Key Performance Indicators of ewe productivity: importance of ewe body condition score and liveweight on pregnancy outcomes and lamb performance to weaning.

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Declaration

I hereby declare this thesis is my own work and has not been submitted for any other degree or award. The data analysed for inclusion in this thesis was collected at three farms located in Sussex, Leicestershire and Lancashire between June 2013 and December 2016. The producer questionnaire in chapter 6 was conducted during 2019.

The work presented is my own. Where sources of information have been used, they have been duly acknowledged. All assistance given to me during the preparation of this thesis is also acknowledged.

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Abbreviations

AHDB	Agriculture and Horticulture Development Board
ARAMS	Animal Reporting and Movement Service
B&LNZ	Beef & Lamb New Zealand (levy board)
BCS	Body condition score
BPS	Basic Payment Scheme
CRM	Customer Relationship Manager
Defra	Department for environment, food and rural affairs
DLWG	Daily live weight gain
EBLEX	English Beef and Lamb Executive (levy board now AHDB)
EID	Electronic identification
EU	European Union
h	hours
Ha	Hectares
KE	Knowledge Exchange
kg	Kilograms
KPI	Key performance indicator
LWT	Liveweight
ME	Metabolisable energy
MJ	Mega joules
MLC	Meat and Livestock Commission
MP	Metabolisable protein
n	number
NFU	National Farmers Union
NSA	National Sheep Association
PLF	Precision livestock farming
SED	Standard error of differences
SEM	Standard error of means
SRW	Standard reference weight
TMR	Total mixed ration
UK	United Kingdom
Δ	Change

Abstract

Body condition score (BCS) is a subjective assessment of the amount of subcutaneous fat reserves along the spinous and transverse processes of ruminants. It is an indicator of current and historical nutritional status and is considered vital for optimal ewe productivity. BCS in sheep has been documented since the early 1900's. It can be considered to be the ratio of the amount of fat to the amount of non-fatty matter in the body of a living animal. A scale of 1 – 5 (1 being very thin and 5 being very fat) was developed during the 1960s.

Chapter 1 consists of a literature review of the published research relating to the impact of ewe BCS and liveweight from weaning of a production cycle to weaning of the subsequent production cycle on ewe fertility and lamb performance to weaning, The second chapter of this thesis analysed the quantitative data captured from the three study farms who collected ewe and lamb data between 2014 and 2016. The data was compared to national figures, where available. The generally accepted industry target of 3% or less barren ewes at scanning was achieved each year at two of the three study farms, and in two out of the three years at the third farm. In addition, between 2 and 4% of ewes scanned pregnant were not in possession of a lamb at tagging (48 h post-lambing). Furthermore, a 20 kg target (AHDB) for lamb weight at 8 weeks post-lambing was predominantly achieved on these commercial sheep flocks, with between 7 and 35 % of lambs below 17 kg at 8 weeks post-lambing (variation was between years and across farms). Data from these farms also indicated that a target of 25 to 28 kg lamb weight at weaning (at 12 weeks) is probably more realistic than the proposed 30 kg target (AHDB).

Two of the three study farms did not achieve the current BCS targets at every production point during the year. This is likely to be a reflection of what occurs on many farms in England. The farm that did achieve target BCS at every production point had the largest litter sizes at scanning, achieved the lamb 8-week target of 20 kg each year, had the lowest percentage of light lambs at 8 weeks and achieved the lamb weaning target of 30 kg in two out of the three years.

Chapters 3 to 5 considered the effects of ewe BCS and liveweight at various points of the production cycle. The effects on pregnancy establishment, that is the proportion ewes pregnant and litter size at scanning (Chapter 3); the effects

on pregnancy outcomes, that is the proportion ewes lambed and litter size at lambing (Chapter 4); and the effects on lamb performance to weaning, specifically combined twin-lamb 8-week weight, combined twin-lamb weaning weight and weight gain between 8 weeks and weaning (Chapter 5). Lamb birthweight was not captured on every farm each year, therefore Chapter 5 focussed on performance at 8 weeks and between 8 weeks and weaning.

Ewe condition at weaning of the preceding production cycle and mating of the subsequent production cycle was associated with litter size at scanning, litter size at lambing, combined lamb 8-week weight and combined lamb weaning weight, but did not associate with proportion ewes pregnant, proportion ewes lambed or lamb weight gain between 8 weeks and weaning. Ewe condition change between weaning (of the preceding production cycle) and mating was not associated with ewe fertility or lamb weight at weaning. Ewe condition at scanning and gain in condition between mating and scanning were each positively associated with ewe fertility and lamb weight to weaning. Finally, ewe condition at 8-weeks, ewe condition at weaning and ewe BCS loss between lambing and 8-weeks were all positively associated with combined lamb weight gain to weaning. However, this relationship differed between farms, depending on ewe BCS at lambing. Ewes at target BCS at lambing (3 units) and mobilising condition during lactation produced heavier lambs at weaning. However, when BCS at lambing was below 3 units, ewes that mobilised less condition produced heavier lambs at weaning.

A survey sent to sheep farmers in England formed the basis of Chapter 6. Of the 384 English respondents, 97% agreed that ewe condition was important in determining flock performance. However, the level of importance they attached to condition, and how farmers assessed this parameter (i.e. BCS, weight, BCS and weight or visual) changed during the production cycle. Most farmers (99%) agreed that condition at mating was most likely to affect flock productivity with the fewest (70%) agreeing that condition at weaning was least likely to affect flock productivity. However, 46% did not record ewe condition data. The barriers to farmers assessing BCS were identified as time and the ability to manage multiple management groups. Finally, farmers confused the term BCS for breeding ewes with selecting lambs for slaughter.

In conclusion, ewe BCS and liveweight at key production stages and change between production stages have a long term association with ewe fertility and lamb performance to weaning.

List of publications arising from this research

Annual Project Report 2014 74210-KPI-Sheep-Validation.pdf (windows.net)

Sheep KPI validation project: phase II Sheep KPI validation project: phase II | AHDB

Autumn 2014 BRP Bulletin BRP-bulletin-autumn-2014-151014.pdf (ahdbdigital.org.uk)

Summer 2015 BRP Bulletin BRP-bulletin-summer-2015-110615.pdf (ahdbdigital.org.uk)

Autumn 2015 BRP Bulletin BRP-bulletin-Autumn-2015-171115.pdf (ahdbdigital.org.uk)

Spring 2016 BRP Bulletin BRP-Spring-Bulletin-2016-290216.pdf (ahdbdigital.org.uk)

Summer 2016 BRP Bulletin BRP-Summer-bulletin-2016-160616.pdf (ahdbdigital.org.uk)

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Introduction

Body condition scoring (BCS) is undertaken by palpation and is a subjective assessment of the amount of subcutaneous fat along the spinous and transverse processes of ruminants (Kenyon *et al.,* 2014). The spinous and transverse processes are most appropriate because it is the location where fat is deposited last and mobilised first (Casey & Stevens, 2016). A scale of 1 – 5 (1 being very thin and 5 being very fat) was developed by (Jefferies, 1961) with additional half and quarter units introduced later (Russel *et al.,* 1969). BCS requires no specialist equipment (Kenyon *et al.,* 2014), however, gathering and restraining ewes to assess condition requires handling facilities and capturing individual ewe data may require additional equipment and software.

Current ewe BCS targets at key production times are categorised by farming system and are based on merging individual research findings (Russel A, 1984; Cannas, 2002; Kenyon, Maloney, & Blanche, 2014). The current targets do not take into consideration historic ewe condition and/or change leading up to each production point. Neither does it factor in the long-term effects of one production cycle on subsequent production cycles.

EU legislation requiring all breeding sheep to be fitted with electronic identification (EID) was introduced in 2010 (AHDB, 2016a). This provided an opportunity to collect large data sets on commercial sheep farms, thus enabling the monitoring of individual ewe performance over time; and linking the performance of lambs to their mothers.

UK livestock farms have historically been low profit margin businesses with a heavy reliance on income from subsidies (DEFRA, 2018). Following the UK's exit from the European Union (EU), the UK Government is expected to withdraw direct agriculture subsidy by 2027, with a decreasing payment schedule from 2021 to 2027 (ADAS, 2019). For sheep farms to survive without direct subsidy, there will need to be a greater emphasis on technical flock performance.

Key Performance Indicators (KPIs) are critical (key) indicators of progress towards a known goal (KPI.org, 2019). It is a term used frequently in several industries worldwide. KPIs are used to monitor business performance and are increasingly being referred to within the agriculture sector. Examples of typical KPIs currently used in the sheep sector include lambs reared per 100 ewes mated, lamb losses from scanning to rearing and lamb daily liveweight gain to weaning (AHDB, 2019c). There is currently no consideration of ewe condition (BCS or liveweight) as a key indicator of flock performance.

The only published survey on the use of BCS by UK sheep farmers reported that 67% of respondents used BCS as a management tool but only 32% assessed BCS by palpation and applied a score (Owen *et al.,* 2017). Additional findings were that 64% nominated the tail region as an area palpated when assessing BCS, suggesting that BCS for breeding ewes was confused with selecting lambs for slaughter. In comparison, Australia reported a much higher uptake, with 96% of producers monitoring ewe condition but, again, fewer (61%) monitored condition by palpation (Jones *et al.,* 2011). In New Zealand, 43% of commercial sheep farmers used BCS as a management tool (Corner-Thomas *et al.,* 2013). There are no known publications relating to barriers facing sheep farmers' willingness to assess ewe condition using BCS.

Therefore, the objectives of this thesis were, firstly, to increase our understanding of the longer-term effects of ewe BCS and liveweight at key points during the annual production cycle in order to determine whether ewe BCS and liveweight at these points could serve as key indicator(s) of flock performance. Secondly, this thesis sought to determine barriers to uptake of formal assessments of ewe condition by either BCS or liveweight measurements. This project is one of the first of its kind to measure the impact of ewe BCS and liveweight, using individual ewe EID, over an extended period of time, in this case on three geographically dispersed flocks in England over three consecutive years.

1 CHAPTER ONE: Literature review

This chapter presents an overview of current sheep flocks within the UK, a detailed review of body condition scoring (BCS) in sheep breeding, and a critical assessment of current research on ewe BCS and liveweight and their effect on ewe fertility and lamb performance to weaning. The chapter also considers the uptake of BCS by commercial flocks within the UK, compared with other sheep producing countries.

1.1 UK sheep industry

The UK is the largest sheep meat producer in Europe and the fourth largest in the World (Lima *et al.*, 2018). The UK produced 288,600 tonnes of sheep meat (mutton and lamb) in 2019 (AHDB, 2020a), comprising 12.8 million lambs (average carcass weight 19.3 kg) and 1.6 million ewes and rams (average carcass weight 25.5 kg) (AHDB, 2020a). There are currently 35,545 sheep holdings in England with an average flock size of 220 breeding ewes (AHDB, 2018a). Figure 1.1 illustrates the percentage of sheep holdings by the number of breeding ewes. The largest category comprises flocks with fewer than 100 ewes (40%). Only 10% of flocks have more than 1,000 breeding ewes.

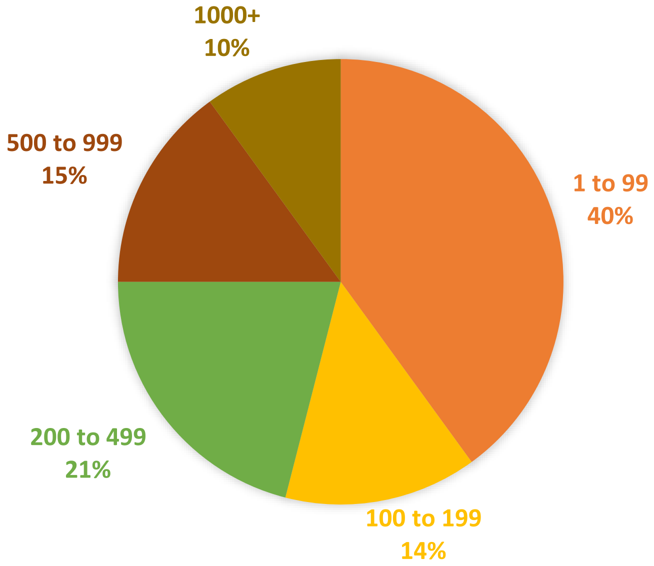


Figure 1.1. Percentage of sheep holdings by flock size (number of breeding ewes) (AHDB, 2020a)

1.1.1 *UK sheep farming systems*

The UK falls into three farming types, owing to its terrain: hill, upland and lowland (NSA, 2019). UK livestock farms have historically been low profit margin businesses with a heavy reliance on income from subsidies (agri-environment and basic payment schemes (BPS) (DEFRA, 2018). The UK's exit from the European Union (EU) and the loss of the EU wide BPS will bring its own challenges. The UK Government is expected to withdraw direct subsidy by 2027, with a decreasing payment schedule form 2021 to 2027 (ADAS, 2019). For UK sheep farms to survive without direct subsidy, there will need to be a greater emphasis on technical flock performance and a focus on cost of production.

1.1.2 *Individual animal identification*

EU legislation requiring all breeding sheep to be fitted with electronic identification, most commonly an electronic ear tag, was introduced in 2010 (AHDB, 2016a). This was followed by the requirement to report sheep movements via the Animal Reporting and Movement Service (ARAMS) (ARAMS, 2020). Defra regulations (DEFRA, 2019) state that an animal must be individually identified within 6 months of birth (if housed overnight), within 9 months of birth (if not housed overnight) or before they are moved off their holding of birth (if this is sooner). These are the absolute maximum ages when identification must be in place. However, some sheep farmers identify lambs using EID tags from approximately 48 h after birth.

1.2 Effect of ewe age on flock performance

Ewe age at mating, or the combination of age with liveweight, affects ewe fertility and lamb growth rate. Lambs reared by first-time lambing ewes are lighter compared to lambs reared by older ewes (Mathias-Davis *et al.,* 2011; Aktas *et al.,* 2015). Ewes aged two and six years at the time of lambing were found to have smaller litter sizes and lower lambing percentages, fewer lambs born alive, reared to 48 h and reared to 100 days, as well as reduced lamb daily liveweight gain to 100 days of age (Ptáček *et al.,* 2017), compared to three, four and five-year old ewes. It is important to provide preferential nutritional treatment to younger ewes and manage two-year-old ewes as a separate management group to ensure good lambing performance (Gonzalez *et al.,* 1997; Morris *et al.,* 2000). Mean litter size increases with ewe age (Hanrahan, 1982; Schoenian and Burfening, 1990). However, culling sheep at six years of age and older was found to reduce lamb mortality (Ptáček *et al.,* 2017) and improve flock performance (Yilmaz *et al.,* 2011; Yavarifard *et al.,* 2015; Vostry & Milerski, 2015; Aliyari *et al.,* 2012). It was also found that litter size, ovulation rate and embryo survival were all lower in two-year-old ewes (Shorten *et al.,* 2013) (Figure 1.2).

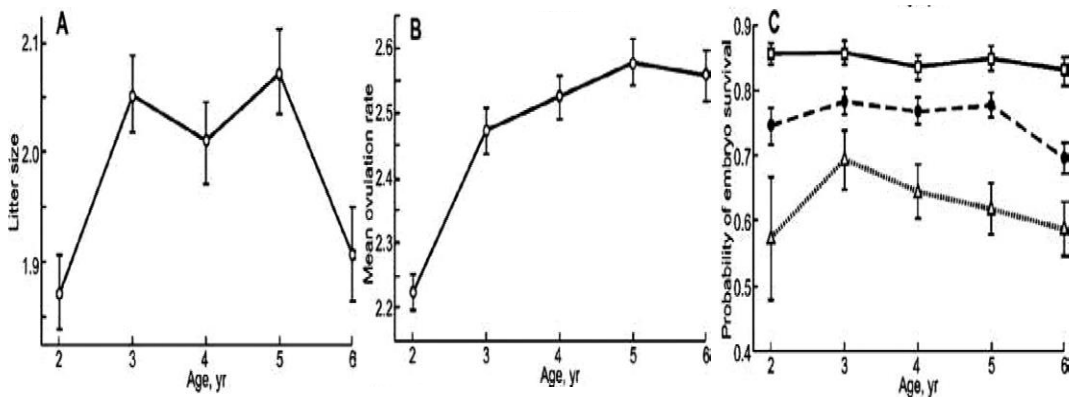


Figure 1.2. The effect of ewe age on litter size (A), mean ovulation rate (B) and probability of embryo survival (C) (Shorten *et al.,* 2013).

1.3 Key performance indicators

The definition of a Key Performance Indicator (KPI) (Marr, 2019) is 'a quantifiable measure used to evaluate the success in meeting objectives for performance'. KPIs are critical (key) indicators of progress towards a known result (KPI.org, 2019). It is a term frequently used in several industries worldwide, to progress business performance and it is increasingly mentioned within the agriculture sector.

A key component of a successful KPI is that it is measurable, enabling businesses to establish if they are achieving their goals (Marr, 2019). KPIs are also useful decision-making tools, enabling businesses to prioritise what they want to achieve in a given timescale. Monitoring KPIs can help sheep producers compare flock performance year-on-year and provide comparisons with other sheep producers (e.g. by breed, system, location). A critical element to being able to calculate sheep KPIs is collection of the data required (AHDB, 2019c). Examples of typical KPIs currently used in the sheep sector include lambs reared per ewe mated, lamb losses from scanning to weaning and average daily liveweight gain (of lambs) to weaning (AHDB, 2019c).

1.4 Body Condition Score (BCS) in sheep

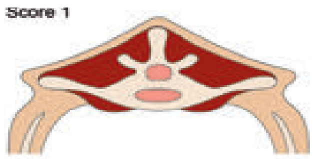
Body fat is a concentrated form of energy which is considered vital for an animal's productivity (and in some situations) for survival (Russel, 1971). Body condition scoring (BCS) is a subjective assessment of the amount of subcutaneous fat along the spinous and transverse processes of ruminants (Kenyon *et al.,* 2014) and an indicator of a ewe's current and historical nutritional status (Caldeira *et al.,* 2007).

BCS in sheep has been investigated and recorded since the early 1900's. It was first defined by (Murray, 1919) as the ratio of the amount of fat to the amount of non-fatty matter in the body of the living animal. A scale of 1 – 5 (1 being very thin and 5 being very fat) was developed by Jefferies, (1961) (Table 1.1). Originally, the technique was based on a scale of whole units, with additional half and quarter units introduced later (Russel *et al.,* 1969). Many producers and advisers who regularly assess condition using BCS score to half or quarter scores. This reflects the fact that changes between entire scores can be large (Fernandez, 2020). On a commercial flock basis, the importance of BCS is not to place an exact score within a quarter score to each individual sheep, but to assign a relative score on which to base management decisions.

BCS is undertaken by palpation (an examination by touching it with the fingers or hands) to examine the sharpness or roundness of the lumbar region (Jefferies, 1961), specifically the spinous and transverse processes (Kenyon *et al.,* 2014) immediately behind the last rib and above the kidneys. The lumbar region is the best site to assess BCS because it is the last part of the growing animal to develop, and the location where fat is deposited last and mobilised first (Casey & Stevens, 2016).

BCS itself requires no specialist equipment (Kenyon *et al.,* 2014). However, gathering and holding the ewes to assess condition requires temporary or permanent handling facilities, and data capture may require additional equipment and software. Handling facilities are commonly available on most sheep farms for other sheep management purposes (e.g. shearing and vaccinating). Ewes should stand in a relaxed position, not tense or crushed by others or held in a restraint (B&LNZ, 2019).

Table 1.1. Description of each unit of body condition score (AHDB, 2019a)

Score		Description
1		The spinous processes are prominent and sharp. The transverse processes are also sharp with fingers passing easily under the end of each process. The eye muscle areas are shallow with little to no fat cover.
2		The spinous processes are smooth but still prominent. The individual processes can still be felt but only as fine corrugations. The transverse processes are smooth and rounded. However, it is possible to pass the fingers under the ends of the processes with some pressure. The eye muscle areas are of moderate depth, with sparse fat cover.
3		The spinous processes are smooth and rounded and individual bones can only be felt with some pressure applied. The transverse processes are also smooth and are well covered. Firm pressure is required to feel over the ends. Eye muscle area is full and covered by a moderate degree of fat cover.
4		With pressure applied, the spinous processes can just be detected although the ends of the transverse processes cannot. Eye muscle areas are full with a thick covering of fat cover.
5		Even with firm pressure applied, spinous processes cannot be detected. It is not possible to detect transverse processes. The eye muscle areas are very full with very thick fat cover. There may be significant deposits of fat cover over the rump and tail.

The main application of BCS is to enhance the efficient use of feed to control the body composition of sheep, to detect differences in body composition not visible by eye due to fleece cover, allowing farmers to be immediately aware of changes in ewe nutritional status; and to establish trends in nutritional status and liveweight (Jefferies, 1961). BCS has been described as having several advantages: easy to use, well tested on farm and a good predictor of condition and nutritive status (van Burgel *et al.,* 2011). BCS can be used by farmers to assess flock nutrition and health, by veterinarians as part of a routine clinical examination (Lovatt, 2010), as part of flock health planning (Sargison & Scott, 2010) and can be used as a welfare assessment protocol (Phythian *et al.,* 2012).

1.4.1 Repeatability of BCS assessment

BCS is a practical technique that can be easily taught and is highly repeatable. However, it is subjective and individuals differ in their scoring. This could limit the effectiveness of BCS as a management tool (Kenyon *et al.,* 2014). The overall consensus of the published research on the accuracy and repeatability of assessor condition scoring, however, are positive (Table 1.2). There are advisory steps to take, especially if data is utilised for research. For example, using the same experienced assessors throughout and providing periods of calibration.

Table 1.2. Summary of research published on BCS assessor repeatability.

Reference	Repeatability of assessors
Everitt, 1962	Variation between and within assessor, no values stated.
Russel *et al.*, 1969	Between: >70% total agreement; <20% varied by 0.5 unit; <10% varied by 1 unit. Within: >80% total agreement; <15% varied by 0.5 unit; <5% varied by 1 unit.
Yates & Gleeson, 1975	Inexperienced assessors can have difficulty achieving consistency between assessments. Assessors found latter stages of pregnancy difficult to assess BCS.
Evans, 1978	Need consistency between assessments of individual animals. Variation could be reduced if two assessors scored each ewe.
Teixeira *et al.*, 1989	Repeatability of 90% within individuals and 80% between individuals.
Calavas *et al.*, 1998	BCS easier to master by individuals in their own flocks but harder across flocks with different assessors.
van Burgel *et al.*, 2004	Reported differences between operators. Differences changed as BCS varied (deviation widened as BCS improved). Possible to create calibration equations to adjust BCS values recorded by different assessors.
van Burgel *et al.*, 2011	Experienced scorers achieve high levels of consistency up to 0.25 units. High accuracy levels, difference between repeat assessments (on the same sheep) was less than 0.25 units 98% of the time.
Phythian *et al.*, 2012	Experienced scorers can achieve high levels of consistency up to 0.25 units. Consistency improved with calibration of assessors.
Kenyon *et al.*, 2014	Greatest variability amongst less experienced assessors who would benefit the most from retraining. Need to determine how often assessors should calibrate to ensure consistency.

1.5 Current BCS targets for sheep producers

The current advice to English sheep producers regarding ewe BCS targets at key production points during the year are categorised by farming system (Table 1.3). This is indicative of the expected ewe performance on different systems, rather than being breed specific. The target is for individual ewes to achieve these targets rather than a flock average (Kenyon *et al.*, 2014), with 90% of the flock achieving the target at each production point, acknowledging that 5% fall either side of that target (AHDB, 2019a).

Table 1.3. Current industry targets for ewe BCS (AHDB, 2014b)

	Weaning	Mating	Scanning	Lambing	Weaning
Lowland breeds	2.5	3.5	3	3	2.5
Upland breeds	2	3	2.5	2.5	2
Hill breeds	2	2.5	2	2	2

Ewes are likely to need to gain up to one unit of BCS between weaning of one production cycle and mating of the subsequent production cycle to achieve the target BCS at mating (2.5 to 3.5 units) (Kenyon *et al.,* 2014) with BCS maintained during early pregnancy. During mid-pregnancy, ewes will likely lose BCS (0.5 unit) due to the demands of pregnancy and a reduction in grazing quality and quantity (Russel, 1984). Ewes should aim to be at BCS 2.5–3 units at lambing with further losses expected during lactation. At weaning, ewes should not be below BCS 2-2.5 units (Cannas, 2002).

1.6 Impact of ewe condition one month pre-mating and the mating period on flock performance.

Determinants of a successful early pregnancy are nutrition, disease, the environment (e.g. weather and rainfall) and genetics (Spencer, 2013). Factors believed to affect embryo survival are pre-mating weight, ewe age and ovulation rates (Shorten *et al.,* 2013). Once an ovum is fertilised by a sperm, the resultant embryo begins the process of travelling down through the oviduct and into the uterus, this takes approximately three days (Kelly, 1986). During this early stage, the embryo is unattached and receives nutrients for its survival from fluids secreted by the uterus (Bazer et al,. 2012). Attachment of the embryo to the lining of the uterus takes place 15 to 30 days after fertilisation. Once the embryo has implanted into the uterus, it becomes known as the fetus. Collectively there are several periods of vulnerability in the first month post-fertilisation, and it is thought that a quarter of embryos fail to implant and become a fetus (Henderson, 2002).

There are many possible causes for early embryonic losses, some of which would not always be detectable by the farmer. Ewes that suffer embryonic death are often less fertile at the next oestrus cycle (Hulet, 1969).

Nutrition plays an important role in reducing embryo loss because of its influence on the composition of the oviductal and uterine secretions that nourish the embryo prior to implantation in the uterine wall. Nutrition can directly and indirectly influence metabolic pathways (Munoz *et al.,* 2007). The direct influence is through providing essential nutrients to allow the metabolic pathways to occur. The indirect influence is through modification of hormone expression that can affect oocyte maturation, ovulation, embryo development and fetal growth (Munoz *et al.,* 2007) and the viability of lambs at birth (Robinson *et al.,* 2002).

Ewes mated at optimum BCS have increased ovulation rates with ewe BCS at mating of 3 to 3.5 units (for lowland ewes) providing optimum ovulation rates (Gunn *et al.,* 1991; Robinson *et al.,* 2002; Annett & Carson, 2006; Fthenakis *et al.,* 2012; Rooke *et al.,* 2015). However, ewe nutrition in the six months prior to mating affects the ovulation response at mating, this is when ovarian follicles leave the primordial pool and commit to growth (Robinson *et al.,* 2002).

Mating ewes below BCS 2.5 units increased the risk of being barren at scanning while each unit increase of BCS (within a range of 2.5-4 units) increased litter size by 0.13 lambs per ewe and increased lambs reared to weaning by 0.10 per ewe (Bohan & Keady, 2019). Ewe BCS between 3 and 4 units was also found to have an optimal response to the ram at mating time (Todorov & Nedelkov, 2015).

Liveweight at the commencement of mating also has a considerable influence on the reproductive rate of sheep, especially the percentage of twins (Coop, 1962). Higher ewe liveweight and liveweight gain during the mating period resulted in higher ovulation rates with each additional kg of ewe liveweight at mating resulting in an increase of 1-2% in lambing percentage (B&LNZ, 2013a).

Studies relating to ewe BCS and liveweight at mating predominantly report on effects on ovulation rate, litter size at lambing and lamb survival to weaning. Publications relating to the effect of ewe BCS and liveweight on lamb weight gain to weaning tend to focus on the condition of ewes from scanning or lambing, with less research on the effects of ewe condition earlier in the production cycle on lamb weaning weight.

1.7 Impact of ewe condition mid-pregnancy on flock performance

A fetus has contact with the ewe via the placenta, through a series of structures called placentomes (Henderson, 2002). In humans, the placenta continues to grow with the fetus (Kelly, 1992) but in sheep, placental weight peaks at approximately 1 kg during mid-pregnancy (Heasman *et al.,* 1999). If placental development is restricted during mid-pregnancy, there can be consequences on fetal growth, with placental weight and development highly correlated with lamb birthweight (Mellor, 1983; Kelly, 1992; Sen *et al.,* 2013). The fetus weighs 15-20% of its birthweight by mid-pregnancy (Fthenakis *et al.,* 2012).

Robinson, (1990) and Robinson *et al.,* (2002) concluded that ewes at target BCS at mating (3.5 units for lowland ewes) could be allowed to lose up to 0.5 units during the second and third months of pregnancy without detrimental effect on the placenta and subsequent lamb birthweight. The mechanics of this being that the ewe over compensates for under nutrition during this period by producing a larger placenta (Heasman *et al.,* 1998). However, Robinson, (1990) also reported that young ewes are more susceptible to condition loss during mid-pregnancy and that shearlings should maintain BCS and weight through the mid-pregnancy period.

Several studies have shown that restrictions in maternal nutrition during mid-pregnancy leads to one of three outcomes. Firstly, maternal undernutrition during mid-pregnancy has a positive effect on placental development and lamb birthweight (Robinson, 1990; Robinson & Kelly, 1992; Munoz, *et al.,* 2007). Alternatively, maternal undernutrition during mid-pregnancy has negative effects on placental growth and lamb birthweight (Clarke *et al.,* 1988; Orr and Treacher, 1990; Robinson *et al.,* 2002; Addah *et al.,* 2012; Sen *et al.,* 2013). Ewes below target BCS at mating and underfed in mid-pregnancy were lighter at lambing resulting in thinner ewes at weaning (Robinson *et al.,* 2002; Orr and Treacher, 1990). A negative effect of under nutrition during mid-pregnancy lead to delayed follicular development affecting the breeding capacity of offspring, subsequently resulting in reduced flock performance over time (Rae *et al.,* 2001). Finally, no significant impact of nutrition during mid-pregnancy on placental development and lamb birthweight has been reported (Clark and Speedy, 1980; McCrabb *et al.,* 1986; McCrabb *et al.,* 1991; Fogarty *et al.,* 1992; Martin *et al.,* 2012), with Kenyon *et al.,* (2011) reporting no positive effects of offering a diet greater than maintenance to twin bearing ewes during mid-pregnancy. However, some studies have demonstrated that reduced feed intake during mid-pregnancy can be partially compensated for if ewes are subsequently fed to requirements for the remainder of pregnancy (Heasman *et al.,* 1998; Munoz *et al.,* 2007; Corner *et al.,* 2008).

Lamb growth rate to weaning was reportedly affected by ewe BCS at scanning with lambs born to ewes at BCS 2 units at scanning significantly lighter than lambs born to ewes at BCS 3 units (Oldham *et al.,* 2011). Ewe liveweight gain during pregnancy was also positively associated with lamb birthweight but also lamb weight through to weaning (Paganoni *et al.,* 2014), with every 1 kg increase in liveweight during early and late pregnancy resulting in an increase in lamb birthweight (0.032 ± 0.0012 kg) and weaning weight (0.26 ± 0.013 kg).

There are two points worth considering in relation to the effects of nutrition during mid-pregnancy. Firstly, it is predominantly the effects of the undersupply of nutrients that has been studied during this period, with the effect of oversupply of nutrients in mature ewes less well studied. It has been found that high-energy intakes cause impaired placental development and adverse pregnancy outcomes in adolescent sheep (Wallace *et al.,* 2006). Secondly, the focus of studies are mostly on the effects on placental development and lamb birthweight. Fewer studies assess the effect on litter size at scanning and lambing or the longer-term effects on lamb performance to weaning.

1.7.1 Pregnancy scanning

The use of ultrasound scanning between 50 and 100 days post-mating is recognised as a safe and practical means of pregnancy diagnosis (Taverne, 1984) and for determining fetal numbers (White *et al.,* 1984) since the early 1980s. Sheep pregnancy scanning is a useful management tool providing information on the number of pregnant ewes (accuracy of pregnancy diagnosis greater than 99%); number of barren, single, twin and triplet bearing ewes (accuracy of 98%); and subsequently the number of total lambs expected at lambing (accuracy of 97%) (White *et al.,* 1984). Accuracy of scanning can vary between individual operators (White *et al.,* 1984) based on experience (Buckrell, 1988) and age of the fetus (Karen *et al.,* 2006) at the time of scanning. A very experienced operator can accurately scan 150 ewes per hour (Blanden B, Personal Communication).

There are no published or accessible records of annual scanning results in the UK. Scanning results vary based on ewe age, genotype, time of year mated, farming system (lowland, upland, hill), and between years. AHDB have provided target scanning figures for flocks based on farming system (Table 1.4) (AHDB, 2019b).

Table 1.4. Summary of current industry ewe scanning targets (AHDB, 2019b).

	Target	Average	Low
Lowland flocks, no ewe lambs (%)	Over 190	170–190	Under 170
Lowland flocks 20% ewe lambs (%)	Over 175	155–175	Under 155
Hill flocks (%)	Over 135	120–135	Under 120

1.8 Impact of ewe condition in late pregnancy on flock performance

Ewe dietary requirements increase in the last 8 weeks of pregnancy to meet the demands of the growing fetus (AFRC, 1993) (Table 1.5). These increases are to enable 80-85% of fetal growth to occur (Mellor, 1983) and for ewe udder development. No udder development takes place after lambing, therefore nutrition during late pregnancy is crucial for optimal milk production during lactation (Henderson, 2002).

Table 1.5. Metabolisable energy (MJ/day) requirements of housed pregnant ewes (based on a diet of 11MJ/kg DM, assuming no weight lost) (AFRC, 1993).

Ewe liveweight (KG)	No. lambs	7 weeks	5 weeks	3 weeks	1 week
		MJ/day			
50	1	7.9	8.7	9.8	11.2
	2	8.8	10.1	11.9	14.2
60	1	9.1	10.0	11.2	12.8
	2	10.1	11.6	13.7	16.3
70	1	10.2	11.2	12.6	14.4
	2	11.4	13.1	15.3	18.3
	3	12.0	14.0	16.7	20.3
80	1	11.3	12.4	13.9	15.9
	2	12.6	14.4	17.0	20.2
	3	13.3	15.5	18.5	22.5

Good nutrition during late pregnancy will result in a lower incidence of metabolic disease in ewes (e.g. pregnancy toxaemia); optimum lamb birthweight and good lamb vigour (Kenyon & Blair, 2014; Dwyer, 2014; Rooke *et al.*, 2015), high quality colostrum and increased milk yields (Fthenakis *et al.*, 2012), together with reduced lamb losses (ADAS, 2017). Severe under nutrition and low BCS during the last 6 weeks of pregnancy delays the onset of milk secretion, produces lambs with less brown adipose tissue fat reserves and a less pronounced suckling drive (Geenty, 1977), and can reduce total milk yield by between 7 to 35% (Treacher & Caja, 2002).

A review of the difference between the performance of thin and fat ewes during late pregnancy, when provided with an inadequate energy supply, found that fatter ewes (providing the energy deficit is not significant enough to cause metabolic disease) are better at sustaining fetal growth than thinner ewes (Robinson *et al.,* 2002). They also found that thin ewes provided with unlimited access to feed consumed more than fat ewes. However, ewes mobilising fat during late pregnancy resulted in ewe and lamb behavioural problems at lambing time. Ewes take longer to interact with their lambs after birth, display more aggression towards their lambs and spend less time licking and grooming their lambs (Dwyer, 2014). Lambs born to underfed ewes were slower to stand and suck and were less active compared with lambs born to ewes that mobilised less body fat (Dwyer *et al.,* 2003); whose lambs stand and suck quicker and are more active in the first three days of life (Dwyer, 2008). Strong, healthy lambs that are up and suckling colostrum within 15 minutes of birth have a 90-95% survival rate at 90 days of age (Gubbins, 2016).

Thompson *et al.,* (2011) reported that ewe condition change during late pregnancy impacts lamb weaning weights, in addition to ewe nutrition during lactation. Lamb weaning weight decreased by 4% for every 0.5 unit of BCS lost during the last four weeks of pregnancy, with lamb weaning weight decreasing by 6% for every 0.5 unit BCS below BCS 3 at lambing (B&LNZ, 2019). Ewes undernourished in late pregnancy required 10% to 20% more energy during lactation compared to ewes fed to requirements during late pregnancy (Geenty & Sykes, 1986).

Lambs born to ewes with a BCS of 2 units are lighter at weaning compared to lambs born to ewes with a BCS of 2.5 or 3 units (Kenyon *et al.,* 2011; Kenyon *et al.,* 2012; Corner-Thomas *et al.,* 2015; Cranston *et al.,* 2017). This finding was supported by B&LNZ, (2019) who reported that ewes have a more sustained milk supply if BCS at lambing is above 2.5 units and less than 1 unit of BCS is lost during lactation. Lambs from target condition ewes at lambing (above BCS 3 units) had a mean weaning weight of 27.2 kg compared to 26.2 kg from thinner ewes (below 2.5 units) (B&LNZ, 2019).

1.9 *Impact of ewe condition during lactation on flock performance*

Ewe energy and protein requirements rise sharply post-partum (AFRC, 1993; Robinson, 1990). As illustrated in Table 1.6, the ME requirements of an 80 kg ewe producing 3 kg milk per day with no liveweight loss is 33.9 MJ/day. This is an increase from 18 MJ/day during the week preceding lambing (Table 1.5). However, the increase in voluntary feed intake in early lactation is slower than the increase in energy requirements, resulting in negative energy balance (Geenty & Sykes, 1986). Voluntary feed intake in the first week of lactation is only 10% higher than two weeks pre-lambing, however intake increase in weeks two and three, continuing to increase until eight weeks post-lambing (Treacher & Caja, 2002). After eight weeks, feed intakes decline slowly until weaning.

Table 1.6. Metabolisable energy (MJ/day) and metabolisable protein requirements (g/day) of housed lactating ewes based on a diet of 11.5MJ/kg DM (AFRC, 1993).

	Milk Yield					
	1.0 (kg/day)		2.0 (kg/day)		3.0 (kg/day)	
Ewe liveweight loss (g/day)	ME	MP	ME	MP	ME	MP
Housed 60 kg ewe (lowland outdoors add 0.3MJ/day)						
0	15.6	146	23.7	222	32.2	297
-50	13.8	140	22.0	216	30.3	291
-100	12.1	134	20.2	209	28.5	285
Housed 80 kg ewe (lowland outdoors add 0.4MJ/day)						
0	17.5	158	25.6	234	33.9	309
-50	15.8	152	23.8	228	32.0	303
-100	14.0	146	22.0	221	30.2	297

Milk production typically peaks at 2 to 3 kg per day in week 3 to 4 of lactation, with 40-50% of total milk produced in the first 4 weeks post-partum (AFRC, 1993). Following its peak, milk production declines naturally.

Lamb growth rates to weaning are affected by ewe feed intake (Coop, 1972; Doney & Peart, 1976; Snowder & Glimp, 1991; Thompson *et al.*, 2011) and/or the mobilisation of ewe body fat (Gibb & Treacher, 1980; Vernon & Finley, 1985). It is not uncommon for feed intake to not meet the nutritional requirements of ewes during lactation. Under these circumstances, ewe milk production and lamb growth to weaning are greatest for ewes that have more fat to mobilise (McNeill *et al.,* 1997; Brand & Franck, 2000; Lambe *et al.,* 2005), with ewes in better condition producing more milk (Bencini & Pulina, 1997). If a ewe has insufficient body reserves and insufficient feed intake, this will result in a decline in milk yield (Treacher & Caja, 2002). If identified, feeding ewes at lower condition can improve lamb growth rates (Kenyon *et al.,* 2004). Lambs reared as singles or twins have higher daily liveweight gains if ewes were in higher BCS at lambing and lost condition between lambing and weaning, or if ewes with lower BCS at lambing were fed to gain condition whilst lactating (Mathias-Davis *et al.,* 2013). Undernutrition during early lactation impairs milk secretion and lamb growth rate, the extent of which depends on ewe BCS (Robinson *et al.,*2002). However, Treacher & Caja, (2002) reported that ewes can recover from short periods (7 to 14 days) of dietary restriction during lactation with little prolonged effect on overall milk yield. However, dietary restrictions lasting 28 days or more reduced overall milk yield.

Ewe liveweight change during pregnancy had more impact on lamb weaning weight than ewe liveweight during lactation (Thompson *et al.,* 2011). One explanation for this finding is that the ewes preferentially partition nutrients to milk production rather than their body reserves during lactation (Morgan-Davies *et al.,* 2006). This finding was supported by Smeaton *et al.,* (1983); Litherland, *et al.,* (1999) who reported that where ewes give birth in moderate condition (e.g. BCS 2.5 units), feeding post-lambing is potentially more valuable than feeding pre-lambing. Ewe milk production influenced lamb growth rate birth to 4 weeks. Morgan *et al., (*2007) and Gibb & Treacher, (1980) reported that daily growth rates of lambs in the first eight weeks were significantly higher for lambs reared by fat ewes (BCS 3.2 units) compared to lambs reared by thin ewes (BCS 2.4 units).

