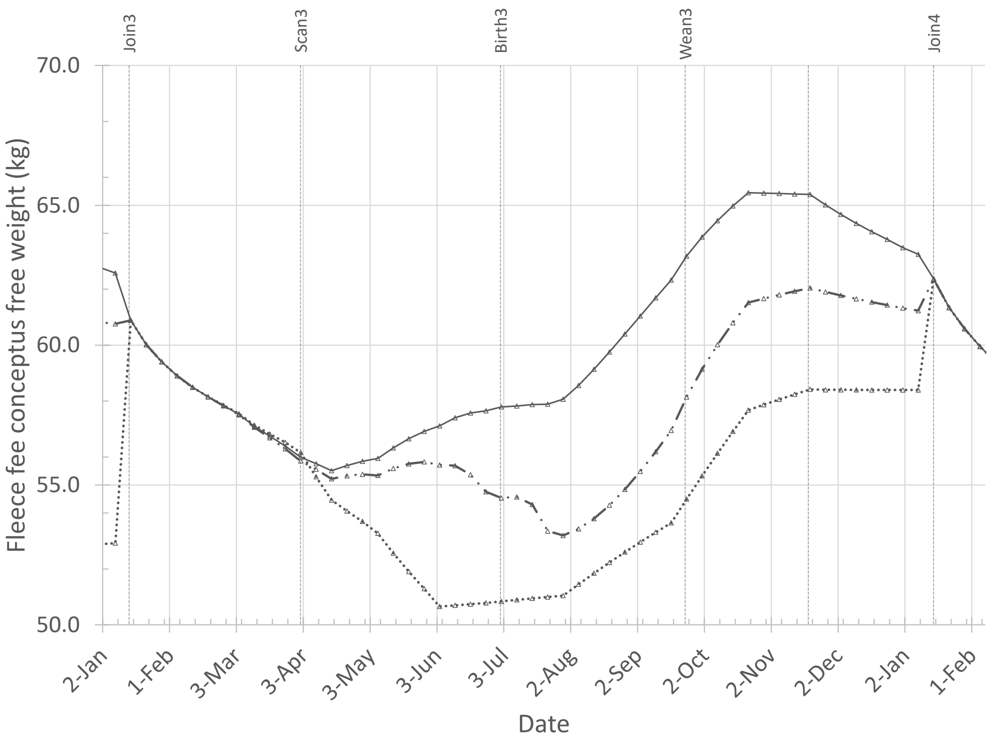

Figure 43: Optimised profile for empty(··), single- (—) and twin-bearing (-··) Merino ewes that have been scanned for pregnancy status

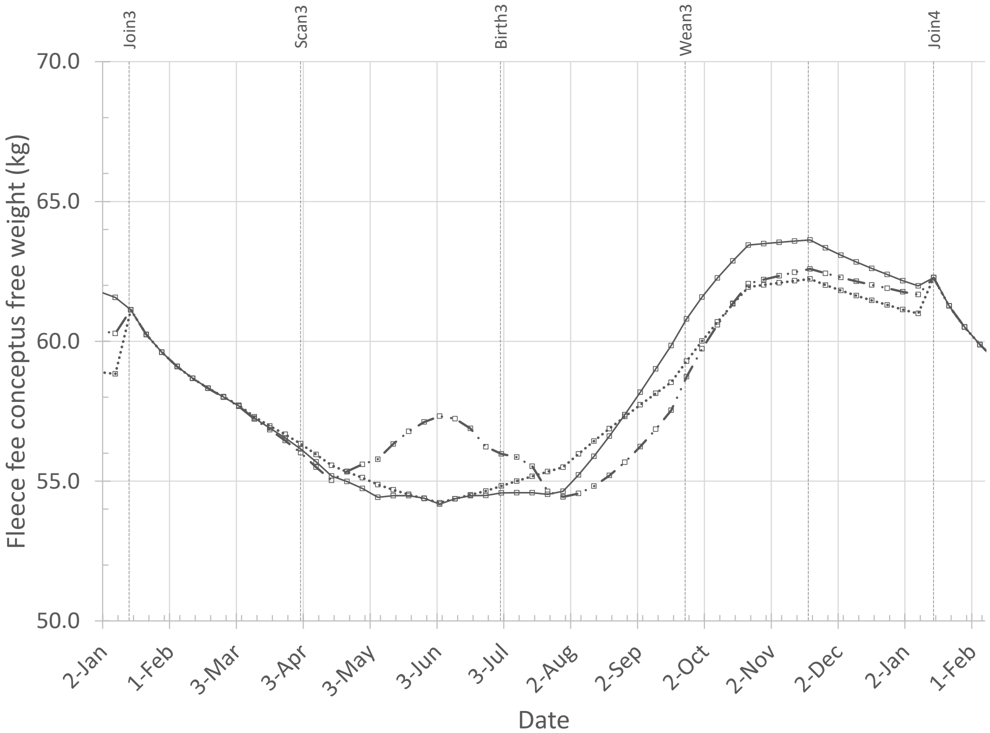

Figure 44: Optimised profile for empty (¨), single- (—) and twin-bearing (-¨) Merino ewes that have been scanned for multiples

Maternal ewes

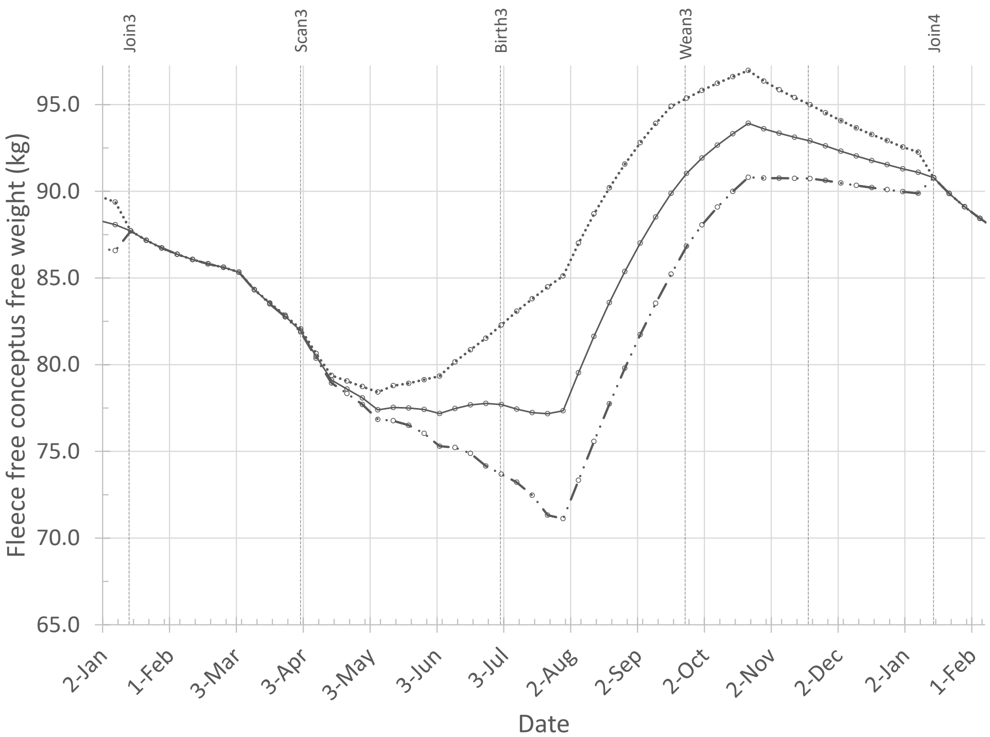

Figure 45: Optimised profile for empty (¨), single- (—) and twin-bearing (-¨) Maternal ewes that have not been scanned

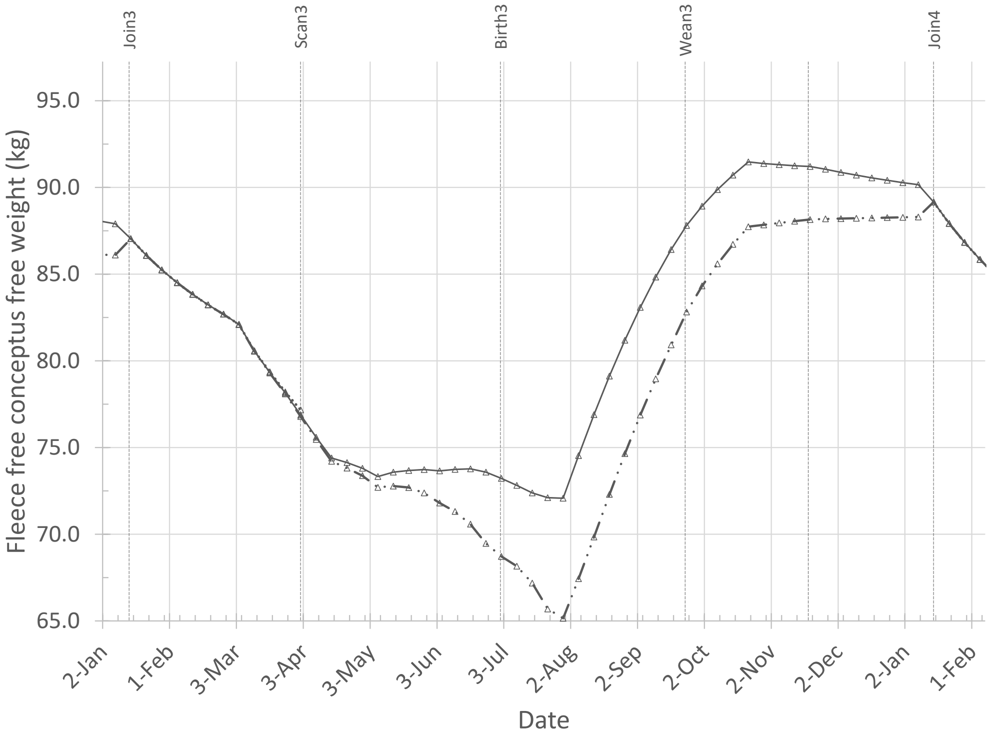

Figure 46: Optimised profile for empty (¨), single- (–) and twin-bearing (-¨) Maternal ewes that have been scanned for pregnancy status

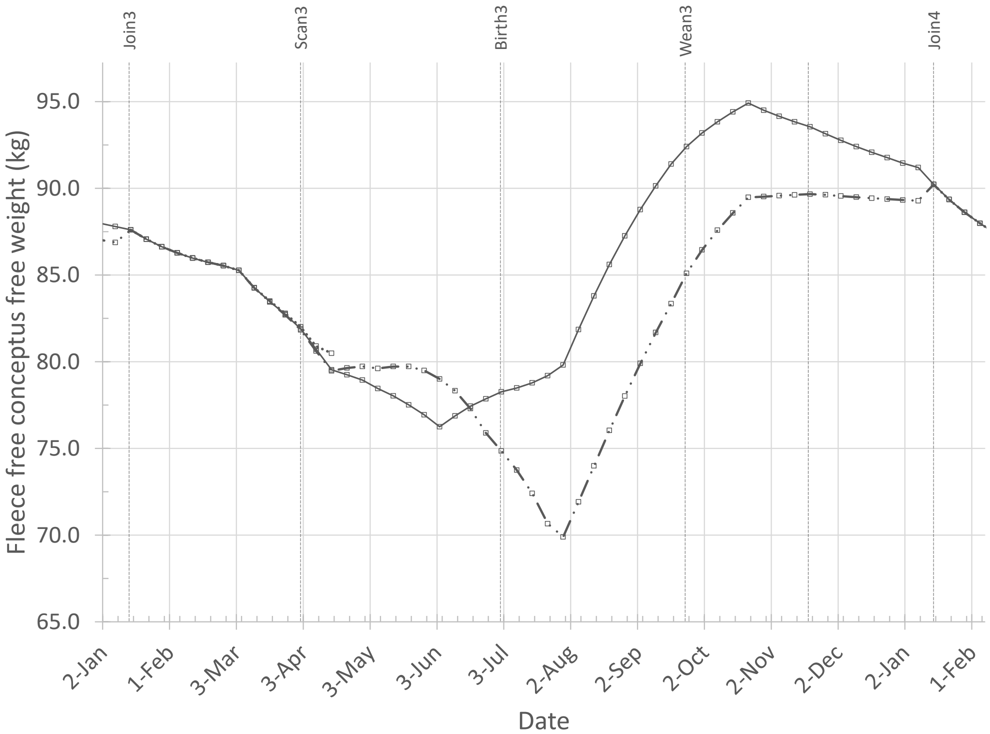

Figure 47: Optimised profile for empty (¨), single- (–) and twin-bearing (-¨) Maternal ewes that have been scanned for multiples

Spring Lambing

Merino ewes

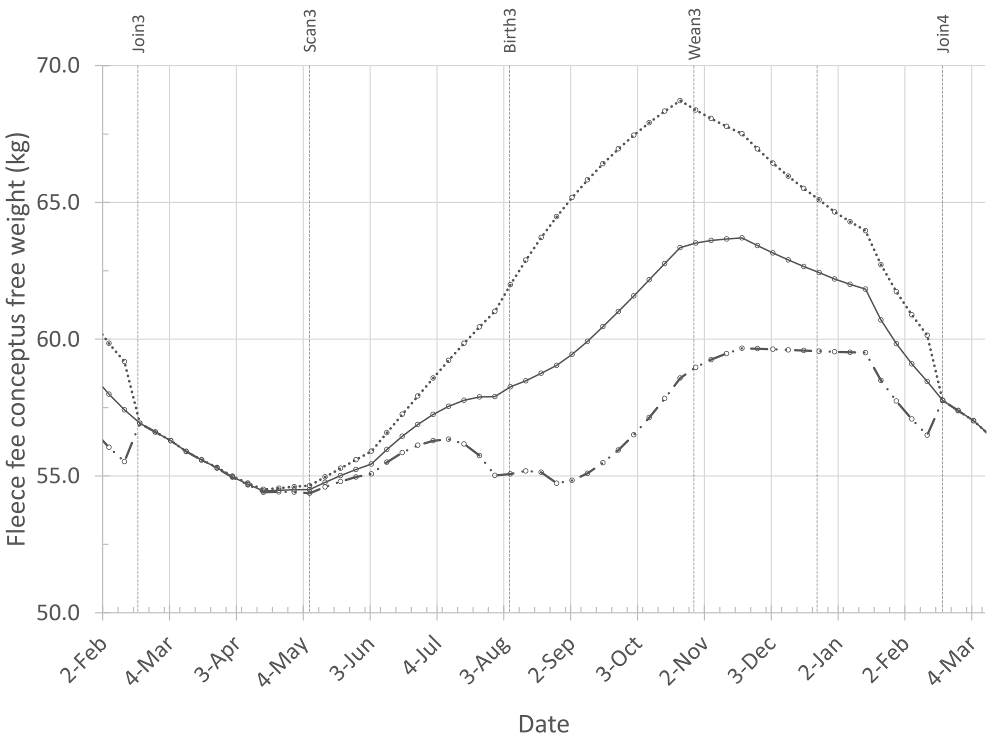

Figure 48: Optimised profile for empty (¨), single- (—) and twin-bearing (-¨) Merino ewes that have not been scanned

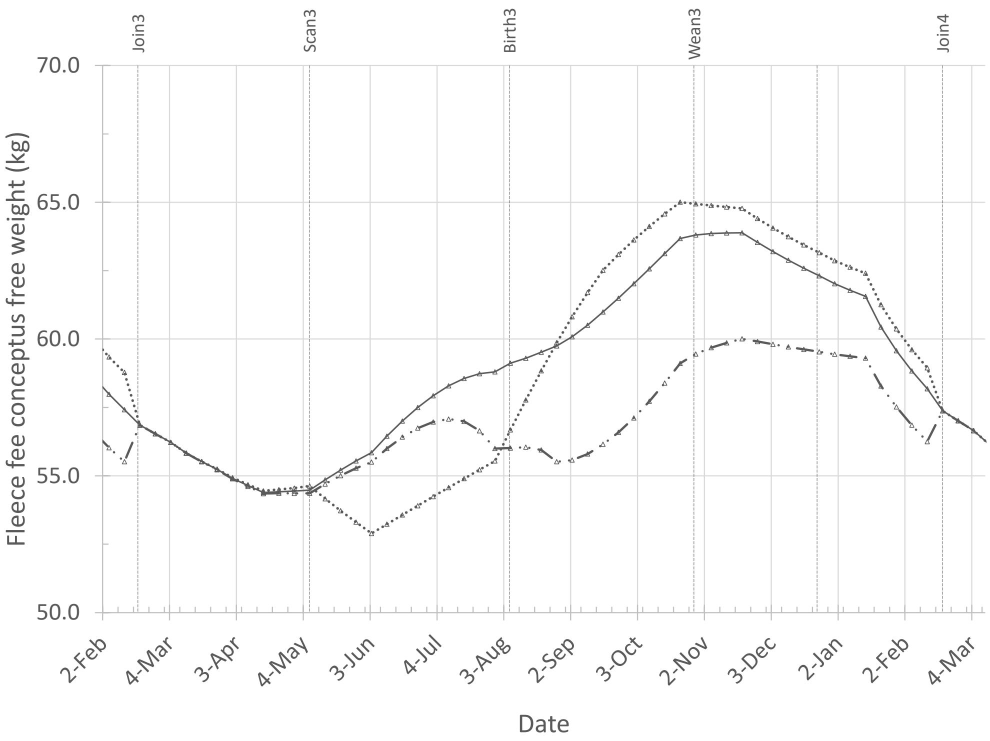

Figure 49: Optimised profile for empty (¨), single- (—) and twin-bearing (-¨) Merino ewes that have been scanned for pregnancy status