Mathias-Davis *et al.,* (2011) reported that ewes at BCS 3 to 3.5 units at scanning or BCS below 3 units at weaning produced heavier lambs at weaning, compared with ewes at BCS greater than 3.5 units at scanning or weaning. These results are similar to Borg *et al.,* (2009), whereby ewes which maintain condition during pregnancy but then lose condition during lactation, perform better. Single and twin reared lambs had the highest growth rates when ewes were in better condition at lambing and lost condition between lambing and weaning, or were reared by ewes with low BCS at lambing and gained BCS between lambing and weaning (Mathias-Davis *et al.,* 2013). This study suggested that, if ewes achieve a high BCS at lambing this is likely to improve lamb growth to weaning. In addition, identifying ewes at low BCS at lambing and preferentially feeding them to increase BCS during lactation may increase single and twin lamb growth rates.

Lamb birthweight and litter size are factors known to impact lamb survival and lamb growth rates to weaning (Khalaf et al., 1979; Nowak & Poindron, 2006; Sheep Net, 2018). Lamb birthweight ranges from 1 kg to 10 kg, with a mean across all ewe ages and birth types of 4.8 kg (Thompson *et al.,* 2004). This was supported by Muir *et al.,* (2003) who reported mean birthweight of 5.2 kg for singles and 4.9 kg for twins. The difference in milk production between ewes rearing a single lamb versus multiple lambs varies between studies. Snowder & Glimp, (1991) suggested a ewe rearing twins produces 13 to 17% more milk, Hatfield *et al.,* (1995) suggested a ewe rearing twins produces 23% more milk in the first 28 days and NRC, (1985) suggested a range of between 20 and 40%.

Ewes rearing two lambs to weaning had lower BCS at weaning, compared to ewes rearing one lamb (Kenyon *et al.,* 2012). Ewes rearing twins are more susceptible to fluctuations or changes in available feeds due to their potentially higher milk production potential (Gibb & Treacher, 1980). However, single and twin lambs reared by thin ewes, but fed to meet nutritional demands, were able to perform as well as lambs reared by ewes in better condition (Mathias-Davis *et al.,* 2013).

Lambs born and reared as singles were heavier at weaning compared with lambs born and reared as twins (Thompson *et al.,* 2011). Litter size during pregnancy had an impact on lamb liveweight gain, with lambs born and reared as singles 3.1 kg heavier at weaning than lambs scanned as twins but reared as a single (Lima *et al.,* 2019). The reason for this could be the regulation of lamb growth by the placenta in multiple lamb pregnancies (Gootwine *et al.,* 2007). Competition for maternal nutrition pre and post birth results in multiple born lambs being lighter at birth and weaning compared to those born and reared as singles (Oldham *et al.,* 2011; Paganoni *et al.,* 2014).

1.9.1 *Decision to wean and preparation for subsequent mating*

Ewes will have likely utilised body reserves for milk production during lactation (Robinson *et al.,* 2002; Robinson *et al.,* 2005), resulting in ewes needing to gain a unit (or more) of condition to reach optimum BCS at mating time (3.5 units for lowland ewes). Ewes require six to eight weeks on grass alone to gain one unit of BCS (Russel, 1984). Ewe BCS should be assessed at weaning and fed to gain the required weight to achieve optimum condition at mating (Robinson, 1983; Robinson, 1990; Robinson *et al.,* 2002). However, a study by Hickson, *et al.,* (2012) indicated that liveweight gain between weaning of one production cycle only had a minor influence on lamb production (lamb birthweight and lamb weight at weaning) in the subsequent production cycle. This study did not look at the effect of ewe BCS change, only liveweight. It does, however, suggest that ewe performance is already determined by weaning of the preceding production cycle. This would support the findings that ewe nutrition in the six months prior to mating affects the ovulation response at mating (Robinson *et al., 2*002).

The timing of weaning should be driven by certain factors, not a pre-determined date in the calendar. These factors are: (i) ewe condition (consider weaning thin ewes or ewes rearing multiple lambs sooner, providing ewes with sufficient time to regain condition and prepare for mating in the subsequent production cycle), (ii) lamb growth rates (ewes and lambs may be competing for food); and (iii) feed availability (grass growth may limit dry matter intake).

1.10 Lamb daily liveweight gain (DLWG)

The heritability of lamb growth rate is 10-15% (Lôbo *et al.,* 2009), with non-genetic factors accounting for the majority of variability in lamb growth rates (Lima *et al.,* 2019). Non-genetic factors that positively influence lamb DLWG are: (i) litter size (with single lambs heavier than multiple lambs (Dimsoski *et al.,* 1999)); (ii) lamb sex (with male lambs heavier than female lambs (Arnold & Meyer, 1988)), and (iii) ewe milk production during lactation (Snowder & Glimp, 1991)). Non-genetic factors that negatively influence lamb DLWG are: (i) ewe age (with younger and older ewes rearing lighter lambs (Dickerson & Laster, 1975)), and (ii) flock disease (for example parasitic gastroenteritis (PGE) and lameness (Lima *et al.,* 2019)).

There are no current published targets for lamb weight at any stage of the production cycle other than an upper limit for carcass weight at the point of slaughter, with many abattoirs paying up to 21 kg carcass weight (AHDB, 2020a). However, weight at the point of slaughter does not take lamb age into account, and age can range from 10 weeks to 14 months (Texel, 2016). Performance recording pedigree producers (e.g. (Signet, 2020; Texel, 2020)) weigh and back-fat scan lambs at 8 weeks post-lambing but this is not common practice on commercial sheep farms.

Current UK advice is to wean lambs at 12 weeks from the mid-point of lambing (AHDB, 2014a), a reduction from the previous advice to wean at 16 weeks (MLC, 1983). New Zealand producers are advised to wean lambs at 10-14 weeks of age (B&LNZ, 2014) and Australian sheep producers are advised to wean lambs when they achieve 45% of mature bodyweight or greater than 20 kg (Thompson *et al.,* 2011). By 12 weeks, few lambs are dependent on their mother's milk as the main source of nutrition (Figure 1.3; AHDB, 2018b). The contribution of ewe milk decreases from 3-4 weeks post-lambing and lamb intake from pasture increases. Lambs are born with a digestive system incapable of digesting forage. Milk is a critical dietary requirement as the lamb converts from a mono-gastric to a ruminant. The time it takes for the rumen to develop and digest forage depends on lamb age, ewe milk supply and the quality and quantity of feeds available to the lambs (Gibb *et al.,* 1981; B&LNZ, 2014). Forage intake usually exceeds milk intake in lambs by 8 weeks of age (Gibb *et al.,* 1981).

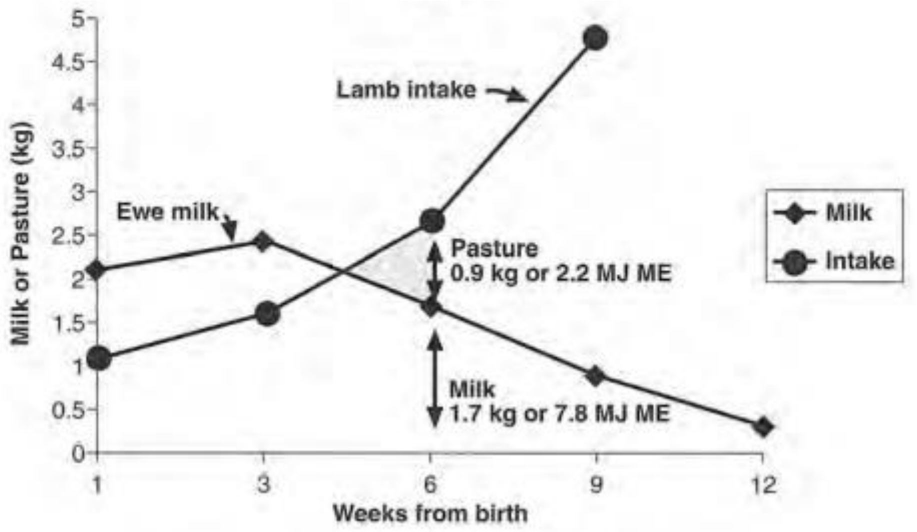


Figure 1.3. Single lamb intake of milk and pasture, by age (weeks) (AHDB, 2018b).

A summary of published DLWG of lambs pre-weaning, highlights a huge variation between lamb potential and what is achieved across all countries (Table 1.7). However, there are no opportunities to collate annual lamb DLWG data achieved in the UK.

Table 1.7. Summary of published data for lamb DLWG

Publication	Mean DLWG (g/day)	Lamb Details	Range (g/day)
Parker & McCutcheon, 1992	317	Birth to 6 weeks Single rear	
Muir *et al.*, 1999	338	Birth to 12 weeks Single rear	
Muir *et al.*, 2000	374	Birth to 12 weeks Single rear	
Muir *et al.*, 2003	282	All lambs Birth to 12 weeks	Range 195 – 340 Single lambs (mean 273; range 229-311) Twin lambs (mean 220; range 159-279)
B&LNZ, 2014	240-260	Birth to 12 weeks	NZ national mean is 80-100
AHDB, 2014a	250	Birth to 12 weeks	

1.11 Ewe liveweight as an alternative to ewe BCS

Some sheep producers have invested in precision farming technology to collect data on flock performance. It is quick and accurate to gather ewe liveweight data without the requirement to palpate individual ewes which is required to determine BCS. However, more equipment is required (e.g. weigh scales that are accurate and calibrated) compared with the need to palpate a ewe. A summary of published research on the use of ewe liveweight as an indicator of ewe condition (compared with BCS) is summarised in Table 1.8.

Table 1.8. The advantages and disadvantages of ewe liveweight measure as an alternative to ewe BCS.

Advantages	Disadvantages
Eliminates the variability between operators when condition scoring (Ferguson *et al.*, 2011)	Non-lactating and non-pregnant ewes with a similar liveweight can exhibit very different BCS scores (Caldeira & Portugal, 2007).
A good indicator of whether ewes are gaining or mobilising weight (Thompson & Meyer, 1994)	There is a wide variation in mature size between individuals and within breeds (Thompson & Meyer, 1994). Skeleton size will have an impact on ewe liveweight (Kenyon *et al.*, 2014).
Liveweight measurements can be corrected for gut fill, wool growth, conceptus and moisture (CSIRO, 2007; Wishart *et al.*, 2017)	Conceptus (van Burgel *et al.*, 2011), fleece size and amount of moisture (Wishart *et al.*, 2017) and gut fill would need to be accounted for and incorporated into farm software packages to allow for use on-farm.
It is important to have a method of assessing ewe condition that it simple and quick but still precise and accurate (Curnow *et al.*, 2011).	Animal age should be considered. As an animal reaches mature size, the fat in tissue deposition increases (Wood *et al.*, 1980; Owens *et al.*, 1993).

1.12 Uptake of BCS in sheep as a tool for assessing ewe condition

There is one publication documenting the uptake and utilisation of ewe BCS as a management tool in the UK. A survey of 105 sheep producers (Owen *et al.*, 2017) reported that 67% of respondents used BCS as a management tool but only 32% assessed BCS by palpation and applied a score. A secondary finding was that 64% nominated the tail region as an area palpated when assessing BCS, and that condition was most commonly assessed when selecting lambs for slaughter or buying and selling breeding stock. The publication suggests that the uptake of assessing ewe condition using BCS is low and that the term BCS is confused with lamb assessment pre-slaughter (Owen *et al.*, 2017). This is supported by the author’s own experience when delivering practical demonstrations on ewe BCS; farmers often consider the tail head a site to assess ewe condition. However, it is worth noting that this is one survey with a relatively small sample size which may not be representative.

Comparing the UK with other large sheep producing countries. Australia reported a much higher uptake with 96% of producers monitoring ewe condition but, again, fewer (61%) monitored the condition using palpation (Jones *et al.,* 2011). Ewe condition was most commonly assessed pre-lambing (when administering a treatment) with scanning identified as the least likely time to assess ewe condition (Jones *et al.,* 2011). A large government funded initiative to promote the use of BCS (Lifetimewool Project) is likely to be the reason for a much higher uptake in Australia. In New Zealand, Corner-Thomas *et al.,* (2013) reported that 43% of commercial sheep farmers used BCS as a management tool and that ewe condition was assessed at weaning, mating and scanning.

1.12.1 Adoption of technology in the UK sheep industry

Precision livestock farming (PLF) is defined as "*managing individual animals by continuous real-time monitoring of health, welfare, production/reproduction, and environmental impact*" (Berckmans, 2017). PLF records data for individual animals using EID technology, sensors, smartphone apps and other available technologies (Vittis & Kaler, 2019). Regular weighing to measure livestock growth rates was the most common PLF measure identified on 42% of mixed enterprise farms (DEFRA, 2020). When asked to cite why farmers had adopted precision farming technology, 78% cited it was to increase productivity or performance, 55% to reduce input costs and 50% to improve animal health and welfare. When asked to cite reasons why lowland grazing farmers were unwilling to adopt precision farming technology, 78% cited it was not relevant to their business, 29% cited the cost or poor cost effectiveness and 16% cited the complexity of the technology (DEFRA, 2020). Farmers suggested that grant aid would be required to fund investment of technology on sheep farms (SheepNet, 2019).

UK farmers are accessing and using technology, with 87% of farmers owning a computer, 71% owning a smartphone and 49% owning a tablet (DEFRA, 2020). Whilst 98% had access to broadband internet, 39% claimed poor internet connection was a barrier to using technology, with 31% citing that poor computer skills were a barrier (DEFRA, 2020).

1.12.2 Adopting best practice and farmer behaviour

Translating research findings into evidence based practice has been a key focus for many organisations including the English levy board (AHDB, 2020b) through the farmer focussed Better Returns Programme (AHDB, 2020c). Various approaches have been undertaken including topic specific manuals; farmer meetings (one to few and one to many); practical demonstrations at farmer focussed events (e.g. NSA, 2019); and the production of webinars, podcasts and YouTube videos. Farmers seek advice relating to productivity from farming press and media (67%), friends, family or colleagues (48%), industry bodies (AHDB, NFU) (43%), with 30% paying a regular specialist advisor (DEFRA, 2020). The methods of disseminating information to sheep farmers specifically relating to ewe condition across six of the largest sheep producing countries in the EU were summarised by SheepNet, (2020) and supported those of DEFRA, (2020) with farming press being the most popular, followed by articles in technical and professional journals, discussion groups, seminars and workshops.

People's willingness to adopt new technologies can be categorised as 'innovator', 'early adopter', 'early majority', 'late majority' or 'laggard' (listed in order of willingness to adopt; (Rogers, 1983). People that fall into the categories of 'innovators' and 'early adopters' actively seek out new technologies, whereas 'laggards' find it harder to change because they are most comfortable doing what they already do (Jones *et al.,* 2011).

The adoption of results and findings from sheep research is dependent on the perceived benefits to the end-user (B&LNZ, 2013a). Knowledge of what farmers perceive to be important research areas will result in better utilisation and assist with the development of data and tools that farmers will adopt and provide greatest benefit to their businesses. Understanding farmer drivers and motivations alongside the original reason for seeking information are also important (Giles, 1983). Extension is only effective if the farmer is interested in the advice (van den Ban & Hawkins, 1996).

The concepts of risk, trust, distrust, infrequent use of advisors and the demeaned de-valuing of one's own knowledge and skills, were all barriers to adopting advice (Ingram, 2008; Rehman, et al., 2007; Silgo & Massey, 2007). There are aspects of the advice process that need to be understood in order to be successful Giles, (1983). These are: caution or suspicion, especially early on in the relationship; working with a stranger can either help or hinder the advice process; trust in the advisor; the farmer will enter the relationship with expectation that may or may not be met; sense of inferiority or failure by having to seek advice; fear of the outcome or message; the need to accept change or risk.

1.13 Working hypothesis

This literature review provides clear evidence that ewe condition affects ewe performance. However, it has also demonstrated there are evidence gaps. Many of the studies discussed assess the impact of ewe BCS and liveweight at i) specific production points e.g. at mating or ii) a time period between two relatively short production points e.g. mating and scanning. Little consideration is given to the subsequent effect on performance, for example, the effect of ewe condition change between mating and scanning on lamb performance to weaning. Therefore, a study to investigate the longer term, continuous effect of ewe condition is required. Chapters 3 to 5 of this thesis sought to determine the effect of ewe condition on ewe fertility and lamb performance to weaning between weaning of one production cycle and weaning of the subsequent production cycle, over three consecutive years on three commercial sheep farms in England.

There is limited published, peer reviewed data on annual farm production data. Where targets are available, there are limited sources relating to the success or failure of these target annually e.g. year-on-year data relating to scanning and lambing performance. Chapter 2 of this thesis provides appropriate detail on the three study farms including project materials and methods and farm production data.

Ewe BCS was developed as a management tool in the 1960s. However, there is limited data, specific to England (or the UK), regarding the number of farmers that assess ewe condition using BCS or an understanding of the barriers preventing them from doing so. Chapter 6 sought to investigate these.

In summary, this thesis aims to investigate the longer term impact of ewe BCS and liveweight (actual and change) on ewe fertility and lamb performance to weaning over three consecutive production cycles. Furthermore, to gain an understanding of farmers' opinions, application of ewe BCS and barriers.

2 CHAPTER TWO: Quantitative overview of study farms

2.1 Introduction

Current BCS targets for UK sheep systems (Table 2.1) are based on a publication by MLC, (1983) that brought together research publications available at that time. These targets are still recommended today (AHDB, 2014b). However, the condition of the ewe in the time interval leading up to mating, was not considered. There are no data relating to the number of farms achieving the current BCS recommendations.

Table 2.1. Current industry targets for ewe BCS (AHDB, 2014b).

	Mating	Scanning	Lambing	Weaning
Lowland	3.5	3	3	2.5
Upland	3	2.5	2.5	2
Hill	2.5	2	2	2

The target is for fewer than 3% of a flock to be barren at scanning (excluding ewe lambs) (Teagasc, 2019). Targets for litter sizes at scanning for lowland sheep producers are around 190% (i.e. 1.9 lambs scanned per ewe mated), reducing to 175% if ewe lambs are included (AHDB, 2019b). There is no requirement or opportunity to collate national scanning data (proportion pregnant or litter size). Therefore, the number of sheep farmers regularly achieving the aforementioned targets is unknown. The same applies for the proportion of ewes lambing and litter size at lambing each year.

In addition to the absence of national data regarding scanning and lambing performance, there are no annually published information on lamb DLWG, other than average carcass weights at slaughter (AHDB, 2019d), which does not account for lamb age and can range from 10 weeks to 14 months.

Lamb weight at 8 weeks post-lambing was incorporated into this project, in addition to lamb weight at weaning, to determine the influence of the ewe on lamb 8-week weight and assess its relevance on lamb performance to weaning. A target of 20 kg was set for each lamb to achieve by 8 weeks and a target of 30 kg by weaning. These targets were calculated based on a lamb birthweight of 5 kg and an average DLWG of 280g/day through to weaning at 12 weeks (Thompson *et al.,* 2004).

The aim of this chapter is to summarise the farm production data collected from the three farms over three consecutive years and to determine study farm performance compared to national targets (where available). Specifically, this chapter aims to summarise flock performance, identify trends, similarities and differences in percentage ewes pregnant, litter size at scanning and flock performance at lambing (number ewes lambed). Furthermore, to assess lamb performance to 8 weeks and weaning, and to identify a suitable target lamb weight for 8 weeks and weaning. Finally, this chapter sought to summarise BCS and liveweight (actual and change) trends for the three study flocks, and to relate these to current national targets.

2.2 Materials and methods

2.2.1 Farm location and size

Farm performance data was collected on three commercial sheep flocks in England over a three-year period (2014 – 2016). The farms were from contrasting geographical regions but were representative of lowland/upland sheep producing areas (Figure 2.1). The farms were similar in as many production aspects as possible e.g. housed for lambing, to enable across farm comparisons. The three farms were selected based on their size and contemporary systems of production (Table 2.2), with all ewes in the flock fitted with EID. The farmers were also willing and capable of collecting the data, were experienced BCS assessors and familiar with the required software programmes for data collection.

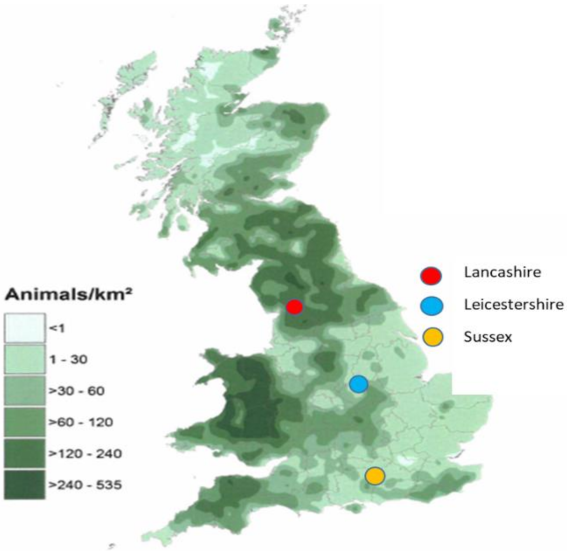


Figure 2.1. Location of study farms relative to UK sheep population density (DEFRA, 2019).

Table 2.2. Characteristic features of the three study farms

	Sussex Farm	Leicestershire Farm	Lancashire Farm
Location	West Sussex	Leicestershire	Lancashire
Farm size	322 Ha	303 Ha	101 Ha
Enterprises	Mixed arable	Sheep only	Sheep and cattle*
Altitude (metres above sea level)	40m	200m	140m
Pasture Type	Permanent pasture/red clover leys	Permanent pasture	Permanent pasture
Soil Type	Chalk and clay	Heavy clay	Mostly clay

*The Lancashire Farm had a separate January lambing flock. These ewes are not included in the analyses because flock size decreased in Year 2 and ceased in Year 3.

2.2.2 Data collection

European legislation requiring all breeding ewes to be fitted with electronic identification (EID) was implemented in 2010 (AHDB, 2016a). Consequently, all breeding ewes on the study farms had EID tags. Lambs were fitted with EID tags within 48 h of birth and linked to the EID of their mothers, enabling lamb performance to be linked to the ewe.

Data was captured using static/panel readers accompanied with digital weigh scales and weigh head monitors or a hand-held psion. The Sussex and Leicestershire Farms used FarmIt 3000 software from Border Software Ltd. The Lancashire Farm used Shearwell Data Ltd software. These software packages were used by the farmers prior to the project starting.

Data was downloaded from the respective software programmes into Microsoft Excel for further analysis and interpretation. Data analyses in this chapter were performed using Microsoft Excel (Excel, 2016) and GraphPad Prism software (GraphPad Prism version 7.00 for Windows).

2.2.2.1 *Ewe management data*

Where possible, ewe and lamb treatments remained consistent across the three farms. All ewes were vaccinated against toxoplasmosis, enzootic abortion and ewes and lambs were vaccinated against clostridial diseases. The farms were provided with a FECPAK G2 to monitor worm burden, with treatments administered based on faecal egg counts. The ewe management data collected on the three farms is summarised in Table 2.3.

Table 2.3. Ewe management data collected on study farms

Data Collected	Description
EID number	UK flock number – unique 5 digit code e.g. UK502367-00346
Genotype	
Year of birth	YYYY e.g. 2009
Parity	All parity 1 ewes were shearlings
Scanning data	Number of fetuses 0, 1, 2, 3+

Ewes were not single-sire mated at the Leicestershire or Lancashire Farms, therefore it was not possible to allocate a sire to each individual lamb. Lleyn ewes were single sired mated at the Sussex Farm in Years 1 and 2 only. However, sire breed information was not utilised in the analysis. Raddles were utilised on all three farms to a greater or lesser extent during the three years. At the Sussex and Lancashire Farms, raddles were used every year. At the Leicestershire Farm, raddles were used from Year 2 onwards.

2.2.2.2 *Ewe feeding pre-lambing and housing management*

The three flocks remained outside with grazed grass as the main feed excluding the period when ewes were housed for lambing. Ewes were housed shortly after scanning in groups based on lambing date (determined by raddle mark), litter size and BCS. Timing of housing was dependant on feed availability and weather.

At the Sussex and Leicestershire Farms, the pre-lambing diet consisted a Total Mixed Ration (TMR) of big bale silage, with soya and beans as a high-quality protein source. The Lancashire Farm fed clamp or big bale silage and compound feed.

2.2.2.3 *Ewe feeding at turn-out*

At the Sussex Farm, ewes were allocated grazing at turn-out based on BCS and the number of lambs reared. Ewes grazed either permanent pastures or red clover leys, with lambs reared by ewes on permanent pastures receiving creep feed from 3-4 weeks of age. At the Leicestershire Farm, lambs reared by shearlings or ewes below BCS 2.5 units received creep feed from 2-3 weeks of age in Years 2 and 3 only.

At the Lancashire Farm, ewes were turned out to grass and received compound feed for 3-4 weeks post-lambing. If grazing conditions were poor (either limited grass quantity or very wet conditions), ewes also received supplementary forage post-lambing. Due to the number of triplet ewes at the Lancashire Farm, ewes were left to rear three lambs with priority feeding.

2.2.2.4 *Ewe BCS and liveweight data*

Individual ewe BCS was determined to the nearest 0.25 unit score. Data was collected by one appointed, experienced assessor per farm at every production point. Each assessor had been trained and their scores were cross checked annually by Lesley Stubbings (industry consultant). BCS data were manually inputted by the assessor, with liveweight data automatically captured using electronic weigh scales. Ewe liveweight was measured to the nearest 0.5 kg. A summary of BCS and liveweight data collection can be found in Table 2.4.

BCS data was quality controlled shortly after data collection at each production point, prior to further analysis. Unusual records such as very low or very high figures e.g. BCS record of 0.5 or 9 removed from the dataset because they were likely an inputting error.

Table 2.4. Ewe BCS and liveweight data collected on study farms

Data Collected	Description
Weaning (preceding production cycle)	Data unavailable for shearling ewes mating for the first time
Mating	Collected over two or three days, as rams were turned out with the ewes in their management groups
Scanning	Data collected on one day
Lambing	Liveweight was not collected. BCS was recorded when lambs were tagged (within 48 h of birth)
8 weeks post-lambing Weaning (12 weeks)	Data collected over two to three weeks, reflecting the lambing spread, based on date of lambing.

2.2.2.5 *Lamb performance data*

Lamb data collected on the three farms is summarised in Table 2.5. Only lambs reared by a ewe are included e.g. artificially reared lambs are not included. The three farms castrated male lambs according to welfare regulations (DEFRA, 2003).

Lamb liveweight data was quality controlled shortly after data collection at each production point, prior to further analysis. Unusual records such as very low or very high figures e.g. lamb liveweight of 85kg at 8 weeks was removed from the dataset.

Table 2.5. Lamb data collected on study farms

Data Collected	**Description**
Date of birth	(DD/MM/YYYY)
Sex	Male (castrate) or Female
Rear type	Single or Twin (Triplet only for the Lancashire Farm) With fewer triplets scanned at the Sussex and Leicestershire Farms, any triplet born lambs were fostered or artificially reared.
Weight and age at 8 weeks post-lambing .	Age range permitted for 8 weeks was 42 to 84 days, in line with Signet recording parameters Weight adjusted for age using following equation (8-week weight/age) x 56 age in days
Weight and age at weaning (12 weeks post-lambing)	Age range permitted for weaning was 75 to 112 days, in line with Signet recording parameters Weight adjusted for age using following equation (weaning weight/age) x 90 age in days

2.3 Results: Flock size, genotype and parity

2.3.1 Sussex Farm

Flock size remained consistent in Years 1 and 2 with a small increase in Year 3 (Table 2.6). Aberfield ewes were introduced as shearlings in the year preceding the project starting, with numbers and parity increasing proportionately during the three years. A cohort of parity 3 Mules (in Year 1) carried on through the project, with replacements switching to Aberfield, until

Year 3 when Mules were reintroduced. Lleyn ewe numbers and parity remained consistent throughout the project (Table 2.6).

Replacement ewes for the Sussex Farm were retained (Lleyn ewes) or purchased as ewe lambs (Aberfield and Mule ewes) and reared on the farm for a year prior to mating.

Other genotypes (Dorset, Southdown, Aberdown and Abermax) were excluded from analyses due to small numbers (fewer than 20 ewes). Twenty-three ewes between parity six and ten were also excluded.

Table 2.6. Flock size, ewe genotypes and parity: Sussex Farm

	Year 1	**Year 2**	**Year 3**
	Number of ewes		
Lleyn	**376**	**384**	**399**
Parity 1	195	93	126
Parity 2	86	169	82
Parity 3	19	68	132
Parity 4	24	16	47
Parity 5	52	38	12
Mule	**289**	**211**	**226**
Parity 1	-	-	80
Parity 2	-	-	-
Parity 3	289	-	-
Parity 4	-	211	-
Parity 5	-	-	146
Aberfield	**285**	**353**	**378**
Parity 1	140	159	70
Parity 2	145	94	140
Parity 3	-	100	86
Parity 4	-	-	82
Parity 5	-	-	-
Total ewes mated	950	948	1003
Shearlings mated	335	252	276

2.3.2 Leicestershire Farm

Flock size increased by approximately 150 ewes between Years 1 and 2, remaining static in Year 3. Ewe genotype and parity were inconsistent between the years. There was a large intake of shearling ewes, accounting for a third of the flock, in Years 2 and 3 following no replacements in Year 1 (Table 2.7). These were all Aberfield ewes, a genotype not previously on the farm. Both Charollais and Mule ewes reduced in number and represented older parities over the three years (Table 2.7).

Ewe replacements were all purchased as ewe lambs and reared on the farm for a year prior to mating.

Table 2.7. Flock size, ewe genotypes and parity: Leicestershire Farm

	Year 1	**Year 2**	**Year 3**
	Number of ewes		
Charollais	**285**	**220**	**93**
Parity 1	-	-	-
Parity 2	148	-	-
Parity 3	34	126	-
Parity 4	103	31	93
Parity 5	-	63	-
Mule	**1051**	**794**	**469**
Parity 1	-	-	-
Parity 2	565	-	-
Parity 3	-	530	-
Parity 4	239	-	469
Parity 5	146	264	-
Parity 6	101		
Aberfield	**0**	**483**	**925**
Parity 1	-	483	502
Parity 2	-	-	423
Parity 3	-	-	-
Parity 4	-	-	-
Total ewes mated	1336	1497	1487
Shearlings mated	0	483	502

2.3.3 Lancashire Farm

Ewe genotypes represented at the Lancashire Farm were Mules and Texel. Their parity was consistent across the years (Table 2.8). Parity 5 ewes who would have been in the early lambing flock were transferred to the March lambing flock, resulting in an increase in flock size and parity between Year 1 and Years 2 and 3 (Table 2.8).

Table 2.8. Flock size, ewe genotypes and parity: Lancashire Farm.

	Year 1	**Year 2**	**Year 3**
		Number of ewes	
Texel	**106**	**173**	**189**
Parity 1	47	60	60
Parity 2	29	44	45
Parity 3	15	35	39
Parity 4	15	15	28
Parity 5	-	19	17
Mule	**238**	**264**	**261**
Parity 1	24	-	40
Parity 2	37	119	107
Parity 3	36	42	34
Parity 4	42	56	43
Parity 5	-	47	19
Total ewes mated (n)	344	437	450
Shearlings mated (n)	71	60	100

2.4 *Results: Timing of key production points*

Lambing at the Sussex Farm occurred two weeks later in Year 2 and a further 2 weeks later in Year 3. As a result, key production points changed over the three year period (Table 2.9).

Table 2.9. Dates of key production points: Sussex Farm

	Year 1	Year 2	Year 3
Mating period	20/10 to 25/11	27/10 to 01/12	02/11 to 07/01
Scanning	20/01/2014	21/01/2015	23/01/2016
Lambing period	10/03 to 21/4	22/03 to 30/04	30/03 to 01/05
8-weeks	13/05/2014	23/05/2015	02/06/2016
Weaning	16/07/2014	23/07/2015	29/07/2016

There were no significant changes to the key production points for the Leicestershire Farm during the three years (Table 2.10).

Table 2.10. Dates of key production points: Leicestershire Farm.

	Year 1	Year 2	Year 3
Mating period	26/10 to 14/01	25/10 to 11/01	28/10 to 07/01
Scanning	16/01/2014	14/01/2015	12/01/2016
Lambing period	18/03 to 30/04	22/03 to 16/04	19/03 to 03/05
8-weeks	26/5 to 3/06	26/05 to 02/06	01/06 to 07/06
Weaning	01/07	01 to 03/07	05/07

At the Lancashire Farm, ewes were scanned three weeks later and lambing started a week earlier in Year 3 (Table 2.11).

Table 2.11. Dates of key production points: Lancashire Farm

	Year 1	Year 2	Year 3
Mating period	18/10 to 15/12	18/10 to 20/12	14/10 to 19/12
Scanning	02/01/2014	03/01/2015	22/01/2016
Lambing period	11/03 to 17/04	11/03 to 29/04	04/03 to 26/04
8-weeks	19/05 to 22/05	21/05 to 29/05	24/05 to 27/05
Weaning	02/07 to 11/07	10/07 to 17/07	08/07 to 16/07

2.5 Results: Ewe performance to lambing

2.5.1 Sussex Farm

The percentage of ewes barren at scanning was highest in Year 1, decreasing marginally in Years 2 and 3 (Table 2.12). Litter size at scanning increased by more than 10% between Years 1 and 2 with only a slight increase in Year 3 (Table 2.12). The number of ewes scanned with multiple lambs increased over the three year period, with fewer singles year-on-year.

The percentage of ewes rearing lamb(s) defined as a ewe assigned at least one lamb at tagging (48 h post-lambing), was 92% or higher at the Sussex Farm.

Table 2.12. Ewe performance to lambing: Sussex Farm

	Year 1	Year 2	Year 3
Ewes mated (n)	976	948	1003
Ewes scanned (n)	976	941	1003
Barren (n)	37 (3.8%)	27 (2.9%)	28 (2.8%)
Single bearing (n)	329	273	270
Twin bearing (n)	508	550	576
Multiple bearing (n)	81	81	112
Scan litter size[1]	1.61 ± 0.74 (161%)	1.72 ± 0.69 (172%)	1.75 ± 0.79 (175%)
Ewes rearing[2] (%)	92	93	94
Lamb litter size[3]	1.52 (152%)	1.63 (163%)	1.67 (167%)

[1] Scan litter size = number lambs scanned /number ewes mated [2] Ewes rearing = ewes with a tagged lamb(s)/number ewes mated [3] Lambs tagged 24-48 h post-partum

2.5.2 Leicestershire Farm

The percentage of barren ewes at scanning was consistent (2%) each year (Table 2.13). Litter size at scanning decreased between Years 1 and 2 but increased again in Year 3 (Table 2.13).

The percentage of ewes rearing lamb(s) defined as a ewe assigned at least one lamb at tagging (48 h post-lambing) was 92% or higher, each year.

Shearling ewes were diagnosed with lungworm post-scanning in Year 2.

Table 2.13. Ewe performance to lambing: Leicestershire Farm.

	Year 1	Year 2	Year 3
Ewes mated (n)	1336	1494	1487
Ewes scanned (n)	1336	1494	1487
Barren (n)	31 (2.3%)	28 (1.9%)	31 (2.1%)
Single bearing (n)	285	422	371
Twin bearing (n)	897	931	928
Multiple bearing (n)	128	105	154
Scan litter size[1]	1.84 ± 0.60 (184%)	1.74 ± 0.62 (174%)	1.81 ± 0.65 (181%)
Ewes rearing[2] (%)	95	92	93
Lamb litter size[3]	1.72 (172%)	1.61 (161%)	1.68 (168%)

[1] Scan litter size = number lambs scanned /number ewes mated [2] Ewes rearing = ewes with a tagged lamb(s)/ number ewes mated [3] Lambs tagged 24-48 h post-partum

2.5.3 Lancashire Farm

The percentage of barren ewes at scanning was 3% or less each year (Table 2.14). The Lancashire Farm consistently achieved over 200% litter size at scanning (Table 2.14). The percentage of ewes rearing lamb(s) defined as a ewe assigned at least one lamb at tagging (48 h post-lambing), was 93% or higher each year.

Table 2.14. Ewe performance to lambing: Lancashire Farm

	Year 1	Year 2	Year 3
Ewes mated (n)	345	437	472
Ewes scanned (n)	345	437	472
Barren (n)	4 (1.2%)	12 (2.8%)	5 (1.1%)
Single bearing (n)	43	59	57
Twin bearing (n)	218	249	267
Multiple bearing (n)	79	114	142
Scan litter size[1]	2.10 ± 0.68 (210%)	2.07 ± 0.74 (207%)	2.16 ± 0.85 (216%)
Ewes rearing[2] (%)	94	93	94
Lamb litter size[3]	1.98 (198%)	1.91 (191%)	2.05 (205%)

[1] Scan litter size = number lambs scanned /number ewes mated [2] Ewes rearing = ewes with a tagged lamb(s)/ number ewes mated [3] Lambs tagged 24-48 h post-partum

2.6 Results: Lamb performance at 8 weeks (adjusted to 56 days)

2.6.1 Sussex Farm

The individual lamb weight target of 20 kg at 8 weeks (adjusted to 56 days) was achieved by 35% of lambs in Year 1, increasing to 64% in Year 2 but decreasing to 41% in Year 3 (Table 2.15). A mean weight of 20 kg at 8 weeks was achieved in Year 2 only. The percentage of light lambs (lambs weighing 17 kg or less at 8 weeks) fluctuated between 15 and 35% over the three year period. Year 2 achieved the highest mean 8-week weight, highest percentage of lambs achieving the individual 20 kg target and the lowest percentage of light lambs (Table 2.15).

The flock experienced a higher incidence of ewe lameness post-housing and navel ill in the lambs in Year 3.

Table 2.15. Lamb performance to 8 weeks (adjusted): Sussex Farm.

	Year 1	Year 2	Year 3
Mean 8-week weight* (kg)	18.6 ± 4.15	21.5 ± 4.56	19.1 ± 4.47
Mean age at 8 weeks (days)	66	55	57
Lambs <17 kg* at 8 weeks (%)	35	15	30
Lambs ≥20 kg* at 8 weeks (%)	36	64	41
Lambs reared as singles at 8 weeks (%)	37	34	47
Lambs reared as twins at 8 weeks (%)	63	66	53

*mean weight, lambs <17 kg and > 20 kg all adjusted to 56 days

2.6.2 Leicestershire Farm

The individual 20 kg target at 8 weeks (adjusted to 56 days) was achieved by 42% of lambs in Year 1, increasing to 64% in Year 2 but decreasing to 58% in Year 3. A mean lamb weight of 20 kg at 8 weeks was achieved in Years 2 and 3. The percentage of light lambs fluctuated between 15 and 23% over the three-year period. Year 2 achieved the highest mean 8-week weight, highest percentage of lambs achieving the individual 20 kg target and the lowest percentage of light lambs (Table 2.16).

Table 2.16. Lamb performance to 8 weeks (adjusted): Leicestershire Farm.

	Year 1	**Year 2**	**Year 3**
Mean 8-week weight* (kg)	19.6 ± 3.86	21.1 ± 4.30	20.5 ± 3.66
Mean age at 8 weeks (days)	58	57	64
Lambs <17 kg* at 8 weeks (%)	23	15	15
Lambs ≥20 kg* at 8 weeks (%)	42	64	58
Lambs reared as singles at 8 weeks (%)	23	39	30
Lambs reared as twins at 8 weeks (%)	77	61	70

*mean weight, lambs <17 kg and > 20 kg all adjusted to 56 days

2.6.3 Lancashire Farm

The individual lamb target of 20 kg at 8 weeks (adjusted to 56 days) was achieved by over 60% of lambs each year. The mean lamb weight at 8 weeks was greater than or equal to 20 kg in all three years, also. The percentage of light lambs varied between 7 and 14% between the years (Table 2.17). Year 2 achieved the highest mean 8-week weight, the highest percentage of lambs achieving the individual 20 kg target and the lowest percentage of light lambs.

Table 2.17. Lamb performance to 8 weeks (adjusted): Lancashire Farm

	Year 1	**Year 2**	**Year 3**
Mean 8-week weight* (kg)	20.0 ± 5.26	21.7 ± 3.26	20.8 ± 3.21
Mean age at 8 weeks (days)	57	58	61
Lambs <17 kg* at 8 weeks (%)	14	7	12
Lambs ≥20 kg* at 8 weeks (%)	62	71	60
Lambs reared as singles at 8 weeks (%)	16	21	25
Lambs reared as twins at 8 weeks (%)	79	64	65
Lambs reared as triplets at 8 weeks (%)	5	8	10

*mean weight, lambs <17 kg and > 20 kg all adjusted to 56 days

2.7 Results: Lamb performance at weaning (adjusted to 90 days)

2.7.1 Sussex Farm

The individual lamb 30 kg target at weaning (adjusted to 90 days) was achieved by 28% of lambs in the flock during Year 1, 42% in Year 2 and 34% in Year 3. Mean lamb weight at weaning was below 30 kg during the three years. Year 2 achieved the highest weaning weight (mean of 26.8 kg) and the highest percentage of lambs (42%) achieving the individual 30 kg target (Table 2.18).

Table 2.18 Lamb performance to weaning (adjusted): Sussex Farm.