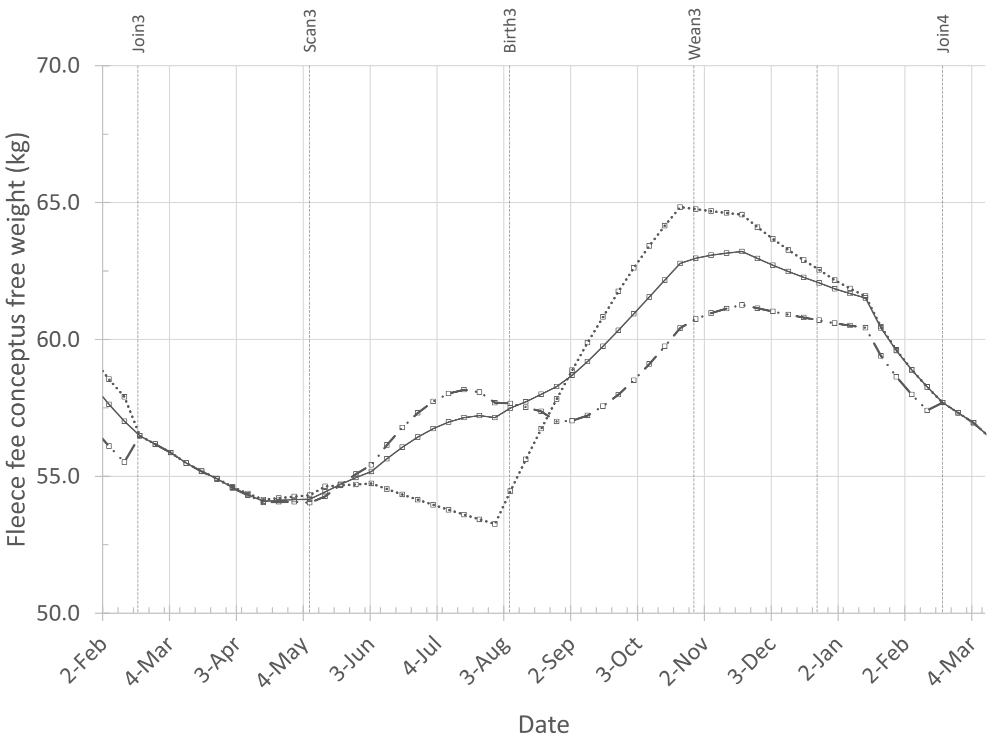

Figure 50: Optimised profile for empty (¨), single- (—) and twin-bearing (-¨) Merino ewes that have been scanned for multiples

Maternal ewes

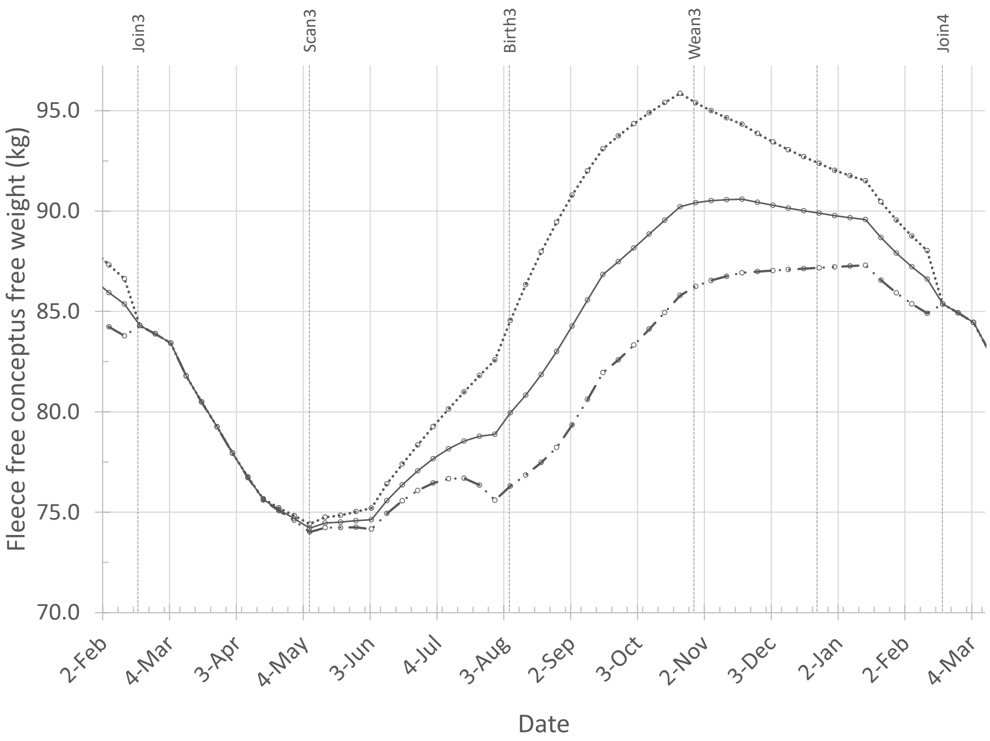

Figure 51: Optimised profile for empty (¨), single- (—) and twin-bearing (-¨) Maternal ewes that have not been scanned

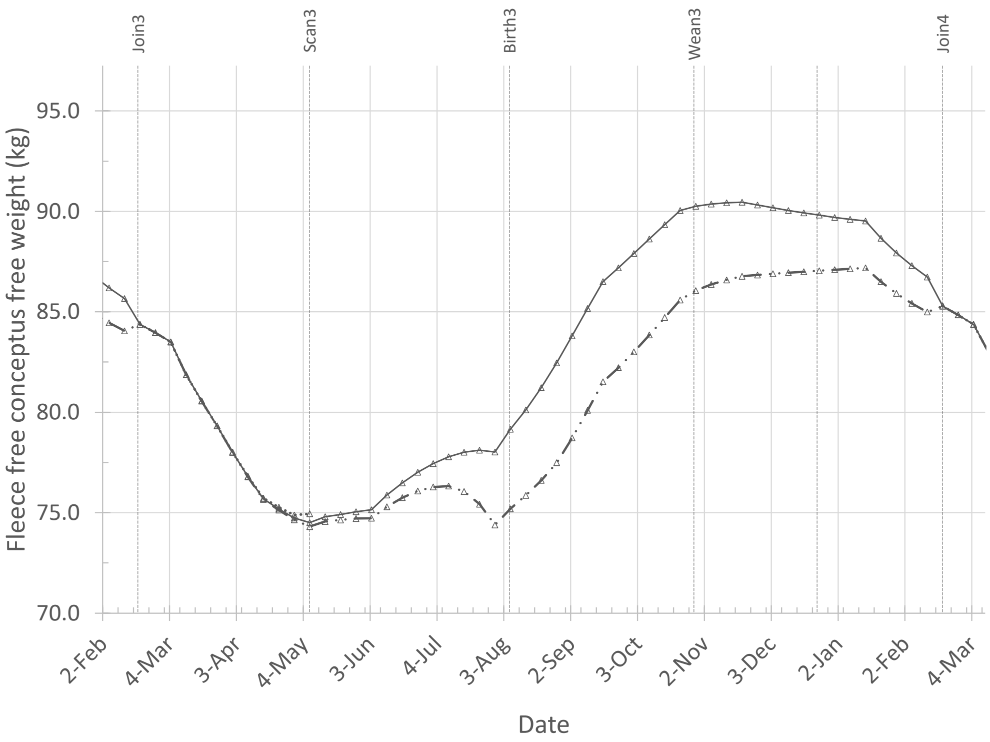

Figure 52: Optimised profile for empty (⋯), single- (—) and twin-bearing (-⋅⋅) Maternal ewes that have been scanned for pregnancy status

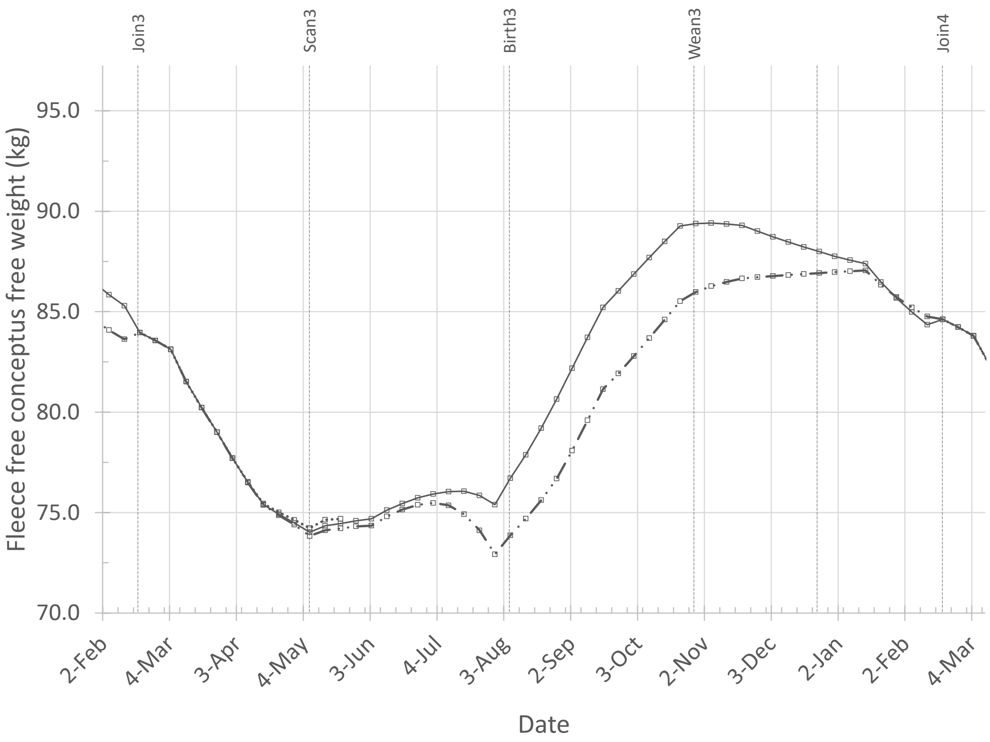

Figure 53: Optimised profile for empty (⋯), single- (—) and twin-bearing (-⋅⋅) Maternal ewes that have been scanned for multiples

Short growing season

Autumn lambing

Merino ewes

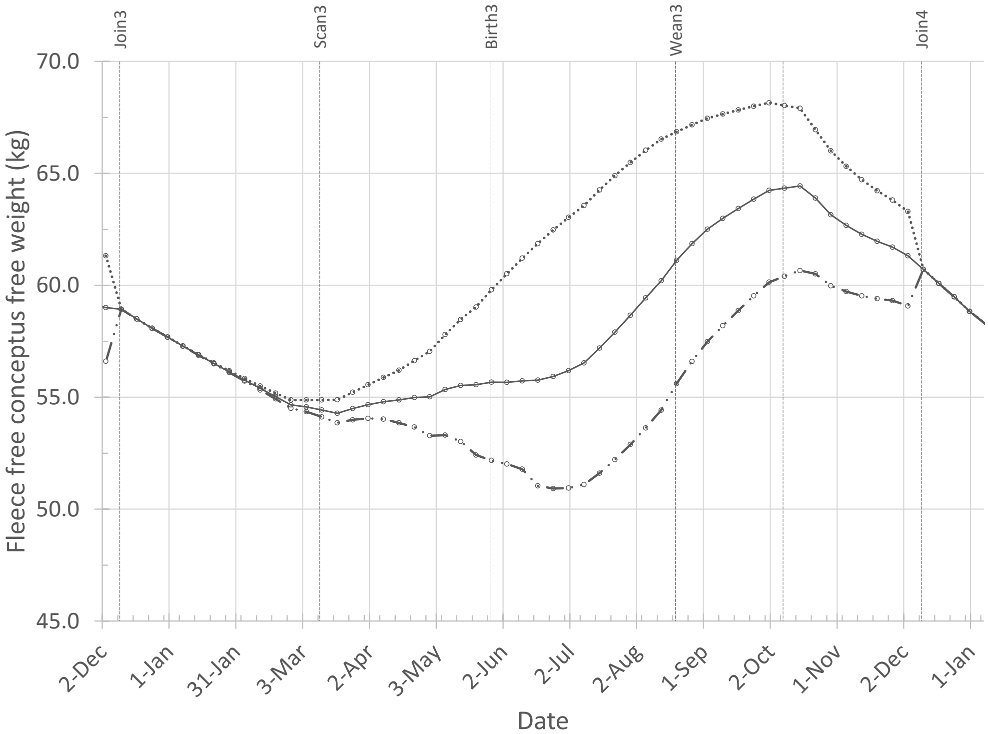

Figure 54: Optimised profile for empty (¨), single- (–) and twin-bearing (-¨) Merino ewes that have not been scanned.

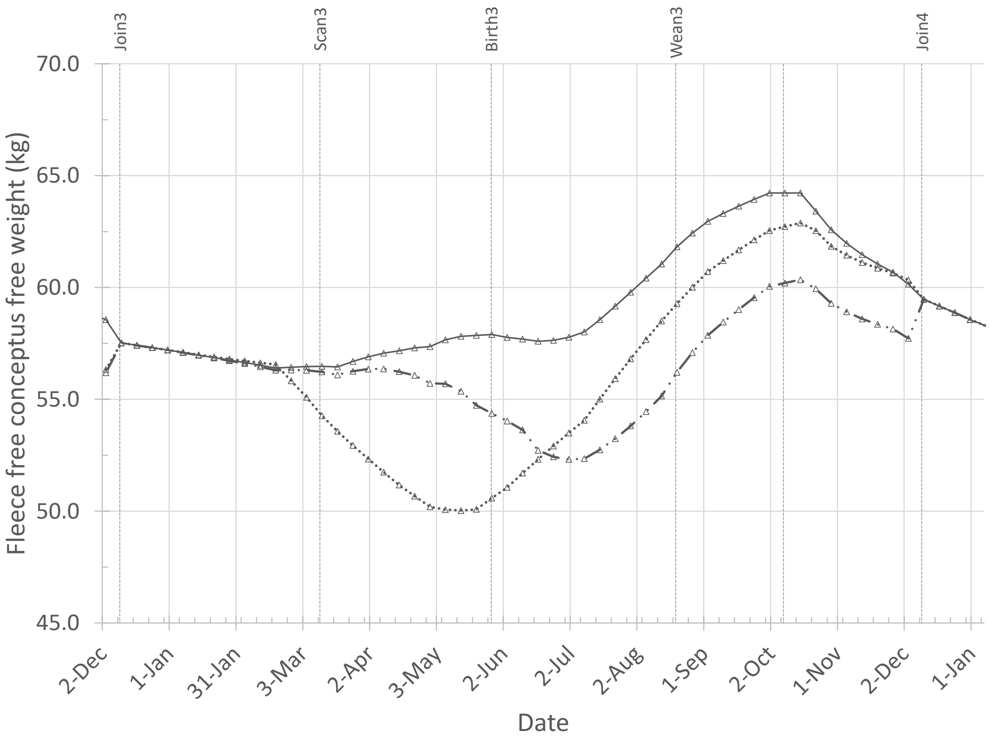

Figure 55: Optimised profile for empty (¨), single- (–) and twin-bearing (-¨) Merino ewes that have been scanned for pregnancy status

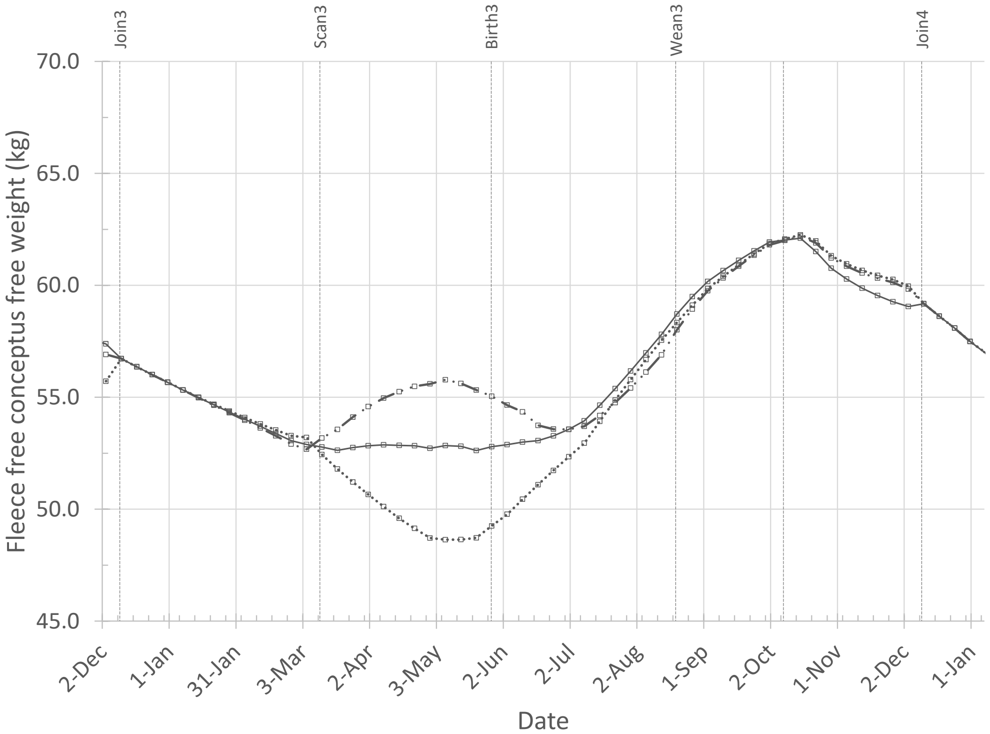

Figure 56: Optimised profile for empty (··), single- (—) and twin-bearing (-··) Merino ewes that have been scanned for multiples