	Year 1	**Year 2**	**Year 3**
Mean weight* at weaning (kg)	25.2 ± 3.81	26.8 ± 5.90	24.0 ± 4.99
Mean age at weaning (days)	117	95	98
Lambs ≥30 kg* at weaning (%)	28	42	34
Lambs reared as singles at weaning (%)	42	34	47
Lambs reared as twins at weaning (%)	58	66	51

*mean weight, lambs > 30 kg adjusted to 90 days

2.7.2 Leicestershire Farm

The individual 30 kg target (adjusted to 90 days) was achieved by 19% of lambs in Year 1, increasing to 39% in Year 2 but decreasing to 15% in Year 3. The mean lamb weight was below 30 kg at weaning during the three years. Year 2 achieved the highest weaning weight (mean of 28.4 kg), with the highest percentage of lambs (39%) achieving the individual 30 kg target (Table 2.19).

Table 2.19 Lamb performance to weaning (adjusted): Leicestershire Farm

	Year 1	**Year 2**	**Year 3**
Mean weight* at weaning (kg)	26.3 ± 4.63	28.4 ± 5.59	24.1 ± 4.00
Mean age at weaning (days)	92	91	107
Lambs ≥30 kg* at weaning (%)	19	39	15
Lambs reared as singles at weaning (%)	23	39	32
Lambs reared as twins at weaning (%)	77	61	68

*mean weight, lambs > 30 kg adjusted to 90 days

2.7.3 Lancashire Farm

The 30 kg target (adjusted to 90 days) was achieved by 49% of lambs in Year 1, increasing to 61% in Year 2 and a slight decrease to 56% in Year 3. The mean lamb weaning weight was greater than 30 kg in Years 2 and 3 (Table 2.20).

Table 2.20. Lamb performance to weaning (adjusted): Lancashire Farm.

	Year 1	Year 2	Year 3
Mean weight* at weaning (kg)	27.01 ± 3.34	30.8 ± 3.26	30.1 ± 5.59
Mean age at weaning (days)	102	98	97
Lambs ≥30 kg* at weaning (%)	49	61	56
Lambs reared as singles at weaning (%)	16	21	22
Lambs reared as twins at weaning (%)	80	73	70
Lambs reared as triplets at weaning (%)	4	6	8

*mean weight, lambs > 30 kg adjusted to 90 days

2.8 Results: Flock BCS and liveweight

A visual illustration of flock BCS and liveweight at the key production stages (weaning, mating, scanning, lambing, 8 weeks and weaning) over the three years is provided in this section. The ewes represented in the data differ across the three years due to the addition of ewe replacements and losses due to culling and ewe mortality.

2.8.1 Sussex Farm

Overall, mean flock BCS at the Sussex Farm improved during the three years Ewe BCS was lowest at weaning, each year. Ewes gained BCS between weaning and mating, resulting in improved mating BCS over the three year period. BCS was maintained between mating and scanning with ewe BCS at scanning, on average, higher than industry target of 3 units (Appendix I Table 1). However, BCS loss occurred between scanning and lambing, each year with ewe BCS at lambing below the industry target of 3 units (Appendix I Table 1). Ewes lost condition during lactation, with most loss occurring between 8 weeks and weaning. The exception to this was in Year 3, where ewes gained BCS between lambing and 8 weeks only to lose it between 8 weeks and weaning. The flock liveweight profile at Sussex Farm followed a similar trend to BCS (Figure 2.3; Appendix I Table 1).

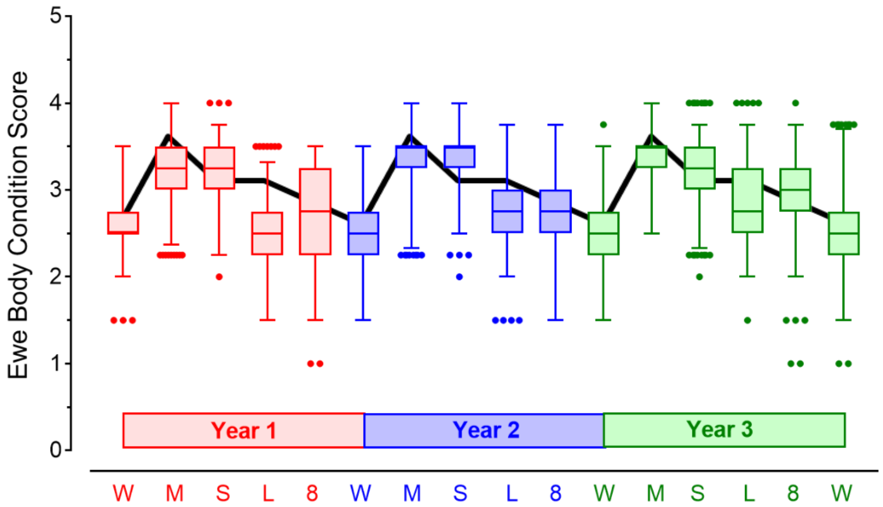


Figure 2.2. Whole flock BCS distribution at key production stages (W - weaning, M - mating, S - scanning, L - lambing and 8 - 8 weeks) for the Sussex Farm. Years 1 (red), 2 (blue) and 3 (green). Box plots show median and interquartile ranges, with whiskers set at 1st and 99th percentiles. (—) denotes current industry BCS targets.

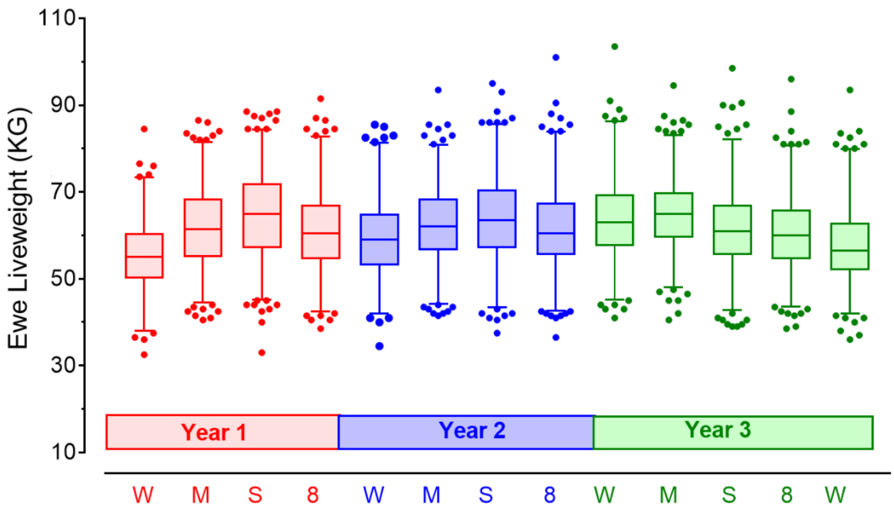


Figure 2.3. Whole flock liveweight distribution at key production stages (W - weaning, M - mating, S - scanning and 8 - 8 weeks) for the Sussex Farm. Years 1 (red), 2 (blue) and 3 (green). Box plots show median and interquartile ranges, with whiskers set at 1st and 99th percentiles.

2.8.2 Leicestershire Farm

Mean flock BCS (Figure 2.4) and liveweight (Figure 2.5) improved over the three year period (Appendix I Table 2). Ewe BCS at weaning was below industry target of 2.5 units each year (Appendix I; Table 2) but did improve by half a unit between Years 1 and 3. Ewes gained the most condition (up to 0.75 units) between weaning and mating. However, flock BCS at mating and scanning failed to reach the target of 3.5 and 3 units, respectively (Appendix I; Table 2). Condition was lost between scanning and lambing, with ewes lambing below industry target of 3 units, each year. BCS loss continued between lambing and 8 weeks. In Year 1, ewes gained BCS between 8 weeks and weaning but lost BCS during this time in Years 2 and 3 (Appendix I; Table 2).

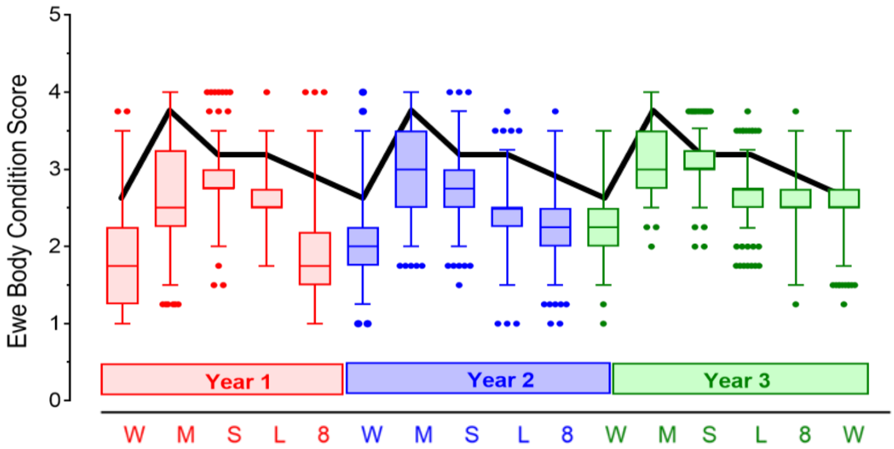


Figure 2.4. Whole flock BCS distribution at key production stages (W - weaning, M - mating, S - scanning, L - lambing and 8 - 8 weeks) for the Leicestershire Farm. Years 1 (red), 2 (blue) and 3 (green). Box plots show median and interquartile ranges, with whiskers set at 1st and 99th percentiles. (—) denotes current industry BCS targets.

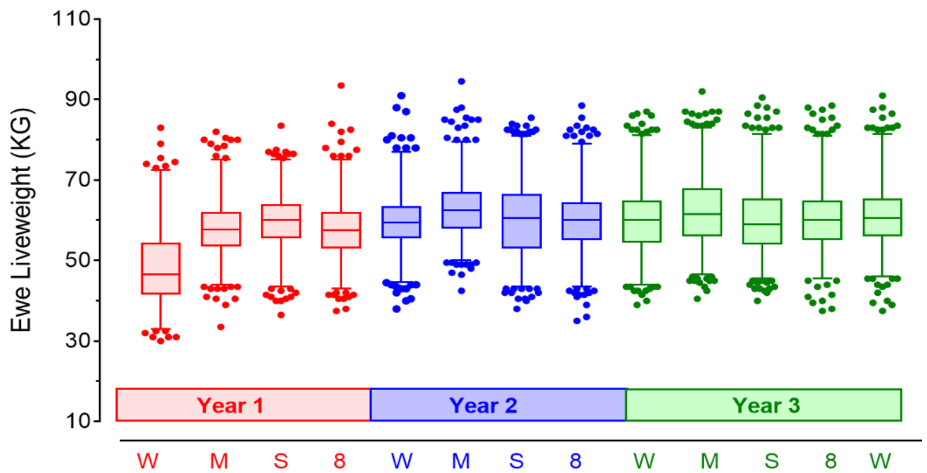


Figure 2.5. Whole flock liveweight distribution at key production stages (W - weaning, M - mating, S – scanning and 8 - 8 weeks) for the Leicestershire Farm Years 1 (red), 2 (blue) and 3 (green). Box plots show median and interquartile ranges, with whiskers set at 1st and 99th percentiles.

2.8.3 *Lancashire Farm*

Mean flock BCS at the Lancashire Farm achieved or exceeded industry targets at most production points during the three years (Figure 2.6; Appendix I Table 3). Rarely did individual ewe BCS fall below 2 units, even at weaning. The flock BCS at weaning exceeded the industry target of weaning at 2.5 units, every year. Ewes gained BCS between weaning and mating with BCS achieving the industry target at mating of 3.5 units each year (Appendix I Table 3). Scanning BCS was absent in Year 2 but overall ewe BCS at scanning was greater than the industry target of 3 units, each year. In Year 1 there was BCS loss between mating and scanning and slight gain in Year 3. Ewes lost condition between scanning and lambing, but ewes lambed above target BCS of 3 units. Ewes continued to lose BCS between lambing and weaning (Appendix I Table 3). However, the loss was less than one unit, resulting in ewes weaning at higher BCS.

Ewe liveweight data was harder to obtain and extract from the farm software. Due to the absence of liveweight data at several production points over the three year period, a liveweight distribution figure is not provided for the Lancashire Farm.

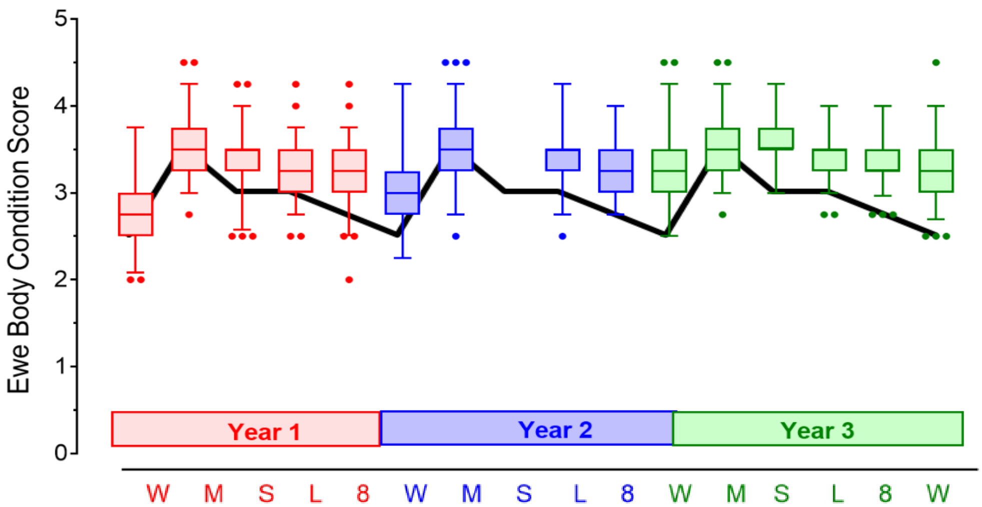


Figure 2.6. Whole flock BCS distribution at key production stages (W - weaning, M - mating, S - scanning, L - lambing and 8 - 8 weeks) for the Lancashire Farm. Years 1 (red), 2 (blue) and 3 (green). Box plots show median and interquartile ranges, with whiskers set at 1st and 99th percentiles. (—) denotes current industry BCS targets.

2.9 Discussion

The three flocks were able to collect ewe BCS and lamb weight data to an excellent standard, with the use of EID and associated software programmes. Ewe liveweight data was harder to obtain and extract from the software programme at the Lancashire Farm. Performance varied between years and flocks, with the three flocks achieving the highest average lamb weights for 8 weeks and weaning in Year 2.

Overall, ewes at the Lancashire Farm exceeded BCS targets at every production stage year-on-year. The BCS of ewes at the Sussex Farm was marginally below target at weaning, mating and lambing. The ewes at the Leicestershire Farm did not achieve target BCS at any production stage.

2.9.1 Farm descriptive data

The three flocks were larger than the national average flock size of 220 breeding ewes (AHDB, 2019d). However, this was not deemed a negative attribute because it provided a large dataset from fewer farms, meaning less variables to consider in terms of flock management. The three flocks were in densely populated sheep counties in England and housed for lambing. A limitation of this study was the bias towards indoor lambing sheep systems.

Ewe BCS was assessed by one operator per farm across the three years. It was not possible for one assessor to visit the three farms. Studies have found that BCS is highly repeatable, 90% within individuals and 80% between individuals (Teixeira *et al.,* 1989). BCS is easier to master by individuals with their own flocks compared to across flocks with different assessors (Calavas *et al.,* 1998); with experienced scorers achieving high levels of consistency, up to 0.25 units (van Burgel *et al.,* 2011; Phythian *et al.,*2012; Kenyon *et al.,* 2014). Consistency improved with calibration of assessors (Phythian *et al.,*2012). To ensure accuracy and consistency in our research, each assessor in this project was calibrated annually by an industry expert, Lesley Stubbings. Assessing ewe condition themselves also meant that the participating farmers could continue condition scoring their ewes once the project ended.

The same, experienced operator pregnancy scanned the ewes at the Sussex and Leicestershire Farms. A second experienced operator scanned the ewes at the Lancashire Farm. Accuracy of pregnancy diagnosis can vary between individual operators (White *et al.*, 1984) based on experience (Fridlund *et al.*, 2011; Buckrell, 1988) and age of the fetus (Karen *et al.*, 2006) at scanning. However, there were no concerns regarding the accuracy of their work on the study farms.

The Lancashire Farm was the only farm to have all genotypes represented at each parity. Both the Sussex and Leicestershire Farms had different genotypes at different parities, with new genotypes introduced during the three years. This resulted in entire parities being absent at Leicestershire Farm but also the newer genotypes being younger, by comparison.

2.9.2 Ewe performance to lambing

The industry target of achieving 3% or less barren ewes at scanning (Teagasc, 2019) was achieved each year at both Leicestershire and Lancashire Farms and two out of the three years at the Sussex Farm.

Litter size at scanning fluctuated across the three years between the farms, with only the Sussex Farm increasing year-on-year. The Leicestershire Farm saw a decrease in litter size at scanning between Years 1 and 2 before increasing again in Year 3. This decline in Year 2 was attributed to the contribution from shearling ewes for two reasons. Firstly, they were younger and accounted for a third of flock and, secondly, a lungworm diagnosis affected condition and performance. The target for lowland flocks (with no ewe lambs) to achieve greater than 190% at scanning (AHDB, 2019b) was achieved by the Lancashire Farm only who consistently achieved over 200% scanning.

The opportunity to collate and benchmark ewe scanning results year-on-year would provide farmers and the industry with year-on-year comparisons on flock performance to scanning. However, a representative sample would be required to reduce potential bias. This would include representation of lowland and hill farms.

The percentage of ewes not rearing a lamb also varied by year and across farms. Overall, between 5 and 8% of ewes did not rear a lamb at tagging (48 h post-lambing). This figure is inclusive of ewes barren at scanning, meaning that between 2 and 4% of ewes scanned pregnant did not have a lamb at tagging. Ewes not rearing a lamb included ewe and lamb mortalities or the absence of a record. As previously discussed, there are no figures to benchmark.

2.9.3 *Lamb performance*

The focus of this study was ewe fertility and lamb growth to weaning. Detailed analysis of neonatal mortality was not a focal point of this research and has not been provided or analysed. The author recognises that neonatal mortality is important and can impact flock performance and profitability, but these parameters are confounded by other factors outside the scope of this research project.

Management group details such as stocking rates, grazing quantity and quality and lamb performance post-weaning were not analysed as part of this project. Birthweight data was not available for all three farms each year. As a result, lamb birthweight does not feature in this project. Lamb performance to weaning utilises data for single and twin reared lambs only for the Sussex and Leicestershire Farms. As few ewes were predicted to have triplets, based on scanning results, the majority of triplet lambs born alive were fostered, resulting in few (if any) ewes rearing triplets. Ewes did rear triplets at the Lancashire Farm and these are included in the 8-week and weaning weight analyses in this chapter. Losses occurred between production points (i.e. tagging, 8 weeks and weaning). Reasons for these losses included mortality, lost record or lambs sold. Finally, to account for the variation in lamb age at 8 weeks and weaning, reflecting date of birth, lamb weight data in this chapter was adjusted to 56 days and 90 days. This enables fairer comparison between years and farms.

2.9.3.1 *Performance at 8 weeks (adjusted to 56 days)*

There are no industry targets for lamb 8-week weight to compare the performance of the three farms. The 20 kg target at 8 weeks was calculated based on mean 5 kg lamb birthweight (Thompson *et al.*, 2004; Gardner, 2007; Gubbins, 2016); and mean DLWG of 270 g/day over a 56 day period. The mean liveweight gain from birth to weaning (at 12 weeks) of 282 g/day (range 195 – 340 g/day) (Muir *et al.*, 2003) and pre-weaning lamb growth rates of 240-260 g/day (B&LNZ, 2014) support this calculation.

The Lancashire Farm was the only flock to achieve the lamb 8-week target of 20 kg (adjusted for lamb age) for each of the three years. The Leicestershire Farm achieved the target two out of three years and the Sussex Farm achieved it once. The flock at the Sussex Farm had a higher incidence of lame ewes at housing, and a navel ill outbreak in lambs during Year 3, both affected flock performance (Angus, 1991; Winter, 2008). All three flocks achieved the 20 kg target in Year 2.

The Lancashire Farm was also the only farm to achieve the recommended BCS targets during the production cycle. Analysis in the following chapters of this thesis will determine the significance of this on lamb performance. The current data suggests that flocks achieving the recommended flock BCS targets are more likely to achieve the lamb performance to 8 weeks. Whilst the target of 20 kg was not achieved on every farm, every year it is still a realistic target to set for lowland commercial sheep farms at 8 weeks.

2.9.3.2 *Light lambs at 8 weeks*

Lambs were classed as 'light' at 8 weeks old if they weighed 15% less than the 20 kg target (in this instance lambs weighing less than 17 kg). The percentage of light lambs varied significantly by year and farm. The range across the three farms over three years was 7 to 35%. Lancashire had less than 15% of their lamb crop light each year (Table 2.17), the Sussex Farm ranged between 15 to 35% (Table 2.15) and the Leicestershire Farm ranged between 15 to 23% (Table 2.16). There are no national targets to compare these and determine good, average or poor performance. However, this data would suggest that it is realistic for flocks to have fewer than 15% of their lambs below 17 kg 8 weeks post-lambing when the target is 20 kg.

Further research is required to establish the causes underlying light lambs. The rumen of a new-born ruminant is a small, non-functional sac, compared with an adult ruminant where the rumen accounts for 80% of the stomach mass (Church, 1969). The abomasum has the fastest growth in the first seven days of life but by three weeks, the rumen becomes the largest with the abomasum remaining similar in size (Wardrop & Coomb, 1960). Rumen development depends on the presence of solid feed to stimulate morphological development (Abou-Ward, 2008). A possible contribution to light lambs is poor ewe milk production and the effects on rumen function in the first three to four weeks.

2.9.3.3 *Lamb performance at weaning (adjusted to 90 days)*

The 30 kg target at weaning (at 12 weeks or 90 days) is calculated based on mean 5 kg lamb birthweight (Thompson et al., 2004) and mean DLWG of 280 g/day over a 90 day period. Similar to lamb 8-week weight, there are no industry targets to compare the performance of the three farms. The Lancashire Farm was the only farm to achieve this target, in Years 2 and 3. Despite achieving 20 kg at 8 weeks in Year 1, lamb performance between 8 weeks and weaning was affected by liver fluke and a diagnosis of triclabendazole resistance on the farm affected performance to weaning. The Sussex and Leicestershire Farms did not achieve the 30 kg target in any year.

Mean liveweight gain from birth to weaning (at 12 weeks of age) can approach 300 g/day (Muir *et al.*, 2003). However, this thesis and other literature sources, suggest a target of 30 kg is on the higher end of what is achievable on most commercial sheep farms. Sheep producers in Australia aim to wean lambs at 45% of their mature bodyweight, or greater than 20 kg (Thompson *et al.*, 2011) with Gascoigne & Lovatt, (2015) recommending lambs should exceed 25 kg at weaning.

2.9.4 Ewe BCS and liveweight

Comparing the flock BCS data to industry recommendations, ewe BCS at weaning, mating and scanning are below target at the Leicestershire Farm (Appendix I; Table 2), on target at the Sussex Farm (Appendix I; Table 1), and exceeding target at the Lancashire Farm (Appendix I; Table 3), each year. The condition at weaning of the preceding production cycle appears to determine the BCS profile for the subsequent production cycle due to the time and potentially feed availability to regain the required condition between weaning and mating.

BCS loss occurred between scanning and lambing for three consecutive years at both the Sussex and Leicestershire Farms. Ewes maintained their condition through to lambing at the Lancashire Farm, in-line with industry targets (AHDB, 2014b). Ewes at the three farms lost BCS between lambing and weaning. It is not uncommon for feed intake to fail to meet the nutritional demands of lactation, resulting in ewes mobilising fat reserves (Gibb & Treacher, 1980; Vernon & Finley, 1985). However, ewe BCS at lambing, BCS loss during lactation and the resulting lamb performance suggests that ewes at the Lancashire Farm maintaining condition to lambing and losing it during lactation is likely to have contributed to the improved performance of lambs at 8-weeks and weaning. This would be supported by (McNeill *et al.*, 1997; Gibb & Treacher, 1980; Brand & Franck, 2000; Lambe *et al.*, 2005) who reported that ewe milk production and lamb growth to weaning is greatest for ewes that have more fat to mobilise.

Mean flock liveweight profile reflected BCS with respect to when weight was lost and gained. However, there are no guidelines relating to the change in ewe liveweight during the production cycle and its impact on flock performance. The only liveweight targets are mating targets for ewe lambs and shearling ewes based on the mature liveweight of ewes. Ewes mated to lamb as ewe lambs should weigh 60% of their mature weight and shearlings should weigh 80% of their mature bodyweight at mating (SAC, 2009).

2.10 Conclusion

Flock performance, in terms of performance at scanning and lamb performance to weaning varied between years and across the three farms. The percentage barren ewes across the three farms were comparable to national targets but only the Lancashire Farm achieved the target litter size at scanning. This data also suggests that, in addition to barren ewes at scanning, up to a further 4% of ewes scanned as pregnant do not rear a lamb 48 h post-lambing.

A lamb target of 20 kg at 8 weeks is realistic and achievable for lowland/upland sheep flocks. However, achieving 30 kg at weaning (12 weeks) appears less achievable. Producers should aim for fewer than 15% of their lamb crop to be 15% lighter than their flock target (for a 20 kg target, this equates to 17 kg). Further work is required to determine the reasons for light lambs at 8 weeks.

The Lancashire Farm was the only farm to achieve the recommended BCS profile during the production cycle. The Lancashire Farm also had the highest litter size at scanning, achieved the 8-week target of 20 kg each year, had the lowest percentage of light lambs at 8 weeks and achieved the weaning target of 30 kg in two out of the three years. This suggests that achieving current BCS targets improves flock performance. The number of farms achieving the national BCS targets is unknown. Two of the three study farms did not to achieve these, suggesting many farms in England could improve flock BCS and subsequently flock performance. It is harder to determine the impact of ewe liveweight on flock performance due to the absence of any targets, although liveweight and liveweight change appear to follow the same trend as BCS (e.g. when BCS was lost or gained, liveweight changed accordingly).

3 *CHAPTER THREE: Factors affecting pregnancy establishment*

3.1 Introduction

The proportion ewes pregnant at scanning is, under most circumstances, high with a target for 97 percent of ewes (2 years and older) to be pregnant at the time of ultrasound scanning (50 to 90 days after mating) (Keady, 2001). Litter size of pregnant ewes is more variable and affected by farming system, ewe genotype and production cycle. There are no national figures available to ascertain the annual proportion ewes pregnant or litter size at scanning in the UK.

Collectively there are several periods of vulnerability in the first month post-fertilisation with about a quarter of embryos failing to implant (Henderson, 2002). A key determinant of a successful pregnancy is the ovulation rate (number of eggs shed at ovulation) followed by embryo and fetal survival. Factors that can affect ovulation rate and fetal survival are pre-mating body condition and nutrition (Shorten *et al.,* 2013), ewe age (Kenyon *et al.,* 2011; Shorten *et al.,* 2013), disease for example infectious abortion (Williams *et al.,* 2005), the environment including extreme weather events and genetics (Spencer, 2013). Often there can be more than one factor, with two or more confounding one another (Gunn & Doney, 1977; Land, 1977; Scaramuzzi & Radford, 1983) e.g. young ewes in poor body condition.

Mating ewes below BCS 2.5 units increases the risk of being barren at scanning (Bohan & Keady, 2019). Ewes mated within the BCS range of 2.5–3.5 units BCS should maintain condition during early pregnancy (Russel, 1984). Increasing BCS at mating within the range of 2.5 and 4 units BCS is estimated to increase litter size by 0.13 lambs per ewe mated (Bohan & Keady, 2019). Liveweight at the commencement of mating has a considerable influence on the reproductive performance of sheep, especially the percentage of twins produced (Coop, 1962). Ewe liveweight and liveweight gain during the mating period results in higher ovulation rates with each extra kg of ewe liveweight at mating increasing lambing percentage by 2% (B&LNZ, 2013a).

Ewes are likely to lose condition during mid-pregnancy due to the demands of pregnancy coinciding with a reduction in the quality and quantity of forage available and can lose up to 0.5 units of BCS (depending on their starting point), with minimal impacts on productivity (Russel, 1984). However, several studies have shown that restrictions in maternal nutrition during mid-pregnancy has mixed effects, most relating to placental growth and lamb birthweight. Some conclude that maternal under nutrition during mid-pregnancy has a positive effect on placental development (Kelly *et al.,* 1992; Heasman *et al.,* 2007; Robinson, 1990), some report a negative effect (Clarke *et al.,* 1988; Orr and Treacher, 1990; Robinson *et al.,* 2002; Addah *et al.,* 2012) and others report no effect (Clark and Speedy, 1980; McCrabb *et al.,* 1986; Kenyon *et al.,* 2011).

The current chapter reports on the effects of ewe age (parity), ewe genotype, BCS and liveweight from weaning to mid-pregnancy (scanning) on proportion ewes pregnant and litter size of pregnant ewes at scanning. Specifically, this chapter sought, firstly, to establish if ewe BCS and/or liveweight, or change in ewe BCS and/or liveweight, at various stages from weaning (in the preceding production cycle) to scanning (in the subsequent production cycle) was associated with pregnancy establishment at scanning.

3.2 Materials and methods

Details relating to the data collection for this analysis are provided in Chapter 2 (2.2.2 Data collection). The current chapter analysed factors that affect the proportion ewes pregnant at scanning and litter size (fetal number) at scanning. Litter size analysis pertained only to those ewes identified as pregnant at scanning. This was determined by transabdominal ultrasonography by an experienced operator at approximately 70-80 days following mating.

Analyses were performed using the GenStat statistical package (18^{th} Edition, VSN International, 2019; https://www.vsni.co.uk/). All proportion data were analysed using generalized linear models that assumed binomial errors and used logit-link functions. For the analysis of litter size (fetal number), the same statistical models were applied but, on this occasion, they assumed Poisson errors and used log-link functions. In the final version of these models, the following terms were fitted for the Sussex and Leicestershire Farms: 'Genotype', 'BCS' or 'Liveweight' or 'Change in BCS or liveweight', together with interactions between these terms. At the Lancashire Farm the term 'Parity' was also included. In the pooled analyses, the following terms were fitted: 'Farm', 'Year', 'BCS' or 'Liveweight' or 'Change in BCS or liveweight', together with interactions between these terms. Probabilities <0.05 was deemed significant. Data are presented as means ± SE.

3.3 *Results: Pregnancy establishment outcomes at scanning*

3.3.1 Sussex Farm: *Pregnancy establishment outcomes at scanning*

3.3.1.1 *Ewe genotype*

Proportion ewes pregnant at scanning was not associated with ewe genotype in any of the three years (Table 3.1). However, litter size at scanning was associated with ewe genotype in Years 1, 2 and 3 ($P<0.001$, $P<0.001$ and $P=0.018$, respectively; Table 3.2). Mule ewes consistently achieved the greatest litter sizes. However, the rankings for Aberfield and Lleyn ewes differed between years.

Table 3.1. Effect of ewe genotype on proportion ewes pregnant at scanning (mean ± SE) in Years 1 to 3 at the Sussex Farm. In each column, proportion pregnant is ranked in order of highest to lowest.

Year 1	Year 2	Year 3
Lleyn	Mule	Lleyn
0.94 ± 0.009	0.97 ± 0.007	0.97 ± 0.005
Aberfield	Aberfield	Aberfield
0.91 ± 0.013	0.96 ± 0.007	0.96 ± 0.007
Mule	Lleyn	Mule
0.90 ± 0.013	0.94 ± 0.007	0.95 ± 0.010

Table 3.2. Effect of ewe genotype on mean litter size at scanning (± SE) in Years 1 to 3 at the Sussex Farm. In each column, litter size is ranked in order of highest to lowest.

Year 1	Year 2	Year 3
Mule	Mule	Mule
1.95 ± 0.040	1.98 ± 0.044	1.96 ± 0.047
Lleyn	Lleyn	Aberfield
1.68 ± 0.031	1.76 ± 0.031	1.86 ± 0.032
Aberfield	Aberfield	Lleyn
1.65 ± 0.036	1.70 ± 0.031	1.77 ± 0.031

3.3.1.2 *Ewe parity*

Proportion pregnant at scanning was not associated with ewe parity during any of the three years (Figure 3.1 A-C). However, litter size at scanning was positively associated with ewe parity for each of the three years ($P<0.001$; Figure 3.1 D-F). On all occasions, litter size at scanning increased as ewe parity increased (between 1 and 5).

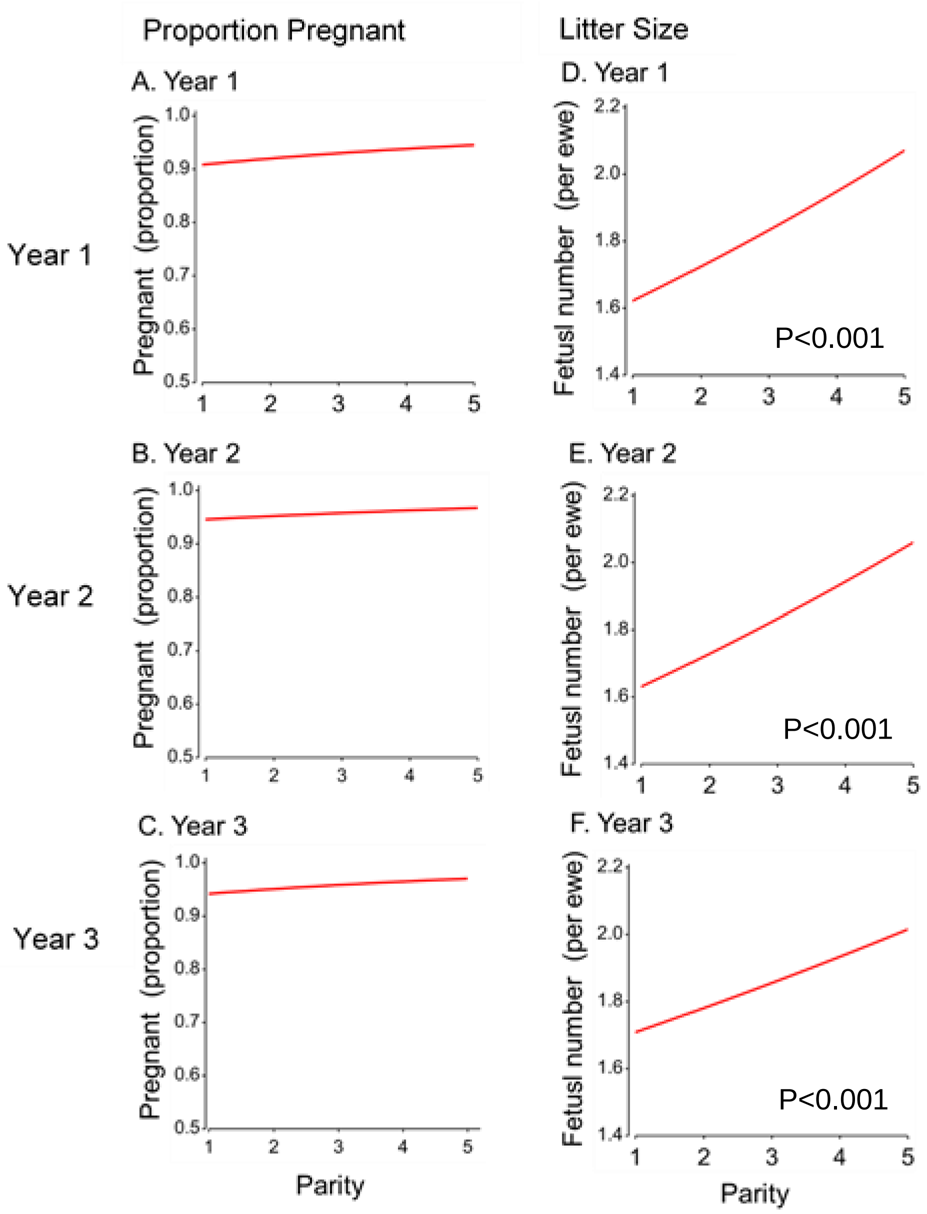


Figure 3.1. Association between **ewe parity** and proportion ewes pregnant at scanning (A-C) and litter size at scanning (D-F) at the Sussex Farm. Year 1 (A, D), Year 2 (B, E) and Year 3 (C, F). (---) denotes generic relationship irrespective of ewe genotype.

3.3.1.3 *Ewe BCS and liveweight at weaning (preceding production cycle)*

In these combined analyses, the effect of ewe genotype and BCS or liveweight at weaning remained as reported in 3.3.1.1 with no effect on proportion pregnant but a significant (P<0.001) effect on litter size at scanning (Table 3.3).

Proportion pregnant at scanning in the subsequent production cycle was not associated with ewe BCS at weaning. However, there was a ewe genotype x BCS interaction in Year 2 (P=0.027; Figure 3.2 B), whereby the proportion ewes pregnant at scanning increased with increasing BCS at weaning for Aberfield and Lleyn ewes but decreased for Mule ewes.

Proportion ewes pregnant in the subsequent scanning was positively associated with ewe liveweight at weaning in Year 2 (P=0.010; Figure 3.2 E). However, there was a ewe genotype x liveweight interaction in Year 3 (P=0.028; Figure 3.2 F). Similar to the interaction with BCS in Year 2, the proportion ewes pregnant at scanning decreased with increasing liveweight at weaning for Mule ewes but not for the other two genotypes.

Litter size at scanning in the subsequent production cycle was positively associated with ewe BCS and liveweight at weaning; but in Year 1 only (P=0.041 and P=0.013, respectively; Figure 3.2 G, J), with just an indication that the same association was present in Year 3 for liveweight (P=0.067; Figure 3.2 L). There were no interactions between ewe genotype and either BCS or liveweight at weaning on litter size in the subsequent production cycle.

Table 3.3. Effect of ewe genotype when modelling for the effects of ewe BCS (units) and liveweight (kg) **at weaning of the preceding production cycle** on mean litter size (± SE) at scanning in the subsequent production cycle in Years 1 to 3 years at the Sussex Farm. In each column, litter size is ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule	Mule	Mule	Mule	Mule	Mule
1.96 ±0.040	1.93 ±0.041	2.00 ±0.045	1.99 ±0.047	2.07 ±0.061	2.02 ±0.060
Aberfield	Lleyn	Lleyn	Lleyn	Aberfield	Aberfield
1.75 ±0.055	1.82 ±0.052	1.83 ±0.038	1.84 ±0.039	1.91 ±0.039	1.91 ±0.038
Lleyn	Aberfield	Aberfield	Aberfield	Lleyn	Lleyn
1.73 ±0.049	1.79 ±0.056	1.80 ±0.044	1.80 ±0.044	1.85 ±0.041	1.86 ±0.041

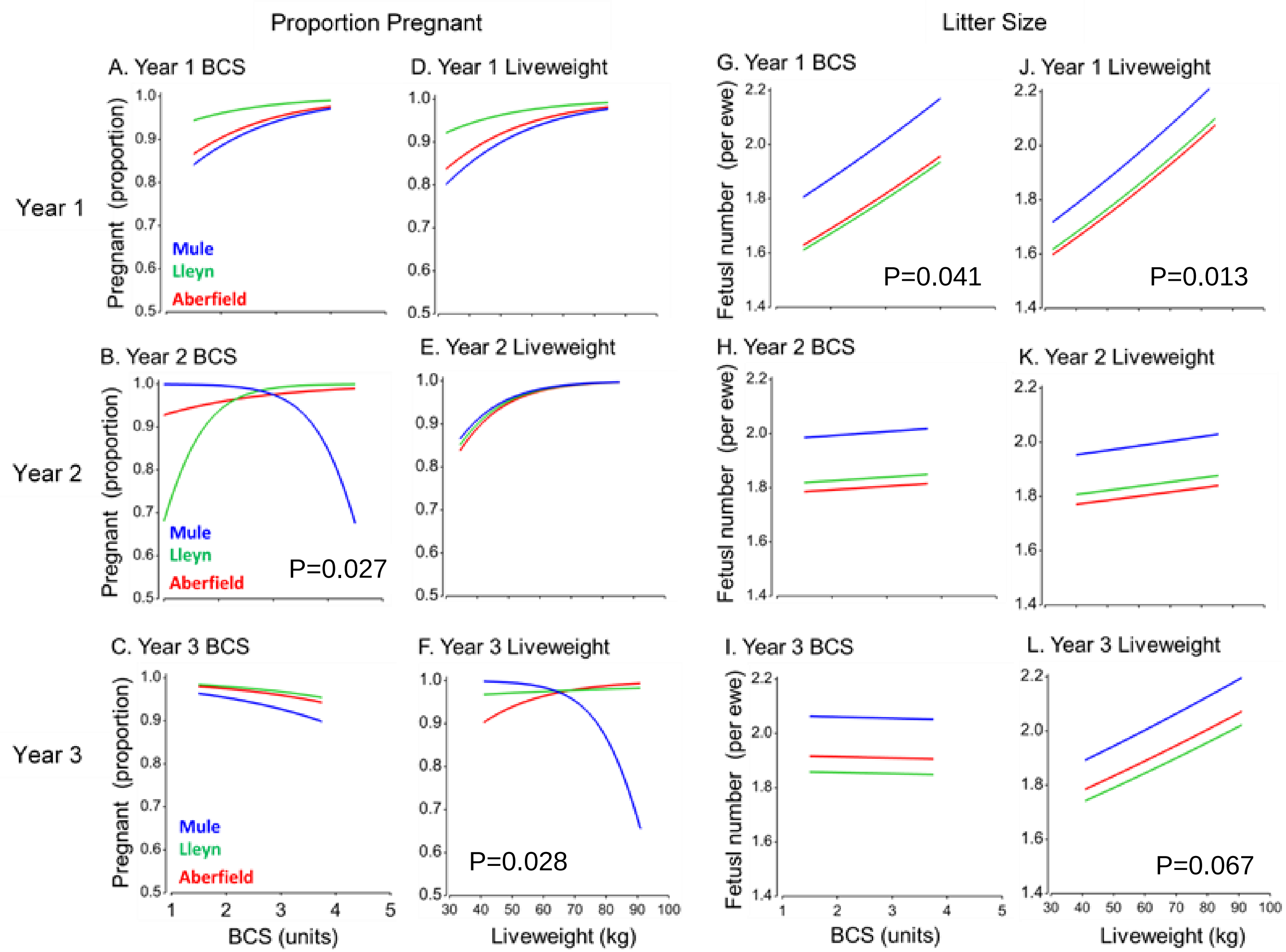


Figure 3.2. Association between ewe BCS (A-C; G-I) and liveweight (D-F; J-L) **at weaning** of the preceding production cycle on proportion ewes pregnant at scanning (A-F) and litter size at scanning (G-L) in the subsequent production cycle at the Sussex Farm (Year 1 (A, D, G, J), Year 2 (B, E, H, K) and Year 3 (C, F, I, L)). Ewe genotype: Aberfield (---), Lleyn (---) and Mule (---).