Maternal ewes

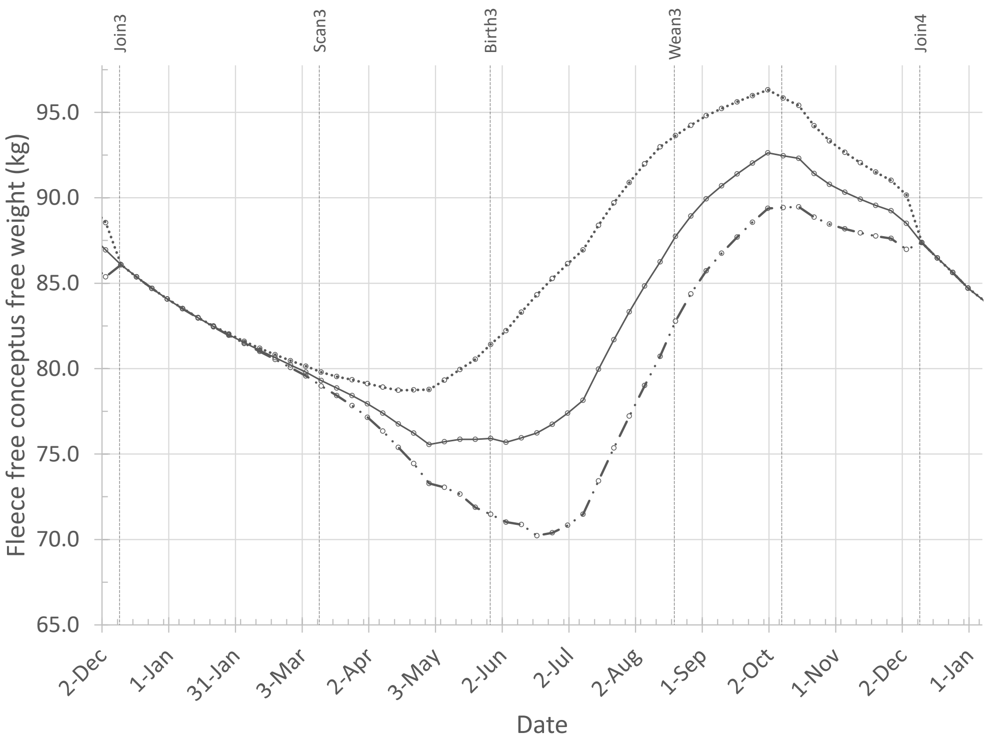

Figure 57: Optimised profile for empty (··), single- (—) and twin-bearing (-··) Maternal ewes that have not been scanned

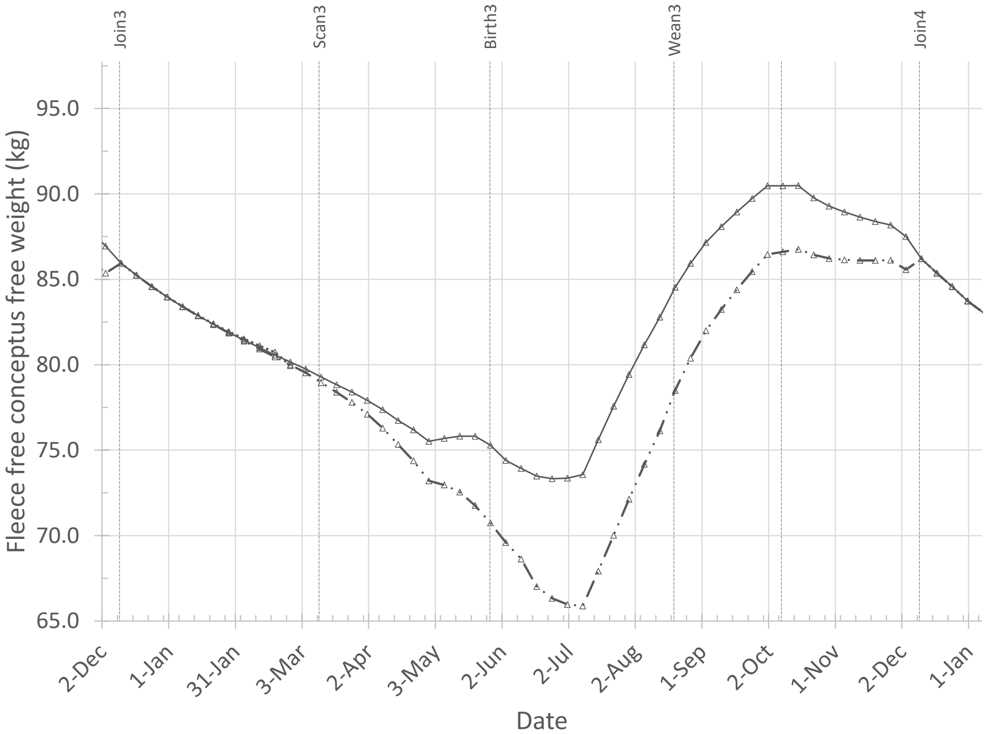

Figure 58: Optimised profile for empty (⋯), single- (—) and twin-bearing (-⋅⋅) Maternal ewes that have been scanned for pregnancy status

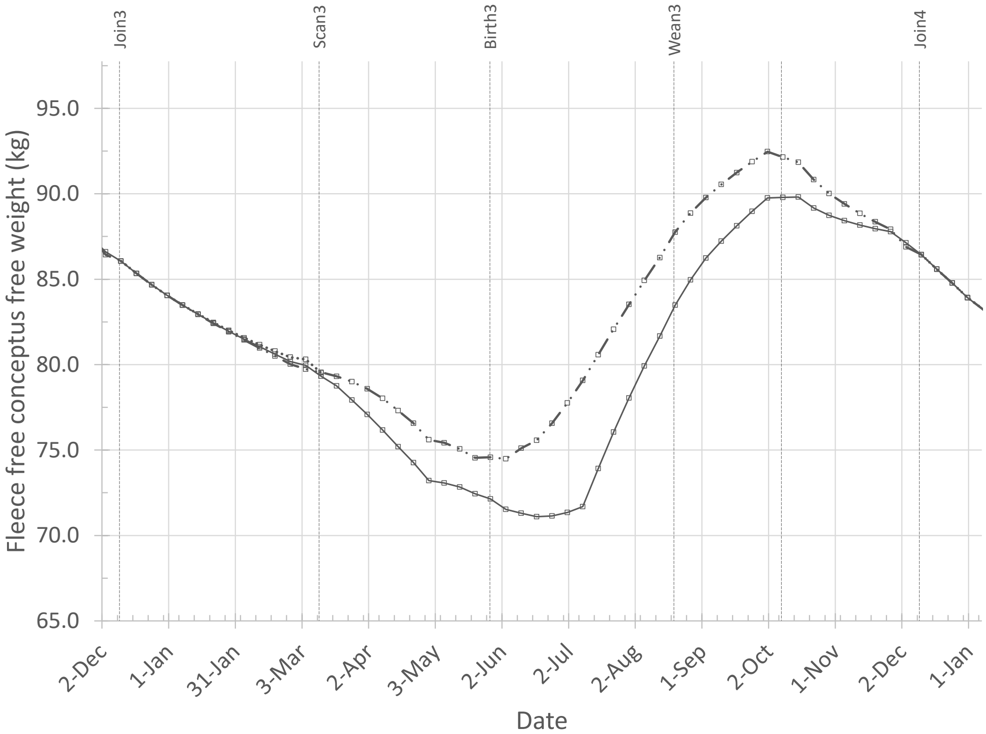

Figure 59: Optimised profile for empty (⋯), single- (—) and twin-bearing (-⋅⋅) Maternal ewes that have been scanned for multiples

Winter lambing

Merino ewes

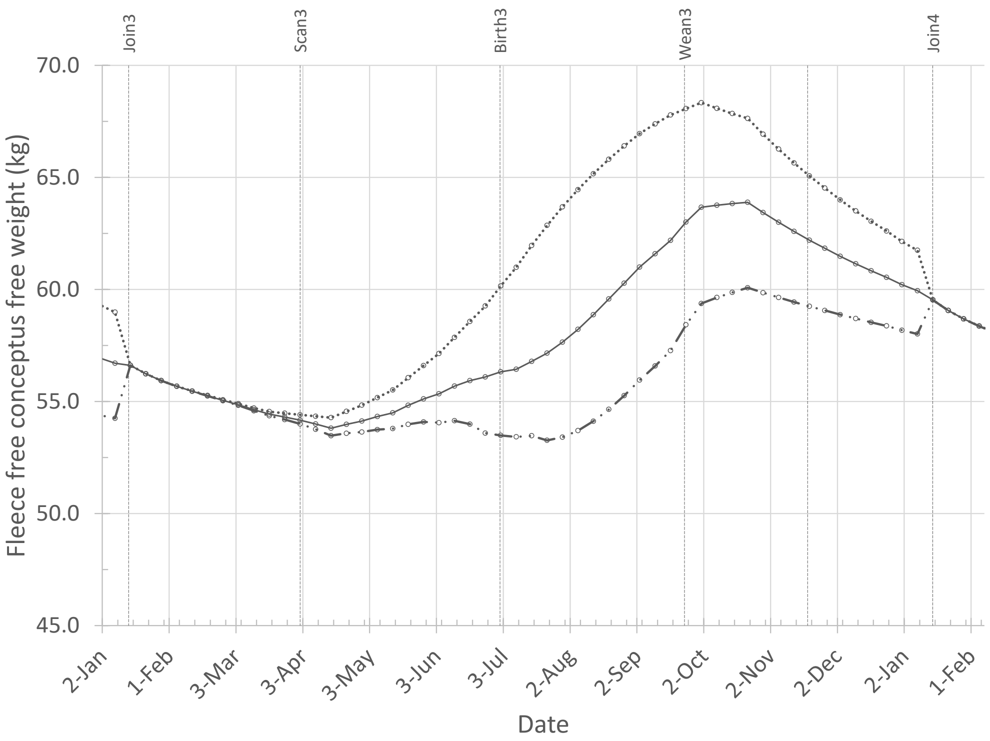

Figure 60: Optimised profile for empty (¨), single- (–) and twin-bearing (-¨) Merino ewes that have not been scanned

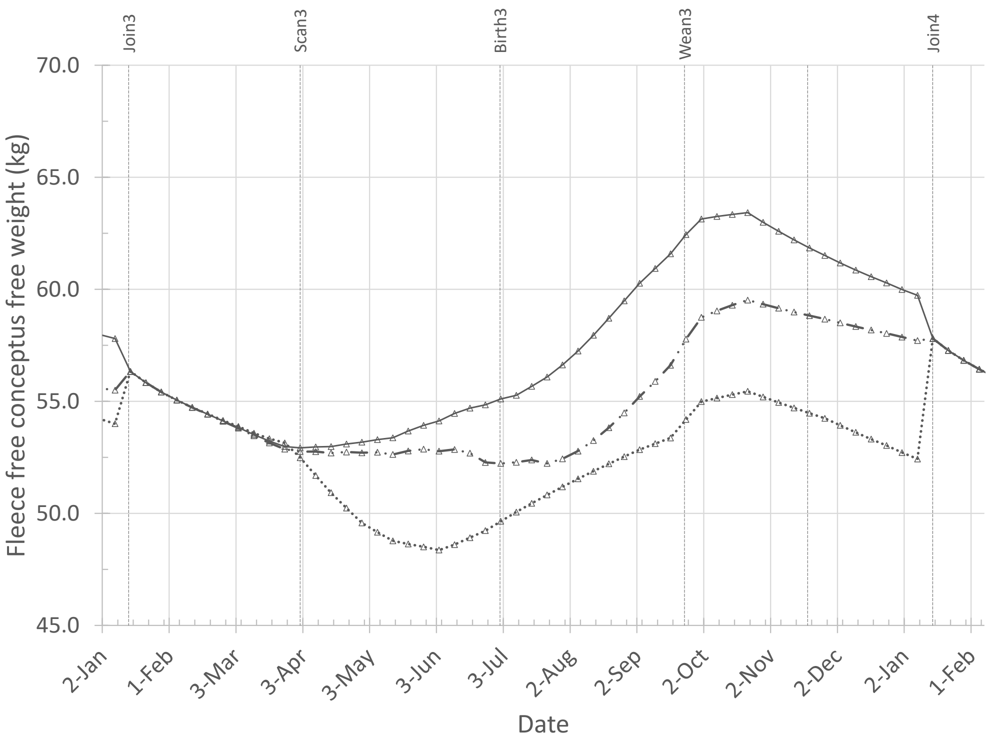

Figure 61: Optimised profile for empty (¨), single- (–) and twin-bearing (-¨) Merino ewes that have been scanned for pregnancy status

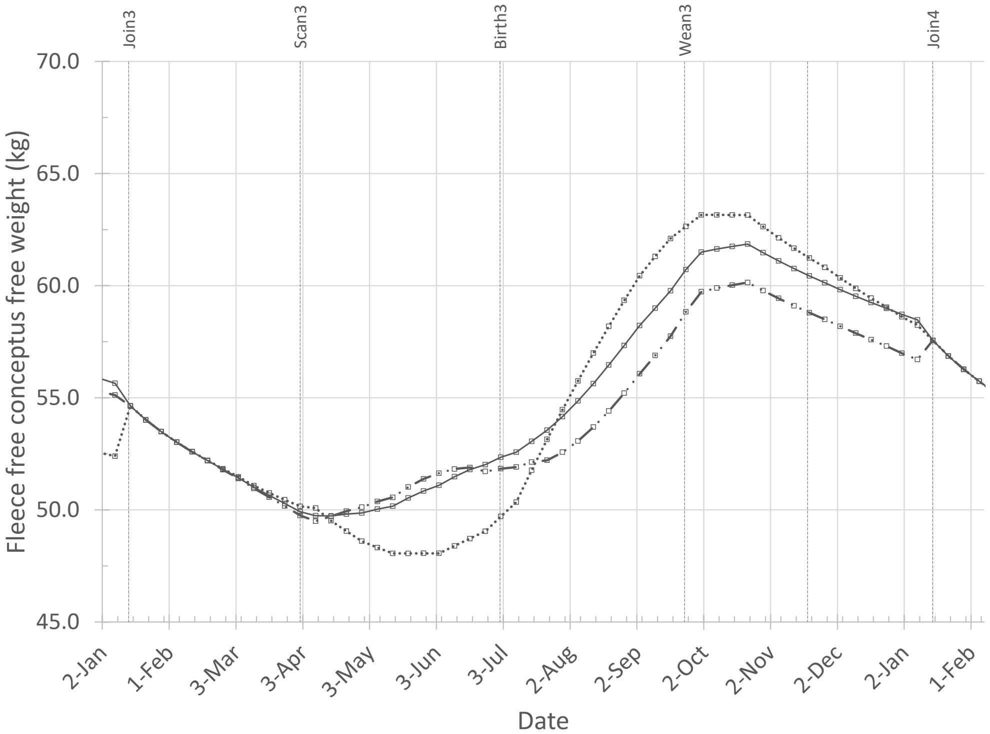

Figure 62: Optimised profile for empty (··), single- (–) and twin-bearing (-··) Merino ewes that have been scanned for multiples

Maternal ewes

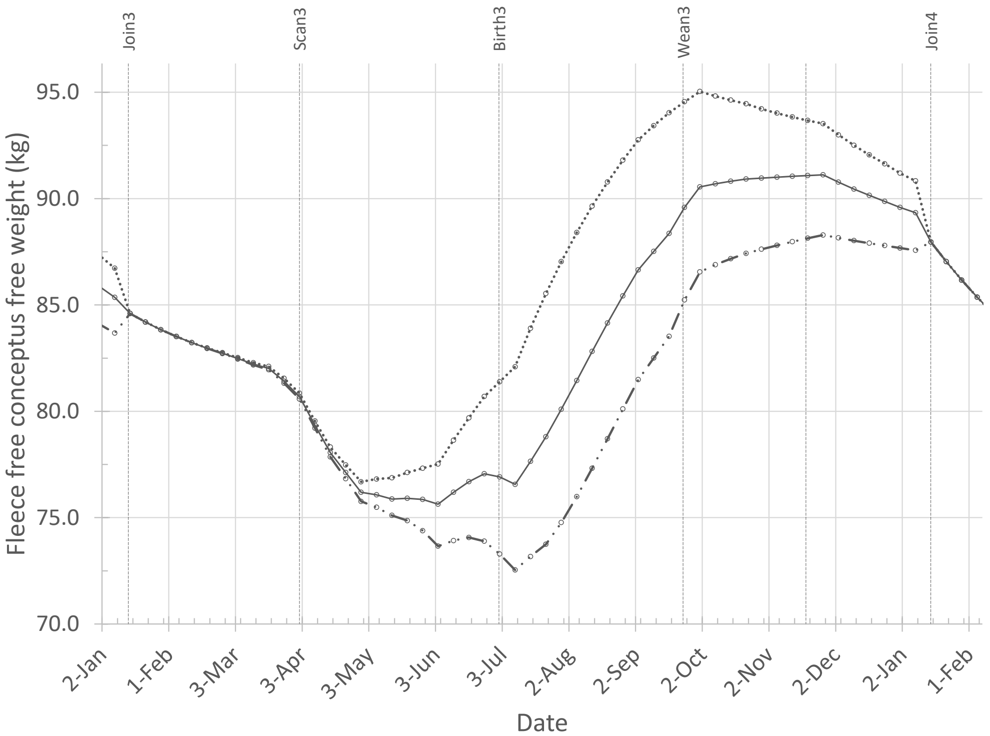

Figure 63: Optimised profile for empty (··), single- (–) and twin-bearing (-··) Maternal ewes that have not been scanned

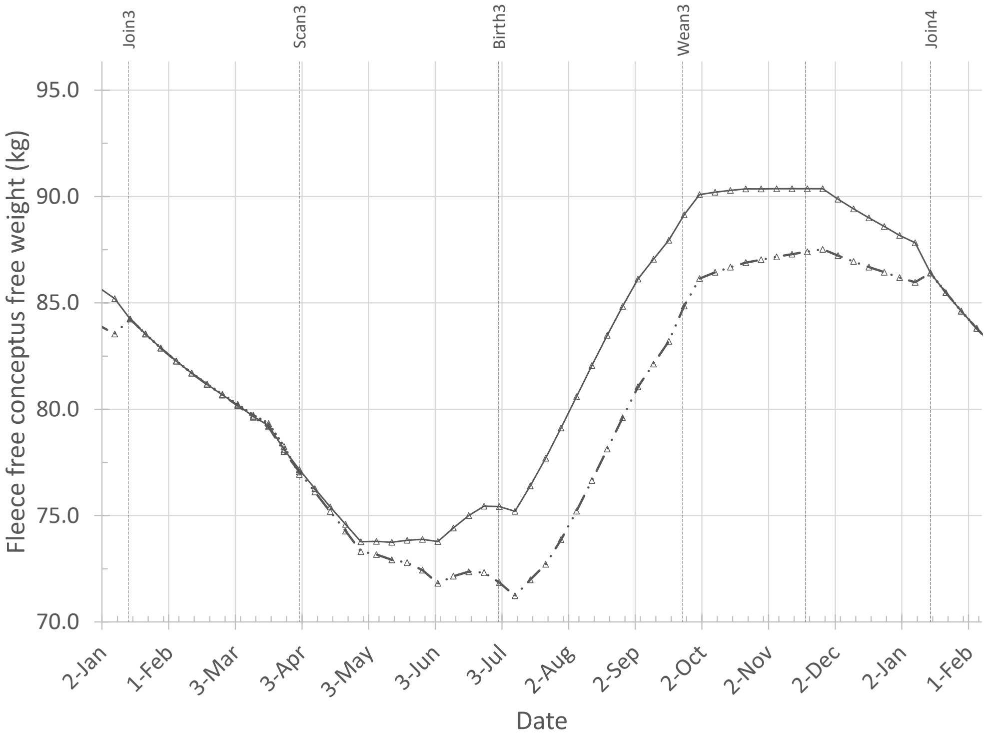

Figure 64: Optimised profile for empty (··), single- (—) and twin-bearing (-··) Maternal ewes that have been scanned for pregnancy status

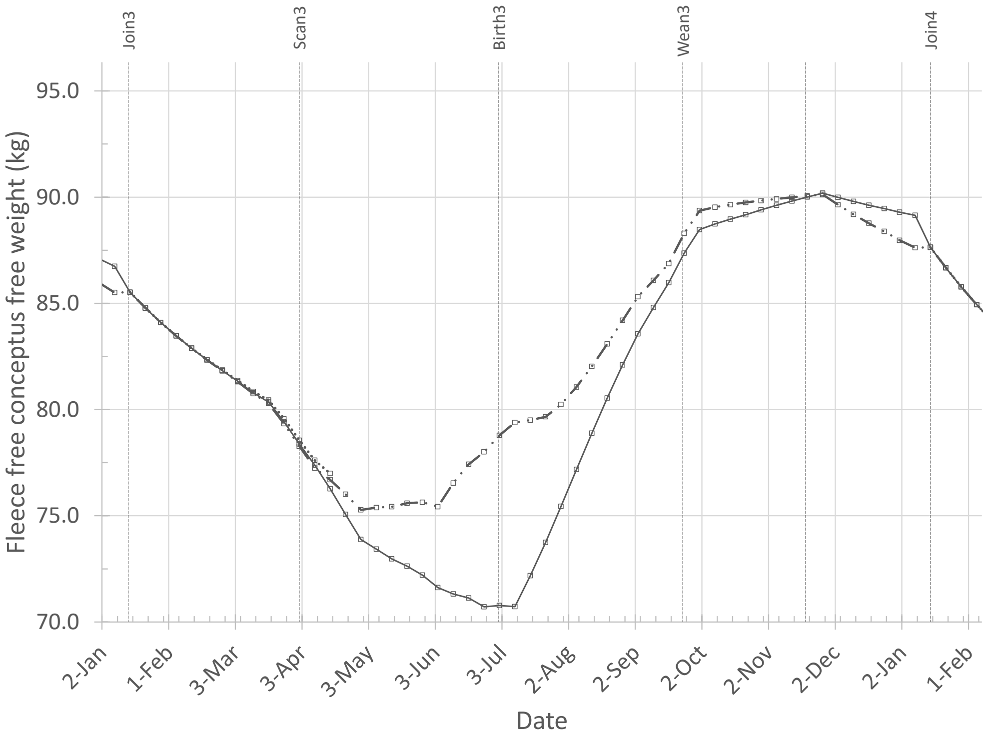

Figure 65: Optimised profile for empty (··), single- (—) and twin-bearing (-··) Maternal ewes that have been scanned for multiples

Spring Lambing

Merino ewes

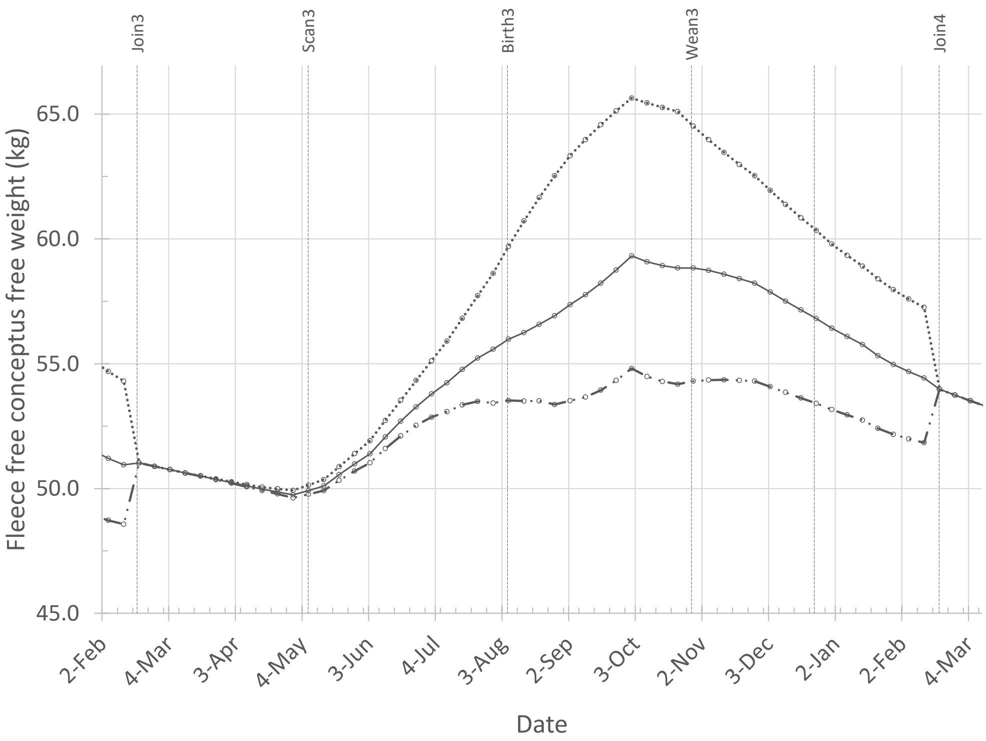

Figure 66: Optimised profile for empty (¨), single- (—) and twin-bearing (-¨) Merino ewes that have not been scanned

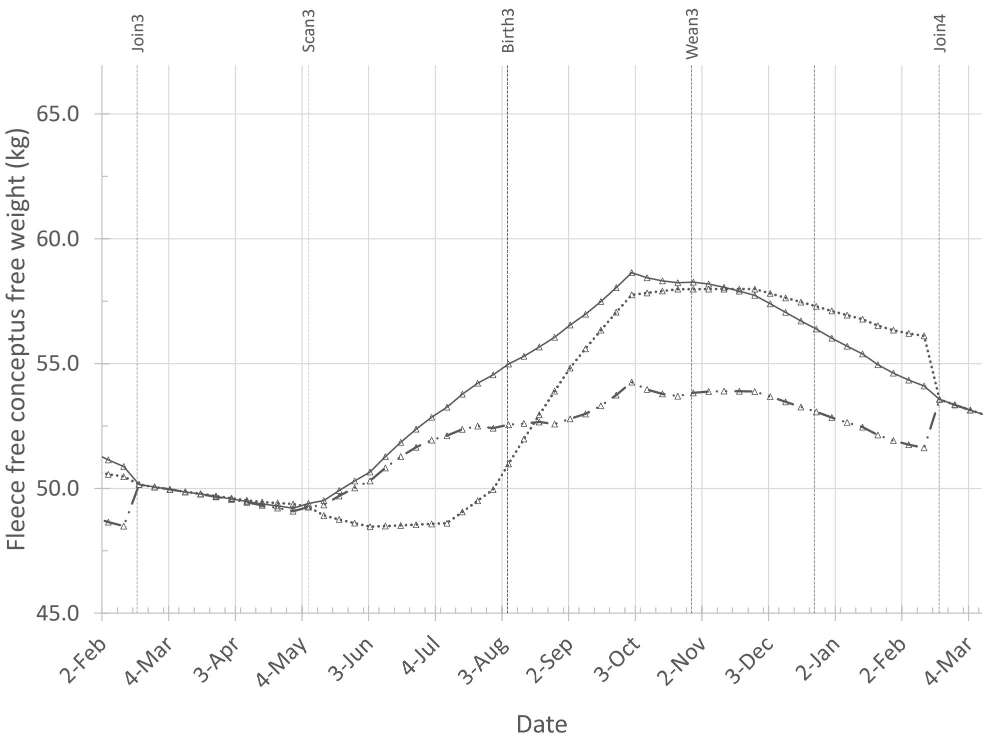

Figure 67: Optimised profile for empty (¨), single- (—) and twin-bearing (-¨) Merino ewes that have been scanned for pregnancy status

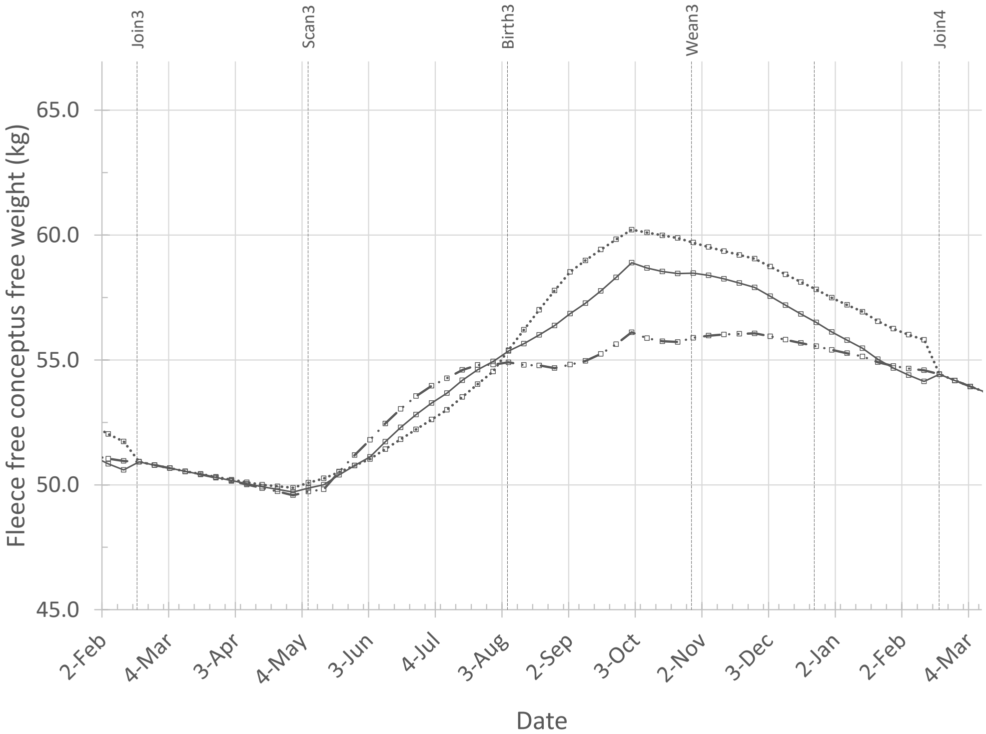

Figure 68: Optimised profile for empty (¨), single- (—) and twin-bearing (-¨) Merino ewes that have been scanned for multiples

Maternal ewes

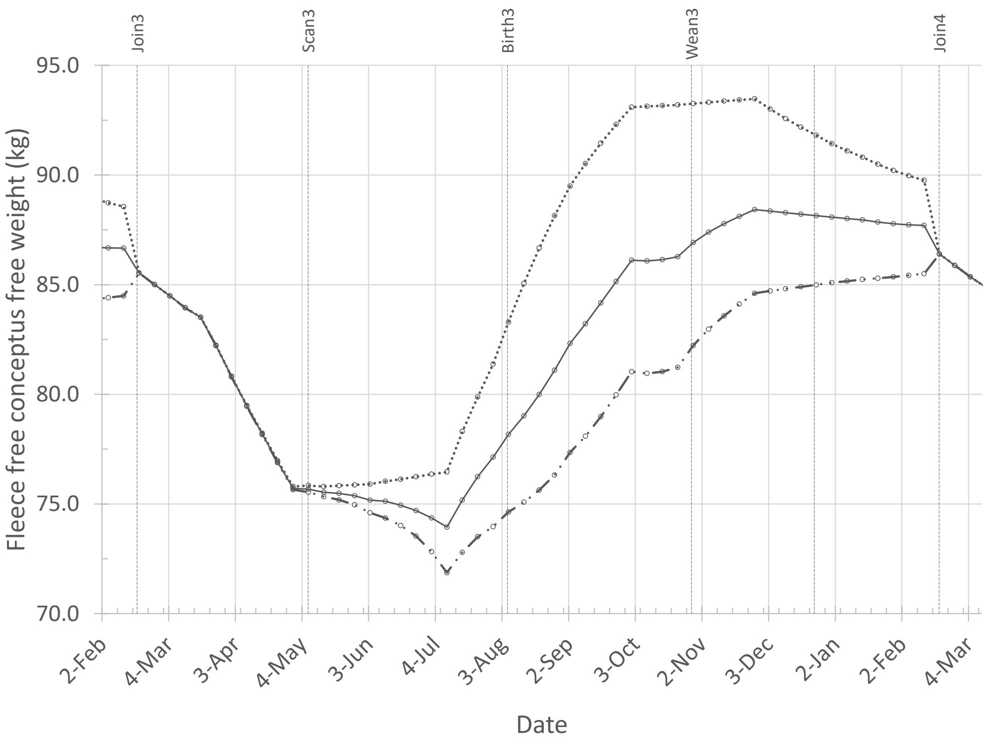

Figure 69: Optimised profile for empty (¨), single- (—) and twin-bearing (-¨) Maternal ewes that have not been scanned

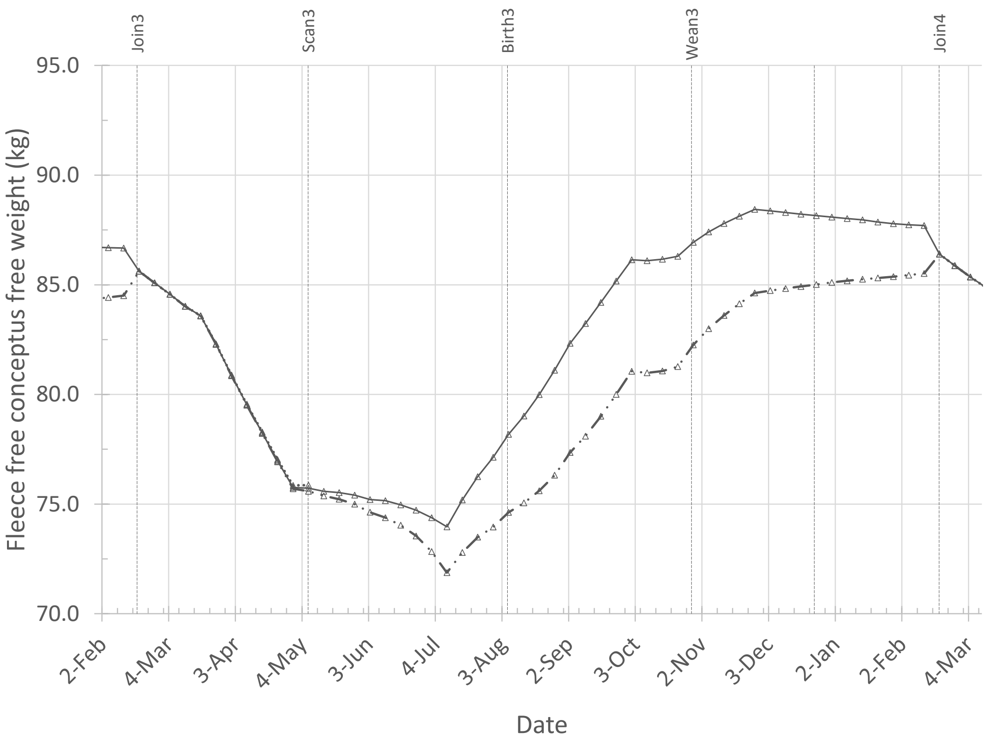

Figure 70: Optimised profile for empty (··), single- (—) and twin-bearing (-··) Maternal ewes that have been scanned for pregnancy status