3.3.1.4 *Ewe BCS and liveweight at mating*

In these combined analyses, ewe genotype continued to only be associated with litter size at scanning. Mule ewes achieved the highest litter size across all three years (P<0.001; Table 3.4).

Proportion pregnant at scanning was not associated with ewe BCS or ewe liveweight at mating (Figure 3.3 A-F). However, there was a ewe genotype x BCS interaction at mating in Year 2 (P<0.001; Figure 3.3 B), whereby the proportion ewes pregnant decreased significantly for Mules when BCS at mating was greater than 3.5 units, but not for the other two genotypes. There was also a ewe genotype x liveweight interaction in Year 3 (P=0.007; Figure 3.3 F). The proportion ewes pregnant decreased with increasing liveweight at mating for Mule ewes, increased for Lleyn ewes, and had little effect in Aberfield ewes.

Litter size at scanning was not associated with ewe BCS at mating (Figure 3.3 G-I). However, litter size at scanning was positively associated with ewe liveweight at mating in Years 1, 2 and 3 (P<0.001, P<0.001 and P=0.002, respectively; Figure 3.3 J-L). Heavier ewes at mating (up to 90 kg) produced larger litters. There was also a ewe genotype x liveweight interaction at mating, but in Year 3 only (P=0.039; Figure 3.3 L). Increasing ewe liveweight at mating resulted in an increase in litter size at scanning for Aberfield and Lleyn ewes, but not for Mule ewes which appeared to decrease.

Table 3.4. Effect of ewe genotype **at mating** when modelling the effects of ewe BCS (units) and liveweight (kg) on mean litter size (± SE) at scanning in Years 1 to 3 at the Sussex Farm. In each column, litter size is ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule 1.94 ±0.040	Mule 1.85 ±0.045	Mule 1.98 ±0.045	Mule 1.88 ±0.046	Mule 2.01 ±0.046	Mule 1.94 ±0.046
Lleyn 1.67 ±0.032	Lleyn 1.73 ±0.035	Lleyn 1.83 ±0.038	Lleyn 1.80 ±0.035	Aberfield 1.83±0.033	Aberfield 1.83 ±0.033
Aberfield 1.65 ±0.040	Aberfield 1.66 ±0.036	Aberfield 1.80 ±0.044	Aberfield 1.69 ±0.032	Lleyn 1.74 ±0.032	Lleyn 1.78 ±0.033

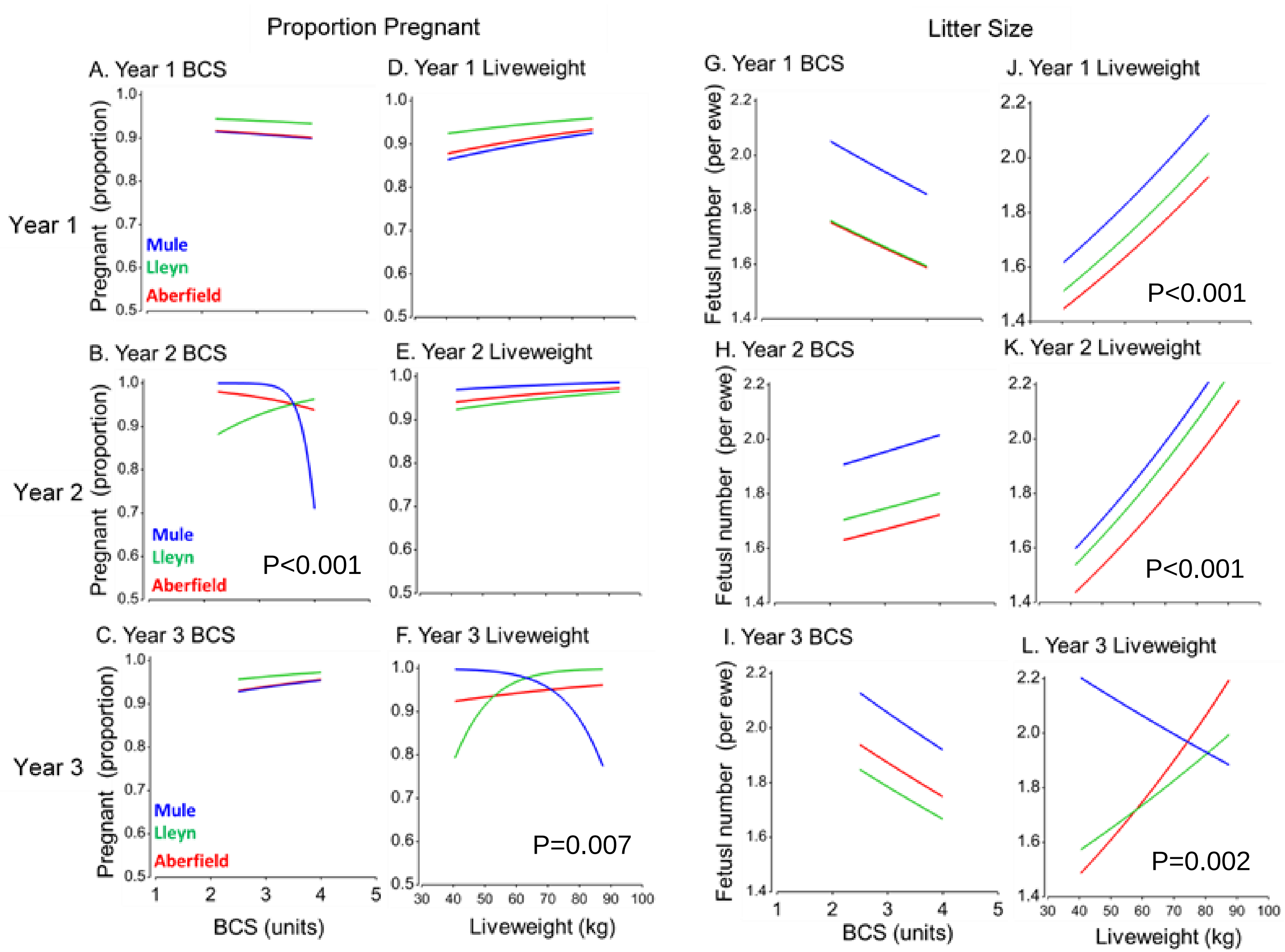


Figure 3.3. Association between ewe BCS (A-C; G-I) and liveweight (D-F; J-L) **at mating** on proportion ewes pregnant at scanning (A-F) and litter size at scanning (G-L) at the Sussex Farm (Year 1 (A, D, G, J), Year 2 (B, E, H, K) and Year 3 (C, F, I, L)). Ewe genotype: Aberfield (**---**), Lleyn (**---**) and Mule (**---**).

3.3.1.5 *Ewe BCS and liveweight change between weaning and mating*

In these analyses, litter size and ewe genotype were significant for all three production cycles (P<0.001). Litter size at scanning was greatest for Mule ewes at scanning; the ranking thereafter of Lleyn and Aberfield ewes differed between years and differed when the effects of BCS and liveweight were modelled (Table 3.5).

Overall, proportion ewes pregnant at scanning was not associated with ewe BCS and liveweight change between weaning and mating. There was a suggestion of a positive association with BCS in Year 3 only (P=0.066; Figure 3.4 C); and a suggestion of a negative association with liveweight in Year 2 only (P=0.083; Figure 3.4 E).

Litter size was not associated with ewe BCS change in Years 2 and 3 (Figure 3.4 B-C), but there was a ewe genotype x BCS interaction on subsequent litter size at scanning in Year 1 (P=0.009; Figure 3.4 G). Litter size decreased as BCS change increased and became positive for Mule and Aberfield ewes, but the opposite was true for Lleyn ewes. There was a positive association with litter size at scanning and ewe liveweight change between weaning and mating, in Year 2 only (P=0.001; Figure 3.4 K).

Table 3.5. Effect of ewe genotype when modelling for the effects of change in ewe BCS (units) and liveweight (kg), **between weaning and mating**, on mean litter size at scanning (± SE) in Years 1 to 3 at the Sussex Farm. In each column, litter size is ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule 1.96 ±0.040	Mule 1.95 ±0.042	Mule 2.00 ±0.046	Mule 1.99 ±0.045	Mule 2.08 ±0.063	Mule 2.05 ±0.059
Aberfield 1.79 ±0.055	Lleyn 1.78 ±0.057	Lleyn 1.83 ±0.041	Lleyn 1.83 ±0.040	Aberfield 1.90±0.039	Aberfield 1.91 ±0.038
Lleyn 1.75 ±0.050	Aberfield 1.78 ±0.052	Aberfield 1.78 ±0.045	Aberfield 1.77 ±0.044	Lleyn 1.86 ±0.041	Lleyn 1.85 ±0.040

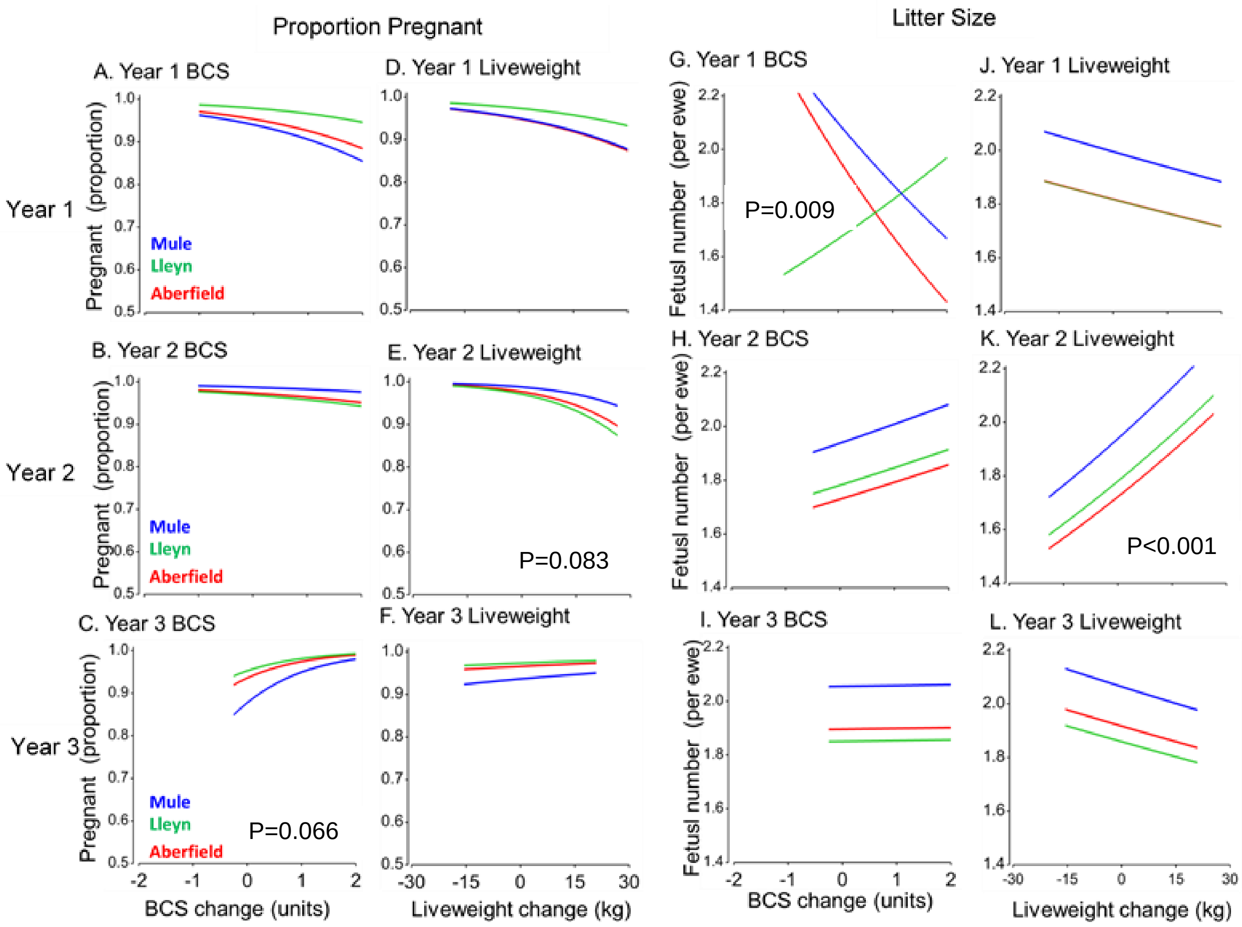


Figure 3.4. Association between ewe BCS change (A-C; G-I) and liveweight change (D-F; J-L) **between weaning of the preceding production cycle and mating** of the subsequent production cycle on proportion ewes pregnant at scanning (A-F) and litter size at scanning (G-L) at the Sussex Farm (Year 1 (A, D, G, J), Year 2 (B, E, H, K) and Year 3 (C, F, I, L)). Ewe genotype: Aberfield (---), Lleyn (---) and Mule (---).

3.3.1.6 *Ewe BCS and liveweight at scanning*

In these analyses, litter size at scanning continued to be associated with ewe genotype (P<0.001; Table 3.6). Similar to weaning and mating, Mule ewes consistently achieved the highest litter size at scanning. The order of Aberfield and Lleyn ewes differed between years. However, the order was consistent between BCS and liveweight.

Proportion ewes pregnant at scanning was positively associated with ewe BCS at scanning, but in Year 2 only (P<0.001; Figure 3.5 B). Litter size at scanning was not associated with ewe BCS at scanning (Figure 3.5 G-I). Proportion pregnant (P<0.001; Figure 3.5 E-F) and litter size at scanning (P<0.001; Figure 3.5 K-L) were positively associated with ewe liveweight at scanning in Years 2 and 3. Heavier ewes at scanning (up to 90 kg) had larger litter sizes at scanning compared to lighter ewes. There were no interactions between ewe genotype and either BCS or liveweight at mating on proportion pregnant or litter size at scanning.

Table 3.6. Effect of ewe genotype when modelling for the effects of ewe BCS (units) and liveweight (kg) **at scanning,** on mean litter size (±SE) in Years 1 to 3 at Sussex Farm. In each column litter size are ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule 1.92 ±0.043	Mule 1.93 ±0.041	Mule 1.99 ±0.044	Mule 1.84 ±0.046	Mule 1.98 ±0.046	Mule 1.89 ±0.047
Lleyn 1.68 ±0.032	Lleyn 1.69 ±0.033	Lleyn 1.77 ±0.031	Lleyn 1.80 ±0.033	Aberfield 1.81±0.033	Aberfield 1.79 ±0.035
Aberfield 1.65 ±0.037	Aberfield 1.65 ±0.037	Aberfield 1.70 ±0.032	Aberfield 1.71 ±0.032	Lleyn 1.73 ±0.031	Lleyn 1.77 ±0.035

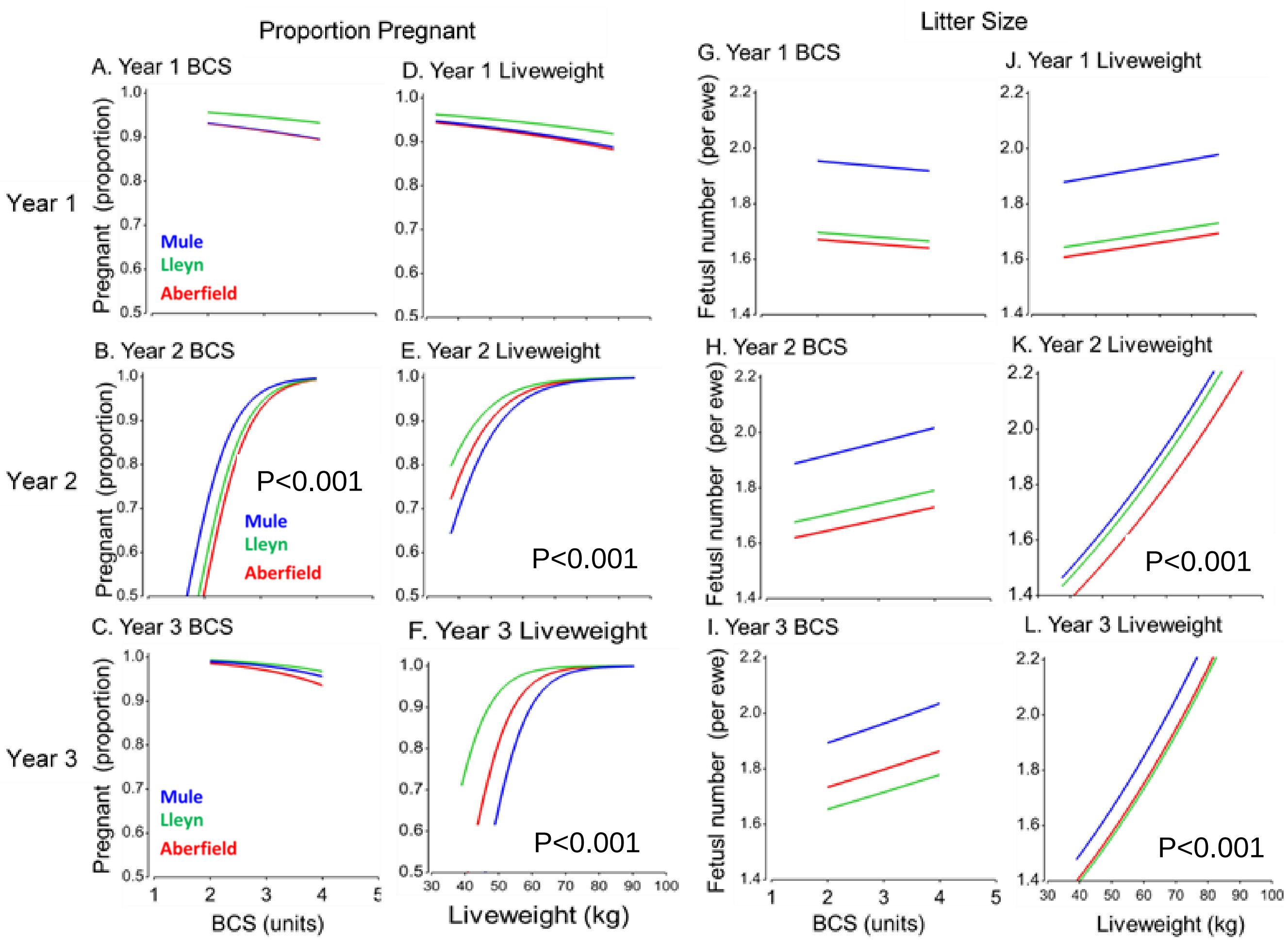


Figure 3.5. Association between ewe BCS (A-C; G-I) and liveweight (D-F; J-L) **at scanning** on proportion ewes pregnant at scanning (A-F) and litter size at scanning (G-L) at the Sussex Farm (Year 1 (A, D, G, J), Year 2 (B, E, H, K) and Year 3 (C, F, I, L)). Ewe genotype: Aberfield (**---**), Lleyn (**---**) and Mule (**---**).

3.3.1.7 *Ewe BCS and liveweight change between mating and scanning*

In these analyses, litter size at scanning continued to be associated with ewe genotype (P<0.001; Table 3.7). Mule ewes consistently achieved the largest litters at scanning. The rankings for genotype differed between BCS and liveweight analyses, and also differed between years for Aberfield and Lleyn ewes.

Proportion ewes pregnant was positively associated with ewe BCS change between mating and scanning in Year 2 (P=0.012; Figure 3.6 B), and positively associated with ewe liveweight change in Years 2 and 3 (P<0.001; Figure 3.6 E-F). The proportion pregnant at scanning increased as BCS and liveweight maintained or increased between mating and scanning. Litter size at scanning was positively associated with BCS gain between mating and scanning, but in Year 3 only (P=0.012; Figure 3.6 I). A similar positive relationship with litter size was also observed for liveweight change in Years 2 and 3 (P=0.005 and P<0.001, respectively; Figure 3.6 L). However, a ewe genotype x liveweight change interaction in Year 2 indicated this was the case for Lleyn and Aberfield ewes but not for Mule ewes (P=0.009; Figure 3.6 K).

Table 3.7. Effect of ewe genotype when modelling for the effects of change in ewe BCS (units) and liveweight (kg) **between mating and scanning**, on mean litter size at scanning (± SE) in Years 1 to 3 at the Sussex Farm. In each column, litter size are ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule	Mule	Mule	Mule	Mule	Mule
1.94 ±0.041	1.92 ±0.041	2.00 ±0.048	1.95 ±0.046	1.98 ±0.050	2.00 ±0.049
Aberfield	Lleyn	Lleyn	Lleyn	Aberfield	Aberfield
1.66 ±0.039	1.69 ±0.032	1.77 ±0.034	1.77 ±0.034	1.80±0.033	1.79 ±0.035
Lleyn	Aberfield	Aberfield	Aberfield	Lleyn	Lleyn
1.66 ±0.033	1.66 ±0.037	1.69 ±0.033	1.69 ±0.033	1.72 ±0.031	1.71 ±0.034

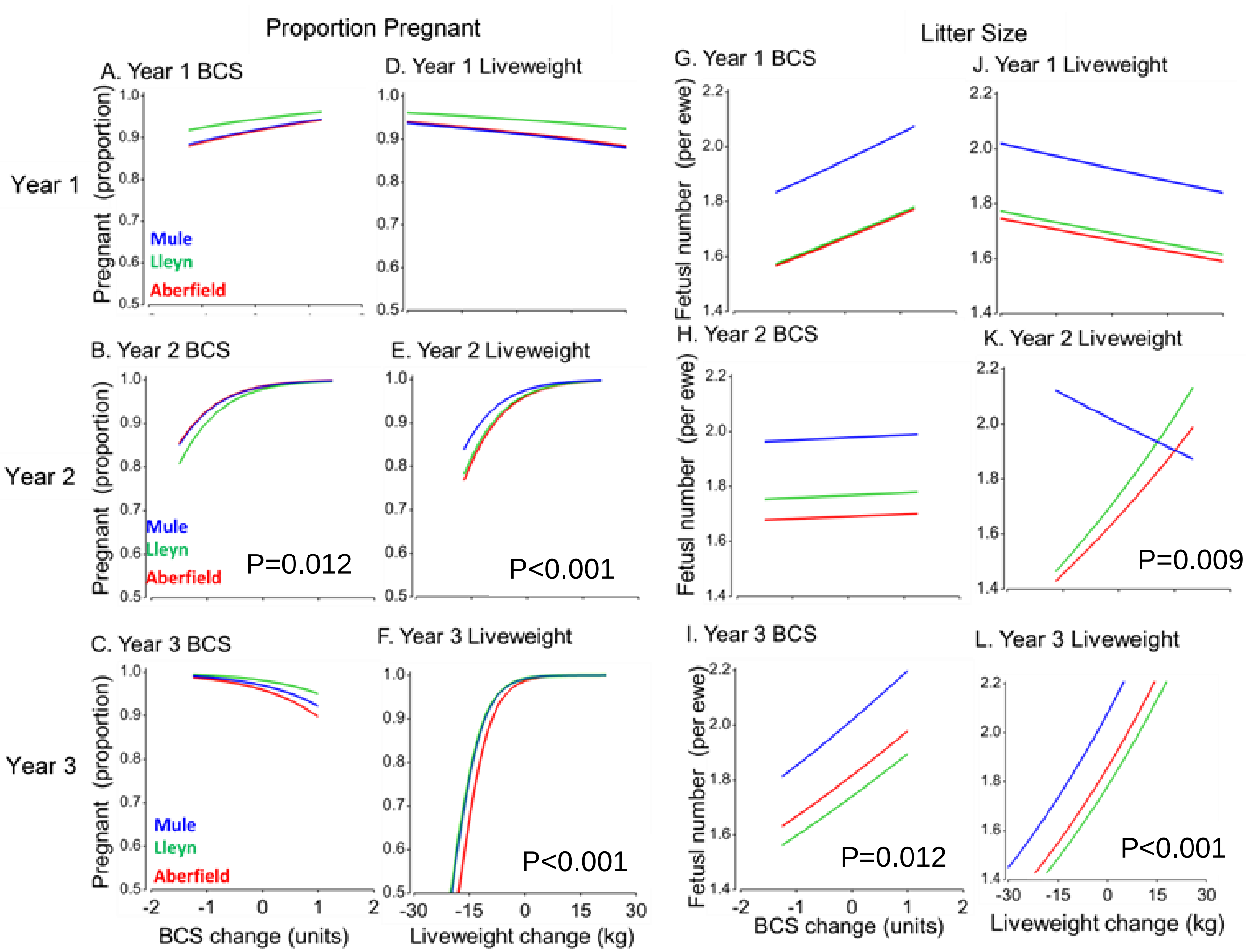


Figure 3.6. Association between ewe BCS change (A-C; G-I) and liveweight change (D-F; J-L) **between mating and scanning** on proportion ewes pregnant at scanning (A-F) and litter size at scanning (G-L) at the Sussex Farm (Year 1 (A, D, G, J), Year 2 (B, E, H, K) and Year 3 (C, F, I, L)). Ewe genotype: Aberfield (**---**), Lleyn (**---**) and Mule (**---**).

3.3.1.8 Key findings for pregnancy establishment: Sussex Farm

Litter size at scanning was consistently highest for Mule ewes in all three years, at each production point (weaning, mating and scanning) and between production points (weaning to mating and mating to scanning). The order thereafter, for Aberfield and Lleyn ewes varied between production points.

Proportion ewes pregnant at scanning was not associated with ewe parity but litter size at scanning was positively associated with ewe parity. Parity 1 ewes had the lowest litter size each year, irrespective of ewe genotype.

Proportion ewes pregnant at scanning was not associated with ewe BCS and liveweight at weaning and mating, or change in BCS and liveweight between weaning and mating; other than for ewe genotype interactions. In contrast, litter size at scanning was associated with these production points, although not consistently across the years; with the exception of ewe liveweight at mating where heavier ewes at mating resulted in higher litter size at scanning for all three years.

Proportion ewes pregnant was associated with ewe BCS and liveweight at scanning, and change in BCS and liveweight between mating and scanning, but only in Years 2 and 3. Overall, ewes with higher BCS and heavier ewes at scanning, and ewes maintaining or gaining condition during this period, were likely to have a higher proportion of ewes pregnant and higher litter sizes at scanning.

3.3.2 Leicestershire Farm: *Pregnancy establishment outcomes at scanning*

3.3.2.1 Ewe genotype

Proportion pregnant at scanning was not associated with ewe genotype (Table 3.8). However, litter size at scanning was associated with ewe genotype for all three production cycles (P<0.001; Table 3.9). Litter size was consistently greater for Mule ewes followed by Charollais and Aberfield ewes.

Table 3.8. Effect of ewe genotype on proportion ewes pregnant at scanning (mean ± SE) for Years 1 to 3 at the Leicestershire Farm. In each column, proportion ewes pregnant are ranked in order of highest to lowest.

Year 1	**Year 2**	**Year 3**
Mule 0.98 ±0.002	Mule 0.99 ±0.002	Charollais 1.00 ±0.000
Charollais 0.96 ±0.005	Aberfield 0.96 ±0.004	Mule 0.99 ±0.002
-	Charollais 0.95 ±0.007	Aberfield 0.97 ±0.003

Table 3.9. Effect of ewe genotype on litter size at scanning (mean ± SE) for Years 1 to 3 at the Leicestershire Farm. In each column, litter size are ranked in order of highest to lowest.

Year 1	**Year 2**	**Year 3**
Mule 1.93 ± 0.017	Mule 1.96 ± 0.020	Mule 2.12 ± 0.028
Charollais 1.72 ± 0.032	Charollais 1.71 ± 0.036	Charollais 1.86 ± 0.058
-	Aberfield 1.52 ± 0.023	Aberfield 1.70 ± 0.018

3.3.2.2 Ewe parity

Proportion pregnant at scanning was not associated with ewe parity (Figure 3.7 A-C) but was positively associated with litter size at scanning for all three years ($P<0.001$; Figure 3.7 D-F). Litter size at scanning increased as ewe parity increased.

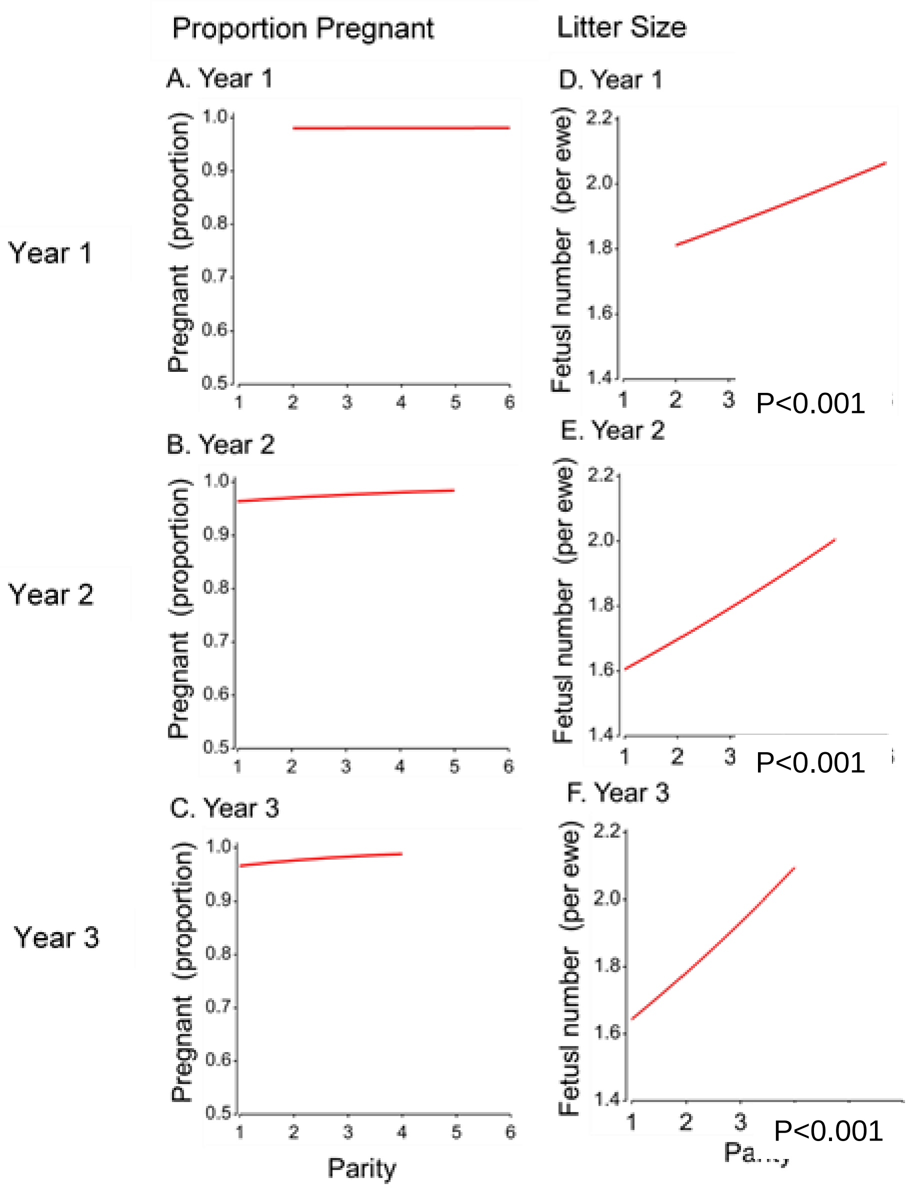


Figure 3.7. Association between **ewe parity** and proportion ewes pregnant at scanning (A-C) and litter size at scanning (D-F) at the Leicestershire Farm. Year 1 (A, D), Year 2 (B, E) and Year 3 (C, F). (---) denotes generic relationship irrespective of ewe genotype.

3.3.2.3 Ewe BCS and liveweight at weaning (preceding *production* cycle)

In these analyses, litter size at scanning was associated with ewe genotype at weaning (P<0.001; Table 3.10). Mule ewes consistently achieved the highest litter sizes at scanning followed by Charollais and Aberfield ewes.

Proportion ewes pregnant at scanning was not associated with ewe BCS and liveweight at weaning of the preceding production cycle (Figure 3.8 A-F). However, litter size at scanning in the subsequent production cycle was positively associated with ewe BCS at weaning; for Years 1 (P<0.001), 2 (P=0.025) and 3 (P=0.013) (Figure 3.8 G-I). Similarly, litter size at scanning in the subsequent year was also positively associated with ewe liveweight at weaning, for Years 1, 2 and 3 (P<0.001; Figure 3.8 J-L). On all occasions, ewes of greater BCS and weight at weaning had larger litters in subsequent scanning. There were no interactions between ewe genotype and either BCS or liveweight at weaning on proportion ewes pregnant or litter size at scanning.

Table 3.10. Effect of ewe genotype when modelling the effects of ewe BCS (units) and liveweight (kg) **at weaning** on mean litter size (±SE) at scanning (of the subsequent production cycle) for Years 1 to 3 at the Leicestershire Farm. In each column litter size is ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule 1.92 ±0.019	Mule 1.92 ±0.019	Mule 1.97 ±0.021	Mule 1.96 ±0.020	Mule 2.12 ±0.030	Mule 1.79 ±0.032
Charollais 1.40 ±0.105	Charollais 1.41 ±0.105	Charollais 1.71 ±0.040	Charollais 1.75 ±0.041	Charollais 1.90 ±0.062	Charollais 1.90 ±0.062
-	-	-	-	Aberfield 1.73 ±0.028	Aberfield 1.79 ±0.032

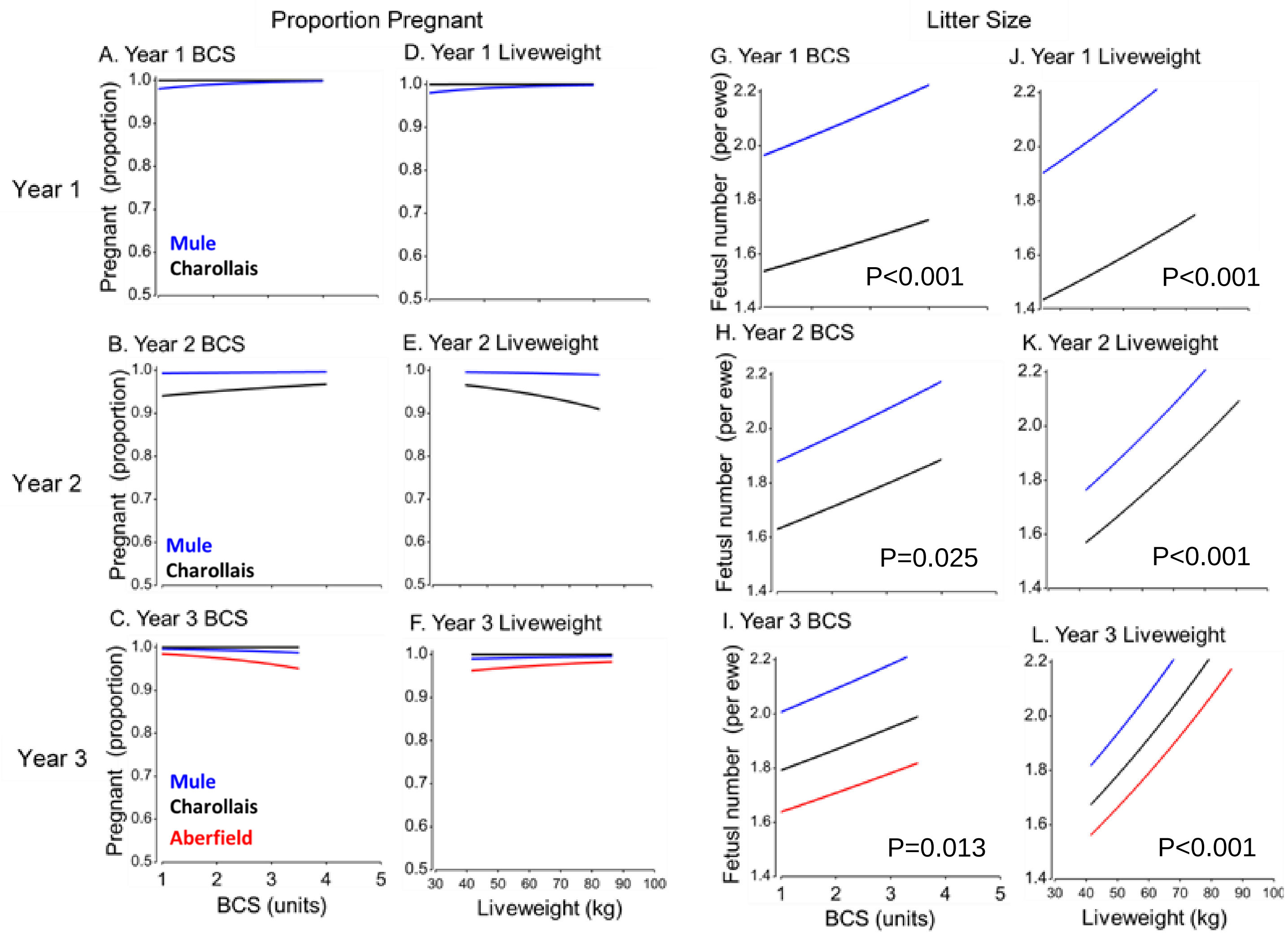


Figure 3.8. Association between ewe BCS (A-C; G-I) and liveweight (D-F; J-L) **at weaning** of the preceding production cycle on proportion ewes pregnant at scanning (A-F) and litter size at scanning (G-L) in the subsequent production cycle at the Leicestershire Farm (Year 1 (A, D, G, J), Year 2 (B, E, H, K) and Year 3 (C, F, I, L)). Ewe genotype: Aberfield (**---**), Charollais (**---**) and Mule (**---**).

3.3.2.4 Ewe BCS and liveweight at mating

In these analyses, litter size at scanning continued to be significantly associated with ewe genotype (P<0.001; Table 3.11). Mule ewes consistently achieved the largest litter sizes at scanning followed by Charollais and Aberfield ewes.

The proportion pregnant at scanning was not associated with ewe BCS and liveweight at mating (Figure 3.9 A-F). Litter size at scanning was positively associated with ewe BCS at mating for Years 1, and 3 (P=0.023; P=0.002; and P<0.001; Figure 3.9 G-I) and positively associated with ewe liveweight at mating for Years 1, 2 and 3 (P<0.001; Figure 3.9 J-L). On all occasions, litter size at scanning increased as ewe BCS and liveweight at mating increased. There were no ewe genotype interactions with BCS or liveweight affecting proportion ewes pregnant or litter size at scanning.