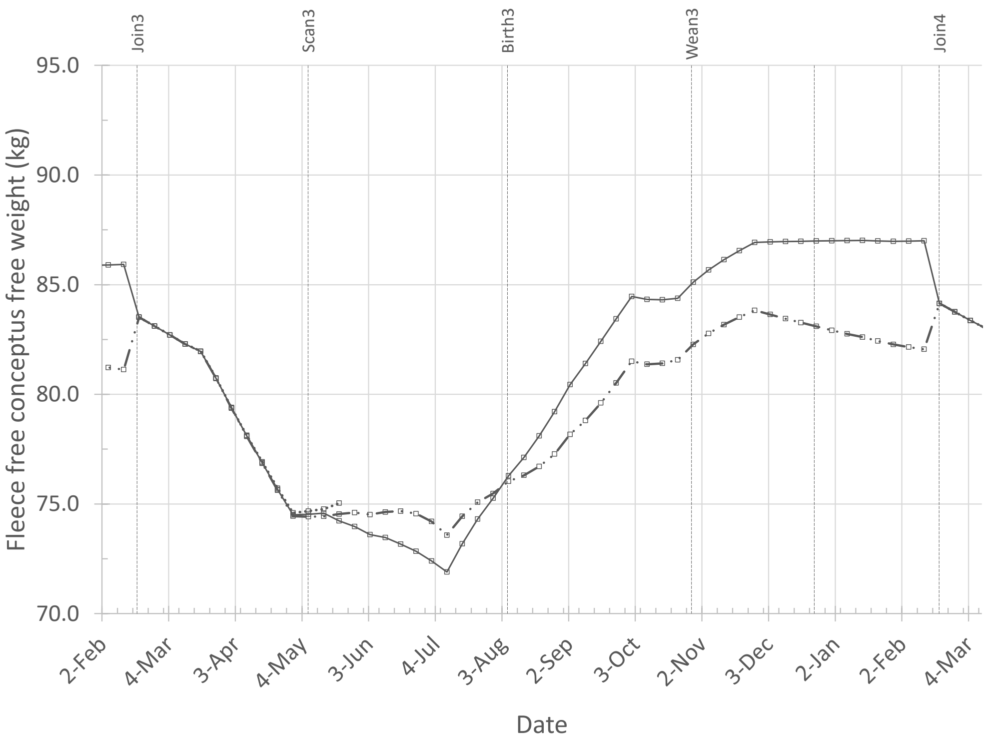

Figure 71: Optimised profile for empty (··), single- (—) and twin-bearing (-··) Maternal ewes that have been scanned for multiples

Sensitivity to Reproductive rate

Long growing season environment

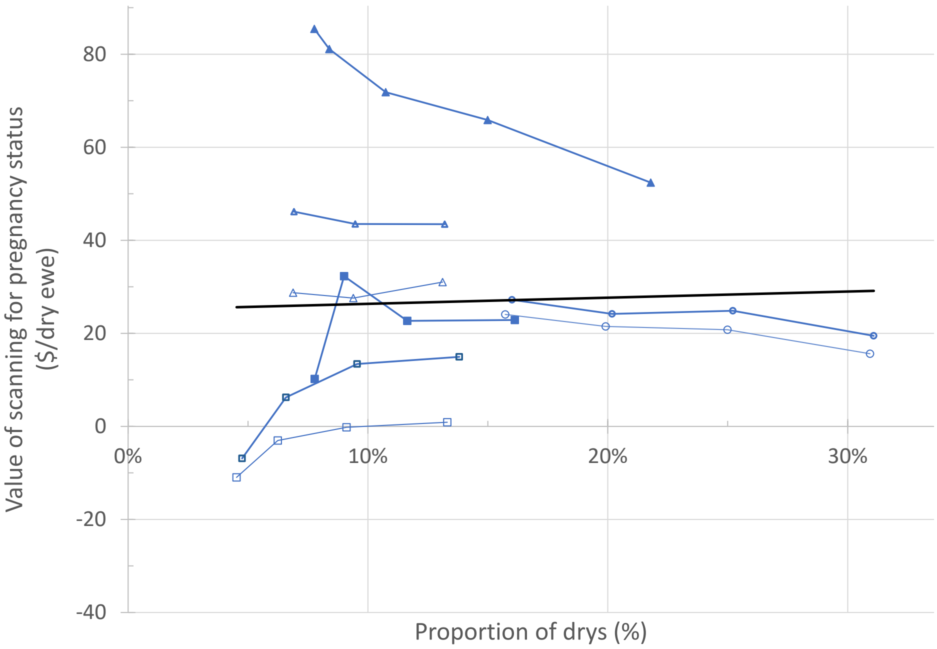

Figure 72: Value of scanning for pregnancy status ($/empty ewe identified) and the impact of altering the proportion of empty ewes in the flock. Merino-Merino open symbols with thick line, Merino-terminal open symbols thin line, Maternals solid symbol. Autumn lambing - circles, Winter lambing – triangles, Spring lambing – squares.

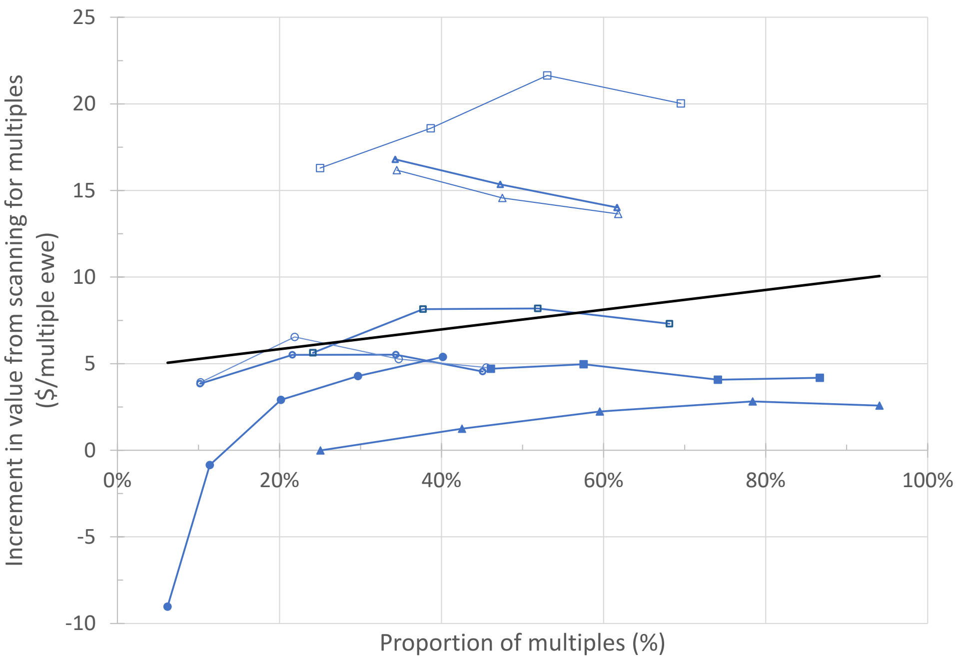

Figure 73: The extra value of scanning for multiples above the value of scanning for pregnancy status ($/multiple ewe identified) and the impact of altering the proportion of multiple bearing ewes in the flock. Symbols as described in the graph above.

Medium growing season environment

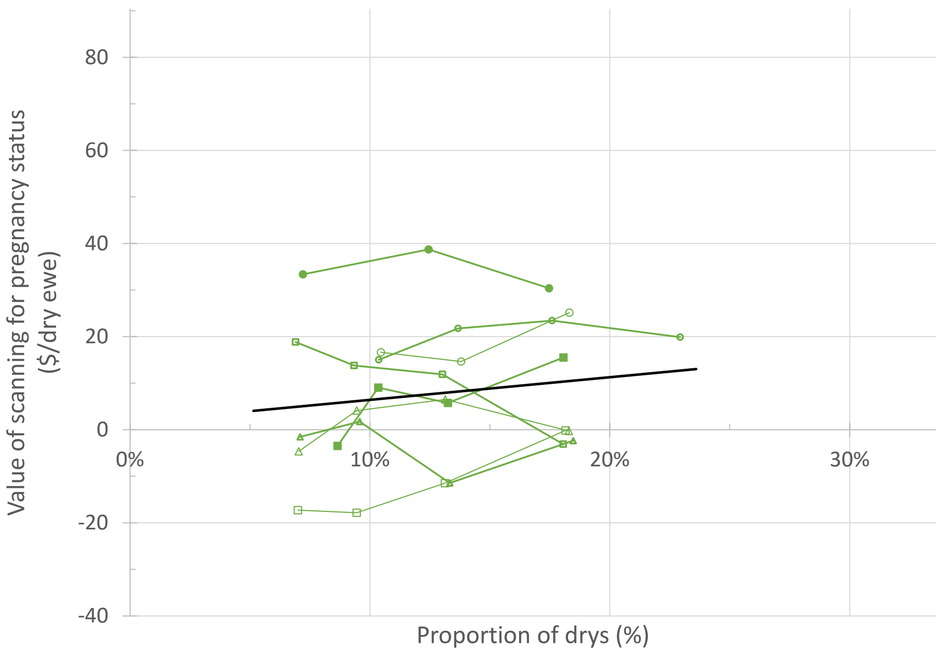

Figure 74: Value of scanning for pregnancy status ($/empty ewe identified) and the impact of altering the proportion of empty ewes in the flock. Merino-Merino open symbols with thick line, Merino-terminal open symbols thin line, Maternals solid symbol. Autumn lambing - circles, Winter lambing – triangles, Spring lambing – squares.

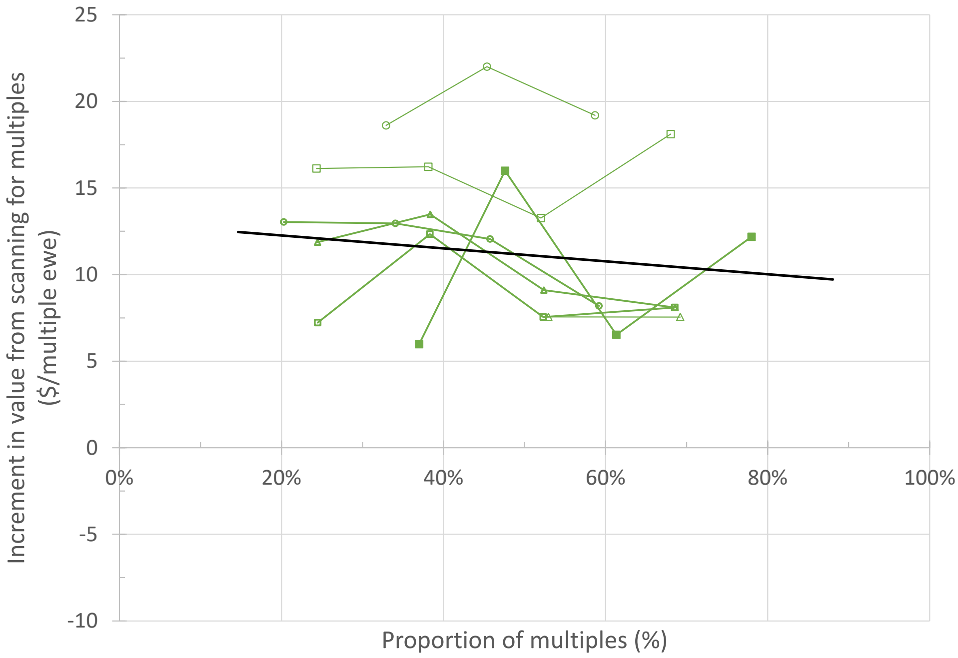

Figure 75: The extra value of scanning for multiples above the value of scanning for pregnancy status ($/multiple ewe identified) and the impact of altering the proportion of multiple bearing ewes in the flock. Symbols as described in the graph above

Short growing season environment

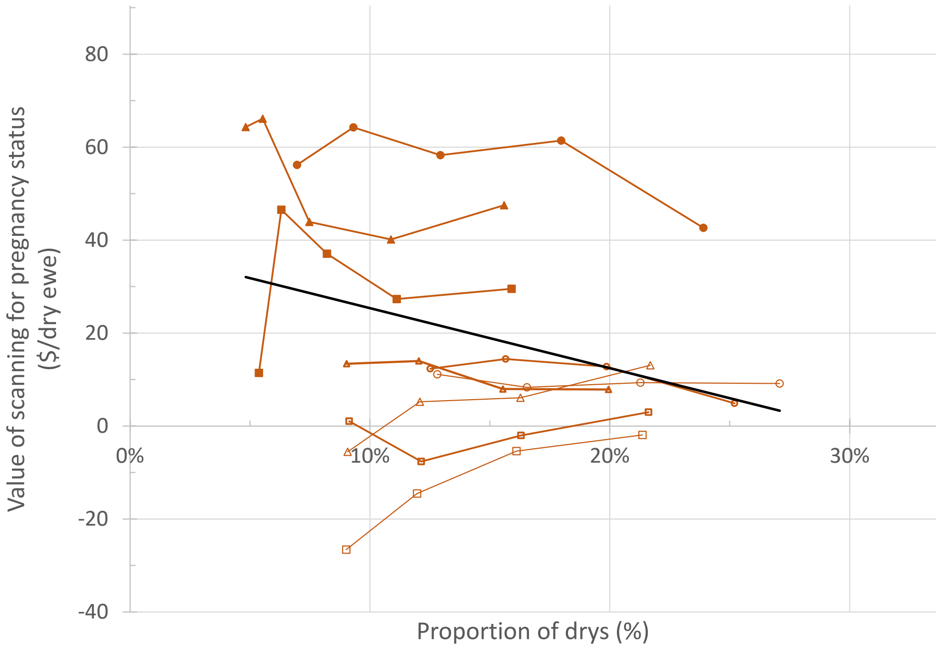

Figure 76: Value of scanning for pregnancy status ($/empty ewe identified) and the impact of altering the proportion of empty ewes in the flock. Merino-Merino open symbols with thick line, Merino-terminal open symbols thin line, Maternals solid symbol. Autumn lambing - circles, Winter lambing – triangles, Spring lambing – squares.

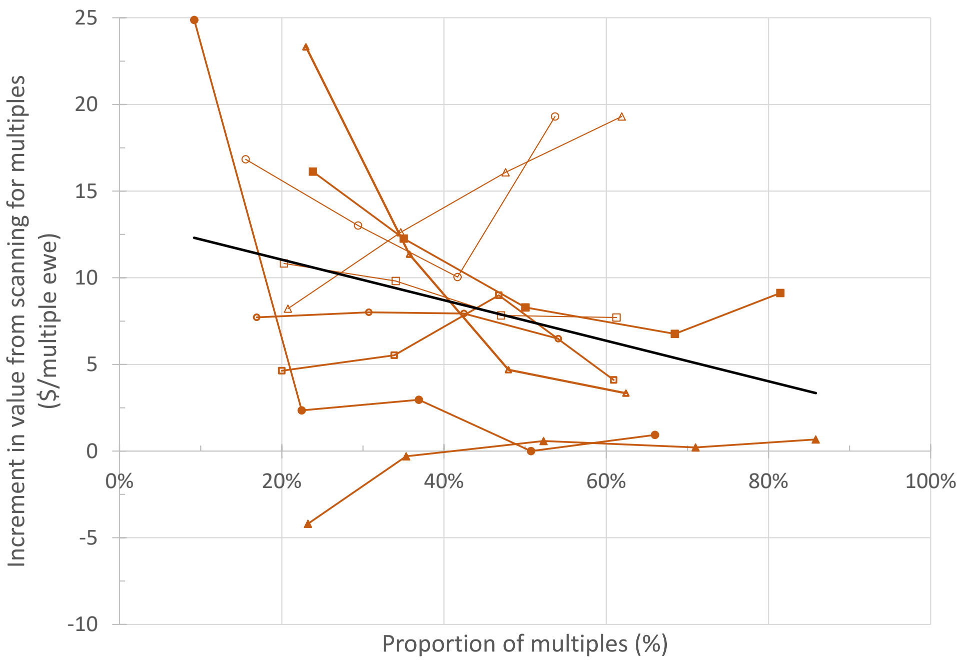

Figure 77: The extra value of scanning for multiples above the value of scanning for pregnancy status ($/multiple ewe identified) and the impact of altering the proportion of multiple bearing ewes in the flock. Symbols as described in the graph above

8.2 Economic analysis of the benefits and costs of pregnancy scanning in sheep: The summer rainfall regions

Project code: L.LSM.0021

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Abstract

Analysis carried out for the winter rainfall regions in southern Australia has shown that there is untapped potential to increase farm profitability by pregnancy scanning ewes and then managing the ewes based on that information. This report describes a gross margin analysis carried out to represent the summer rainfall regions to test if similar potential exist in those areas.