Table 3.11. Effect of ewe genotype when modelling for the effects of ewe BCS (units) and liveweight (kg) **at mating,** on mean litter size (±SE) at scanning in Years 1 to 3 at the Leicestershire Farm. In each column litter size is ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule 1.93 ±0.018	Mule 1.93 ±0.018	Mule 2.00 ±0.024	Mule 1.92 ±0.020	Mule 2.12 ±0.028	Mule 1.96 ±0.040
Charollais 1.67 ±0.036	Charollais 1.70 ±0.032	Charollais 1.70 ±0.036	Charollais 1.66 ±0.036	Charollais 1.85 ±0.058	Charollais 1.76 ±0.068
-	-	Aberfield 1.47 ±0.027	Aberfield 1.58 ±0.025	Aberfield 1.70 ±0.018	Aberfield 1.74 ±0.022

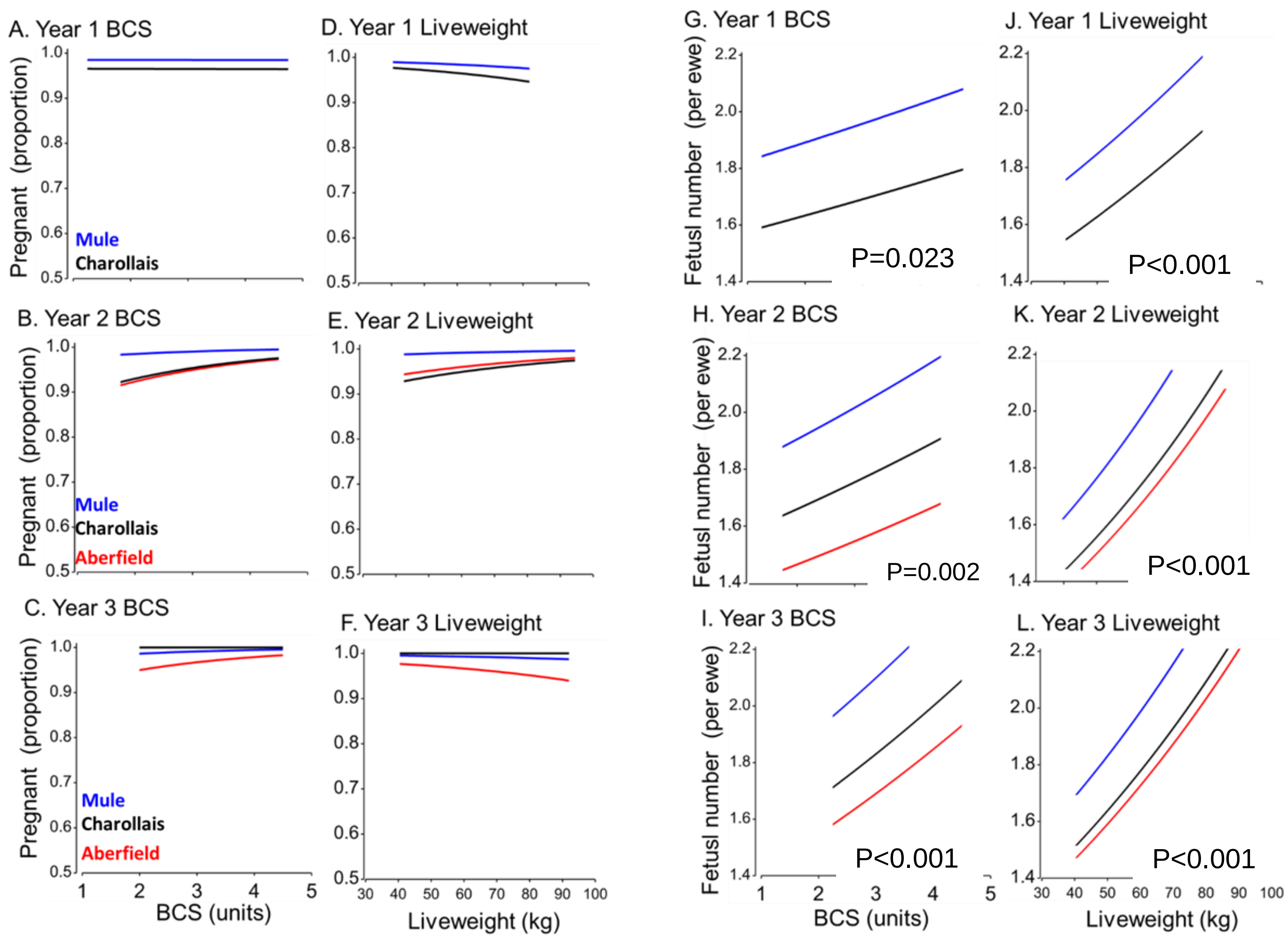


Figure 3.9. Association between ewe BCS (A-C; G-I) and liveweight (D-F; J-L) **at mating** on proportion ewes pregnant at scanning (A-F) and litter size at scanning (G-L) at the Leicestershire Farm (Year 1 (A, D, G, J), Year 2 (B, E, H, K) and Year 3 (C, F, I, L)). Ewe genotype: Aberfield (**---**), Charollais (**---**) and Mule (**---**).

3.3.2.5 Ewe BCS and liveweight change between weaning and mating

In these analyses, litter size at scanning continued to be associated with ewe genotype (P<0.001; Table 3.12). Mule ewes achieved the highest litter sizes at scanning followed by Charollais and Aberfield ewes in Year 3.

Similar to the effects of BCS and liveweight at weaning and mating, the proportion ewes pregnant at scanning was not associated with BCS change between weaning and mating (Figure 3.10 A-F). Litter size at scanning was negatively associated with BCS and liveweight gain between weaning and mating in Year 1 (P=0.005 and P=0.002, respectively; Figure 3.10 G, J); with a suggestion that ewe BCS and liveweight gain were positively associated in Year 3 (P=0.076 and P=0.057, respectively; Figure 3.10. I-L).

Table 3.12. Effect of ewe genotype, when modelling for the effects of change in ewe BCS (units) and liveweight (kg) **between weaning and mating**, on mean litter size at scanning (± SE) in Years 1 to 3 at the Leicestershire Farm. In each column, litter size is ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule 1.92 ±0.019	Mule 1.92 ±0.019	Mule 1.97 ±0.021	Mule 1.97 ±0.021	Mule 2.11 ±0.030	Mule 2.14 ±0.029
Charollais 1.46 ±0.109	Charollais 1.43 ±0.107	Charollais 1.72 ±0.041	Charollais 1.71 ±0.041	Charollais 1.88 ±0.062	Charollais 1.86 ±0.062
-	-	-	-	Aberfield 1.74 ±0.029	Aberfield 1.73 ±0.029

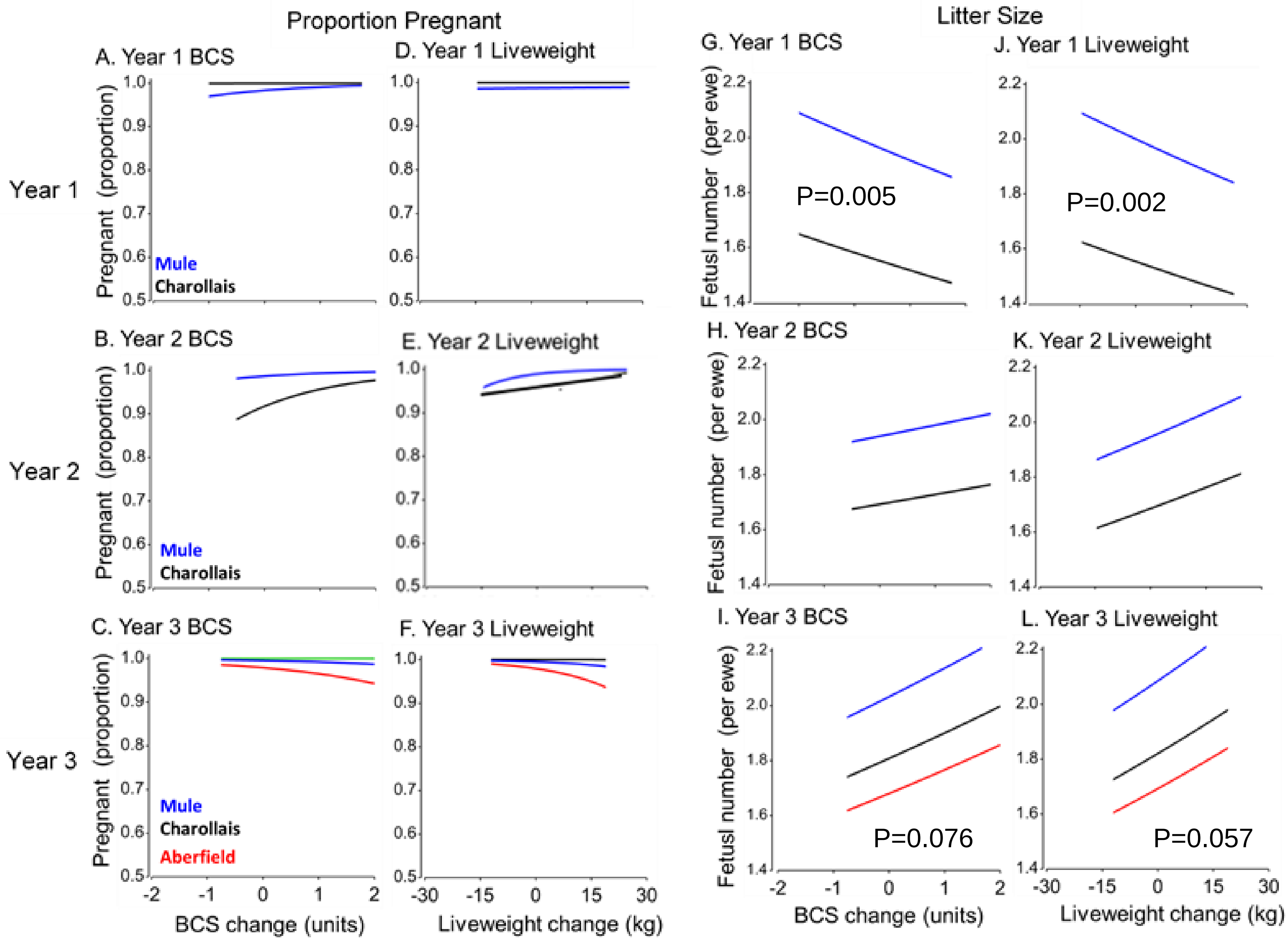


Figure 3.10. Association between ewe BCS change (A-C; G-I) and liveweight change (D-F; J-L) **between weaning of the preceding production cycle to mating in the subsequent production cycle** on proportion ewes pregnant at scanning (A-F) and litter size at scanning (G-L) at the Leicestershire Farm (Year 1 (A, D, G, J), Year 2 (B, E, H, K) and Year 3 (C, F, I, L)). Ewe genotype: Aberfield (**---**), Charollais (**---**), Mule (**---**).

3.3.2.6 Ewe BCS and liveweight at scanning

In these combined analyses, litter size at scanning continued to be associated with ewe genotype (P<0.001; Table 3.13). Mule ewes continued to achieve the highest litter size at scanning followed by Charollais and Aberfield ewes.

Proportion ewes pregnant at scanning was positively associated with ewe BCS at scanning in Years 1, 2 and 3 (P=0.034, P<0.001 and P<0.001, respectively; Figure 3.11 A-C). There was also a ewe genotype x BCS interaction in Year 1 (P=0.011; Figure 3.11 A), whereby Charollais ewes responded positively to increasing BCS at scanning, Mule ewes did not. Proportion ewes pregnant was also positively associated with ewe liveweight at scanning in Years 1 and 2 (P<0.001; Figure 3.11 D-E) with a ewe genotype x liveweight interaction in Year 2 (P=0.018; Figure 3.11 E). Charollais and Aberfield ewes responded positively to increasing liveweight, but Mule ewes responded negatively with increasing ewe liveweight at scanning.

Litter size at scanning was positively associated with ewe BCS at scanning in Years 1 (P<0.001), 2 (P<0.001); and to a lesser extent, Year 3 (P=0.099; Figure 3.11 G-I). Litter size was also positively associated with ewe liveweight at scanning in Years 1, 2 and 3 (P<0.001; Figure 3.11 J-L). However, there was a ewe genotype x BCS interaction (P=0.018; Figure 3.11 H), and a ewe genotype x liveweight interaction (P<0.001; Figure 3.11 K), both in Year 2. Litter size at scanning increased with increasing ewe BCS for Charollais ewes, compared to Mule and Aberfield ewes.

Table 3.13. Effect of ewe genotype, when modelling the effects of ewe BCS (units) and liveweight (kg) **at scanning,** on mean litter size (±SE) at scanning in Years 1 to 3 at the Leicestershire Farm. In each column litter size is ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule 1.92 ±0.017	Mule 1.91 ±0.017	Mule 1.97 ±0.020	Mule 1.84 ±0.022	Mule 2.13 ±0.028	Mule 1.90 ±0.031
Charollais 1.72 ±0.032	Charollais 1.74 ±0.032	Charollais 1.73 ±0.036	Charollais 1.70 ±0.035	Charollais 1.89 ±0.062	Charollais 1.83 ±0.055
-	-	Aberfield 1.49 ±0.023	Aberfield 1.68 ±0.029	Aberfield 1.70 ±0.018	Aberfield 1.80 ±0.020

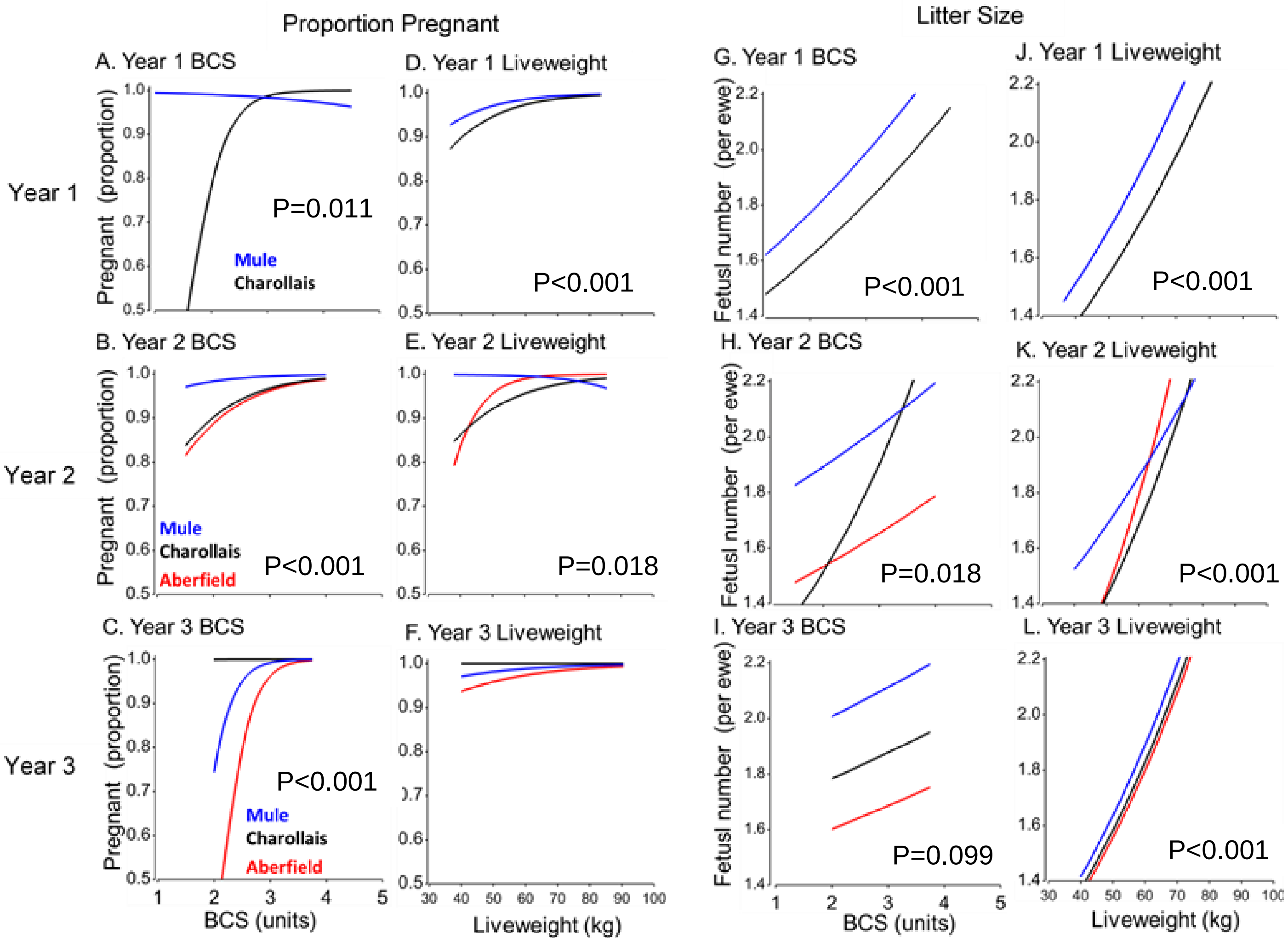


Figure 3.11. Association between ewe BCS (A-C; G-I) and liveweight (D-F; J-L) **at scanning** on proportion ewes pregnant at scanning (A-F) and litter size at scanning (G-L) at the Leicestershire Farm (Year 1 (A, D, G, J), Year 2 (B, E, H, K) and Year 3 (C, F, I, L)). Ewe genotype: Aberfield (**---**), Charollais (**---**) and Mule (**---**).

3.3.2.7 Ewe BCS and liveweight change between mating and scanning

Litter size at scanning continued to be associated with ewe genotype (P<0.001; Table 3.14). As demonstrated at all previous production points, Mule ewes had the largest litters at scanning followed by Charollais and Aberfield ewes.

Proportion ewes pregnant at scanning was positively associated with ewe BCS gain between mating and scanning, but in Year 3 only (P<0.001, Figure 3.12 C). This was also true for liveweight in Years 1 and 3 (P<0.001; Figure 3.12 D, F). In contrast, litter size at scanning was negatively associated with BCS change between mating and scanning, but in Year 3 only (P=0.008; Figure 3.12 I). However, there was a ewe genotype x BCS change interaction in Year 1 only (P=0.003; Figure 3.12 G). Litter size at scanning increased with Mule ewes gaining BCS between mating and scanning, but litter size decreased with BCS gain for Charollais ewes. Litter size at scanning was positively associated with liveweight change in Years 1, 2 and 3 (P<0.001; Figure 3.12 J-L), with a ewe genotype x liveweight change interaction in Year 1 (P=0.005; Figure 3.12 J). Overall, litter size increased for both Mule and Charollais ewes with weight gain between mating and scanning.

Table 3.14. Effect of ewe genotype, when modelling for the effects of change in ewe BCS (units) and liveweight (kg) **between mating and scanning**, on mean litter size at scanning (± SE) in Years 1 to 3 at the Leicestershire Farm. In each column, litter size is ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule 1.92 ±0.019	Mule 1.91 ±0.018	Mule 1.94 ±0.022	Mule 1.90 ±0.022	Mule 2.12 ±0.028	Mule 2.11 ±0.028
Charollais 1.72 ±0.040	Charollais 1.77 ±0.034	Charollais 1.72 ±0.037	Charollais 1.76 ±0.034	Charollais 1.82 ±0.059	Charollais 1.94 ±0.061
-	-	Aberfield 1.53 ±0.025	Aberfield 1.57 ±0.025	Aberfield 1.70 ±0.018	Aberfield 1.70 ±0.018

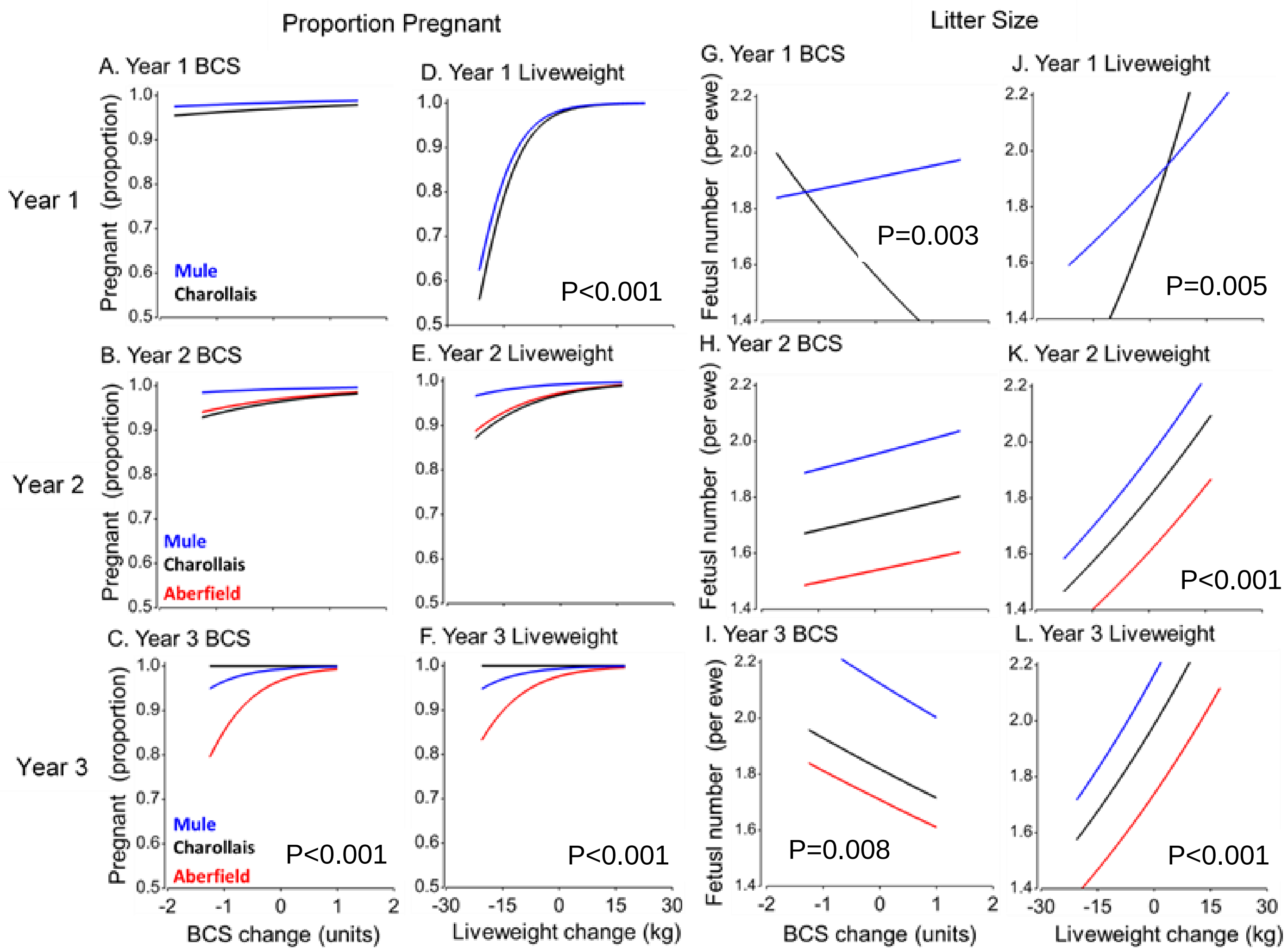


Figure 3.12. Association between ewe BCS change (A-C; G-I) and liveweight change (D-F; J-L) **between mating and scanning** on proportion ewes pregnant at scanning (A-F) and litter size at scanning (G-L) at the Leicestershire Farm (Year 1 (A, D, G, J), Year 2 (B, E, H, K) and Year 3 (C, F, I, L)). Ewe genotype: Aberfield (**---**), Charollais (**---**) and Mule (**---**).

3.3.2.8 Key findings for pregnancy establishment: Leicestershire Farm

As seen at the Sussex Farm, Mule ewes consistently achieved the largest litter sizes at scanning. This was followed by Charollais and Aberfield ewes across the three years at the Leicestershire Farm. Proportion ewes pregnant at scanning was not associated with ewe genotype.

Similar to the associations at the Sussex Farm, litter size at scanning was positively associated with ewe parity across all three years ($P<0.001$) but was not associated with proportion ewes pregnant at scanning. However, parity was not equally represented across years and not all genotypes were represented within each parity.

Proportion ewes pregnant at scanning was not associated with ewe BCS and liveweight at weaning, at mating, or change in BCS and liveweight between weaning and mating. In contrast, litter size at scanning was consistently, and positively, associated with ewe BCS and liveweight at weaning and mating across the three years. Litter size at scanning was negatively associated with BCS and liveweight change between weaning and mating, but in Year 1 only. This suggests that excessive gains over this period may have a detrimental effect.

The time periods where proportion ewes pregnant at scanning were associated with BCS and liveweight were at scanning and between mating and scanning. However, these associations were not consistent between the three years. Similarly, litter size at scanning was positively associated with ewe BCS and liveweight at scanning, and change in ewe BCS between mating and scanning, with ewe liveweight more consistent compared to ewe BCS.

3.3.3 Lancashire Farm: Pregnancy establishment outcomes at scanning

Parity was evenly distributed between the two genotypes at the Lancashire Farm (Table 2.8). Parity was always significant in its own right, but interactions with genotype, ewe BCS and weight were infrequent, inconsistent and relatively minor when they occurred. For these reasons, parity was not included as an 'interactive term' in the analyses at the Lancashire farm but as a 'block'. The effect of ewe parity is reported for this farm.

3.3.3.1 *Ewe genotype*

Proportion ewes pregnant at scanning was not associated with ewe genotype (Table 3.15). Litter size at scanning was associated with ewe genotype in Years 1 (P=0.003), 2 (P=0.005); and to a lesser extent, Year 3 (P=0.085). The ranking between genotypes was consistently greater for Mule ewes followed by Texel ewes (Table 3.16).

Table 3.15. Effect of ewe genotype on proportion pregnant at scanning (mean ± SE) at the Lancashire Farm. In each column, proportion pregnant are ranked in order of highest to lowest.

Year 1	**Year 2**	**Year 3**
Mule 0.99 ± 0.002	Texel 0.98 ± 0.006	Texel 1.00 ± 0.000
Texel 0.97 ± 0.006	Mule 0.96 ± 0.006	Mule 0.98 ± 0.004

Table 3.16. Effect of ewe genotype on litter size at scanning (mean ± SE) at the Lancashire Farm. In each column, proportion pregnant are ranked in order of highest to lowest.

Year 1	**Year 2**	**Year 3**
Mule 2.17 ± 0.040	Mule 2.20 ± 0.041	Mule 2.23 ± 0.043
Texel 1.96 ± 0.057	Texel 2.02 ± 0.048	Texel 2.12 ± 0.047

3.3.3.2 *Ewe parity*

Proportion ewes pregnant at scanning was not associated with ewe parity (Table 3.17) but litter size at scanning was associated in all three years (P<.001; Table 3.18). The effects were not consistent between years, however, parity 1 ewes consistently achieved the lowest litter size at scanning.

Table 3.17. Effect of ewe parity on proportion pregnant at scanning (mean ± SE) at the Lancashire Farm. In each column, proportion pregnant is ranked highest to lowest.

Year 1	Year 2	Year 3
Parity 4 1.00 ± 0.000	Parity 4 0.99 ± 0.008	Parity 5 & 3 1.0 ± 0.000
Parity 1 0.99 ± 0.003	Parity 5 & 3 0.97 ± 0.010	Parity 2 0.99 ± 0.005
Parity 2 0.98 ± 0.006	Parity 2 0.96 ± 0.009	Parity 1 0.99 ± 0.003
Parity 3 0.96 ± 0.010	Parity 1 0.95 ± 0.015	Parity 4 0.96 ± 0.008

Table 3.18. Effect of ewe parity on litter size at scanning (mean ± SE) for Years 1 to 3 at the Lancashire Farm. In each column, litter size is ranked highest to lowest.

Year 1	Year 2	Year 3
Parity 4 2.33 ± 0.082	Parity 3 2.31 ± 0.076	Parity 2 2.27 ± 0.054
Parity 2 2.20 ± 0.075	Parity 5 2.27 ± 0.081	Parity 4 2.27 ± 0.081
Parity 3 2.16 ± 0.086	Parity 4 2.14 ± 0.076	Parity 5 2.25 ± 0.011
Parity 1 1.98 ± 0.082	Parity 2 2.08 ± 0.050	Parity 3 2.20 ± 0.081
	Parity 1 1.86 ± 0.078	Parity 1 1.94 ± 0.062

3.3.3.3 *Ewe BCS and liveweight at weaning (preceding production cycle)*

In these analyses, Mule ewes consistently achieved the highest litter sizes at scanning, followed by Texel ewes. However, the differences were only statistically significant for BCS in Year 1 (P=0.018) and for liveweight in Year 2 (P=0.040; Table 3.19). Litter size at scanning was associated with ewe parity, but in Year 1 only (P<0.001). The rankings were not consistent between years, however parity 1 was always the lowest ranking.

Proportion ewes pregnant at scanning was not associated with ewe BCS at weaning in the preceding production cycle (Figure 3.13; A-C). There was a suggestion that ewe liveweight at weaning was associated; for Year 2 only (P=0.053; Figure 3.13 D). Litter size at scanning was positively associated with ewe BCS and liveweight at weaning; also for Year 2 only (P=0.043 and P=0.006, respectively; Figure 3.13 H, J). In both cases, litter size at scanning increased with increasing BCS and liveweight at weaning. There were no interactions between ewe genotype and either BCS or liveweight at weaning on proportion ewes pregnant or litter size at scanning.

Table 3.19. Effect of ewe genotype when modelling the effects of ewe BCS (units) and liveweight (kg) **at weaning** on mean litter size (±SE) at scanning (of the subsequent production cycle) in Years 1 to 3 at the Lancashire farm. In each column, litter size is ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule 2.19 ±0.052	-	Mule 2.19 ±0.047	Mule 2.19 ±0.043	Mule 2.25 ±0.052	Mule 2.24 ±0.052
Texel 2.00 ±0.061	-	Texel 2.09 ±0.060	Texel 2.06 ±0.053	Texel 2.21 ±0.057	Texel 2.22 ±0.058

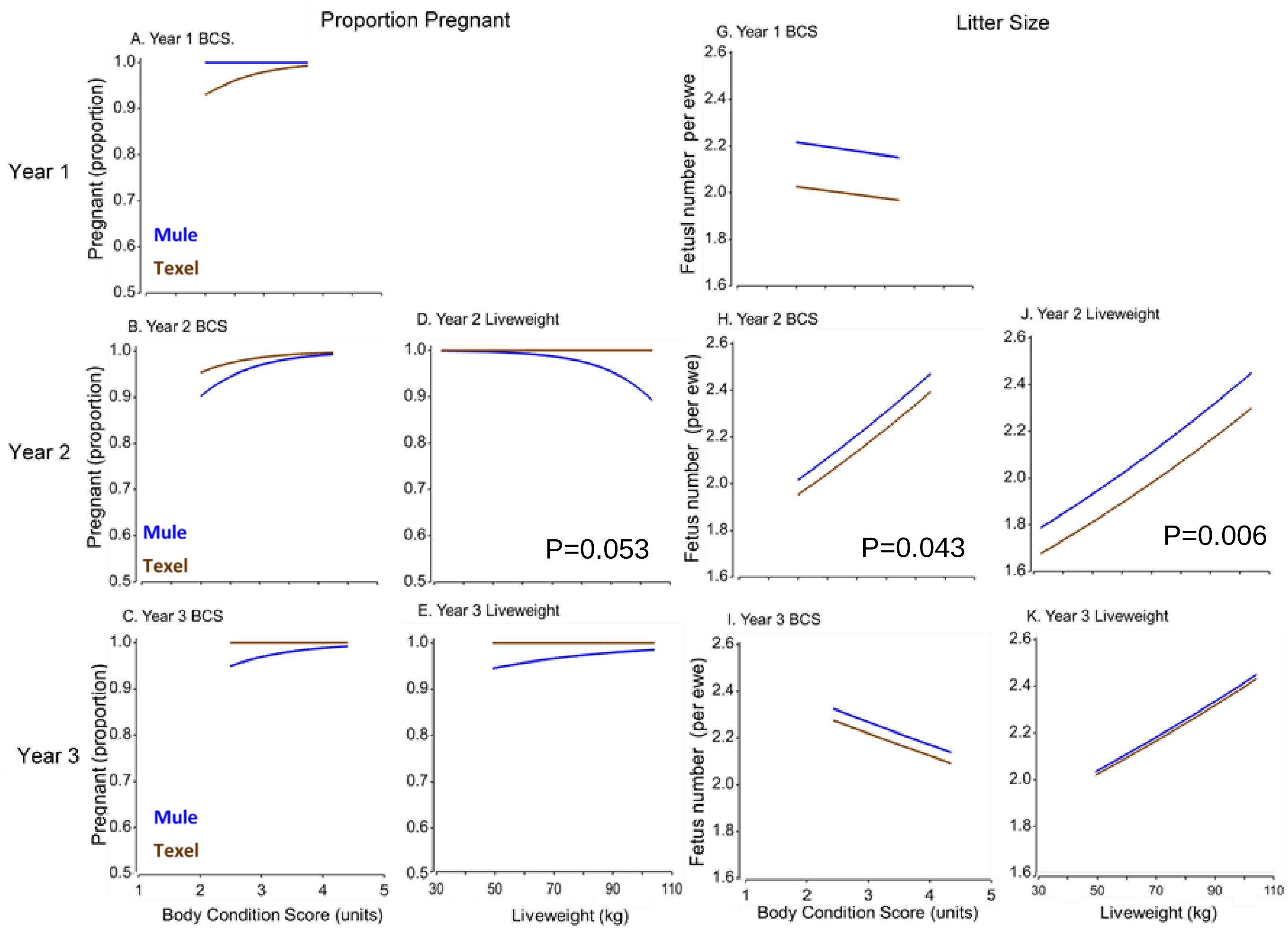


Figure 3.13. Association between ewe BCS (A-C; G-I) and liveweight (D-E; J-K) **at weaning of the preceding production cycle** on proportion ewes pregnant at scanning (A-E) and litter size at scanning (G-K) in the subsequent production cycle at the Lancashire Farm (Year 1 (A, G), Year 2 (B, D, H, J) and Year 3 (C, E, I, K)). Ewe genotype: Mule (**---**) and Texel (**---**).

3.3.3.4 *Ewe BCS and liveweight at mating*

Similar to weaning, litter size at scanning was associated with ewe genotype at mating (P<0.001; Table 3.20). Mule ewes consistently achieved the largest litter sizes at scanning followed by Texel ewes. Proportion ewes pregnant at scanning or litter size at scanning were not associated with ewe parity when included in the combined analysis for BCS and liveweight at mating.

Proportion ewes pregnant at scanning was not associated with ewe BCS at mating (Figure 3.14 A-C); with a suggestion that ewe liveweight at mating was associated, but in Year 3 only (P=0.090; Figure 3.14 F). Litter size at scanning was not associated with ewe BCS at mating (Figure 3.14; G-I). However, litter size at scanning was positively associated with ewe liveweight at mating in Years 1 (P=0.006), 2 (P=0.004) and, to a lesser extent, Year 3 (P=0.088; Figure 3.14 J-L). Higher litter sizes at scanning resulted from heavier ewes at mating. There were no interactions between ewe genotype and BCS or liveweight at mating affecting proportion pregnant or litter size at scanning.

Table 3.20. Effect of ewe genotype when modelling for the effects of ewe BCS (units) and liveweight (kg) **at mating**, on mean litter size (±SE) at scanning in Years 1 to 3 at the Lancashire farm. In each column, litter size is ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule 2.18 ±0.039	Mule 2.16 ±0.033	Mule 2.16 ±0.042	Mule 2.17 ±0.040	Mule 2.20 ±0.043	Mule 2.19 ±0.043
Texel 1.94 ±0.056	Texel 1.98 ±0.048	Texel 2.06 ±0.052	Texel 2.05 ±0.048	Texel 2.14 ±0.048	Texel 2.15 ±0.049

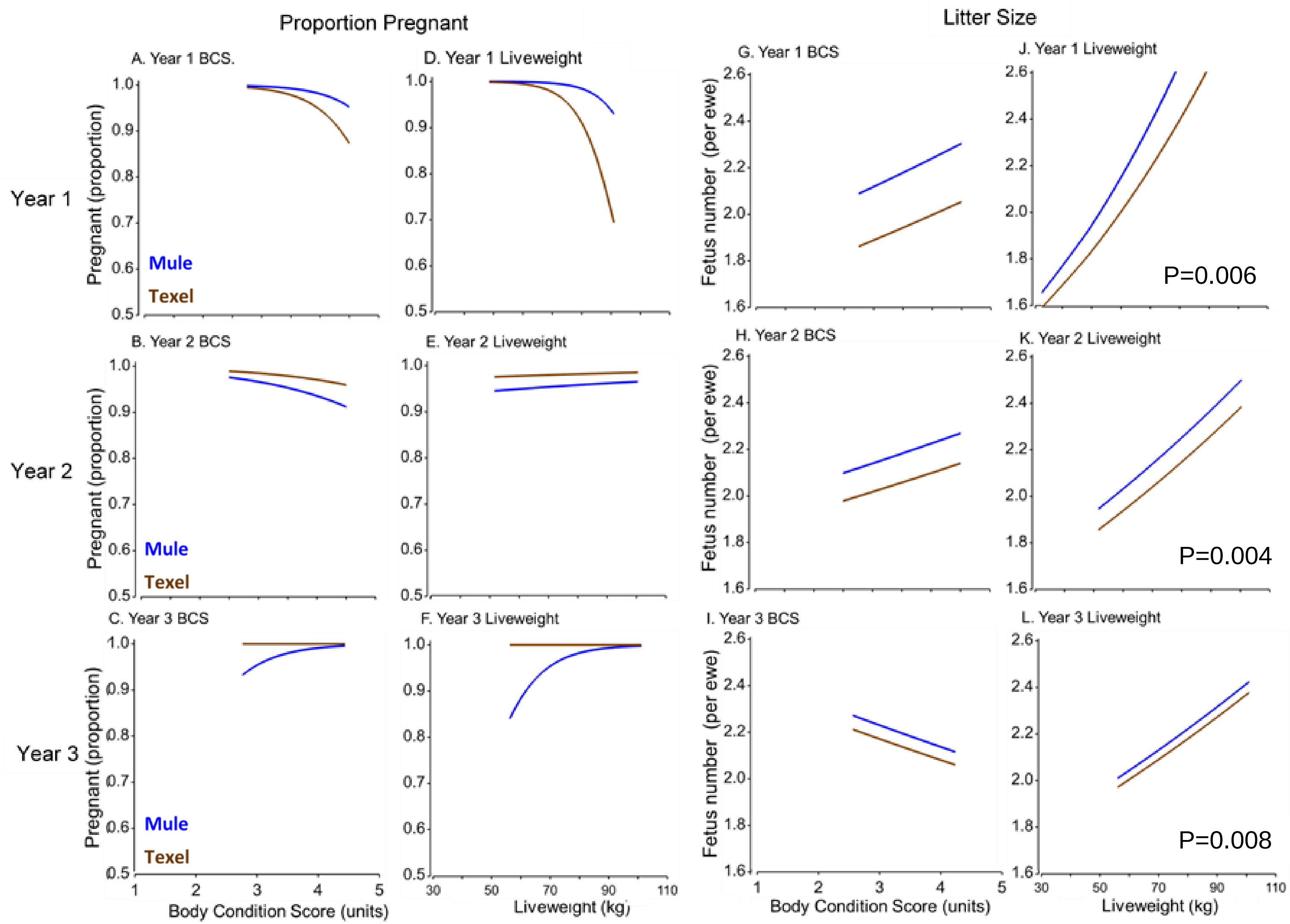


Figure 3.14. Association between ewe BCS (A-C; G-I) and liveweight (D-F; J-L) **at mating** on proportion ewes pregnant (A-F) and litter size at scanning (G-L) at the Lancashire Farm (Year 1 (A, D, G, J), Year 2 (B, E, H, K) and Year 3 (C, F, I, L)). Ewe genotype: Mule (**---**) and Texel (**---**).

3.3.3.5 Ewe BCS and liveweight change between weaning and mating

The association between litter size at scanning and ewe genotype was inconsistent between years (Table 3.21). Mule ewes achieved the highest litter size at scanning followed by Texel ewes, but these results were only statistically significant for BCS in Year 1 (P=0.018). Litter size at scanning was not associated with ewe genotype when modelling the effects of liveweight. Neither proportion ewes pregnant at scanning nor litter size at scanning were associated with ewe parity.

Proportion ewes pregnant at scanning was not associated with ewe BCS change between weaning and mating (Figure 3.15 A-C). Ewe liveweight gain between weaning and mating was positively associated, but in Year 3 only (P=0.045; Figure 3.15 E). Litter size at scanning was not associated with ewe BCS and liveweight change between weaning and mating of the subsequent production cycle in any of the three years (Figure 3.15 F-J). There were no ewe genotype x BCS and liveweight change interactions between weaning and mating affecting proportion pregnant or litter size at scanning.