The winter rainfall analysis showed that the benefit from pregnancy scanning was associated with utilising the information for 5 management changes.

- Culling the "passengers" – the scanned empty – to improve future reproductive outcomes
- Reducing the nutrition to the empty ewes and diverting that feed to the pregnant ewes
- Increasing nutrition to the multiple bearing ewes
- Allocating the multiple bearing ewes to the better lambing paddocks
- Including birth type when selecting the replacement breeding ewes

This gross margin analysis did not have sufficient analysis capacity to optimise the management of the empty ewes and multiple bearing ewes, so we have used the optimum identified in the modelling analysis. Similarly, we have evaluated fewer scenarios for time of lambing, reproduction rate of the flocks and prices because the modelling analysis indicated that profitability was not greatly affected.

The important production assumptions to calculate the profitability of pregnancy scanning include:

11. The gross margin analysis was carried out assuming that the agreement between scanning and the lambing outcome was 100%.
12. Feed budgeting to represent the effect of the differential management on supplementary feeding and stocking was done using expert input and discussion with individual farmers.
13. Relationship describing lamb mortality and the connection with level of ewe nutrition and the chill index at lambing were sourced from the GrazPlan suite of models.
14. Impact of BTRT (birth type/rearing type) and dam nutrition on the lifetime productivity of the progeny. The source of these relationships was the LifetimeWool (LTW) project.

15. Response in subsequent flock reproductive rate from culling once or twice-empty ewes. The values used in the analysis were derived from the 'Passenger vs performers' research project which had analysed merino research flocks.
16. Paddock allocation at lambing. The effect of altering paddock allocation was based on calculations using the lamb survival equations in the GrazPlan models that include relationships for both 'wool' and 'meat' sheep and the effect of altering chill.
17. The differences in lifetime reproduction of the replacement born as singles or multiples was based on unpublished results of the Lifetime Maternals project

The results demonstrate that similar to the winter rainfall region, pregnancy scanning is an important strategy for improving profitability and improving lamb survival in the sheep meat and wool industries. The average value across scenarios of scanning for multiples and implementing optimum management was calculated as $4.44/ewe, this is similar to the value calculated for the winter rainfall regions of $5.75/ewe.

The scenario and sensitivity testing in this analysis was not as comprehensive as the modelling analysis in the southern regions, however, the conclusions from this analysis confirm that the extension messages are consistent across regions. The one exception is that the gross margin analysis indicated that for maternal flocks, scanning for multiples was not always more profitable than scanning for pregnancy status only. In the low price scenarios it was more profit. Currently maternal based flocks are uncommon in this region, however, it is uncertain whether the difference quantified is real or due to less detail in the feed budget and lamb survival calculations in the gross margin analysis than the modelling analysis.

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Introduction

Reducing reproductive wastage is a major opportunity for improvement across all sheep regions and breeds in Australia. Scanning ewes to establish reproductive potential and then managing to that potential is a critical step to lift lamb marking percentages and profitability. However, 69% of all sheep producers do not scan for foetal numbers and are therefore not fully aware of the potential within their flocks. Furthermore, there are conflicting messages in industry about the profitability of pregnancy scanning flocks. Therefore, achieving some clarity on scenarios where scanning is likely to increase profit would help industry.

A detailed modelling analysis of the profitability of pregnancy scanning has been carried out for the winter rainfall areas of southern Australia. That analysis showed that profit could be increased, for all scenarios examined, from scanning flocks to identify empty ewes, single bearing- and multiple bearing-ewes. A range of scenarios were examined in the modelling analysis including:

1. Regions: Long, medium and short growing season
2. Genotype: Merino ewes mated to merino rams, Merino ewes with surplus ewes mated to a terminal sire and a maternal genotype
3. Flock reproduction rate: Average, lower and higher reproductive rates.
4. Time of lambing: Autumn/early winter, winter, late winter/spring.
5. Prices for wool, meat and grain.

However, that analysis did not represent the summer rainfall regions of Australia. This gross margin analysis has been carried out to fill the gap. In the modelling analysis a comprehensive range of the benefits that can be gained from pregnancy scanning was included. It was identified that some of the benefits contributed the majority of the profit increase. Only those benefits have been included in this analysis. These benefits are:

9) separation of multiple-bearers from single bearing and empty ewes and better allocation of pasture or supplementary feed based on specific nutritional requirements reflecting litter size. This can include
    a) preferential nutrition of ewes during pregnancy based on litter size to increase total lamb survival by targeting the animals that have the greatest survival response from increasing nutrition for ewes to reduce mortality of lambs due to starvation and mis-mothering or
    b) preferential nutrition of multiple bearing ewes to maximise the lifetime wool production benefits achieved from improved pregnancy nutrition. The lifetime effect of improved nutrition is similar for both single and twin bearing ewes but the twin bearing ewe has more progeny to express the benefit.
    c) selling the empty ewes to reduce total flock feed demand.
    d) reducing nutrition to empty ewes that are retained to reduce total flock feed demand
10) selling empty ewes as a premium price product during winter, being a period of low supply.
11) Culling the ‘passengers’, culling empty ewes to remove the low performing ewes from the flock which increases the average reproduction rate of the animals retained.
12) improve allocation of dams to lambing paddocks based on litter size
    a) better allocation of limited shelter resources and better lambing paddocks to the ewes that will generate the biggest response, which is likely to be those with multiple foetuses
    b) optimising the mob size at lambing based on litter size, because survival of twins is more responsive to smaller mob size than singles.
13) Including birth type information when selecting the replacement ewes for the breeding flock.

Method

A gross margins analysis was carried out that included the costs of pregnancy scanning and all the benefits from scanning that were shown to be important in the winter rainfall regions. In the gross margin analysis, it was necessary to estimate the impact of the alternative management on the amount of grain feeding required and the stocking rate of the ewes with different pregnancy outcomes. These assumptions were informed by a survey of producers in the region that were already pregnancy scanning their flocks. The gross margin calculations account for changes in flock structure that result from increasing lamb survival or altering the number of ewes pregnant or lactating with singles or twins.

Three genotypes were examined in the analysis:

4. 'Merino-Merino' - Merino ewes mated to Merino rams. The production system is a self-replacing flock comprising a fine wool genotype. Surplus young ewes and all wethers are sold off shears after the hogget shearing at approximately 18 months of age. Young ewes are first mated to lamb at 2 years of age. Old ewes (culled for age) are sold off shears at 6.5 years of age.
5. 'Merino-terminal' – A self-replacing flock based on the same ewe genotype as the 'Merino' flock. Cull for age ewes (culled for age at 6.5 yo) are mated to terminal sires to produce first cross prime lambs. Old ewes (culled for age) are sold off shears at 7.5 years of age.
6. 'Maternal' – a self-replacing flock based on a maternal composite genotype. Surplus young ewes and wethers are sold as lambs and young ewes that are retained are mated at between 7 and 8.5 months of age (depending on time of lambing). Old ewes (culled for age) are sold off shears at 6.5 years of age.

The times of lambing examined for the three flocks were:

- Merino x merino
    - 20 September,
- Merino x terminal
    - 01 September,
    - 20 September,
- Maternal
    - 01 August,
    - 01 September.

Production assumptions

The important production assumptions to calculate the profitability of pregnancy scanning include:

Scanning agreement

The gross margin analysis was carried out assuming that the agreement between scanning and the lambing outcome was 100%. In the detailed modelling analysis the reduction in the value of scanning associated with only an 85% agreement between scanning and lambing results was calculated. In that analysis the average reduction in profit was $0.55/ewe scanned, so this gross margins analysis may be overestimating the value of scanning by this amount.

Feed budget

Feed budgeting to represent the effect of the differential management on supplementary feeding and stocking was done using expert input and discussion with individual farmers.

Lamb Mortality due to exposure and mis-mothering

Relationship describing lamb mortality and the connection with level of ewe nutrition and the chill index at lambing were sourced from the GrazPlan suite of models (Freer *et al.* 2012). These relationships calculate a transformed mortality index from ewe body condition at birth (BC), birth type (BT) & chill index. The mortality index is back transformed to mortality.

$$tMortalityIndex\ Wool\ sheep = -9.95 - 1.71BC + 0.0098chill + 1.1(twin)$$

$$tMortalityIndex\ Meat\ sheep = -8.90 - 1.49BC + 0.0081chill + 0.82(twin)$$

$$Mortality = 1/(1 + e^{-tMortality})$$

Body condition (BC) is defined as ewe LW divided by normal weight (where normal weight is the weight of a well grown animal of the same age). A BC of 1.0 is equivalent to a CS of 3.

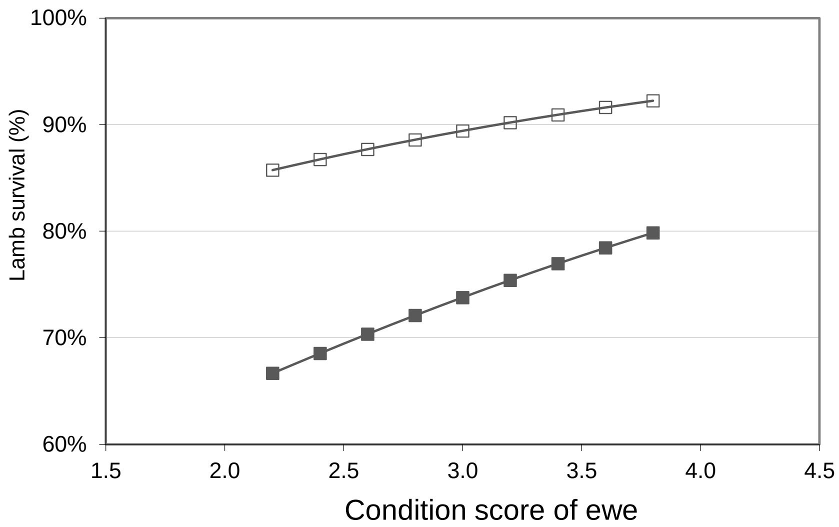

Figure 1: Lamb mortality of single and twin born lambs from ewes with different CS at lambing estimated using the GrazPlan equations for Wool & Meat sheep.

An important driver of the profitability of different nutrition of single and twin bearing ewes is the difference in the predicted change in mortality of singles and twins if the nutrition of the ewes is improved and the ewes are in better condition at birth. If twin lamb survival is more responsive to improved dam nutrition, then differential feeding in favour of twins is likely to increase profit, whereas if the responses are similar, then differential feeding will have little impact and if the single survival is more responsive then differential feeding in favour of singles is likely to increase profit.

The GrazPlan equations predict that twin survival is most responsive if the chill index is below 1100 kJm-2.hr for ‘Wool’ genotypes and 1200 for ‘Meat’ genotypes (Figure 2). The calculations done in the detailed modelling comparing the GrazPlan and LTW equations showed a larger effect of differential nutrition on single and twin survival using the LTW relationships. Therefore, by using the GrazPlan relationships this analysis may be under estimating the benefits of scanning and differential management.

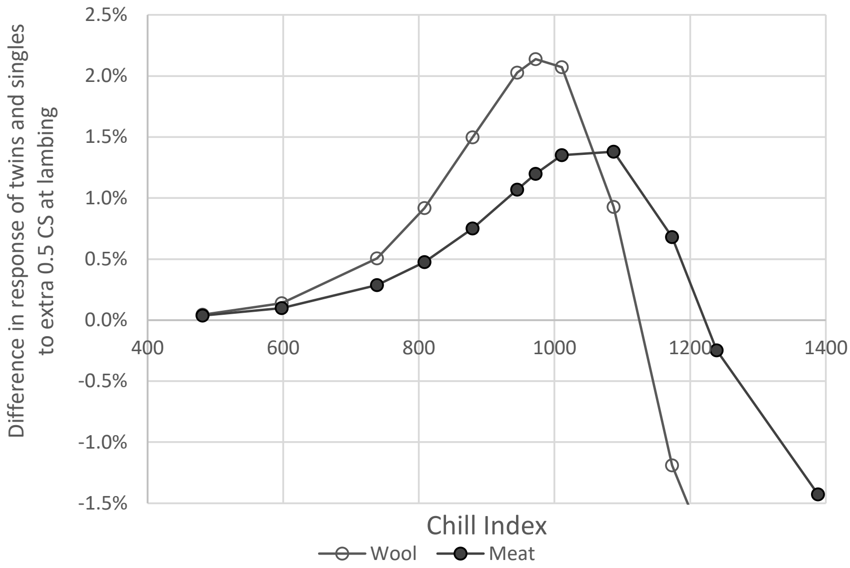

Figure 2: The difference in response to improved nutrition for twin bearing ewes versus single bearing ewes with different levels of chill index, estimated using the GrazPlan relationships for wool and meat sheep. A positive value indicates twin lamb survival is more responsive and a negative value indicates singles are more responsive.

Impact of dam nutrition on progeny lifetime productivity

The LTW project quantified the impact of dam LW and LW change during pregnancy on the progeny lifetime wool production. A higher CS at lambing increase progeny CFW and reduced progeny FD over their lifetime. The coefficients determined in the trial are in Table 1.

Table 121: Impact of ewe liveweight profile during pregnancy on the progeny clean fleece weight and fibre diameter. Source: Thompson *et al.* 2011

	CFW	Fibre diameter
LW at joining	0.012	0
LW change early pregnancy	0.022	-0.019
LW change late pregnancy	0.021	-0.031

Peri-natal ewe mortality

Ewe mortality around the time of birth was estimated in the LTW project from CS of the ewe at the point of lambing. Transformed mortality was calculated from CS at lambing, this was back transformed and an adjustment made for twin bearing ewes.

$$tMortality = -0.4045 - 1.4535 Ewe\ CS_{lambing}$$

$$Mortality_{singles} = 1/(1 + e^{-tMortality})$$

$$Mortality_{twins} = Mortality_{singles} + 0.0225$$

Single and twin bearing ewes are estimated to be equally responsive to improved CS at lambing if starting at the same CS. However, if ewes are fed the same during gestation, the twins will be lower CS at lambing and hence slightly more responsive to improved nutrition than the singles. Twins at CS2.5 would generate 0.4% better improvement in ewe survival from feeding to gain 0.5CS than single bearing ewes at CS2.75.

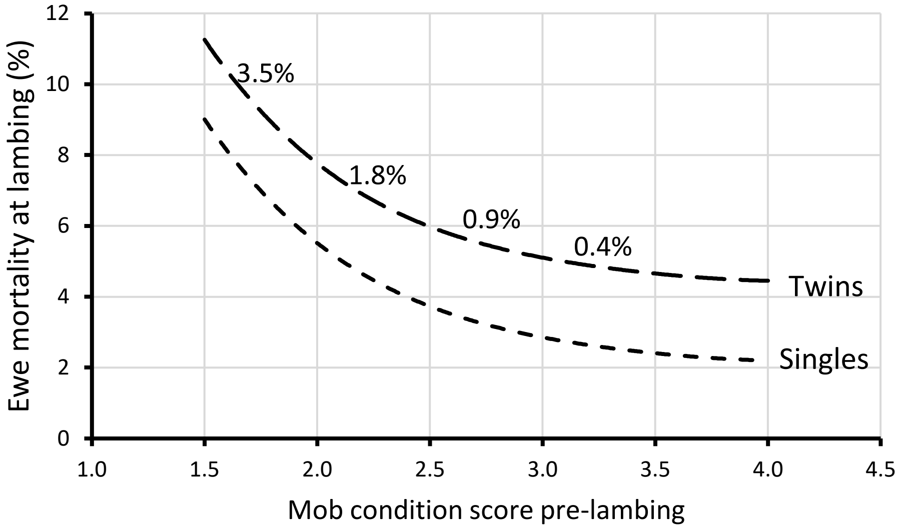

Figure 3: Ewe mortality at lambing based on information in the Lifetime Ewe management program.

Response due to culling once or twice-empty ewes

Work carried out by the NSW DPI (Lee *et al.* 2009) has shown that there is large variation in the lifetime reproductive performance of individuals in a flock. They analysed the D-Flock, C-Flock and QPlu$ flocks and the top 50% of ewes produced between 0.62 and 0.75 more lambs each year than the bottom 50%. Other work by NSW DPI quantified the gains of adopting a system of culling the "passengers" at 3.5yo if they hadn't raised a lamb after 2 lambing opportunities. That work showed a net benefit of approximately 4% gain due to culling the passengers. Scanning and identifying the empty ewes allows culling the 'passengers'. A subsequent empirical analysis (Hatcher *et al*. 2018) that examined a wider range of industry datasets did not demonstrate such large gains and showed gains in total flock number of lambs weaned of between 0 and 2.5% from culling twice-empty ewes. This second analysis covered a shorter duration than the first and as such captured less of the genetic effects of culling on scanning performance.