Table 3.21. Effect of ewe genotype when modelling the effects of change in ewe BCS (units) and liveweight (kg) **between weaning and mating**, on mean litter size at scanning (± SE) in Years 1 to 3 at the Lancashire farm. In each column, litter size is ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule 2.19 ±0.052	-	Mule 2.17 ±0.050	Mule 2.17 ±0.048	Mule 2.25 ±0.052	Mule 2.28 ±0.051
Texel 2.00 ±0.061	-	Texel 2.16 ±0.073	Texel 2.16 ±0.068	Texel 2.20 ±0.058	Texel 2.18 ±0.055

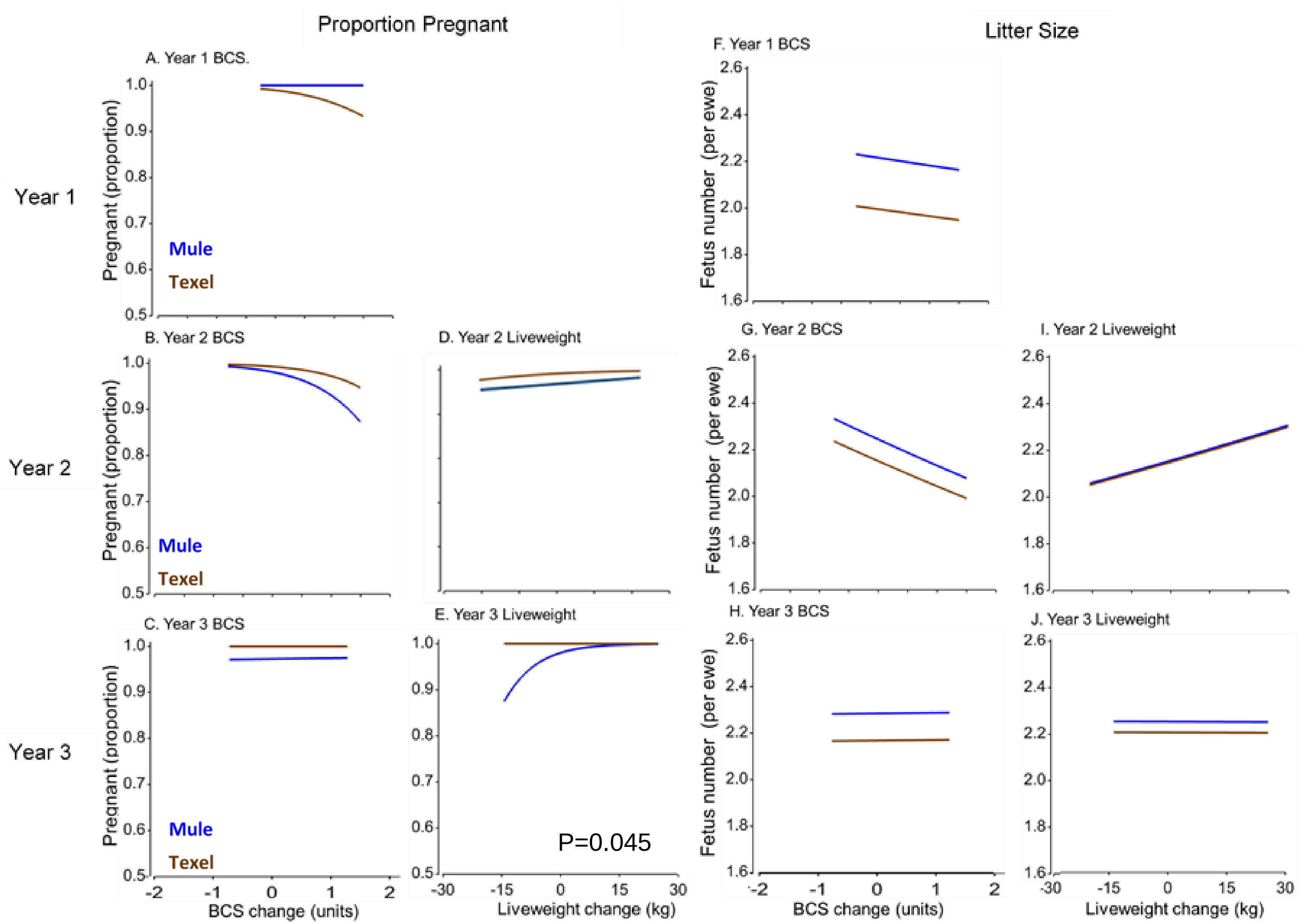


Figure 3.15. Association between ewe BCS change (A-C; F-H) and liveweight change (D-E; I-J) **between weaning of the preceding production cycle and mating** of the subsequent production cycle on proportion ewes pregnant at scanning (A-E) and litter size at scanning (F-J) at the Lancashire Farm (Year 1 (A, F), Year 2 (B, D, G, I) and Year 3 (C, E, H, J)). Ewe genotype: Mule (---) and Texel (---).

3.3.3.6 *Ewe BCS and liveweight at scanning*

Ewe liveweight data at scanning in Years 1 and 2 and ewe BCS data at scanning in Year 2 were not available.

As with weaning and mating, litter size at scanning continued to be associated with ewe genotype in analyses with ewe BCS and liveweight at scanning. Larger litter sizes were achieved by Mule ewes followed by Texel ewes (P=0.001; Table 3.22). Proportion ewes pregnant at scanning was not associated with ewe parity but litter size was negatively associated with ewe parity, but in Year 1 only (P=0.002).

Proportion ewes pregnant at scanning was associated with ewe BCS and ewe liveweight at scanning, but in Year 3 only (P<0.001 and P=0.001, respectively; Figure 3.16 B, C). Proportion ewes pregnant increased with higher BCS and heavier weight. Litter size at scanning was not associated with ewe BCS at scanning in either Years 1 or 3 (Figure 3.16 D-E). However, ewe liveweight was positively associated in Year 3 (P<0.001; Figure 3.16 F). There were no ewe genotype x BCS or liveweight change interactions between weaning and mating affecting proportion pregnant or litter size at scanning.

Table 3.22. Effect of ewe genotype when modelling the effects of ewe BCS (units) and liveweight (kg) **at scanning** on mean litter size (±SE) at scanning in Years 1 to 3 at the Lancashire farm. In each column, litter size is ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule 2.18 ±0.040	-	-	-	Mule 2.21 ±0.043	Mule 2.18 ±0.042
Texel 1.98 ±0.058	-	-	-	Texel 2.14 ±0.049	Texel 2.16 ±0.047

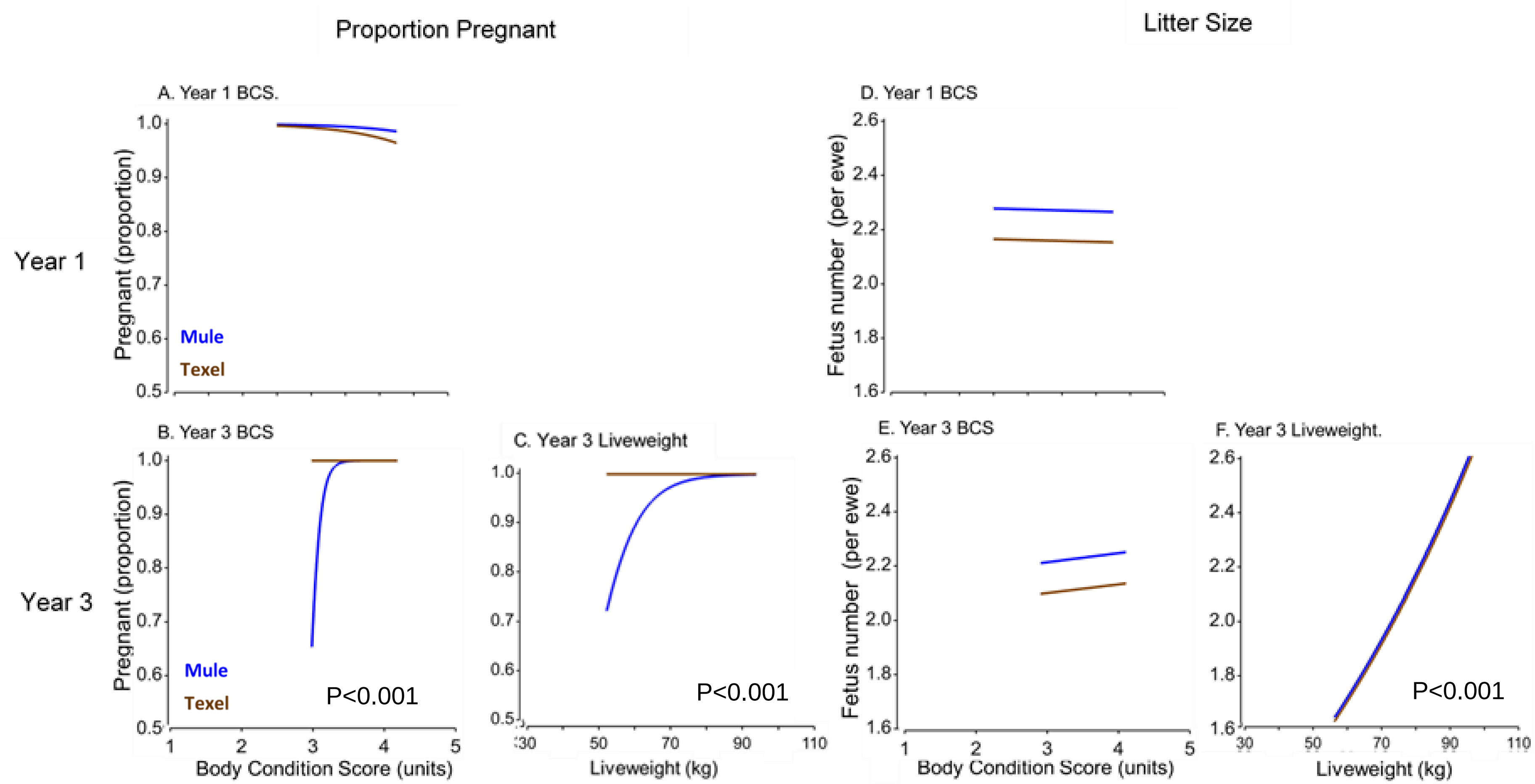


Figure 3.16. Association between ewe BCS (A-B; D-E) and liveweight (C, F) **at scanning** on proportion ewes pregnant at scanning (A-C) and litter size at scanning (D-F) at the Lancashire Farm (Year 1 (A, D), and Year 3 (B, C, E, F)). Ewe genotype: Mule (**---**) and Texel (**---**).

3.3.3.7 *Ewe BCS and liveweight change between mating and scanning*

Ewe liveweight data at scanning in Years 1 and 2 and ewe BCS data at scanning in Year 2 were not available.

In these analyses, litter size at scanning was associated with ewe genotype and BCS in Year 1 only (P=0.002; Table 3.14). Genotype was not found to be significant when modelling the effects of liveweight. As demonstrated at all previous production points, Mule ewes had the largest litters at scanning. Proportion ewes pregnant and litter size at scanning were not associated with ewe parity.

Proportion ewes pregnant at scanning was positively associated with BCS and weight gain between mating and scanning, but in Year 3 only (P<0.001 and P=0.003, for BCS and weight respectively; Figure 3.17 B-C). Litter size at scanning was negatively associated with ewe BCS change between mating and scanning, in Year 1 (P=0.006; Figure 3.17 D). However, there was a ewe genotype x BCS interaction in Year 3 (P=0.024; Figure 3.17 E), whereby Texel ewes were more responsive to BCS gain compared to Mule ewes. Litter size at scanning was positively associated with ewe liveweight gain between mating and scanning, in Year 3 (P<0.001; Figure 3.17 F).

Table 3.23. Effect of ewe genotype when modelling the effects of change in ewe BCS (units) and liveweight (kg) **between mating and scanning** on mean litter size at scanning (± SE) in Years 1 to 3 at the Lancashire Farm. In each column, litter size is ranked highest to lowest.

Year 1		**Year 2**		**Year 3**	
BCS	**Liveweight**	**BCS**	**Liveweight**	**BCS**	**Liveweight**
Mule 2.19 ±0.040	-	-	-	Mule 2.21 ±0.043	Mule 2.21 ±0.041
Texel 1.98 ±0.057	-	-	-	Texel 2.13 ±0.048	Texel 2.11 ±0.045

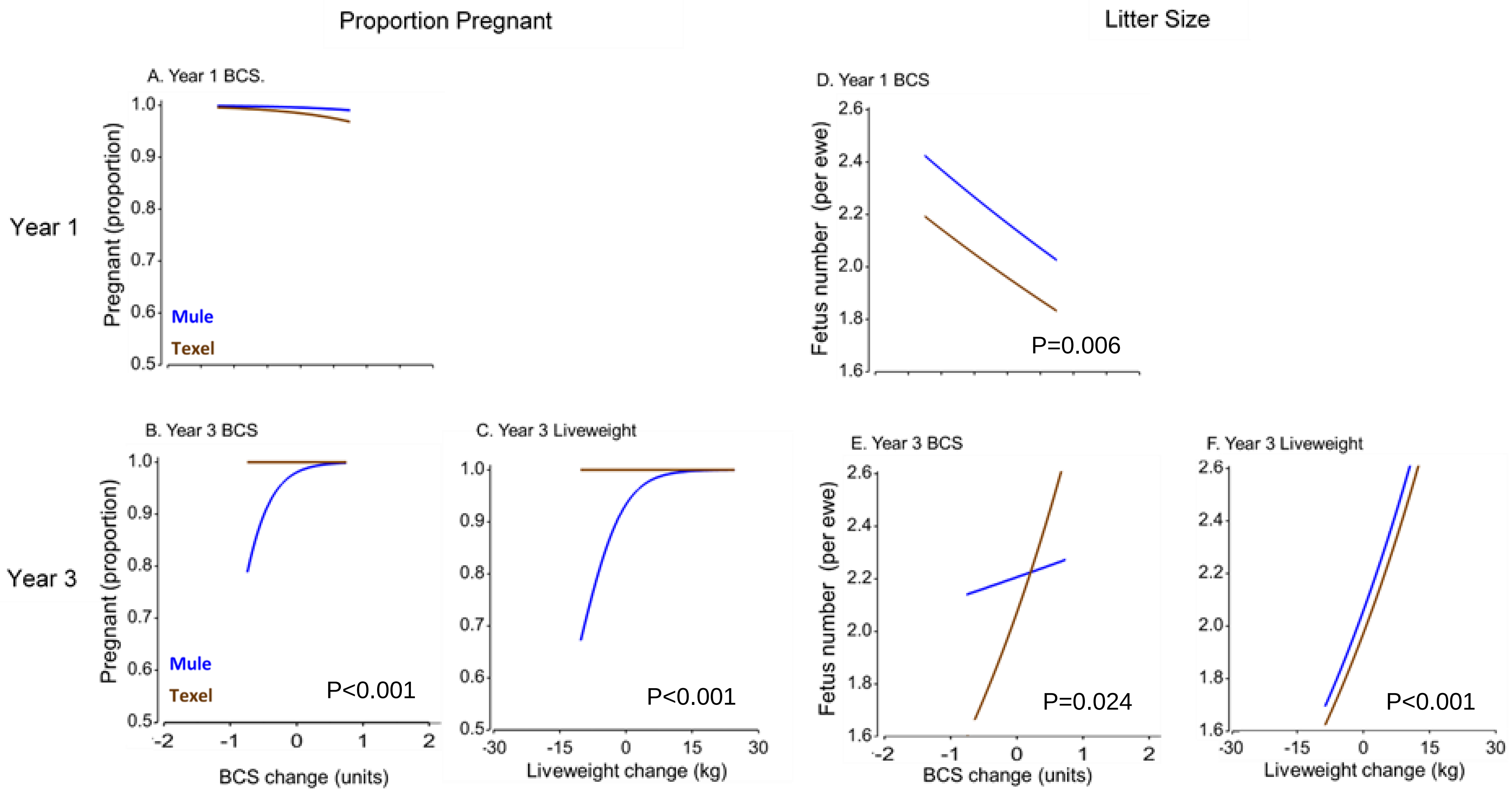


Figure 3.17. Association between ewe BCS change (A-B;D-E) and liveweight change (C, F) **between mating and scanning** on proportion ewes pregnant at scanning (A-C) and litter size at scanning (D-F) at the Lancashire Farm (Year 1 (A, D), and Year 3 (B, C, E, F)). Ewe genotype: Mule (**---**) and Texel (**---**).

3.3.3.8 *Key findings for pregnancy establishment: Lancashire Farm*

As seen at both the Sussex and Leicestershire Farms, Mule ewes consistently produced the largest litters at scanning, although the difference between the two genotypes at each production point was not always statistically significant. Parity 1 ewes consistently had the smallest litters at scanning.

Proportion ewes pregnant at scanning was not associated with ewe BCS and liveweight at either weaning or mating. There were associations between litter size at scanning and ewe BCS and weight at weaning, but in Year 2 only. Litter size at scanning was positively associated with ewe liveweight at mating for all three years.

Proportion ewes pregnant and litter size at scanning were not associated with ewe BCS or liveweight change between weaning and mating.

Unfortunately, BCS and liveweight data at scanning was not available for all three years. Where data was available, there appeared to be an association with proportion ewes pregnant and litter size at scanning for both ewe BCS and liveweight at scanning, and BCS and liveweight change between mating and scanning. Ewes gaining BCS and weight achieved larger litters at scanning; although it seems that Texel ewes were more responsive to weight gain than Mule ewes.

3.3.4 Pooled data across the three farms

When comparing observations between individual farms the following themes begin to emerge. Firstly, there was no consistent association on proportion ewes pregnant at scanning with ewe BCS and ewe liveweight at weaning and mating. Furthermore, there were no consistent associations on either proportion pregnant or litter size at scanning with ewe BCS and weight change between weaning and mating. There were, however, associations on litter size at scanning between ewe BCS and weight at weaning, and at mating; although these differed between farms and across years.

Both proportion pregnant at scanning and litter size at scanning were associated with ewe BCS and weight at scanning, and BCS and weight change between mating and scanning. Although, again, these were not consistent and varied between farms and across years.

Mule ewes were the only genotype present on all three farms. They consistently achieved the highest litter size at scanning on all three farms.

To assess the overall impact of ewe BCS and liveweight at key stages of the production cycle, data across the three years from the three study farms were combined and analysed (Table 3.24). All significant relationships represent a positive association between proportion pregnant and litter size at scanning on BCS, liveweight, and change in BCS and liveweight between production stages.

Table 3.24. Summary of merged analysis of factors affecting proportion pregnant and litter size at scanning across the three production cycles for the Sussex, Leicestershire and Lancashire Farms combined.

	Proportion Pregnant	**Litter Size**
Weaning BCS	n/s	<0.001 (+)
Weaning LWT	n/s	<0.001 (+)
Mating BCS	n/s	=0.002 (+)
Mating LWT	n/s	<0.001 (+)
Δ BCS weaning - mating	n/s	n/s
Δ LWT weaning - mating	n/s	n/s
Scanning BCS	<0.001 (+)	<0.001 (+)
Scanning LWT	<0.001 (+)	<0.001 (+)
Δ BCS mating - scanning	<0.001 (Gain +)	<0.001 (Gain +)
Δ LWT mating - scanning	<0.001 (Gain +)	<0.001 (Gain +)

n/s=not significant LWT=liveweight Δ= change BCS=body condition score

Overall, considering all production-cycle time points, proportion ewes pregnant was less affected by BCS and liveweight than litter size at scanning (Table 3.24). Those relationships that existed lay between the time of mating and scanning, i.e. embracing the period of conception and early pregnancy. In contrast, there was a positive association between litter size at scanning for all production points relating to BCS and liveweight. However, neither proportion ewes pregnant or litter size at scanning were associated with BCS or liveweight change between weaning and mating. Pregnancy data represents the cumulative effects of up to three inseminations per ewe during the breeding period. It was not possible to determine the number of ewes successfully inseminated at each service in this study.

3.3.4.1 Ewe BCS and liveweight at weaning (preceding production cycle)

In the merged analyses, proportion ewes pregnant was not associated with ewe BCS and liveweight at weaning of the preceding production cycle (Table 3.24, Figure 3.18 A-B). This observation was consistent with individual farm by year analyses (Appendix II. Table 1). However, litter size at scanning in the subsequent production cycle increased with increasing ewe BCS and liveweight at weaning (P<0.001; Figure 3.18 C-D). Again, these observations were broadly consistent across the three farms (Appendix II. Table 1).

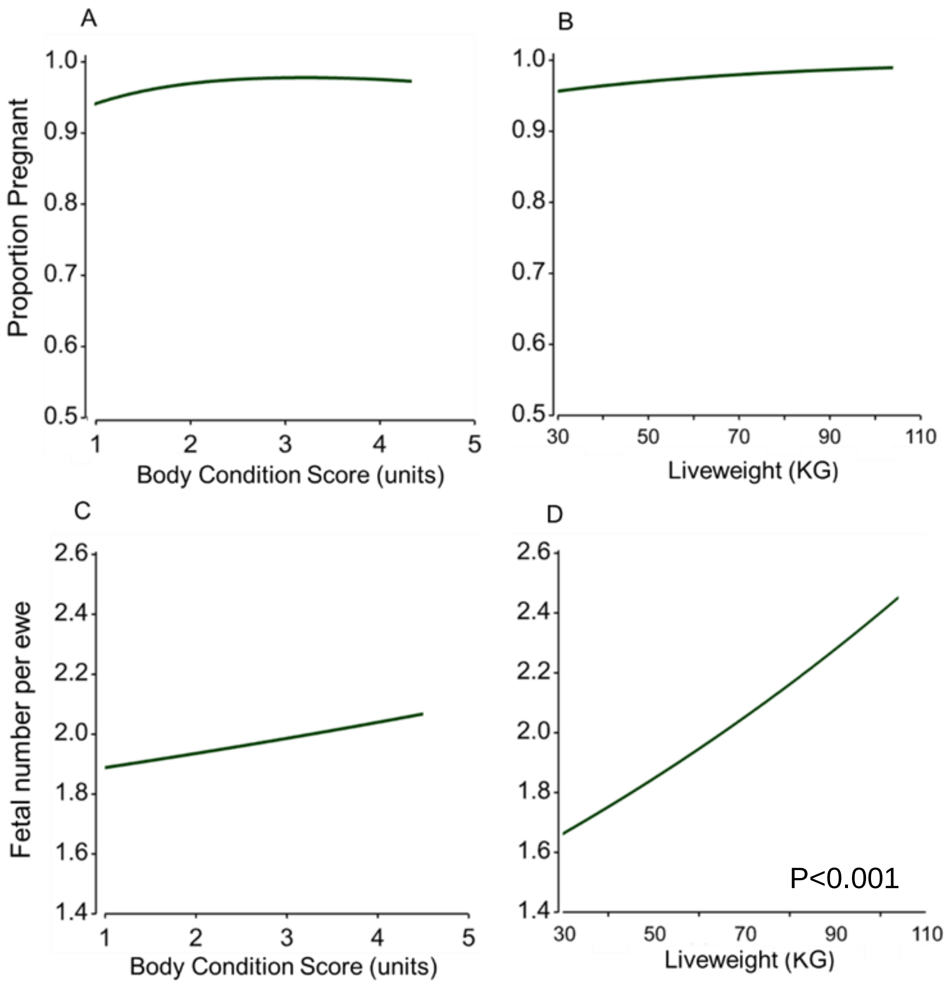


Figure 3.18. Association between ewe BCS (A, C) and liveweight (B, D) **at weaning of the preceding production cycle** on proportion ewes pregnant (A-B) and litter size at scanning (C-D) in the subsequent production cycle for the combined analyses.

3.3.4.2 Ewe BCS and liveweight at mating

Similar to the findings at weaning, analyses of the merged data found that the proportion ewes pregnant at scanning was not associated with ewe BCS and liveweight at mating (Figure 3.19 A-B). These observations were supported by the individual farm by year analyses (Appendix II. Table 2). In contrast, litter size at scanning was positively associated with both ewe BCS (P=0.002; Figure 3.19 C) and liveweight (P<0.001; Figure 3.19 D) at mating. Individual farm by year analyses broadly support these findings for liveweight. However, ewe liveweight had more of an effect than ewe BCS on farms with higher BCS at mating (i.e. Lancashire and Sussex Farms) compared with the Leicestershire Farm.

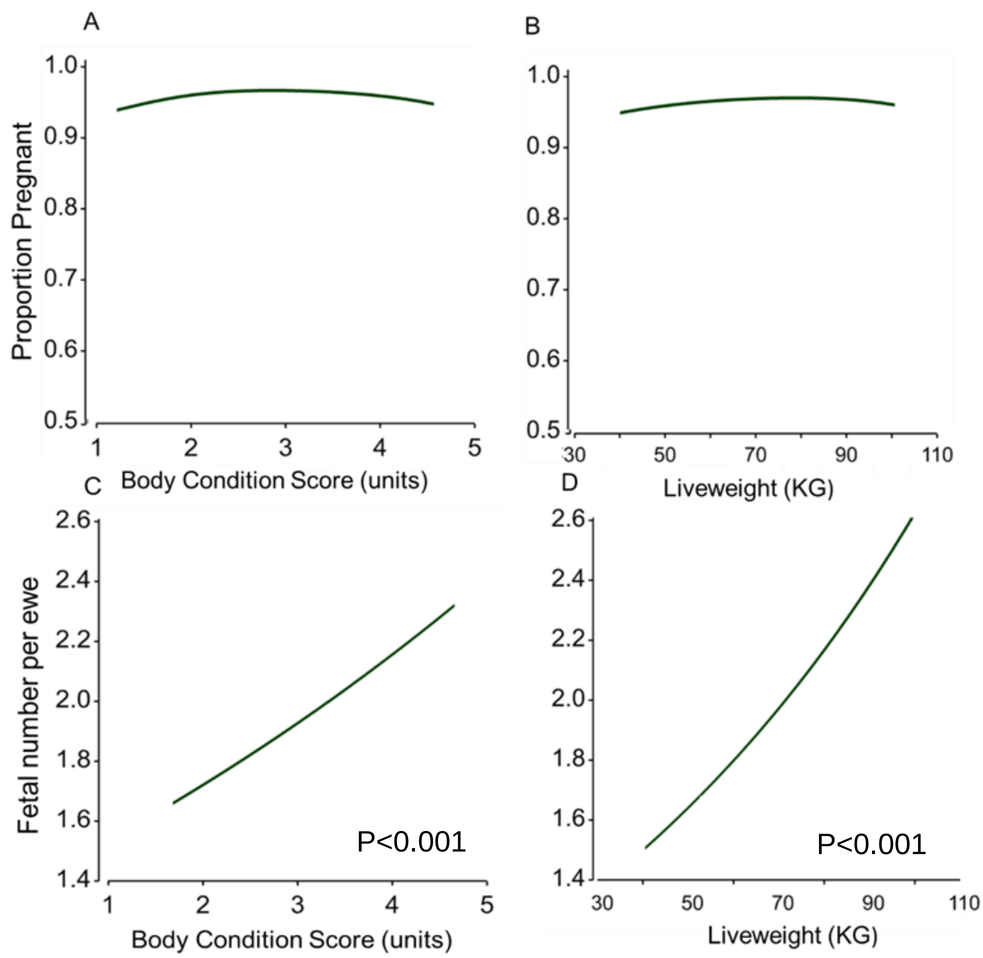


Figure 3.19. Association between ewe BCS (A, C) and liveweight (B, D) **at mating** on proportion ewes pregnant (A-B) and litter size at scanning (C-D) for the combined analyses.

3.3.4.3 Ewe BCS and liveweight change between weaning and mating

Analyses of the merged data found that proportion ewes pregnant (Figure 3.20 A-B) or litter size at scanning (Figure 3.20 C-D) were not associated with ewe BCS and liveweight change between weaning and mating. These observations were consistent for the individual farm by year analyses, relating to proportion ewes pregnant and broadly consistent with individual farm results for litter size at scanning (Appendix II. Table 3). The exception to this was the Leicestershire Farm in Year 1, where there was a negative association for litter size at scanning with BCS and weight gain between weaning and mating. BCS at weaning for the Leicestershire flock in Year 1 was the lowest of the three farms. Many ewes failed to achieve the mating target of 3.5 units.

Further analyses, incorporating weaning BCS and liveweight into the model alongside BCS and weight change, found no interaction between these variables on either proportion ewes pregnant or litter size at scanning. This indicates that the change required to have an effect on pregnancy establishment is not determined by the starting BCS or weight.

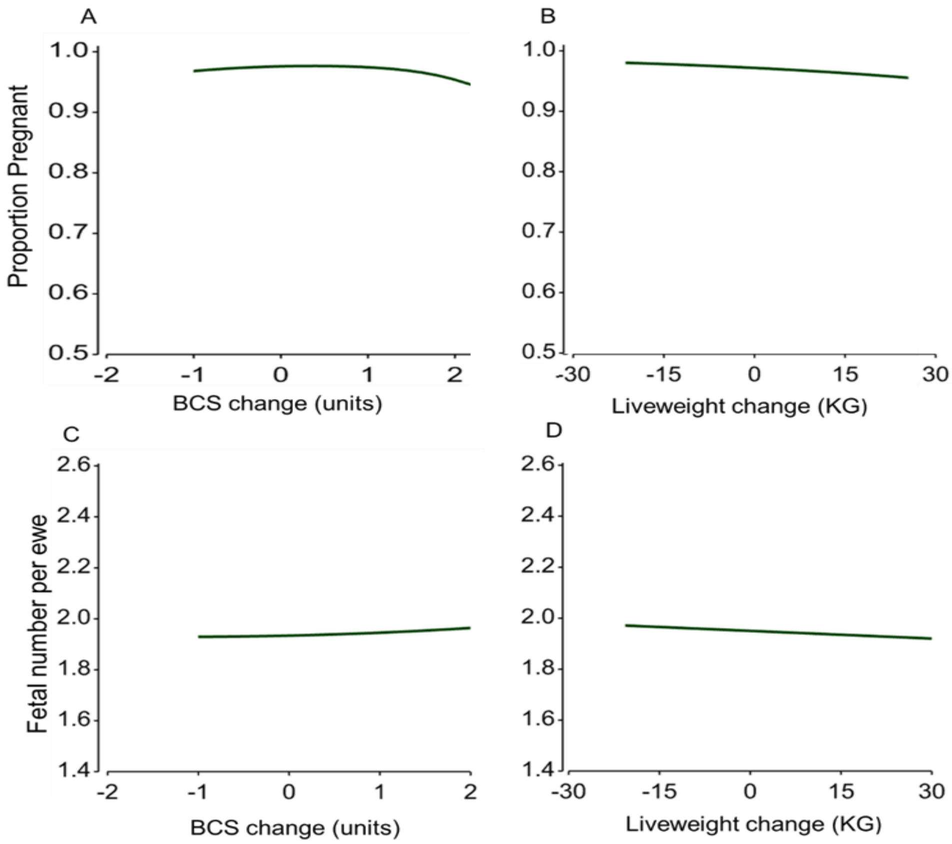


Figure 3.20. Association between ewe BCS change (A, C) and liveweight change (B, D) **between weaning and mating** on proportion ewes pregnant (A-B) and litter size at scanning (C-D) for the combined analyses.

3.3.4.4 Ewe BCS and liveweight at scanning

Analyses of the merged data highlighted the positive associations of proportion ewes pregnant (P<0.001; Figure 3.21 A-B) and litter size at scanning (P<0.001; Figure 3.21 C-D) with ewe BCS and liveweight at scanning. On all occasions, proportion ewes pregnant and litter size at scanning increased with increasing ewe BCS and weight. However, these observations were less consistent for the individual farm by year analyses and varied between years and across farms (Appendix II. Table 4). However, any significant associations observed were all positive.

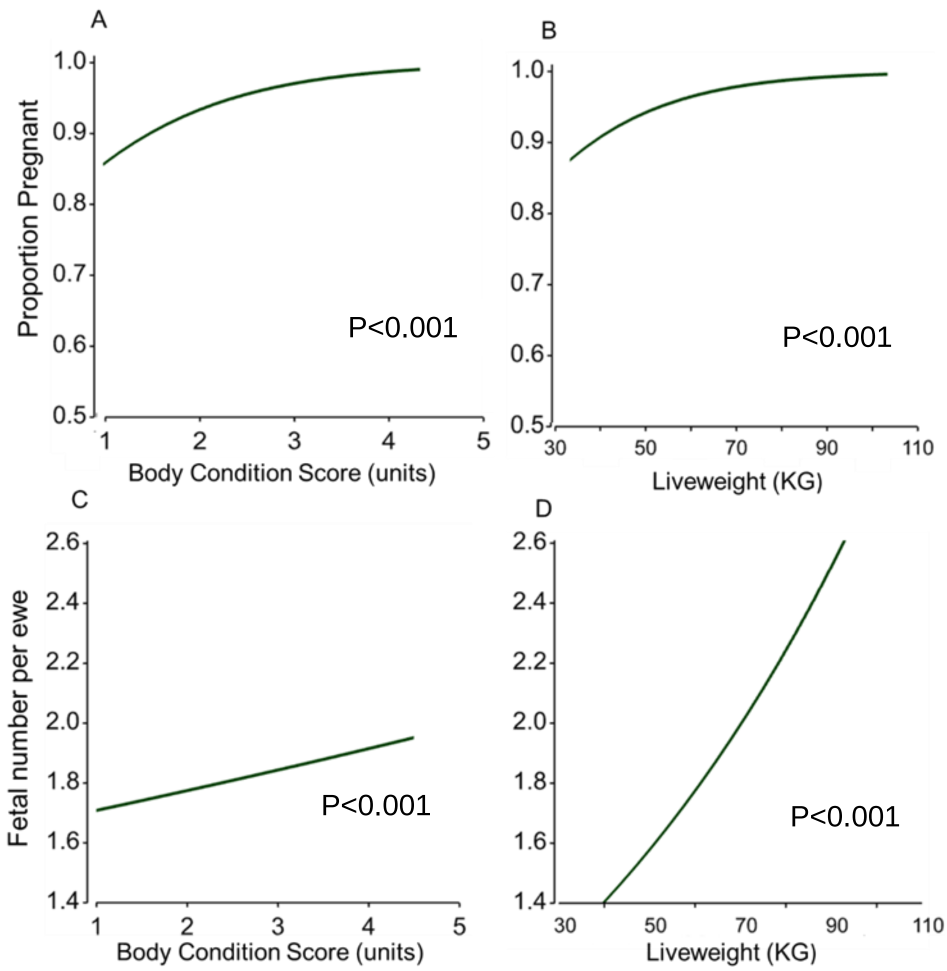


Figure 3.21. Association between ewe BCS (A, C) and liveweight (B, D) **at scanning** on proportion ewes pregnant (A-B) and litter size at scanning (C-D) for the combined analyses.

3.3.4.5 Ewe BCS and liveweight change between mating and scanning

In the merged analyses, both proportion ewes pregnant (P<0.001; Figure 3.22 A-B) and litter size at scanning (P<0.001; Figure 3.22 C-D) were positively associated with ewe BCS and weight gain between mating and scanning. However, individual farm by year analyses revealed some variation in response to proportion pregnant at scanning (Appendix II. Table 5). In contrast, the association between litter size at scanning and ewe liveweight change between mating and scanning was more consistent across years and between farms, and supports the overall merged data results.

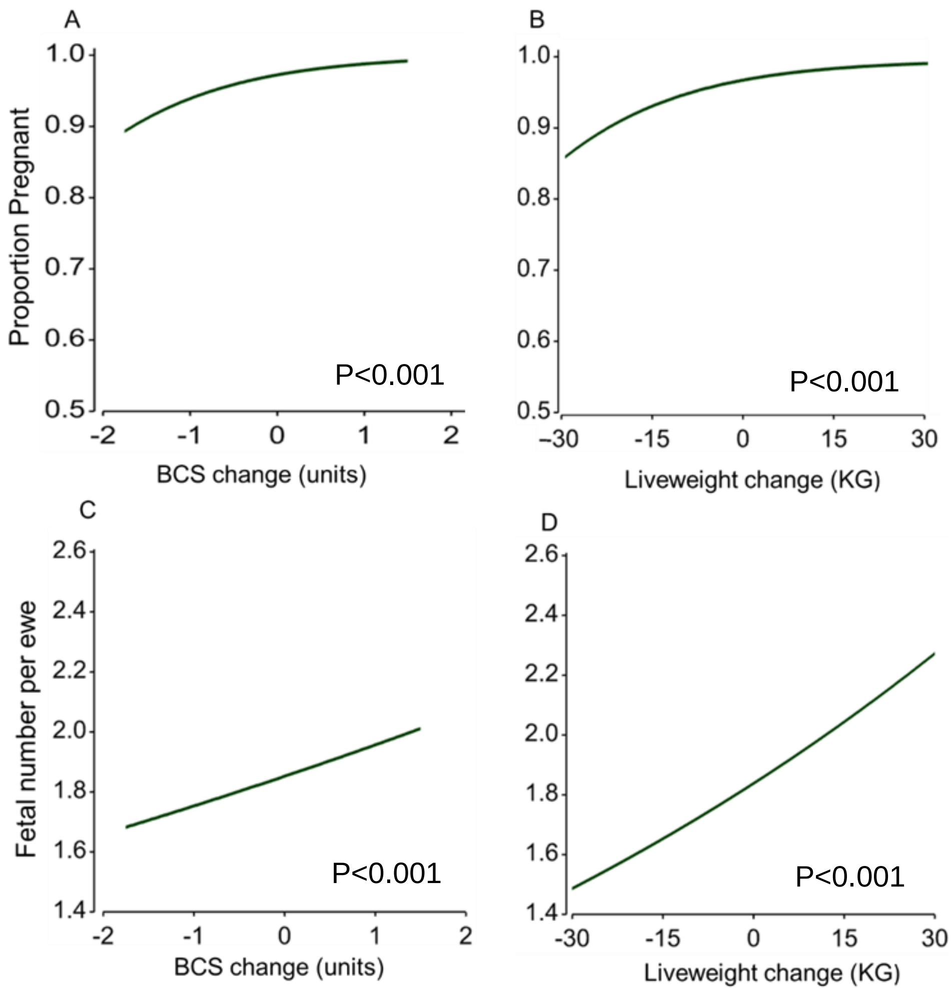


Figure 3.22. Association between ewe BCS change (A, C) and liveweight change (B, D) **between mating and scanning** on proportion ewes pregnant (A-B) and litter size at scanning (C-D) for the combined analyses.

3.4 Discussion

The accuracy of pregnancy scanning and repeatability of BCS assessors are discussed in Chapter 1 (1.7.1) of this thesis.

3.4.1. Ewe genotype and parity

Proportion ewes pregnant was not associated with ewe genotype at the three farms each year. It is worth noting that differences between the genotypes existed but were marginal. However, litter size at scanning was strongly associated with ewe genotype at the three farms, each year. Mule ewes consistently outperformed all other genotypes (Aberfield, Charollais, Lleyn and Texel) in this regard. The Mule is a cross-bred sheep sired, most commonly, by a Swaledale ewe and a Bluefaced Leicester ram (NEMSA, 2020). This is an example of crossbreeding resulting in hybrid vigour or heterosis which is defined as 'the increased performance above the average of the parents' (Donald *et al.,* 1963). Levels of hybrid vigour are highest for reproductive and survival traits compared with growth and fleece traits (Mitchell, 2000), and could be one explanation for the consistent high performance of Mule ewes across the three farms, irrespective of parity and age.

There were no associations between proportion ewes pregnant and ewe parity between years or across farms. It is possible that no effect was found on proportion ewes pregnant due to the age of ewes mated in this study. Ewes were mated to lamb as two-year olds (shearlings). Ewes mated to lamb as one-year olds (ewe lambs) generally have lower proportions pregnant and reduced litter sizes. While there is huge variation both within and between breeds (Quirke *et al.,* 1981), it is not uncommon for 20-40% of mated ewe lambs to not become pregnant (Dyrmundsson, 1973). This could be due to delayed puberty through age or liveweight. Another potential reason for a high proportion ewes pregnant at scanning is the cumulative effect of up to three inseminations per ewe, as a result of the rams being with the ewes for this length of time.

Litter size at scanning, however, was associated with ewe parity at all three farms for each production cycle ($P<0.001$). On all occasions, the lowest parity ewes had the lowest litter size at scanning. This was predominantly parity 1 ewes (two year old shearlings), with the exception of the Leicestershire flock that had no parity 1 ewes in Year 1. This finding is supported by other research that reported lower litter sizes in ewes aged two compared with ewes age three, four and five years (Shorten *et al.,* 2013; Ptáček *et al.,* 2017). Ovulation rate was lower at two years, increasing up to age six. However, two-year-old ewes also had lower embryo survival than older ewes, resulting in lower fertility (Shorten *et al.,* 2013).

3.4.2. Weaning of one production cycle to one-month post-mating of subsequent production cycle

There is limited published data on the effects BCS and liveweight at weaning of the preceding production cycle on pregnancy establishment of ewes in the subsequent production cycle. There is more research investigating the effects of ewe condition at and around the time of mating on pregnancy outcomes.

Due to the design of this study, it is not possible to determine if a non-pregnant ewe resulted as a consequence of failure to conceive or early embryonic failure There is an effect of BCS on return to service (Bastiman, 1972; Gunn *et al.,* 1972; Kenyon *et al.,* 2004), but ewe genotype may determine the minimum BCS and the rate of return to service.

Ewes with larger litters at scanning either had an increased ovulation rate and/or increased embryo survival meaning they had overcome the vulnerable month post-fertilisation where implantation in the uterus occurs (Henderson, 2002). Nutrition during this period influences oviduct and uterine secretions which, in turn, influences pregnancy rate and litter size (Robinson *et al.,* 2002).

Ovulation rate marks the maximum potential number of lambs that could be produced per ewe (Kenyon *et al.,* 2014). Ewe ovulation rate is sensitive to a ewe's nutritional status in the six months leading up to ovulation (Robinson *et al.,* 2005). Nutrition is thought to alter the number of follicles leaving their primordial pool, which in turn affects the number of ova released at mating time (Robinson *et al.,* 2005). This could be one explanation why weaning BCS and liveweight have an effect on litter size at scanning in the subsequent production cycle, but does not affect the proportion ewes pregnant, as was found in the current analyses.

Studies undertaken by Hickson *et al.,* (2012) found that ewe liveweight change between weaning and mating had no effect on the number of fetuses scanned or lambs born, which supports the findings in our research. Ewes at optimum

BCS at mating have increased ovulation rate. However, research has found that both very low and very high BCS have the potential to negatively affect fertility in breeding ewes (Kenyon *et al.,* 2004; Maurya *et al.,* 2009; Sejian *et al.,* 2009; Yilmaz *et al.,* 2011). Low BCS at mating results in reduced cyclical activity, reduced ovulation rate, poorer ova survival and a higher risk of early embryonic death (Fthenakis *et al.,* 2012). This could be one explanation why mating condition affects litter size, but not the proportion ewes pregnant at scanning. Increasing BCS at mating between BCS 2.5 and 4 units increased litter size by 0.13 lambs per ewes (Bohan & Keady, 2019).

An increase of embryo mortality in ewes of high BCS is consistent with the findings of Parr, (1992). Ewes fed well above maintenance displayed lower progesterone concentrations and were less likely to maintain pregnancy due to increased embryo mortality (Smith, 1991). It has also been reported that, for optimal response to the ram at mating, ewes are required to be between BCS 3 and 4 (Todorov & Nedelkov, 2015).

Assessing the impact of ewe nutrition in early life, the role of epigenetics on the formation of reproductive organs, post-natal development, timing of puberty and ovulation rate are increasingly being investigated (Robinson *et al.,* 2002; Robinson *et al.,* 2005; Kenyon and Blair 2014). However, these considerations were outside the scope of this research. It was not possible as part of this study to ascertain ovulation rate, embryo or fetal loss prior to scanning.

Our data analyses suggest that weaning BCS and liveweight has a longer term effect on subsequent flock productivity. Greater emphasis is required at, and leading up to weaning, to reduce the long-term effect of poor flock condition in subsequent years. Ewes will inevitably be required to gain condition after lactation but excessive loss of BCS and/or weight leading up to weaning is detrimental on litter size in the subsequent production cycle. The lack of association between BCS and weight gain between weaning and mating further supports the importance of ewe condition at weaning. When preferential feed is available and ewes are given sufficient time (10 weeks or more), the effects of poor condition at weaning cannot be reversed.

3.4.3. One-month post-mating to scanning (mid-pregnancy)

Research concerning the effects of ewe BCS and liveweight at scanning, and changes between mating and scanning, mostly relate to the development and weight of the placenta, lamb birthweight and subsequent lamb survival at lambing time. There is less evidence relating to the effects during this time on proportion ewes pregnant and litter size at scanning.

The current recommendation for UK sheep farmers is to allow mild condition score loss (0.5 units), depending on their starting point (3.5 units for lowland ewes) with minimal impacts on productivity (Russel, 1984). This would naturally occur during mid-pregnancy due to the demands of the conceptus and a reduction in the quality and quantity of forage available. However, this is not advised for young ewes (ewe lambs or shearlings) who are more susceptible to condition score loss during mid-pregnancy (Robinson, 1990). During mid-pregnancy the placenta grows to its full size (Fthenakis *et al.,* 2012). If a problem occurs during the formation of the placenta, there can be longer term consequences on fetal growth and lamb birthweight (Sen *et al.,* 2013), as placental weight is highly associated with lamb birthweight (Mellor, 1983).

Several studies have shown that restrictions in maternal nutrition during mid-pregnancy can have one of three outcomes. The majority of these relate to placental development and lamb birthweight only. Firstly, maternal undernutrition during mid-pregnancy has a positive effect on placental development and lamb birthweight (Robinson, 1990; Robinson & Kelly, 1992; Munoz *et al.,* 2007). It is thought that increased blood flow occurs when placental development has been compromised. However, Heasman *et al.,* (1998) and Munoz *et al.,* (2007) both specified that ewes must subsequently be fed to requirements for the remainder of pregnancy in order to accommodate the increasing metabolic demands of the gravid uterus. Secondly, maternal undernutrition during mid-pregnancy has a negative effect on placental growth and lamb birthweight (Clarke *et al.,* 1988; Orr and Treacher, 1990; Robinson *et al.,* 2002; Addah *et al.,* 2012; Sen *et al.,* 2013). Ewes below target BCS at mating and underfed in mid-pregnancy were lighter at lambing resulting in thinner ewes at weaning (Robinson *et al.,* 2002; Orr and Treacher 1990). A negative effect of under nutrition during mid-pregnancy leads to delayed follicular development affecting the breeding capacity of offspring, subsequently resulting in reduced flock performance over time (Rae *et al.,* 2001). Finally, no significant impact of nutrition during mid-pregnancy on placental development and lamb birthweight has been reported (Clark and Speedy, 1980; McCrabb *et al.,* 1986; McCrabb *et al.,* 1991; Fogarty *et al.,* 1992; Martin *et al.,* 2012), with

Kenyon *et al.,* (2011) reporting no positive effects of offering a diet greater than maintenance to twin bearing ewes during mid-pregnancy.

The results of this chapter suggest that ewes maintaining or gaining BCS and weight between mating and scanning, resulting in better condition at scanning, increases proportion pregnant and litter size at scanning, thus, challenging the current advice to allow half a unit condition loss or 5 percent liveweight loss between mating and scanning.

3.5. Conclusion

Overall, ewe BCS and liveweight between weaning of the preceding production cycle and scanning of the subsequent cycle, and change in ewe BCS and liveweight between production points, have an impact on pregnancy establishment. However, the frequency of impact on litter size at scanning are greater than proportion pregnant at scanning. Increased BCS and liveweight at scanning, and maintenance or gain of BCS and weight between mating and scanning, appear to be the most critical factors. Contrary to current advice, these results suggest that ewes should maintain or gain condition (BCS and weight) between mating and scanning. This chapter analyses the effects on proportion pregnant and litter size at scanning only and not placental weight, lamb birthweight or lamb survival.

In addition, ewe BCS and liveweight at weaning and mating contribute to increased litter size at scanning. However, change between weaning and mating does not. Ewe condition at weaning should be a key focus to avoid longer term detrimental effects on flock fertility where ewes are in poor condition at weaning.

Individual farm by year analyses indicated that, on farms with lower mean flock BCS, liveweight is less influential compared with farms with higher mean flock BCS.

4 CHAPTER FOUR: Factors affecting pregnancy outcome at lambing

4.1 Introduction

Data relating to proportion ewes lambed and litter size at lambing is less commonly available on most commercial sheep farms, compared to proportion pregnant and litter size at scanning. The main reason for this concerns the lack of data capture around lambing time due to high demand for resources during the lambing period (McHugh *et al.,* 2020). When data is collected, the main emphasis concerns the number of lambs born (dead or alive) compared to numbers scanned, and a focus on peri-natal lamb losses (DAERA-NI, 2018; AHDB, 2020d), with less emphasis on proportion ewes lambed. There are no industry target figures relating to the proportion ewes lambed for sheep farmers to benchmark against, other than the proportion ewes barren at scanning. However, the number is likely to be significant given that up to 30 percent of lamb losses occur between scanning and lambing (HCC, 2016). These losses can occur as a consequence of ewe mortality and late fetal loss (Allworth *et al.,* 2016; Hinch & Brien, 2013).

A considerable body of data exists on ewe energy and protein requirements during late pregnancy (i.e. last six to eight weeks of gestation). Their importance relating to ewe health, colostrum and milk production is well documented (Mellor, 1983; Henderson, 2002; Fthenakis *et al.,* 2012; Kenyon & Blair, 2014; Dwyer, 2014; Rooke *et al.,* 2015). However, this research has predominantly concentrated on the immediate period (last 6 weeks) leading up to lambing, with less consideration given to the longer term impact of ewe BCS and liveweight on ewe productivity in the months preceding late gestation.

Flock BCS targets from weaning of the preceding production cycle to scanning of the subsequent production cycle are discussed in Chapter 3. In the period between scanning and lambing, it is advised that ewes maintain BCS and lamb at a BCS of around 3 units (AHDB, 2014b; B&LNZ, 2020). In order to maintain condition during this period, the increasing energy and protein demands of late pregnancy (for lamb growth, udder development and colostrum production) must be provided from the diet. A 70 kg ewe with two fetuses has an energy requirement of 11 MJ ME/day 8 weeks pre-lambing, rising to 18MJ ME/day one week pre-lambing (AFRC, 1993). Ewes that cannot obtain these requirements from the diet will likely mobilise adipose tissue.

Research assessing the impact of ewe BCS reports effects on ewe mortality (Morgan-Davies *et al.,* 2008; Agric WA, 2018), lamb survival and neonatal viability (Kenyon & Blair, 2014; Dwyer, 2014; Rooke *et al.,* 2015), lamb birthweight (Khalaf, *et al.,* 1979; Nowak & Poindron, 2006), milk production (Snowder & Glimp, 1991; Robinson *et al.,* 2002) and lamb growth rates to weaning (Gibb & Treacher, 1980; Treacher & Caja, 2002; Lima, *et al.,* 2019; B&LNZ, 2020).

The current chapter reports on proportion ewes lambed and litter size at lambing, and their associations with ewe BCS and liveweight from weaning of the preceding production cycle to lambing of the subsequent production cycle using data pooled across the three participating farms and three production cycles. Similar to Chapter 3, this chapter sought to establish if pregnancy outcome at lambing was associated with ewe BCS and/or liveweight, or change in ewe BCS and/or liveweight, at various stages from weaning (in the preceding production cycle) to lambing (in the subsequent cycle).

4.2 Materials and methods

Litter size analysis pertained only to those ewes identified as pregnant at scanning. Ewes scanned as triplets did not rear three lambs at the Sussex and Leicestershire Farms. If three lambs were born alive, one was removed and fostered onto a ewe with a single lamb (to rear twins) or to a ewe who had lost a lamb. Lambs were tagged and linked to a ewe 24-48 h post-partum but changes to litter size were done immediately post-partum. Therefore, it was not possible to establish if a ewe scanned with three lambs, but who reared two, had one lamb fostered or one lamb die. It was also not possible to determine which ewes a foster lamb came from, only which ewes received a foster lamb.

For these reasons, analysis of litter size at lambing was restricted to ewes scanned with one or two lambs. The Lancashire Farm did allow ewes to rear triplets but for reasons of consistency across farms, these ewes were removed from the analysis. This effectively removed data for 906 ewes (from the three farms over the three production cycles) from a dataset that encompassed 7,771 ewes (i.e. 11.7%), leaving 6,865 ewes for analysis. A total of 525 ewes (7%) had no lambing record with 241(3%) of those barren at scanning, meaning 284 ewes (4%) did not record a live lamb at tagging 48 h post-lambing, despite being scanned as pregnant.

Finally, neither ewe liveweight at lambing nor lamb birthweight were analysed due to inconsistent approaches and recording of these data between years at the Sussex and Leicestershire Farms; and the absence of birthweight data at the Lancashire Farm. Further details relating to data collection for analysis are provided in 2.2.2 Data collection.

4.2.1 Statistical analyses

Analyses were performed using the GenStat statistical package (18th Edition, VSN International, 2019; https://www.vsni.co.uk/). All proportion data were analysed using REML Generalized Linear Mixed Models (GLMM) that assumed binomial errors and used logit-link functions. For the analysis of litter size, the same statistical models were applied but, on this occasion, they assumed Poisson errors and used log-link functions. In the final version of these models, the following terms were fitted: 'Farm', 'Year', 'BCS' or 'Liveweight' or 'Change in BCS or liveweight', together with interactions between these terms. Probabilities <0.05 was deemed significant.

4.3 Results: Pooled data across the three study farms

4.3.1 Ewe BCS and liveweight at weaning (preceding production cycle)

The proportion ewes lambed and litter size at lambing were not associated with ewe BCS at weaning in the preceding production cycle (Figure 4.1 A, C). Similarly, the proportion ewes lambed was not associated with ewe liveweight at weaning (Figure 4.1 B). However, litter size at lambing was positively associated with ewe weaning liveweight in the previous year (P<0.001; Figure 4.1 D).

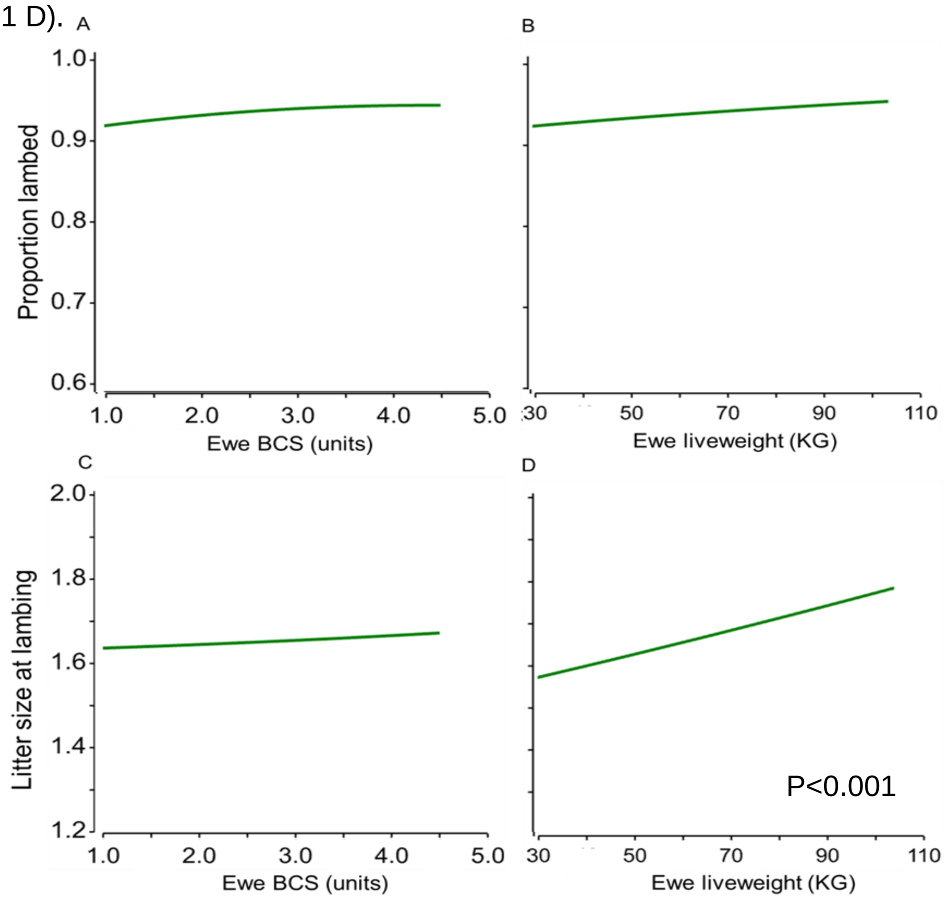


Figure 4.1. Association between ewe BCS (A, C) and liveweight (B, D) **at weaning of the preceding production cycle** on proportion ewes lambed (A-B) and litter size at lambing (C-D) for the combined analyses.

4.3.2 Ewe BCS and liveweight at mating

The proportion ewes lambed and litter size at lambing were not associated with ewe BCS at mating (Figure 4.2 A, C). As observed for weaning, the proportion ewes lambed (Figure 4.2 B) was not associated with ewe liveweight at mating but litter size at lambing was positively associated with ewe liveweight at mating (P<0.001; Figure 4.2 D).

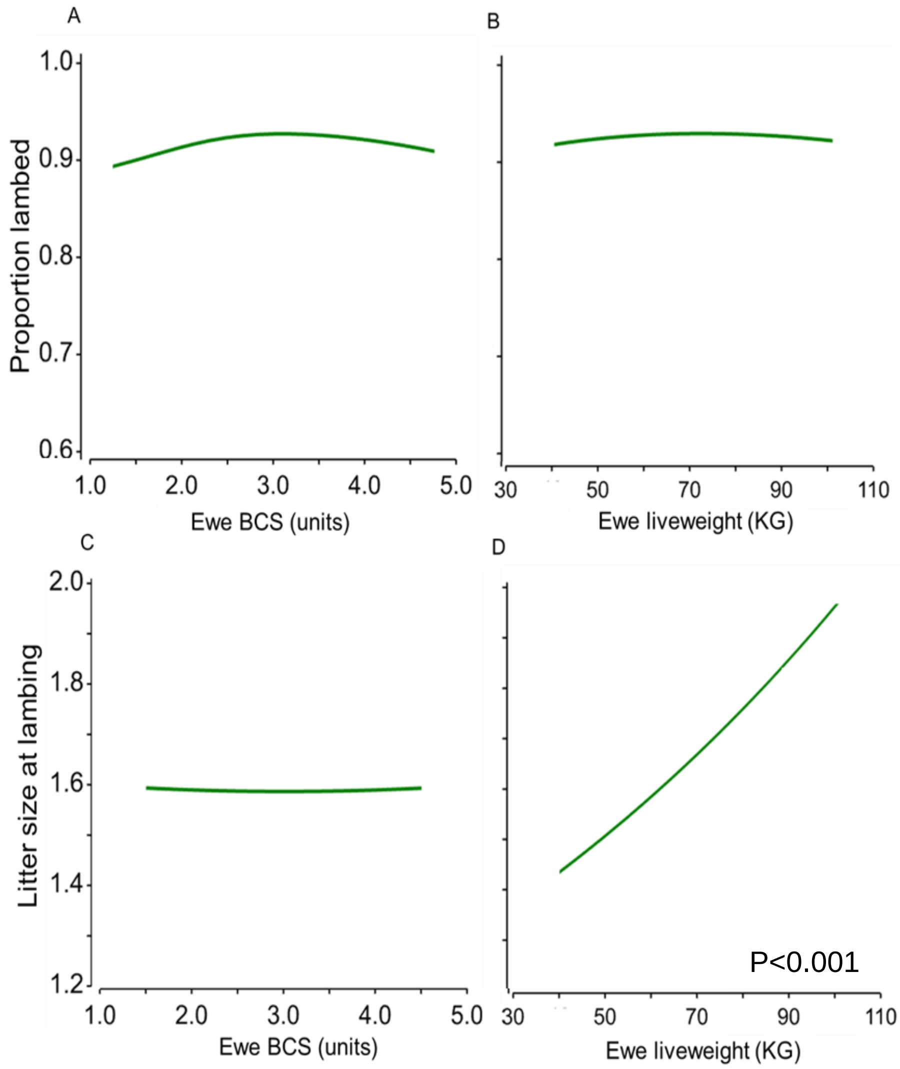


Figure 4.2. Association between ewe BCS (A, C) and liveweight (B, D) **at mating** on proportion ewes lambed (A-B) and litter size at lambing (C-D) for the combined analyses.

4.3.3 Ewe BCS and liveweight change between weaning and mating

The proportion ewes lambed (Figure 4.3 A, C) and litter size at lambing (Figure 4.3 B, D) were not associated with ewe BCS and liveweight change from weaning of the preceding production cycle to mating of the subsequent production cycle.

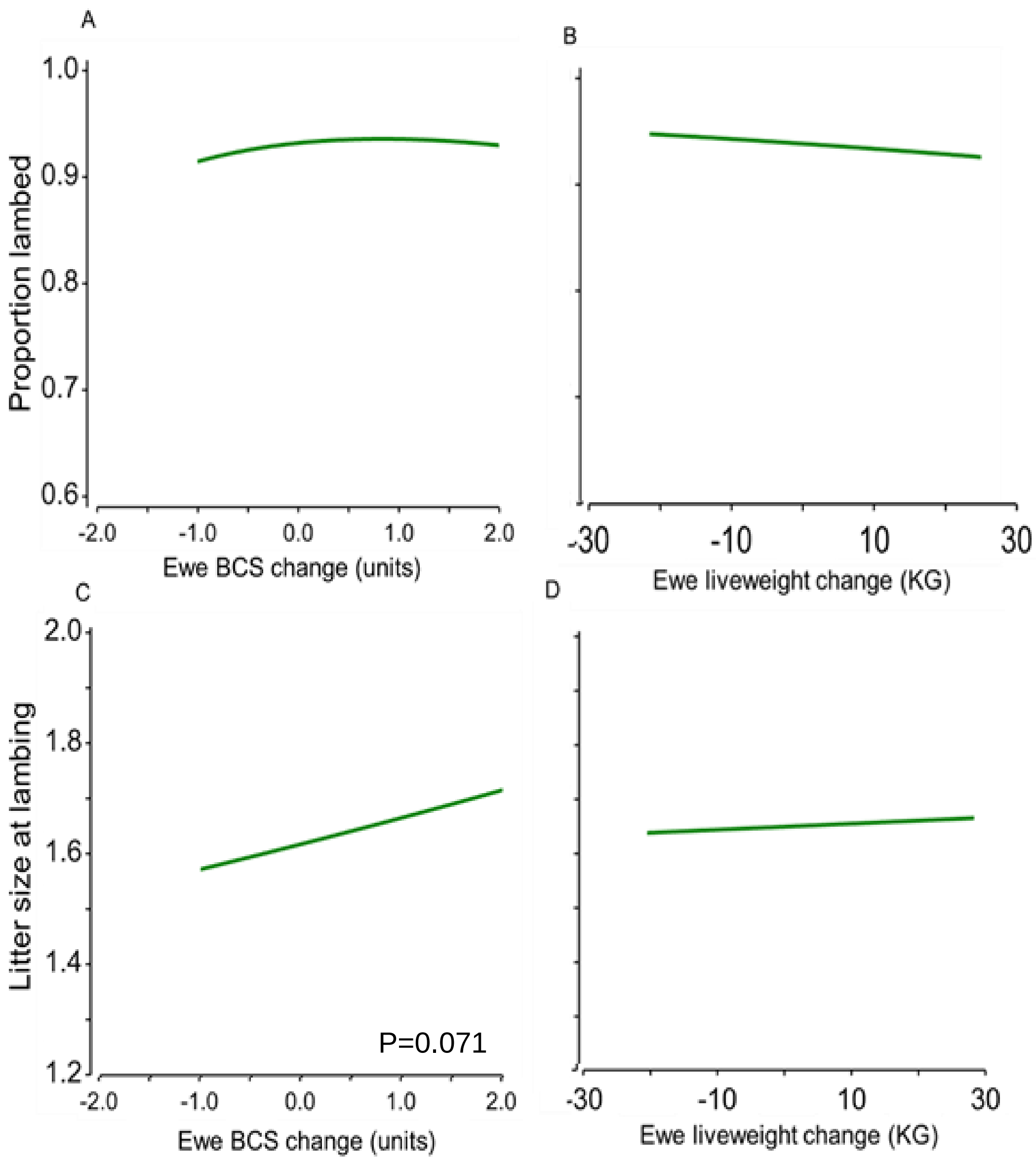


Figure 4.3. Association between ewe BCS change (A, C) and liveweight change (B, D) **between weaning of the preceding production cycle and mating** of the subsequent production cycle on proportion ewes lambed (A-B) and litter size at lambing (C-D) for the combined analyses.

4.3.4 Ewe BCS and liveweight at scanning

The proportion ewes lambed (P<0.001; Figure 4.4 A-B) and litter size at lambing (P<0.001; Figure 4.4 C-D) were both positively associated with ewe BCS and liveweight at scanning.

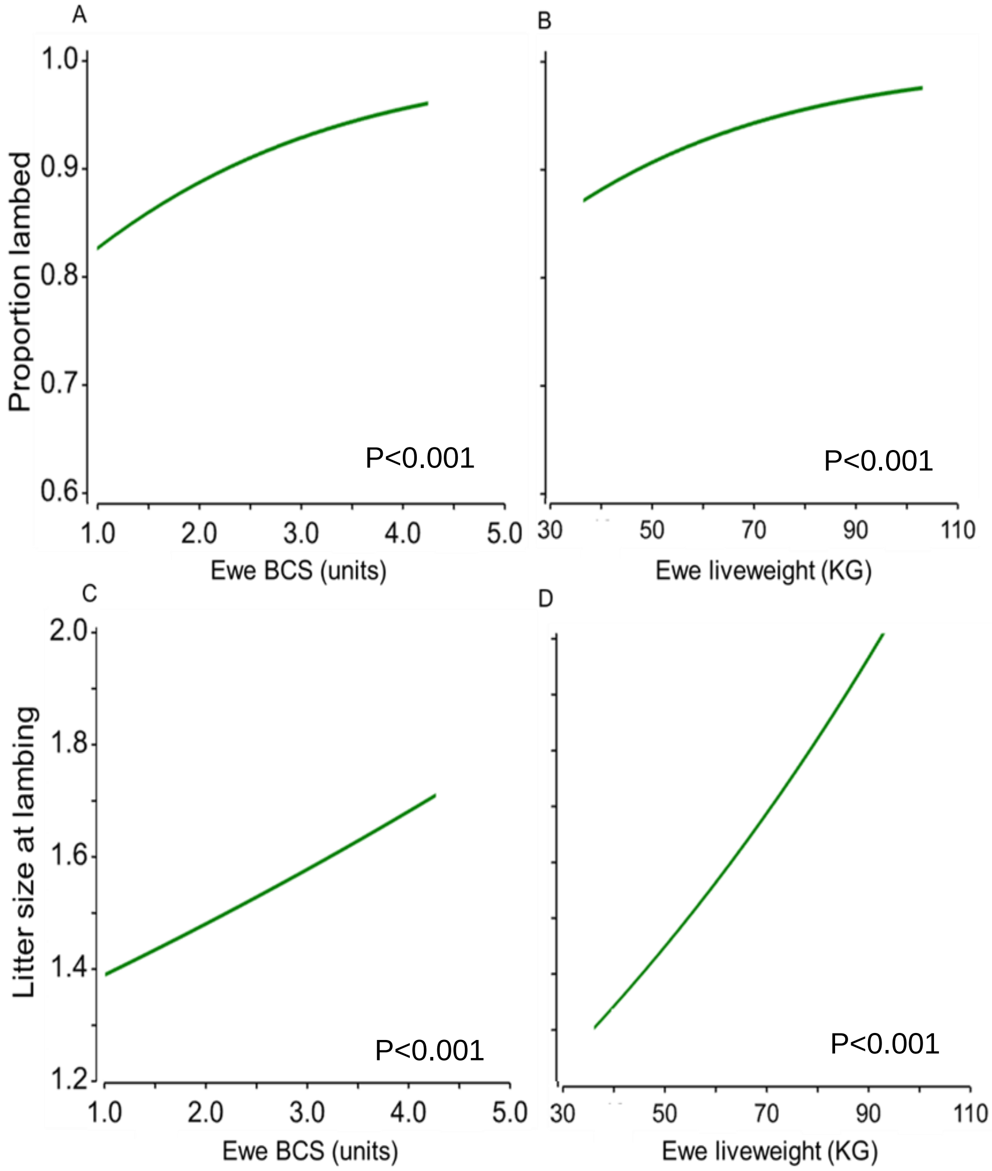


Figure 4.4. Association between ewe BCS (A, C) and liveweight (B, D) **at scanning** on proportion ewes lambed (A-B) and litter size at lambing (C-D) for the combined analyses.

4.3.5 Ewe BCS and liveweight change between mating and scanning

The proportion ewes lambed (P<0.001; Figure 4.5 A-B) and litter size at lambing (P<0.001; Figure 4.5 C-D) were positively associated with ewe BCS and liveweight gain between mating and scanning.

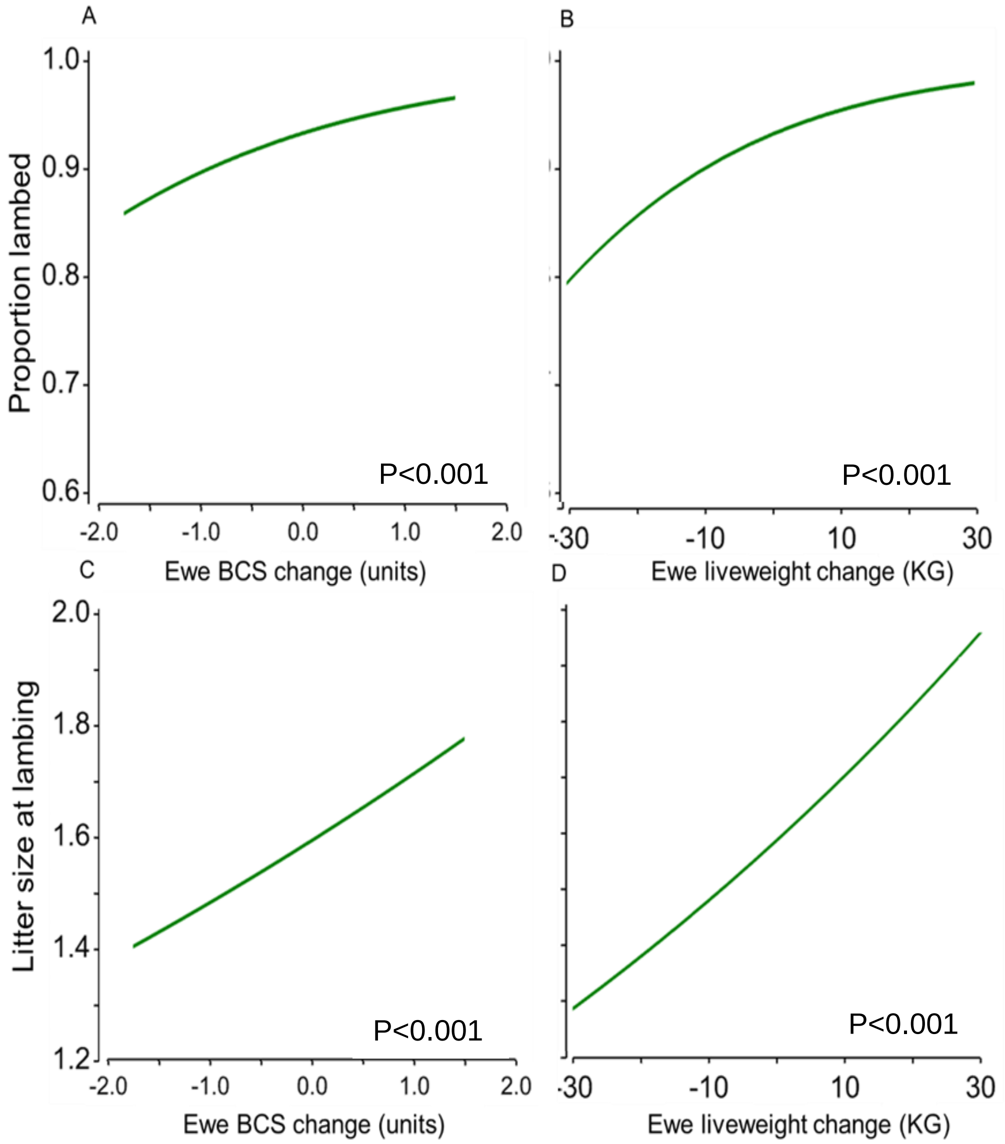


Figure 4.5. Association between ewe BCS change (A, C) and liveweight change (B, D) **between mating and scanning** on proportion ewes lambed (A-B) and litter size at lambing (C-D) for the combined analyses.

4.3.6 Ewe BCS at lambing

The proportion ewes lambed was not associated with ewe BCS at lambing (Figure 4.6 A). Litter size at lambing was negatively associated with ewe BCS at lambing (P=0.002; Figure 4.6 B), with larger litter size associated with ewes at lower BCS at lambing.

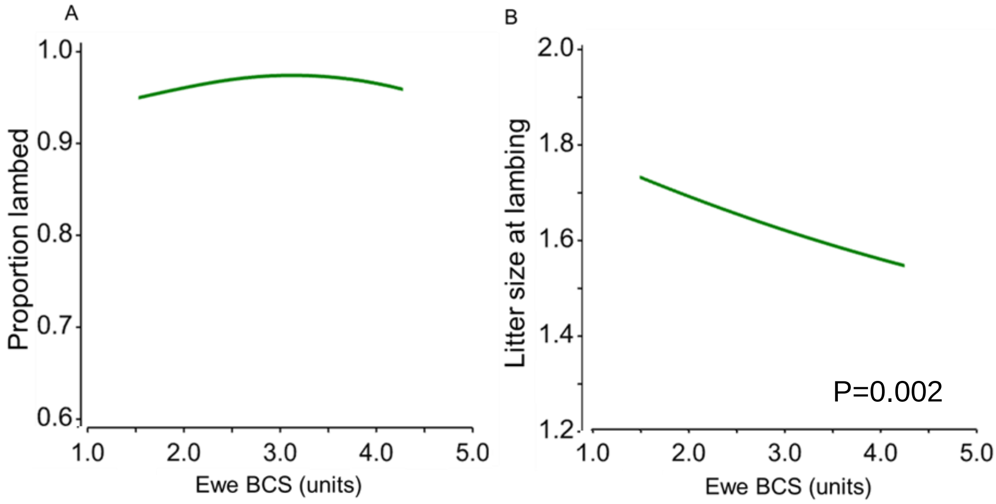


Figure 4.6. Association between ewe BCS **at lambing** on proportion ewes lambed (A) and litter size at lambing (B) for the combined analyses.

4.3.7 Ewe BCS change between scanning and lambing

The proportion ewes lambed was not associated with ewe BCS change between scanning and lambing (Figure 4.7 A). Litter size at lambing was negatively associated with ewe BCS gain (P<0.001; Figure 4.7 B), with larger litters at lambing associated with ewe BCS loss between scanning and lambing.

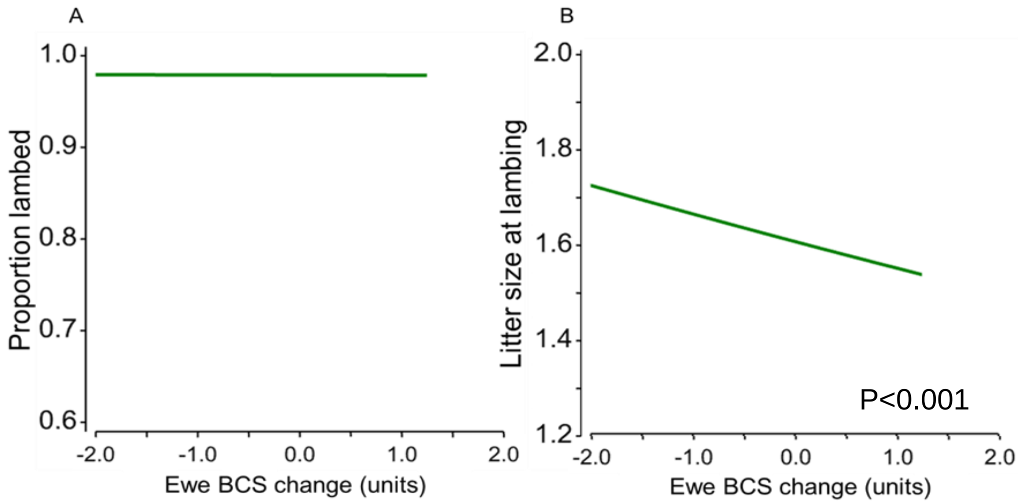


Figure 4.7. Association between ewe BCS change **between scanning and lambing** on proportion ewes lambed (A) and litter size at lambing (B) for the combined analyses.

4.4 Discussion

In summary, the proportion ewes lambed was positively associated with both BCS and liveweight at scanning, and change in BCS and liveweight between mating and scanning only (Table 4.1). Litter size at lambing was associated with ewe liveweight at weaning, mating and scanning (Table 4.1) and associated with ewe BCS at scanning and lambing only. Litter size at lambing was also associated with change in BCS and liveweight from mating through to lambing. These observations are consistent with those reported in Chapter 3 for individual farms. These observations, from data pooled across the three study farms and three production cycles, are consistent with those derived from analyses of individual production cycles for each of the three participating farms.

Table 4.1. Summary of effects of ewe BCS and liveweight (LWT) and change (Δ) on pregnancy outcome (proportion ewes lambed and litter size at lambing) across the three production cycles for the Sussex, Leicestershire and Lancashire Farms combined.

	Proportion Lambed	**Litter Size at Lambing**
Weaning BCS	n/s	n/s
Weaning LWT	n/s	<0.001 (+)
Mating BCS	n/s	n/s
Mating LWT	n/s	<0.001 (+)
Δ BCS weaning - mating	n/s	n/s
Δ LWT weaning - mating	n/s	n/s
Scanning BCS	<0.001 (+)	<0.001 (+)
Scanning LWT	<0.001 (+)	<0.001 (+)
Δ BCS mating - scanning	<0.001 (Gain +)	<0.001 (Gain +)
Δ LWT mating - scanning	<0.001 (Gain +)	<0.001 (Gain +)
Lambing BCS	n/s	=0.002 (Gain -)
Δ BCS scanning - lambing	n/s	<0.001 (Gain -)

n/s=not significant + positive association - negative association

In addition to the 3% barren at scanning, a further 4% did not record a live lamb at tagging 24-48 h post-partum, despite being scanned as pregnant. There are no national benchmark figures available to compare this figure. The most commonly quoted indicator of barren ewes at lambing is the incidence of abortions, with less than 2% the benchmark (NADIS, 2018). There were very few reports of abortion incidents at the three farms during the project. Other likely causes for the lack of lamb records would be ewe mortality, lamb losses between scanning and lambing, a lamb born dead or a lamb dying before tagging. Another possibility could be the failure to record the data at lambing time, although this is the least likely reason.

4.4.1 Weaning of one production cycle to one-month post-mating of subsequent production cycle

Litter size at lambing was not associated with ewe BCS at weaning and mating, however it was associated with liveweight at these two time points. At weaning in particular, ewes in poor condition (i.e. around 1.5 units) would not only be required to replenish adipose tissue, they would also need to replace body protein (Robinson *et al.,* 2002); perhaps indicating that lean body mass or intra-abdominal fat reserves, rather than subcutaneous body fat *per se* (as determined by BCS), may be a more important factor at this very early stage in the production cycle. This theory is supported by Caldeira and Portugal, (2007) who reported that intermuscular fat represented the largest fat depot in ewes at BCS scores below 3 units and Russel *et al.,* (1969) reported that intermuscular fat would be mobilised between BCS 2 and 1 units. Both Russel *et al.,* (1969) and Caldeira and Portugal, (2007) found that subcutaneous fat was the largest deposition site in ewes above BCS 3 units.

Our findings suggest that preventing ewes from losing too much condition and/or weight by weaning in the preceding production cycle may have a positive effect on ewe productivity in the subsequent season. Ways to avoid this happening could include weaning earlier and/or providing additional feed to ewes during lactation (Corner-Thomas, 2017; AHDB, 2014a). There are no national figures available on lamb age at weaning, however personal communication with sheep producers suggests the majority weaned lambs are between 14 and 16 weeks of age, not the recommended 12 weeks (Geenty, 2000). The age of lambs at weaning is discussed further in Chapter 6. The cost implications of additional feed for ewes post-lambing are often prohibitive but our findings suggests there may be longer term benefits.

A positive relationship between litter size at lambing and ewe liveweight at mating was also observed by Coop, (1962) and B&LNZ, (2013a) who reported that each extra kg of ewe liveweight at mating resulted in a 2% increase in lambing percentage. However, contrary to the findings in this chapter, many studies have found BCS at mating to have a positive effect on litter size.

Gonzalez *et al.,* (1997) reported that increasing ewe BCS at mating (between the range of BCS 2 and 4 units) increased the proportions of multiple bearing ewes. Fthenakis *et al.,* (2012) reported that ewes mated at an optimum BCS of 3 to 3.5 units had increased ovulation rates, leading to increased number of lambs born, and Bohan & Keady, (2019) found that each unit increase in BCS at mating (within the range of 2.5 to 4.0 units) increased litter size by 0.13 lambs per ewe. The lack of association between ewe BCS at mating on litter size at lambing in this chapter, compared to other research, could be the exclusion of triplet bearing ewes from the analyses for reasons previously explained (4.2 Materials and methods). Bohan & Keady, (2019) also reported that mating ewes at a BCS below 2.5 units increased the risk of being barren. Whilst there was no effect of BCS on proportion ewes lambed in our study, it is worth noting that the number of ewes mated below BCS 2.5 units was negligible (Appendix I.).

Whilst litter size at lambing was positively associated with ewe liveweight at weaning and mating, it was not associated with change in liveweight (or BCS) between weaning of the preceding production cycle and mating. These findings are supported by Gonzalez *et al.,* (1997) who found that, whilst ewe liveweight during or at the end of the mating period had significant influences on the number of lambs born, there were no significant effect of changes in either liveweight or BCS over the 4 weeks prior to mating or during the mating period. These findings are extended by Hickson *et al.,* (2012), who reported that liveweight gain following weaning in the previous season had little influence on lamb birthweight and lamb survival. Whilst our findings did not investigate the effects on lamb birthweight or survival, they do indicate that the proportion ewes lambing or litter size at lambing are not affected by liveweight change between weaning and mating. The lack of association between proportion ewes pregnant, and litter size at scanning, and ewe BCS and liveweight change between weaning and mating was also reported in Chapter 3. One explanation for the lack of association between BCS and weight change between weaning and mating on litter size at lambing is that the condition of the ewe at weaning has pre-determined the next production cycle. Robinson *et al.,* (2005) reported that a ewe's ovulation rate is sensitive to her nutritional status in the six months leading up to ovulation.