The results from both these analyses are not well suited to providing inputs for this economic analysis because they calculated the benefit over the whole flock rather than generating data by age group that is necessary for the gross margins analysis that represents flock age structure based on individual age group data. Using the data is made more difficult because culling the 'passengers' increases the proportion of young ewes in the flock and these animals have a lower reproductive performance, so the impact on the reproductive performance of the older ewes is greater than indicated by the above numbers. Estimations based on differences between age groups and typical age structures indicate that culling twice-empty ewes in the above datasets increased the subsequent scanning rate of the retained animals by 5%. This benefit was applied in this analysis if ewes were scanned and the empty ewes were sold, either at scanning or at the subsequent shearing. A further 1% genetic improvement over the whole flock was included extra to the benefit in the current generation.

The South Australian component of the PvP project analysis included the impacts of selling empty maidens (once-empty) or selling twice-empty after the second lambing opportunity. Culling twice-empty increased flock NLW by 1.2% and culling once-empty increased by 2.1%, an improvement of 70% over culling twice-empty (it was associated with selling 4 times the number of ewes). Part of the extra benefit associated with culling once-empty is the extra year for which the passengers have been removed. Calculations done using a flock structure similar to the SA research flock retaining the ewes for 4 matings and accounting for the number of joinings that will be improved as a result of culling once or twice-empty showed that a 25% higher response was required to replicate the flock level response. In this analysis the 25% scalar of the benefit of culling once-empty relative to twice-empty was included and evaluated.

The merino flock was assumed to sell twice empty ewes and the maternal flock was assumed to sell all empty ewes (once-empty). For the Merino flock the empty ewes were sold at shearing. For the maternal flock the sale was at scanning.

Improved paddock allocation at lambing

Lambing paddock has an impact on lamb survival which may be due to exposure or aspect or other as yet unidentified factors. Although the reasons have not all been elucidated, farmers know which are their better lambing paddocks and can allocate the multiple bearing ewes to these paddocks. It is likely that the survival of the multiple bearing lambs will be more responsive to the better conditions and there will be more lambs survive in total if the multiples are identified and allocated to the better paddocks. For this analysis the benefits of changing paddock allocation at lambing was based on exposure and chill, because weather records indicated that chill factor was high enough that these benefits would be greater than adjusting mob size.

Exposure & chill index

Paddocks on-farm vary in the level of exposure and this alters the level of chill experienced by the lambs at birth. Differential allocation of ewes to paddocks based on level of exposure could increase average lamb survival if the less exposed paddocks are allocated to the ewes whose progeny are most responsive.

At low chill levels twin lamb survival is more responsive whereas at high chill levels (>=1100 for 'wool' genotypes and >=1250 for 'meat' genotypes) the single lamb survival is more responsive (Figure 9).

The GrazPlan relationships were used to calculate the net benefit in lamb mortality if the ewes are differentially allocated to lambing paddocks for birth. It was assumed that the 'good' paddocks had chill factor 50 $kJ/m^2/hr$ lower than average and the 'poor' paddocks were 50 $kJ/m^2/hr$ higher than average. The average chill index was 1109, 1049 & 1005 if lambing 1 Aug, 1 Sep & 20 Sep.

The net overall flock benefit (Table **3**2) is the accumulation of:

- the improvement in the mortality of the twins that would have been born in the 'poor' paddock that are now born in the 'good' paddock. The values are derived from Figure **9**4 and for the average chill in this environment (as determined by time of lambing). For example, the increase in twin survival for Merinos lambing 20 Sep is 21.0%.
- the increase in mortality of the singles that would have been born in the good paddock that are now born in the 'poor' paddock. The increase for Merinos lambing 20 Sep is 11.6%.
- the number of lambs born per ewe allocated to the different paddocks
- the proportion of 'good' versus 'poor' paddocks, which is assumed to be 50% based on working on average chill level.
- the proportion of singles and twins. These proportions affect the number of ewes that can be reallocated from their respective undifferentiated paddocks.
- The relative stocking density of singles and twins during the lambing period. The calculations have been carried out based on the DSE/hd of single and twin bearing ewes.
- The number of ewes that can be reallocated. This is determined by the lesser of the number of DSE of single-bearing ewes in the sheltered paddocks that can be moved to exposed paddocks or the number of DSE of twin-bearing ewes in the exposed paddocks that can be moved to the sheltered paddocks.

Table 2: Calculation of the benefit associated with altering paddock allocation to reduce the net flock lamb mortality. The mortality is based on calculations using the GrazPlan relationships for Wool & Meat sheep with chill index ranging plus and minus 50 units either side of 1000 kJ/m²/hr.

Flock	Scenario	% twins	Change in Mortality*		Proportion of ewes that are re-allocated		Net benefit
			Singles	Twins	Singles	Twins	
Merino	Medium chill	35	+11.6	-21.0	32	50	-3.6
Maternal	Medium chill	50	+6.9	-12.3	50	42	-2.3

* change in mortality of twins that move from exposed to sheltered paddocks (percentage points)
of singles that move from sheltered to exposed paddocks (percentage points)

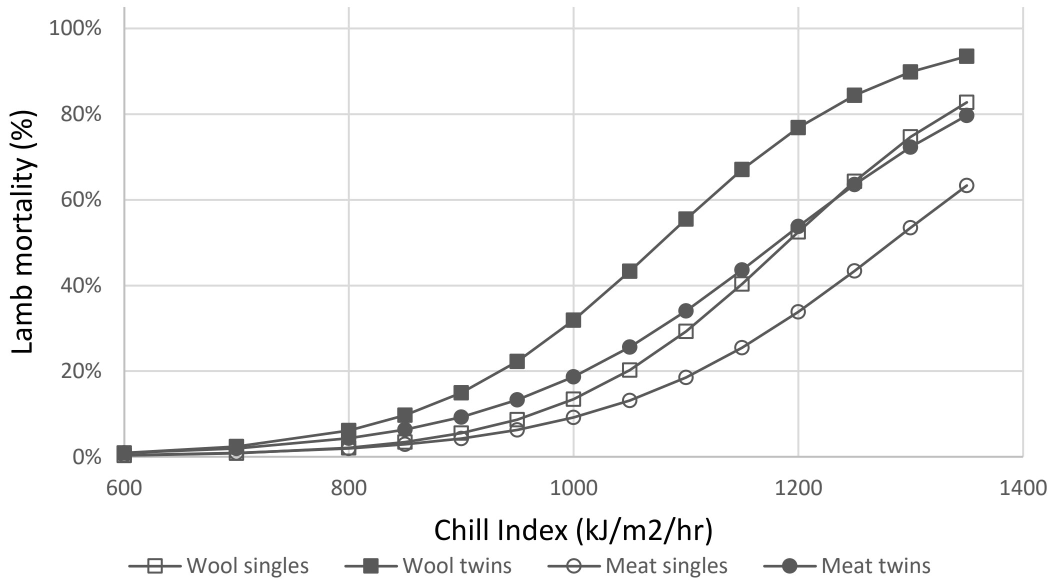

Figure 4: Predicted mortality at birth of single and twin born lambs from 'wool' sheep and 'meat' sheep for a range of chill index . Predictions based on the GrazPlan equations.

Cost assumptions

The cost of scanning includes both the cost of the contractor and the labour cost associated with pushing the ewes through the scanning crate and the mustering that is required per mob. The assumption is that all labour is provided by casual labour and the cost varies between $0.31/ewe if scanning pregnancy status only, and up to $0.40/ewe if scanning for multiples. The cost of casual labour is assumed to be $256 per day ($32/hr all-inclusive for an 8 hour day).

Table 3: The assumptions used for the cost of contracting. Source of contract cost: Cousins Merino Services if more than 2000ewes to scan. Less than 2000ewes add $0.10/hd.

	Pregnancy status only	Multiples
The contractor#		
Contract cost ($/hd)	$0.50	$0.75
Travel	$0.02	$0.02
Throughput (hd/day)	3000	2000
Farmer provided labour		
Yard work – labour units	2	2
Cost per hd	$0.17	$0.26
Mustering	$0.06	$0.06
Other costs		
R&M on infrastructure & Fuel	$0.08	$0.08
Total cost	$0.83	$1.17

based on contract cost if greater than 2000 ewes being scanned (source: Cousins Merino Services)

Price scenarios

Four price scenarios for meat were examined based on the percentiles of the prices received over the period 2004 to 2020. The values tested were the 50th, 70th and 90th percentile plus April 2022 prices.

Three price scenarios for wool were examined based on the percentiles of the prices received over the period 2004 to 2020. The values tested were the 20th and 80th percentile plus the prices being received in Apr 2022 (Table 4).

Table 4: Standard prices (in bold type) and the range examined in this analysis.

Commodity		units	Percentile					
			20th	50th	70th	80th	90th	April 22
Wool[1]	16µ	c/kg clean (flc)	2150			3272		3063
	17µ	c/kg clean (flc)	1862			2833		2652
	18µ	c/kg clean (flc)	1513			2303		2156
Meat[2]	Lamb	c/kg DW		501	600		809	805
	Mutton	c/kg DW		334	416		601	673
	Breeders	$/hd		73	92		132	135

[1]Source: Mecardo Wool Price Percentiles (2004-current) @ 21/12/21 & FD spread percentiles @ Oct2020
[2]Source: Mecardo Lamb & Sheep Market Price Percentiles (2004-current) @ 26/5/22

Ewes that are 5½ years old or younger can be sold into the breeding market for a premium above the mutton price. Ewes of 18 months old receive a 10% premium over CFA ewes. There are differences in price during the year associated with selling emptys at scanning for a premium price relative to sale at next shearing. The price premium received for selling at scanning compared with selling at shearing was 10%.

Livestock management & Flock productivity

Three genotype systems were examined in the analysis:

4. 'Merino-Merino' - Merino ewes mated to Merino rams. The production system is a self-replacing flock comprising a fine wool genotype. Surplus young ewes and all wethers are sold off shears after the hogget shearing at approximately 18 months of age. Young ewes are first mated to lamb at 2 years of age. Old ewes (culled for age) are sold off shears at 6.5 years of age.
5. 'Merino-terminal' – A self-replacing flock based on the same ewe genotype as the 'Merino' flock. Surplus young ewes and all 6.5 yo ewes are are mated to terminal sires to produce first cross prime lambs. Old ewes (culled for age) are sold off shears at 7.5 years of age.
6. 'Maternal' – a self-replacing flock based on a maternal composite genotype. Surplus young ewes and wethers are sold as lambs and young ewes that are retained are mated at between 7 and 8.5 months of age (depending on time of lambing). Old ewes (culled for age) are sold off shears at 6.5 years of age.

Best practice animal husbandry was applied for all ewes and lambs in each system and tasks such as crutching and shearing were undertaken using contract labour. Production characteristics (CFW, FD, reproductive rate and lamb survival) are outlined in Table 5 for each time of lambing evaluated for each genotype.

Table 5: Summary of productivity if ewes aren't scanned for each flock type and time of lambing. The standard time of lambing for each flock is in bold type.

		Merino	Merino x terminal		Maternal	
		20-Sep	1-Sep	20-Sep	1-Aug	1-Sep
Reproductive rate	4yo (%)	118	130	130	150	150
Lamb survival	Singles (%)	82	87	87	90	90
	Twins (%)	72	77	77	80	80
Weaning %	Flock ave (%)	90	98	98	125	125
CFW Adult ewes	kg/hd clean	3.4	3.4	3.4	4.0	4.0
FD Adult ewes	M	16.9	16.9	16.9	26	26
Supplement fed	Kg/ewe	25	25	25	25	25

The region

The region represented in the analysis is typical of the Northern Tablelands. The region is dominated by merino fine wool production. Stocking rates typically vary between 4-11 DSE/ha with an average of approximately 8 DSE/ha, depending on the degree of pasture improvement of the farm. Scanning rates vary between 100-140%, averaging 118%. Weaning rates vary between 75-100%, with an average of 90%. However, weaning rate has been reported to vary considerably depending on seasonal conditions, with rates as low as 25% reported during drought. Clean adult clean fleece weights average 3.5 kg and 17 µm.

The Analysis

The gross margin analysis was carried out for each flock scenario (genotype (3) x TOL (2 for Maternal & MxT, 1 for MxM), each price scenario (6) and each pregnancy scanning scenario (not scanned, scan for pregnancy status only, scan for multiples (3)). Several sensitivity analyses were conducted to test key variables. For all scenarios the increase in flock gross margin from scanning was calculated per ewe on the farm at scanning.

Nutrition Profiles assumed

An important component of the value of pregnancy scanning is the differential nutritional management that is possible when pregnancy status or litter size has been identified. Differential nutritional management can begin at scanning and is associated with different feed requirements and different production levels for:

- Liveweight and the effects on
    - reproduction rate
    - value at sale
- ewe mortality
- fleece weight and fibre diameter of the ewe
- progeny birth weight and lamb survival
- progeny fleece production

The liveweight profile for ewes carrying different numbers of lambs during pregnancy for each level of scanning was based on the results from the modelling analysis (Figure 105, Figure 116 & Figure 127) because the gross margin analysis does not have a sufficiently powerful feed budget to develop optimum nutrition profiles. All the production outcomes above were based on these profiles.

The profiles from the detailed modelling show that during late pregnancy, if ewes are not scanned (e.g. Figure 105) then the empty ewes gain weight relative to the single bearing ewes and the twin bearing ewes lose weight. In the period prior to scanning the ewes with different numbers of foetuses are managed together and the weights diverge slightly due to differences in energy requirements. If the ewes are scanned for pregnancy status, then in late pregnancy the optimum management is to reduce the nutrition level of the empty ewes (e.g. Figure 116). If the ewes are scanned for multiples, then the single- and multiple-bearing ewes can be differentially fed and the optimum management is to increase the feed to the multiple bearing ewes (e.g. Figure 127).

The ewes that conceived in different cycles were managed as a single mob and the value that could be achieved from foetal aging was not quantified in this analysis.

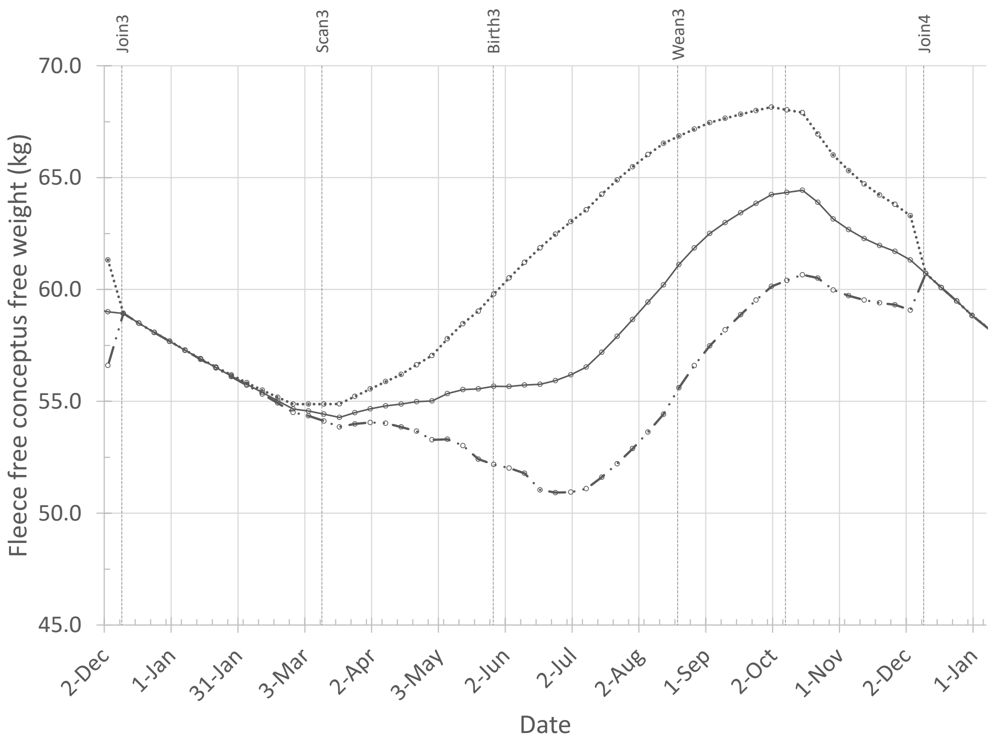

Figure 5: Example of optimum profile for empty (··), single-bearing (—) and twin-bearing ewes (-··) from the detailed modelling if the flock is not scanned.

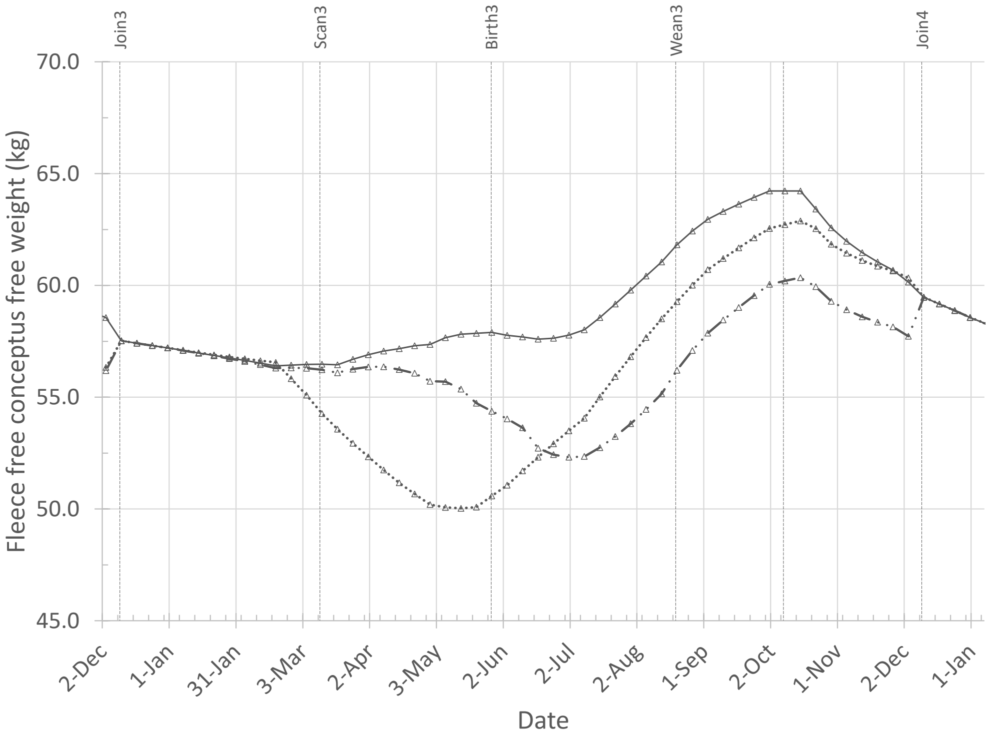

Figure 6: Example of optimum profile for empty (··), single-bearing (—) and twin-bearing ewes (-··)if the flock is scanned for pregnancy status and the non-pregnant ewes are identified and differentially managed.

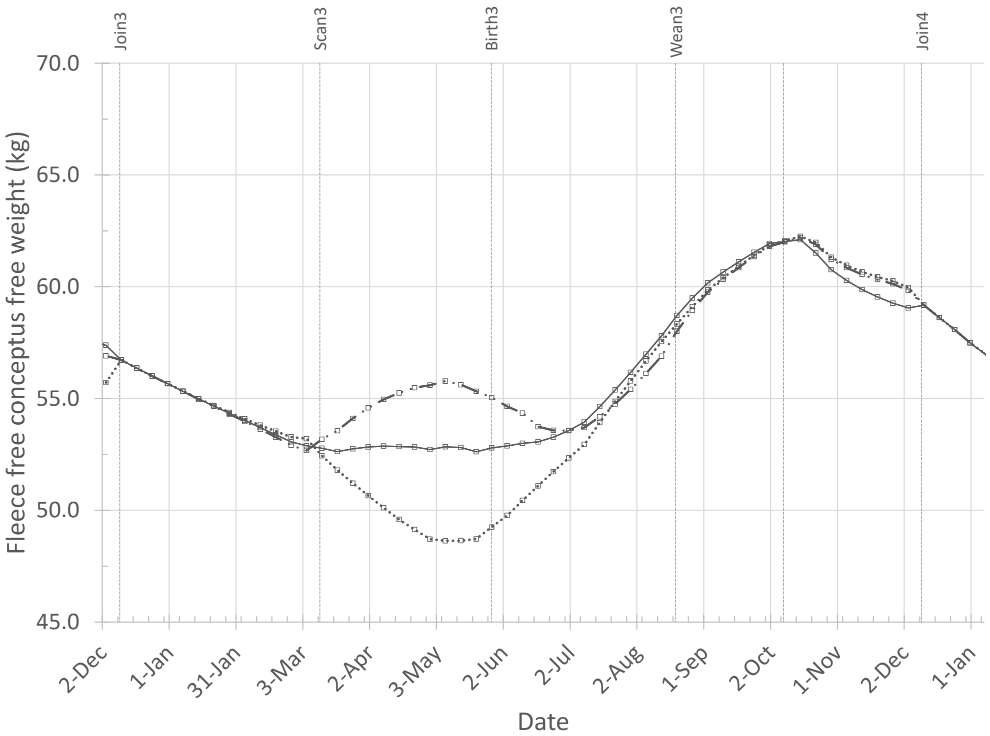

Figure 7: Example of optimum profile for empty (··), single-bearing (—) and twin-bearing ewes (-··) if the flock is scanned for multiples and the empty, sinlge- and multiple-bearing ewes are differententially managed.

Sensitivity Analysis

Sensitivity was carried out to provide more detail on the contribution of some of the important components that contribute to the profitability of scanning. Sensitivity analysis was carried out on the following variables for both flock scanning options with the other variable held at the standard values:

- Time of lambing - which affects chill index, ewe DSE rating through the feed limiting period of the year and the proportion of time emptys are held into the feed limiting period of the year based on when they can be identified and sold after scanning,
- Empty ewe protocol – including retaining, selling after scanning empty twice and selling after scanning empty once,
- Prices – in addition to current prices (circa. April 2022), 20th 20th and 80th wool price percentiles, and 50th 70th and 90th sheep price percentiles.
- Reproduction rate (scanning percentage) – 3 levels: scale ± 25% & +12.5% from standard.
- Wether cull for age – 1.5 and 5.5 years of age

Results & Discussion

Value of scanning

Scanning for multiples increased profit by an average of $4.44 per ewe scanned, furthermore scanning for multiples increased profit in all scenarios tested provided that the information was utilised to:

- Identify the empty ewes and
- improve feed allocation during pregnancy to allocate less to any empty ewes retained and increase the allocation to the multiple bearing ewes
- improve the allocation of the single and twin bearing ewes to the better lambing paddocks
- select replacement progeny accounting for birth type (Table 6).

Scanning was more profitable for the earlier lambing for both the genotypes for which 2 times of lambing were examined. For the Maternal genotype, the value of scanning was $0.27 higher for the lambing at the beginning of August compared with the beginning of September. For the Merino mated to a terminal sire the value of scanning was $0.46 higher if lambing on 1 September compared with lambing on 20 September (Table 6).

Table 6: The increase in farm profit from scanning for multiples and implementing optimum management ($/ewe scanned) for each of the flock types and times of lambing. Estimated for 100% agreement between scanning results & lambing outcome.

	Time of Lambing		
Flock	1-Aug ($/ewe)	1-Sep ($/ewe)	20-Sep ($/ewe)
Merino			3.85
Mer-TS		7.52	7.06
Maternal	2.01	1.74	
Overall Average		4.44	

Scanning for pregnancy status only was also profitable in all scenarios tested, but was less valuable than scanning for multiples and only added $1.60 per ewe scanned (Table 7). The extra value of scanning for multiples as opposed to scanning for pregnancy status was greater in merino-based flocks than in maternal flocks. Maternal flocks showed less additional value in scanning for multiples and there were some scenarios in which scanning for pregnancy status only was more profitable than scanning for multiples. This differs from the result found in the winter rainfall zone and could be due to difference between the winter rainfall region and the summer rainfall region or more likely it is due to the details missed in the more simplistic gross margin analysis.

Table 7: The increase in farm profit from scanning for pregnancy status ($/ewe scanned) for each of the flock types and times of lambing.

	Time of Lambing		
Flock	1-Aug ($/ewe)	1-Sep ($/ewe)	20-Sep ($/ewe)
Merino			1.16
Mer-TS		1.86	1.78
Maternal	1.64	1.57	
Overall Average		1.60	

Rules of thumb

- scanning for multiples and implementing optimum nutritional management, optimal management of emptys and optimal paddock allocation increased profit for all genotypes at all times of lambing. The average increase in profit was $4.44 per ewe scanned.
- Scanning for pregnancy status only is also more profitable than not scanning, but the benefits ($1.60/ewe) are less than scanning for multiples.

Sensitivity Analysis

Empty ewe protocol

For the Merino and maternal flocks selling the empty ewes was the more profitable management, contributing between $0.24 & $1.15/ewe to the value of scanning (Table 8). These values are similar to the values for the spring lambing flocks in the winter rainfall zone, which is equivalent to the time of lambing for which the summer rainfall sensitivity was carried out.

For the merino flock with surplus ewes mated to a terminal sire, selling the empty ewes reduced profit. This was not tested in the winter rainfall regions but it occurs because selling the empty ewes reduces the number of surplus ewes that can be mated to the terminal sire. For this flock retaining the empty ewes was between $0.45 & $0.80/ewe more profitable than selling twice-empty.

For the maternal flock - that has a sufficient weaning percentage to be self-replacing – there was very little difference between selling once-empty or twice-empty ewes. The exception to this was with current prices, for which it was $2.20/ewe more profitable to sell once dry ewes.

Table 8: The value of scanning for pregnancy status or for multiples for the 3 flock types in the summer rainfall region if different management of the empty ewes. Note: blank cells for once-empty indicates that the flock can't self-replace with the extra numbers culled.

	Pregnancy Status			Multiples		
Flock	Retain ($/ewe)	Once-empty ($/ewe)	Twice-empty ($/ewe)	Retain ($/ewe)	Once-empty ($/ewe)	Twice-empty ($/ewe)
Merino	0.93		1.17	4.03		4.41
Mer-TS	1.78		0.96	7.61		7.16
Maternal	0.41	1.55	1.56	1.41	2.11	2.29

Rules of Thumb

- Identifying and selling the empty ewes increased profit for flocks that were not mating surplus ewes to terminal sires.
- Identifying and selling the empty ewes reduced profit for flocks that were mating surplus ewes to terminal sires.
- There is little difference in profit whether the empty ewes are sold as once- or twice-empty.

Flock reproduction rate

Flocks with higher reproduction rates benefit more from scanning (Figure 8), however the contribution from managing the multiple-bearing ewes and the empty-ewes changes. The contribution from managing the empty ewe reduces because there are fewer empty ewes but this is offset by an increase in the number of multiple bearing ewes and the extra value available here.

The results for the summer rainfall region show the total value for scanning reaching a maximum value at a scanning percentage about 130% and then reducing. Note: farm profit continues to increase with increasing scanning percentage, it is just the contribution from scanning that is falling. This result is different to that found in the detailed modelling analysis and it is likely that this result is due to the more simplistic gross margin analysis. The result is even more stark in the maternal flock and a contributing factor is the increasing number of triplet-bearing ewes as reproductive rate increases. In this gross margin analysis the use of the pregnancy scanning information to increase reproductive rate was fixed and the management of the triplets was not being optimised. In flocks with high reproductive rates it is more important to use the results to improve lamb survival rather than achieving further improvements in reproductive rate.

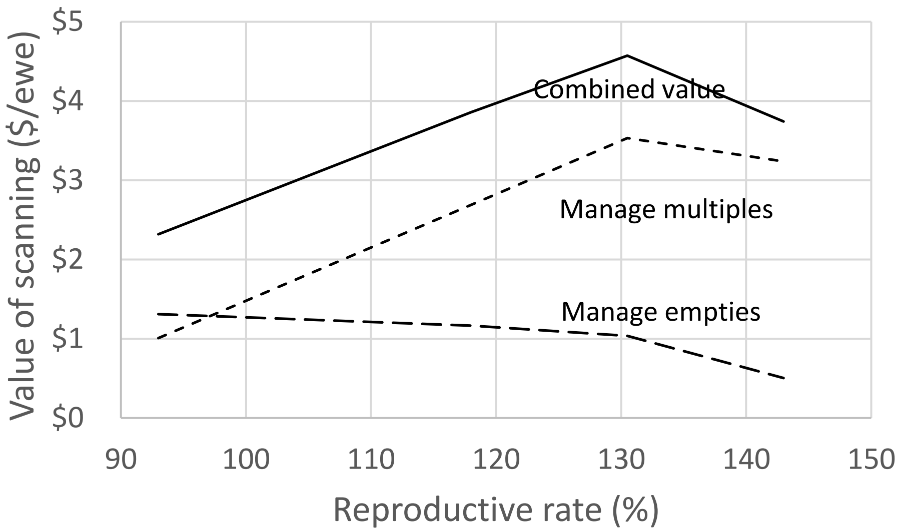

Figure 8: Flock reproduction rate effects the value of scanning and the contribution of the components associated with managing the empty ewes and the multiple-bearing ewes.

Rules of Thumb

- As reproductive rate increases, the reduction in the value of managing fewer empty ewes is offset by the increase in value of managing the extra multiple bearing ewes.
- In flocks with high reproductive rates it is more important to use the scanning information to improve lamb survival rather than achieving further improvements in reproductive rate.

Wether sale age

With the merino genotype evaluated in this analysis and the standard prices for wool and particularly the premium for finer wool, retaining the wethers to 5.5yo was more profitable than selling at 18 months of age. The value of scanning expressed as '$ per ewe' is also higher for the flock retaining older wethers ($6.05/ewe) than the flock selling at 18 months ($4.41/ewe). However, the higher value is due to the reduced number of ewes rather than a greater increase in profit per farm, because when the wethers are retained to 5.5yo the size of the ewe flock is much reduced. The value of scanning expressed as '$/ha' reduces by 20% when wethers are retained ($11.10/ha compared with $13.35/ha).

Rules of thumb

- Scanning for multiples is profitable for fine-wool flocks that are focussing on wool production and retaining older wethers as well as flock focussed on increasing meat production.

Prices

Changing wool prices across the range of price scenarios examined had little effect on the value of scanning for any of the three flocks (Figure 9). This is because adopting scanning has little effect on the total quantity of wool produced. In contrast varying the meat price did alter the value of scanning because the quantity of lamb produced is increased for a flock that scans.

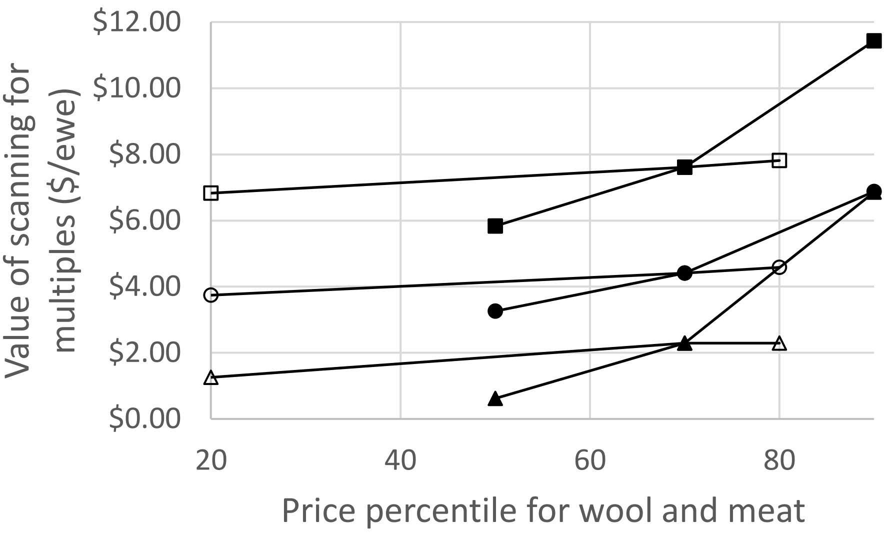

Figure 9: Changing the price of wool (open symbols) and meat (closed symbols) on the value of scanning for multiples for the merino-terminal flock (□), the merino flock (○) and the maternal flock (Δ).

Rules of Thumb

- The value of scanning is sensitive to the price of meat.
- The prices used in this analysis are below the current the prices being received therefore the value predicted for scanning is an underestimate of what would be currently achieved. With current meat & wool prices the value of scanning averages $9.50 per ewe.
- The value of scanning is not altered by the price of wool because there is little change in the total quantity of wool produced when the flock is scanned.

Conclusions/recommendations

- The findings of this gross margin analysis are consistent with the detailed modelling analysis carried out for the winter rainfall regions.
- Scanning for multiples was slightly less valuable than assessed in the winter rainfall regions and increased farm profit by an average of $4.44/ewe scanned compared with $5.75 in the winter rainfall region.
- Scanning for multiples generally increases farm profit more than scanning for pregnancy status, the exceptions were the low price scenarios for the maternal breeds.
- The value of scanning is increased with higher meat prices
- The value of scanning maternals is less than the value of scanning merinos.

8.3 List of planned scientific publications from the project

Young JM, Brown D and Brien FD. 'Pregnancy scanning for fetal number in sheep is profitable across a range of environments, times of lambing and genotypes' (for submission to the journal '*Animal Production Science*').

Bunter KL, Refshauge G, Jacobson C (or nominees) and Brien FD. 'Agreement between fetal counts at pregnancy scanning and lambing records' (for submission to the journal '*Animal Production Science'*).

Refshauge G, Costa-Alvarenga T, Harris A and Brien FD. 'Australian sheep pregnancy scanners - demographics, skills and training needs' (for submission to the journal '*Animal Production Science'*).

8.4 List of associated resources

1. 'Business case for pregnancy scanning & precision management of lambing groups', consisting of:
    - Initial fact sheets on the business case for pregnancy scanning
    - Detailed set of fact sheets on the business case for pregnancy scanning, and
    - 'Pregnancy Scanning Sheep – A guide for Producers'

2. Key extension messages from Project L.LSM.0021 'Increasing lambing percentages through better use of pregnancy scanning technology'

3. A Power Point slide package on pregnancy scanning

4. A guide for sheep scanners, entitled '*Video imagery for training of Australian sheep pregnancy scanners*'

5. A library of video imagery of pregnancy scanning of sheep. This includes imagery of normal and abnormal scans, at a range of gestational ages.

6. Recordings of 2 workshops for pregnancy scanners, held on the 7th of July 2021 and the 27th of July 2022

7. A list of sheep pregnancy scanners in Australia