4.4.2 One-month post-mating to scanning (mid-pregnancy)

Consistent with results from individual farms reported in Chapter 3, the proportion ewes lambed and litter size at lambing were each positively associated with ewe BCS and liveweight at scanning, and gain in BCS and liveweight between mating and scanning. This contradicts the current recommendations for sheep producers, where a loss of up to half a unit of BCS (or ~5 percent of liveweight) is considered best practice (Gunn *et al.,* 1991). Research findings on this topic, however, are variable. Most studies focus on placental size. Some conclude that maternal undernutrition up to mid-pregnancy has a positive effect on placental development and no negative impact on lamb birthweight (Clarke *et al.,* 1988; Munoz *et al.,* 2007; Addah *et al.,* 2012), others report that undernutrition up to mid-pregnancy has a negative effect on lamb birthweight (Orr and Treacher, 1990; Rae *et al.,* 2001; Robinson *et al.,* 2002), whilst there are other studies that found no effect on lamb birthweight (Robinson 1990; McCrabb *et al.,* 1986; Clark and Speedy, 1980). The current study was not able to investigate the effects of BCS or liveweight on placental size or lamb birthweight.

4.4.3 Scanning (mid-pregnancy) to lambing (late pregnancy)

Ewes at the Sussex and Leicestershire Farms mobilised BCS between scanning and lambing (Appendix I.). A number of studies have investigated the effects of low levels of nutrition during late pregnancy on both ewe and subsequent lamb performance (Robinson *et al.,* 2002; Addah *et al.,* 2012; Dwyer, 2014; Kenyon and Blair, 2014; Rooke *et al.,* 2015). Much of the research surrounding the impact of ewe condition and its effect on lamb performance relates to lamb birthweight (Kenyon and Blair, 2014), which we were not able to measure in this study. However, no research has reported a positive association between lower ewe BCS at lambing and BCS loss between scanning and lambing positively contributing to litter size at lambing, as seen in this research. Most studies indicate that lower BCS at lambing have a detrimental effect on lamb performance (Robinson *et al.,* 2002; Kenyon *et al.,* 2012; Dwyer, 2014; Corner-Thomas *et al.,* 2015). Our analyses does not establish cause and effect but associations between two variables (i.e. litter size and BCS at lambing). These data indicate that, on the whole, ewe energy requirements were not met during late pregnancy and so consequently these ewes lost BCS, with twin bearing ewes losing more condition than single bearing ewes.

4.5 Conclusion

Supporting the findings in Chapter 3, both proportion ewes lambed and litter size at lambing were associated with ewe BCS and liveweight at various points during the production cycle. Litter size at lambing was more often associated with ewe liveweight than BCS. This study indicates that ewe liveweight, but not BCS, at weaning and mating may each affect litter size at lambing; perhaps indicating that lean body mass or intra-abdominal fat reserves, rather than subcutaneous body fat *per se* (as determined by BCS), may be a more important factor at this very early stage in the production cycle.

Lambing outcomes (i.e. proportion ewes lambed and litter size at lambing) were positively associated with ewe liveweight and BCS at scanning, and ewe liveweight and BCS gain between mating and scanning. This was also found in Chapter 3. This suggests that the current advice of allowing BCS and weight loss between mating and scanning should be reconsidered. The current study indicates that ewes should, at least, maintain BCS and weight between mating at scanning.

This study suggests that preparation for a ewe's production cycle begins from or even before weaning of the preceding production cycle. Preventing ewes from losing too much condition and/or weight by weaning in the preceding production cycle, perhaps by weaning lambs earlier, may have a positive effect on ewe productivity in subsequent production years.

5 CHAPTER FIVE: Factors affecting weight of twin lambs to weaning

5.1 Introduction

Ewe nutrition requirements increase post-partum. The energy requirement of a 70 kg ewe increases from 18 MJ/day one week pre-lambing to 33 MJ/day in early lactation (assuming a milk yield of 3 kg milk/day and no weight loss) (AFRC, 1993). If dietary intake does not meet the increased requirements (through grazing or supplementary feed), this will result in a loss of milk yield, unless the ewe has sufficient body reserves (Vernon & Finley, 1985; Treacher & Caja, 2002). Under these conditions, milk production and lamb growth to weaning are greatest for ewes that have more body fat to mobilise (McNeill *et al.,* 1997; Brand & Franck, 2000; Lambe *et al.,* 2005). Ewe milk yield will increase if BCS at lambing is above 2.5 (B&LNZ, 2020).

The heritability of lamb growth rate is between 10-15% (Lôbo *et al.,*2009), with non-genetic factors accounting for the majority of variability in lamb performance (Lima *et al.,* 2019). Non-genetic factors that influence lamb daily liveweight gain (DLWG) include litter size (singles heavier than multiples) (Dimsoski *et al.,* 1999), lamb sex (males heavier than females) (Arnold & Meyer, 1988), lamb birthweight (low and high birthweights increasing morbidity) (Sheep Net, 2018), lamb behaviour at birth (lamb vigour and time taken to stand and suck affecting survival) (Dwyer, 2008), ewe age (younger and older ewes rearing lighter lambs) (Dickerson & Laster, 1975) and disease (e.g. lameness and navel ill) (Lima et al., 2019).

Peak milk yield occurs at approximately four weeks post-partum, with ewes producing 40-50 percent of total milk yield during the first four weeks of lactation (AFRC, 1993). The first measure of flock performance on most commercial sheep farms is lamb weight and ewe condition at weaning. A measure of ewe and lamb performance at 8 weeks post-lambing was incorporated into this project to determine the effects of the ewe BCS and liveweight on early lamb performance and to determine whether this had an impact on performance to weaning.

There are no national statistics available to stipulate the age of lambs at weaning in the UK. Best practice advice is for lambs to be weaned at around 90 days (12 weeks) (AHDB, 2014a). Personal communication with several sheep producers suggests there is variation to this in practice, with many weaning at 14 weeks and older.

Chapter 2 proposed a target of lamb performance to 8 weeks and weaning of 20 kg and 30 kg, respectively. The current chapter reports on factors that influence the weight of twin lambs by farm and production cycle. Finally, individual farm by year data was pooled for twin then single lambs to establish if there were differences between the impact of ewe BCS and liveweight based on number of lambs reared.

Therefore, the current chapter reports on the effects of lamb age, lamb sex, ewe BCS and liveweight (actual and change) from weaning of the preceding production cycle to weaning of the subsequent production cycle on the performance of twin lambs to weaning (90 days). Specifically, this Chapter sought, firstly, to establish if ewe BCS and/or liveweight, or change in ewe BCS and/or liveweight, at various stages from weaning to weaning was associated with combined lamb 8-week weight, combined lamb weaning weight and weight gain between 8 weeks and weaning. A secondary objective was to determine if lamb 8-week weight was an indicator of lamb performance to weaning.

5.2 Materials and methods

Detailed methodology and data collection protocol can be found in Chapter 2 (2.2.2 Data collection).

The current chapter analysed factors that affect the performance of twin lambs to weaning (at approximately 90 days post-lambing). Factors affecting combined lamb 8-week weight, combined lamb weaning weight and lamb weight gain between 8 weeks and weaning were analysed for each farm for the three (consecutive) production cycles. The analysis pertained only to those ewes rearing two lambs from birth through to weaning.

Analyses were performed using the GenStat statistical package (18th Edition, VSN International, 2019; https://www.vsni.co.uk/). All data were analysed using General Linear Regression models. In the final version of these models, the following terms were fitted for the Sussex and Leicestershire farms: ‘Lamb age’, ‘Lamb sex’, ‘Genotype’, ‘BCS’ or ‘Liveweight’ or ‘Change in BCS or liveweight’, together with interactions between these terms. At the Lancashire farm the term ‘Parity’ was also included. In the pooled analyses, the following terms were fitted: ‘Farm’, ‘Year’, ‘BCS’ or ‘Liveweight’ or ‘Change in BCS or liveweight’, together with interactions between these terms. Probabilities <0.05 was deemed significant. Data are presented as means ± SE.

5.3 Results

5.3.1 Sussex Farm: Summary of effects on lamb weight to weaning

5.3.1.1 *Ewe genotype*

Combined lamb 8-week weight and combined lamb weaning weight were associated with ewe genotype in Years 1, 2 and 3 ($P<0.001$; Table 5.1). Lamb weight gain between 8 weeks and weaning was associated with ewe genotype in Years 1 and 2 ($P=0.021$, $P<0.001$ respectively; Table 5.1). Lambs reared by Mule ewes achieved the heaviest 8-week and weaning weights and gained the most weight between 8 weeks and weaning. The order thereafter (Aberfield and Lleyn) differed between years.

Table 5.1. Effect of **ewe genotype** on combined lamb 8-week weight, combined lamb weaning weight and weight gain between 8 weeks and weaning (mean ± SE) for Years 1 to 3 at the Sussex Farm. Lamb weights are ranked highest to lowest.

	Year 1	Year 2	Year 3
8-week weight (KG)	Mule 44.8 ±0.92 Lleyn 41.1 ±1.07 Aberfield 39.6 ±0.51	Mule 42.5 ±0.91 Lleyn 41.6 ±0.61 Aberfield 38.9 ±0.44	Mule 39.7 ±0.69 Lleyn 38.8 ±0.56 Aberfield 36.6 ±0.60
Weaning weight (KG)	Mule 64.7 ±1.52 Lleyn 62.8 ±1.31 Aberfield 58.6 ±0.18	Mule 58.9 ±0.89 Lleyn 58.4 ±1.33 Aberfield 53.7 ±0.64	Mule 49.5 ±0.81 Lleyn 48.6 ±0.67 Aberfield 45.3 ±0.65
Weight change 8 weeks to weaning (KG)	Mule 21.7 ±1.04 Lleyn 19.9 ±1.20 Aberfield 19.0 ±0.57	Mule 16.8 ±0.76 Lleyn 16.5 ±0.51 Aberfield 14.9 ±0.37	Mule 10.3 ±0.36 Aberfield 9.9 ±0.37 Lleyn 9.2 ±0.29

5.3.1.2 *Ewe parity*

Combined lamb 8-week weight was positively associated with ewe parity in Years 1, 2 (P<0.001; Figure 5.1. A-B) and 3 (P=0.014; Figure 5.1. C). Combined lamb weaning weight was positively associated with ewe parity in Years 1 and 2 only (P<0.001; Figure 5.1. D-E). Lamb weight gain between 8 weeks and weaning was not associated with ewe parity (Figure 5.1. G-I).

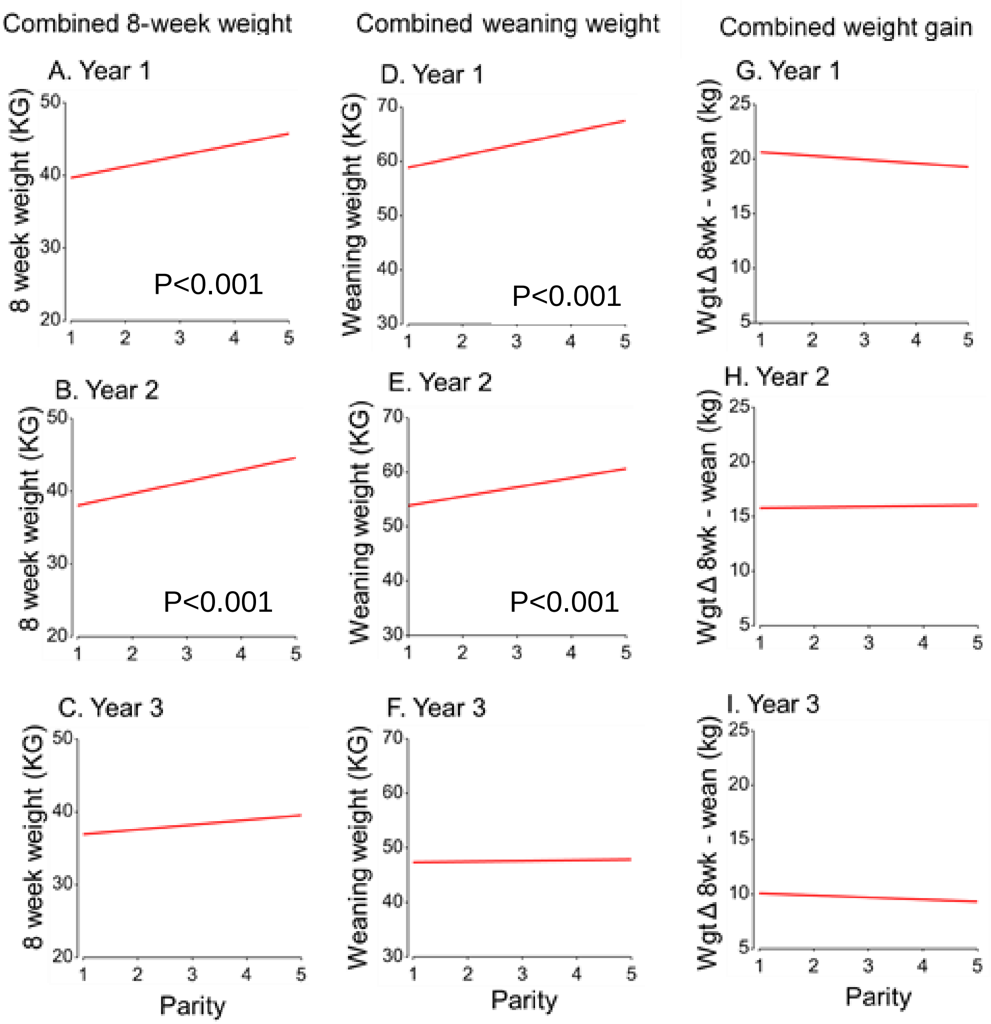


Figure 5.1. Association between **ewe parity** on combined lamb 8-week weight (A-C), combined lamb weaning weight (D-F) and lamb weight gain between 8 weeks and weaning (G-I) in Years 1 (A, D, G), 2 (B, E, H) and 3 (C, F, I) at the Sussex Farm.

5.3.1.3 *Ewe BCS and liveweight at weaning (preceding production cycle)*

There was a suggestion that combined lamb 8-week weight was positively associated with ewe BCS at weaning of the preceding production cycle, but in Year 3 only (P=0.065; Figure 5.2 C). Combined lamb weaning weight and lamb weight gain between 8 weeks and weaning were not associated with ewe BCS at weaning; except for ewe genotype x BCS interactions in Year 3 (P<0.001; Figure 5.2 O). On both occasions, lamb weaning weight and weight gain between 8 weeks and weaning increased with increasing ewe BCS at weaning for lambs reared by Aberfield ewes, compared to lambs reared by Mule and Lleyn ewes that responded negatively to increasing BCS.

Combined lamb 8-week weight was positively associated with ewe liveweight at weaning of the preceding production cycle in Year 2 (P=0.002; Figure 5.2 E) and 3 (P<0.001; Figure 5.2 F). There was a suggestion that lamb weaning weight was positively associated with ewe liveweight at weaning in Year 1 (P=0.089; Figure 5.2 J); this relationship was significant in Years 2 (P<0.001; Figure 5.2 K) and 3 (P=0.007; Figure 5.2 L). There was also a suggestion that lamb weight gain between 8-weeks and weaning was positively associated with ewe liveweight at weaning, but in Year 2 only (P=0.058; Figure 5.2 Q).

5.3.1.4 *Ewe BCS and liveweight at mating*

There was a suggestion that combined lamb 8-week weight was positively associated with ewe BCS at mating, but in Year 2 only (P=0.095; Figure 5.3 B). Combined lamb weaning weight was not associated with ewe BCS at mating (Figure 5.3 G-I) but lamb weight gain between 8 weeks and weaning was positively associated with ewe BCS at mating, in Years 1 (P=0.020; Figure 5.3 M) and 3 (P=0.007; Figure 5.3 O).

Combined lamb 8-week weight was positively associated with ewe liveweight at mating in Years 1, 2 and 3 (P<0.001; Figure 5.3 D-F), with a ewe genotype x liveweight interaction also in Year 1 (P=0.007; Figure 5.3 D). Lamb 8-week weight increased with increasing ewe liveweight at mating for lambs reared by Aberfield and Lleyn ewes but not for lambs reared by Mule ewes.

Combined lamb weaning weight was positively associated with ewe liveweight at mating in Years 1, 2 and 3 (P<0.001; Figure 5.3 J-L) but lamb weight gain between 8 weeks and weaning was not associated with ewe liveweight at mating (Figure 5.3 P-R).

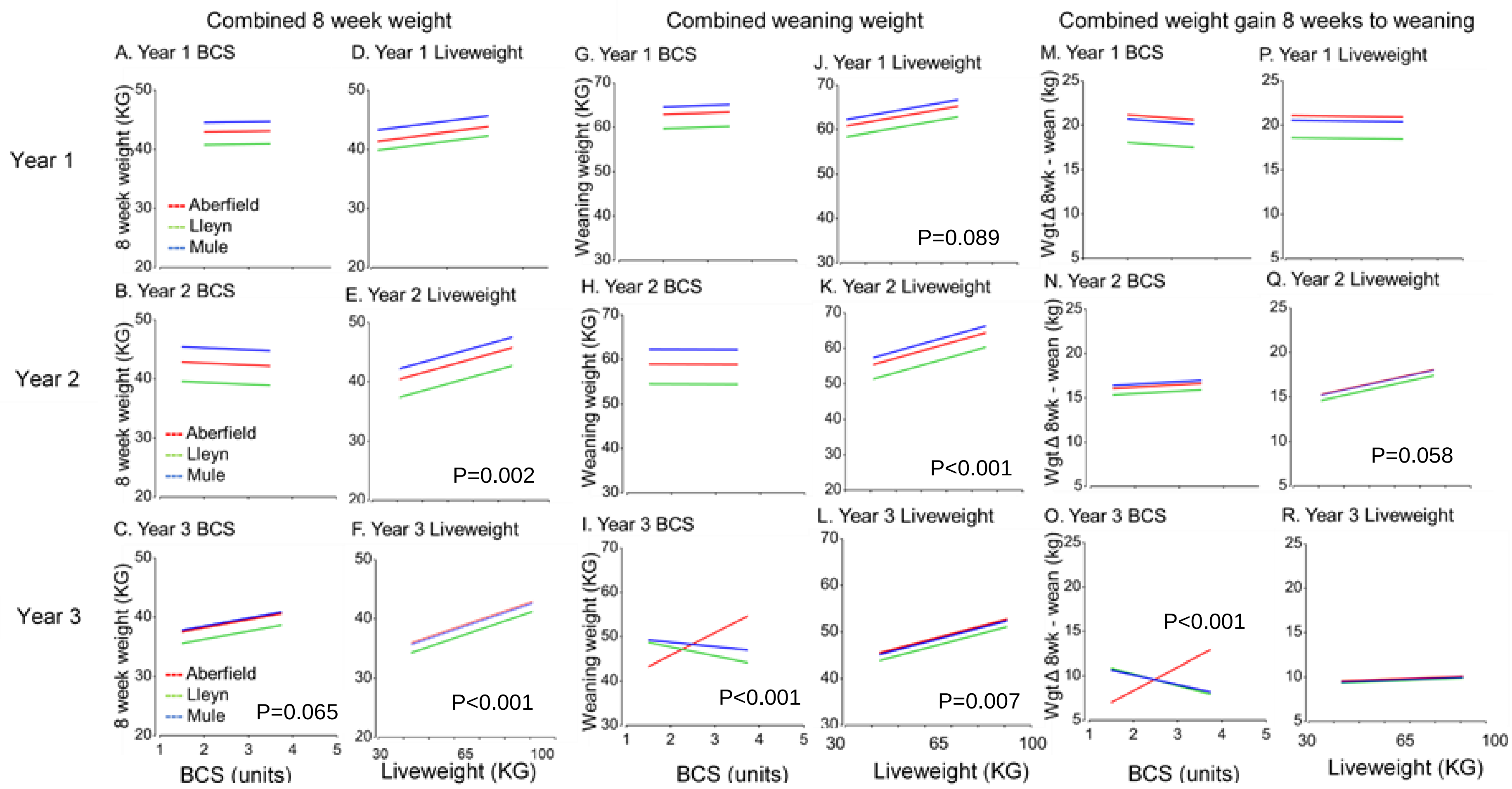


Figure 5.2. Association between ewe BCS (A-C, G-I, M-O) and liveweight (D-F, J-L, P-R) **at weaning** of the preceding production cycle on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) in the subsequent production cycle at the Sussex Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

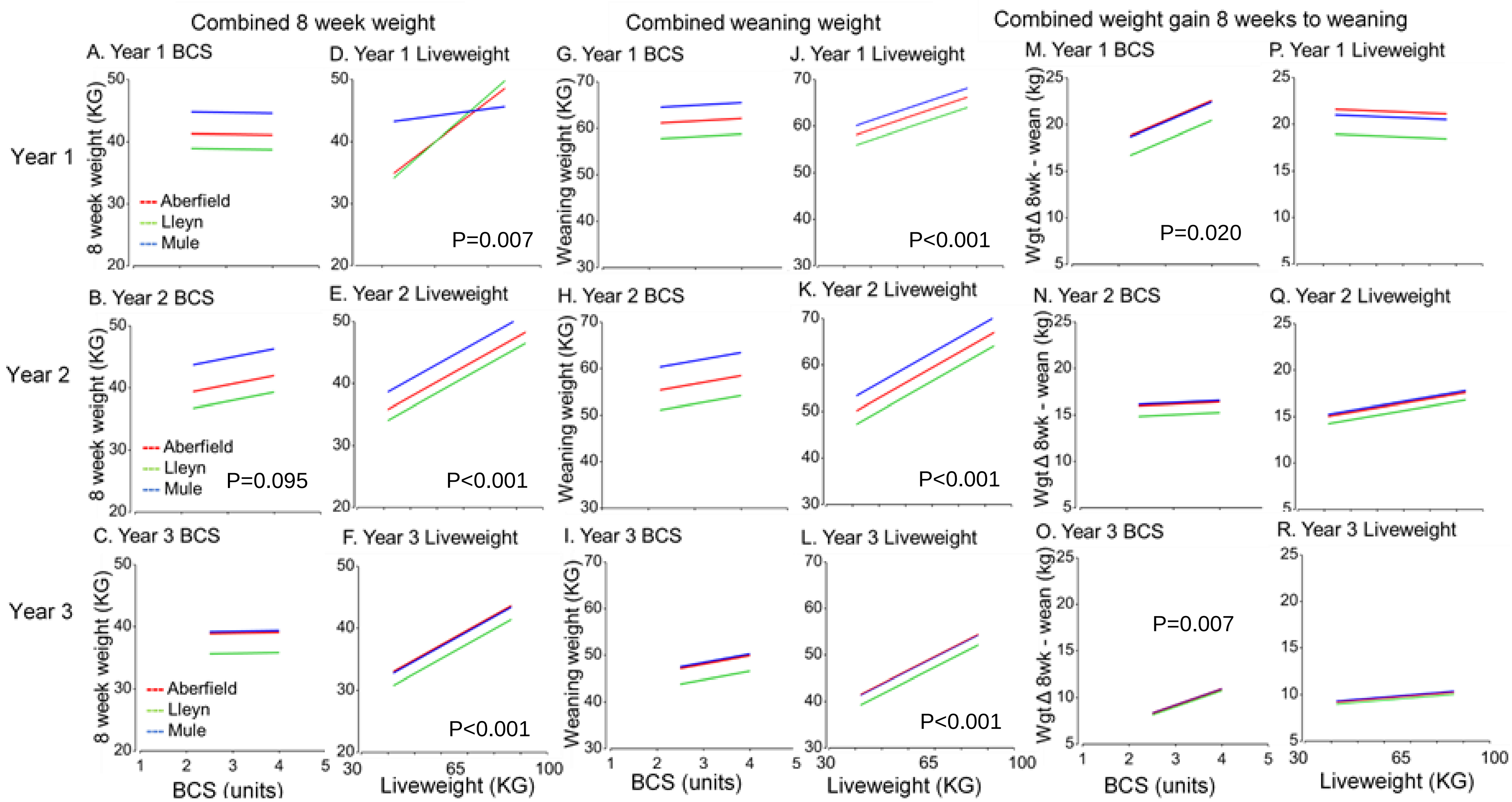


Figure 5.3. Association between ewe BCS (A-C, G-I, M-O) and liveweight (D-F, J-L, P-R) **at mating** on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) at the Sussex Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

5.3.1.5 *Ewe BCS and liveweight change between weaning and mating*

Combined lamb 8-week weight was positively associated with ewe BCS change between weaning of the preceding production cycle and mating of the subsequent production cycle, but in Year 2 only (P=0.014; Figure 5.4. B). There was a suggestion that combined lamb weaning weight was also positively associated with BCS change, also in Year 2 only (P=0.085; Figure 5.4. H). There were ewe genotype x BCS change interactions affecting combined lamb weaning weight (P=0.036; Figure 5.4. I) and lamb weight gain between 8 weeks and weaning (P=0.012; Figure 5.4. O), but in Year 3 only. On both occasions, lamb weaning weight and lamb weight gain between 8 weeks and weaning for lambs reared by Aberfield ewes decreased with ewe BCS gain, compared to lambs reared by Mule and Lleyn ewes.

Combined lamb 8-week weight was positively associated with ewe liveweight change between weaning of the preceding production cycle and mating of the subsequent production cycle, but in Year 2 only (P=0.041; Figure 5.4. H). Combined lamb weaning weight and lamb weight gain between 8 weeks and weaning were not associated with ewe liveweight change.

5.3.1.6 *Ewe BCS and liveweight at scanning*

Combined lamb 8-week weight was positively associated with ewe BCS at scanning in Years 1 (P=0.016; Figure 5.5. A), 2 (P<0.001; Figure 5.5 B); and to a lesser extent, in Year 3 (P=0.090; Figure 5.5 C). Combined lamb weaning weight was also positively associated with ewe BCS at scanning in Years 1 (P=0.045; Figure 5.5 G), 2 (P=0.002; Figure 5.5 H) and 3 (P=0.004; Figure 5.5 I). Lamb weight gain between 8 weeks and weaning was not associated with ewe BCS at scanning (Figure 5.5 M-O).

There was a suggestion that combined lamb 8-week weight was positively associated with ewe liveweight at scanning in Year 1 (P=0.096; Figure 5.5 D); this relationship was significant in Years 2 and 3 (P<0.001; Figure 5.5 E-F). Combined lamb weaning weight was positively associated with ewe liveweight at scanning in Years 2 and 3 (P<0.001; Figure 5.5 K-L). Lamb weight gain between 8 weeks and weaning was positively associated with ewe liveweight at scanning, but in Year 2 only (P=0.043; Figure 5.5 Q).

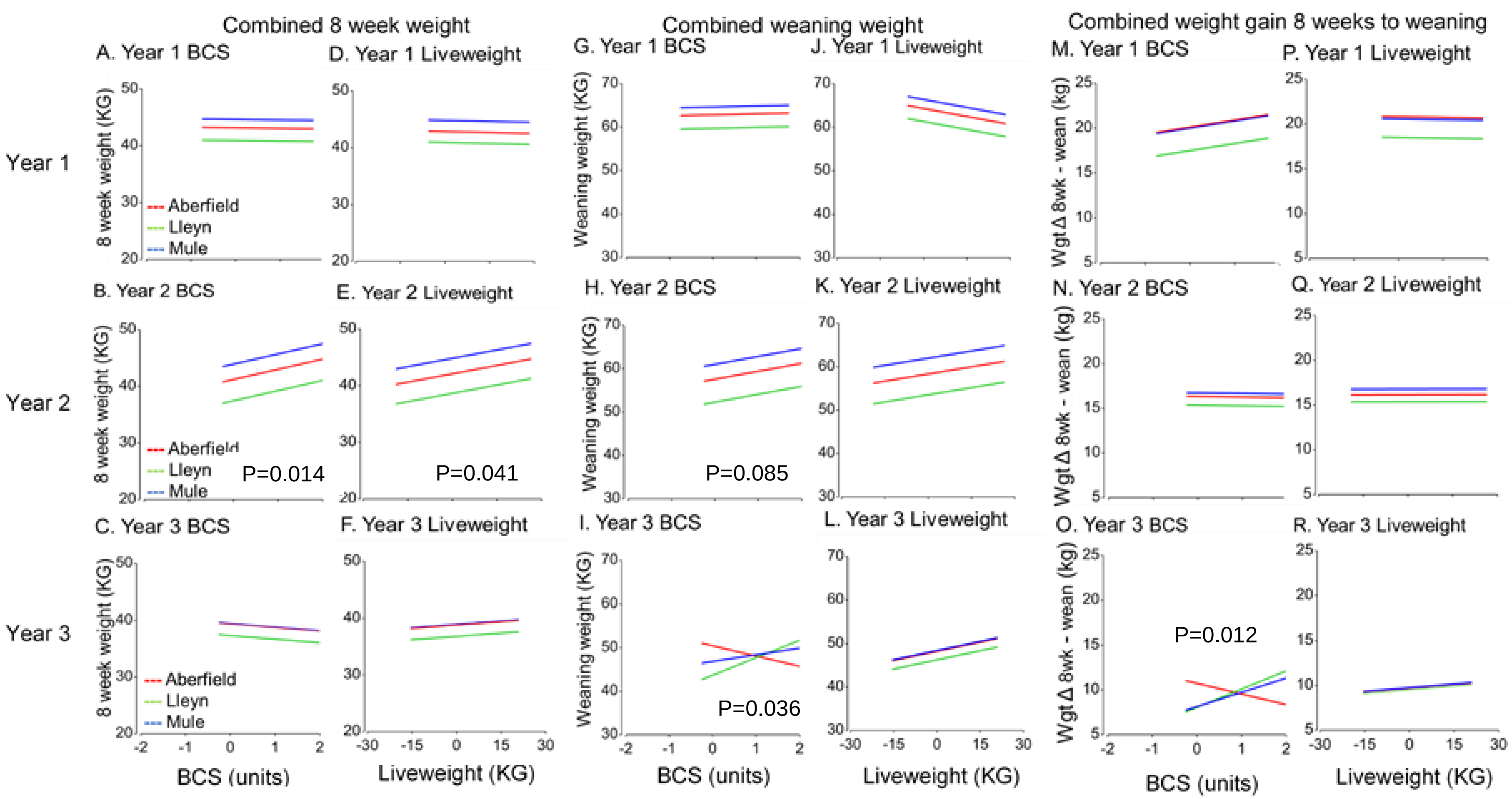


Figure 5.4. Association between ewe BCS change (A-C, G-I, M-O) and liveweight change (D-F, J-L, P-R) **between weaning of the preceding production cycle to mating** of subsequent production cycle on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) at the Sussex Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

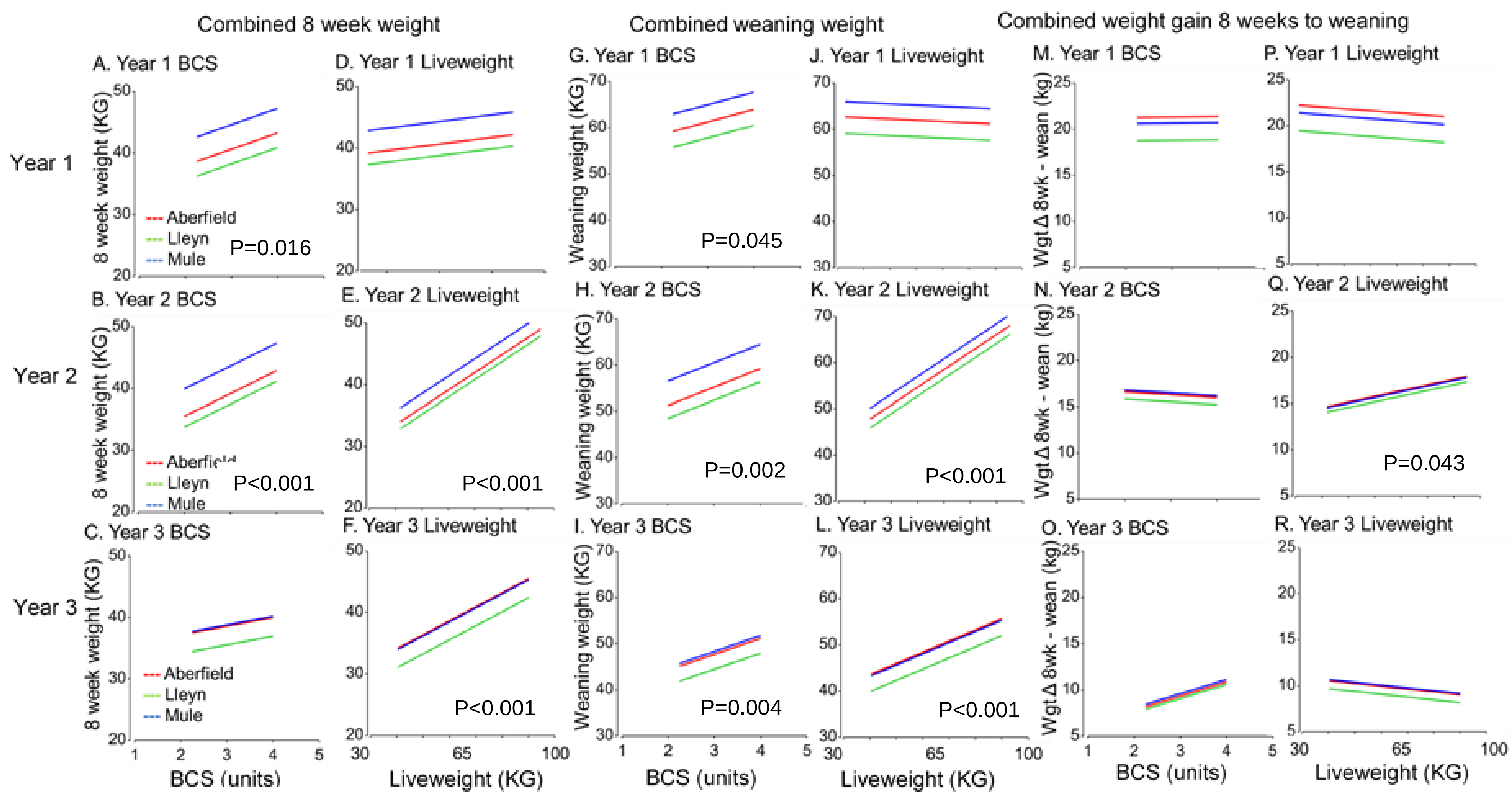


Figure 5.5. Association between ewe BCS (A-C, G-I, M-O) and liveweight (D-F, J-L, P-R) **at scanning** on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) at the Sussex Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

5.3.1.7 *Ewe BCS and liveweight change between mating and scanning*

Combined lamb 8-week weight was positively associated with ewe BCS gain between mating and scanning in Years 1, 2 and 3 (P=0.028; P=0.015; P=0.008; Figure 5.6 A-C). There was a suggestion that combined lamb weaning weight was positively associated with ewe BCS gain in Years 1 and 3 (P=0.078; P=0.062; Figure 5.6 G-I). Lamb weight gain between 8 weeks and weaning was not associated with ewe BCS change between mating and scanning, other than a suggested ewe genotype x BCS change interaction in Year 1 (P=0.066; Figure 5.6 M). Lamb weight gain between 8 weeks and weaning increased for ewes that gained BCS between mating and scanning for lambs reared by Aberfield ewes, compared to lambs reared by Mule and Lleyn ewes that responded negatively to BCS gain.

There was an indication that combined lamb 8-week weight (P=0.069; Figure 5.6 D) and combined lamb weaning weight (P=0.066; Figure 5.6 J) were negatively associated with ewe liveweight gain between mating and scanning, but in Year 1 only. In Year 2, combined lamb 8-week weight (P=0.017; Figure 5.6 E) and combined lamb weaning weight (P=0.012; Figure 5.6 K) were positively associated with ewe liveweight gain. Lamb weight gain between 8 weeks and weaning was not associated with ewe liveweight change between mating and scanning (Figure 5.6 P-R).

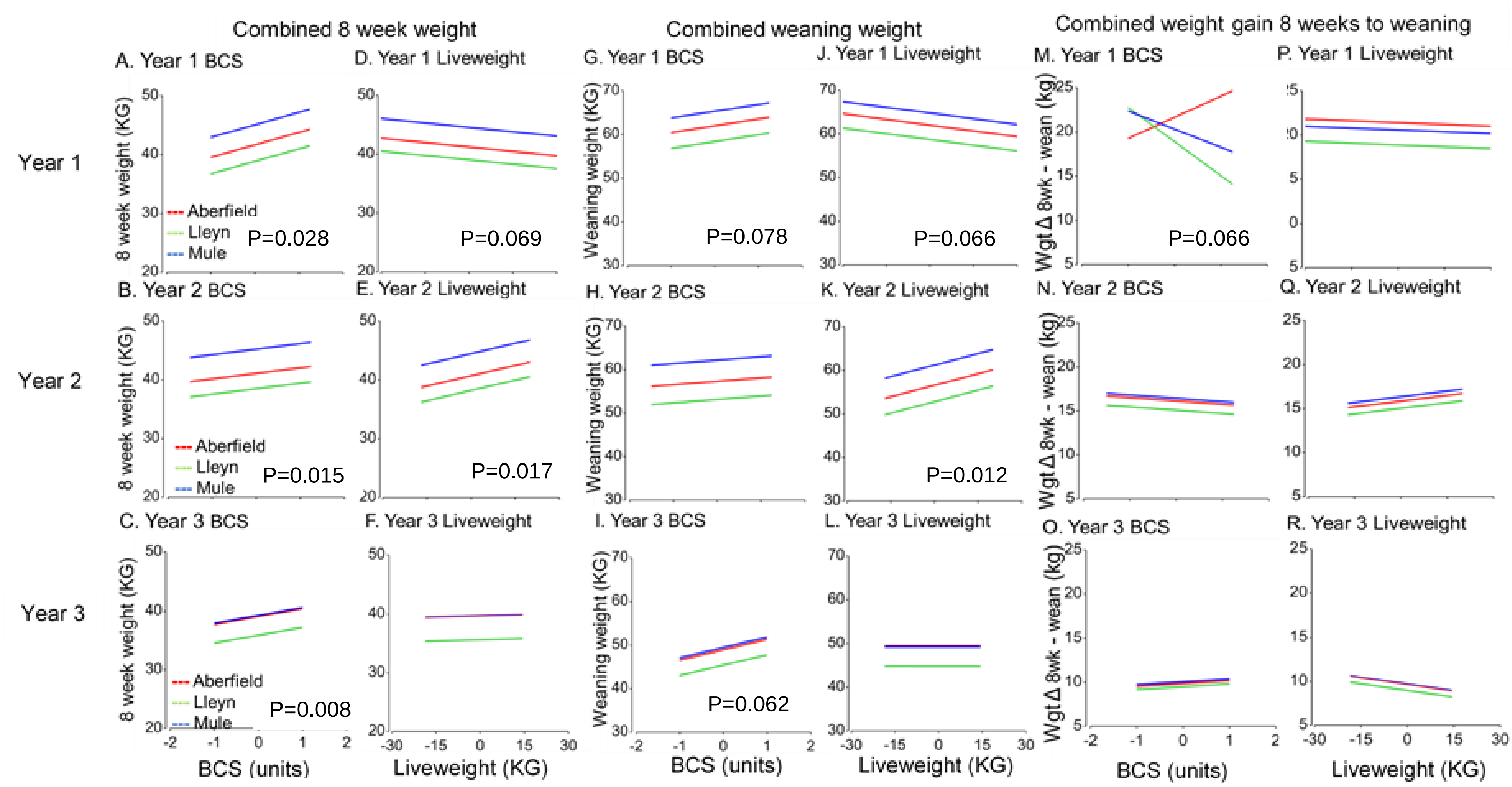


Figure 5.6. Association between ewe BCS change (A-C, G-I, M-O) and liveweight change (D-F, J-L, P-R) **between mating and scanning** on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) at the Sussex Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

5.3.1.8 *Ewe BCS at lambing*

Combined lamb 8-week weight and combined lamb weaning weight were positively associated with ewe BCS at lambing in Years 2 and 3 (P<0.001; Figure 5.7 B-C for 8-week weight and P<0.001; Figure 5.7 E; P=0.018; Figure 5.7 F for weaning weight). Lamb weight gain between 8 weeks and weaning was positively associated with ewe BCS at lambing in Year 1 (P=0.003; Figure 5.7 G) and, to a lesser extent, in Year 3 (P=0.061; Figure 5.7 I). There was genotype x BCS interaction in Year 2 (P=0.048; Figure 5.7 H), whereby lambs gained weight between 8 weeks and weaning with increasing ewe BCS at lambing when reared by Aberfield and Lleyn ewes, compared to lambs reared by Mule ewes, that saw a decline in lamb weight gain as ewe BCS increased.

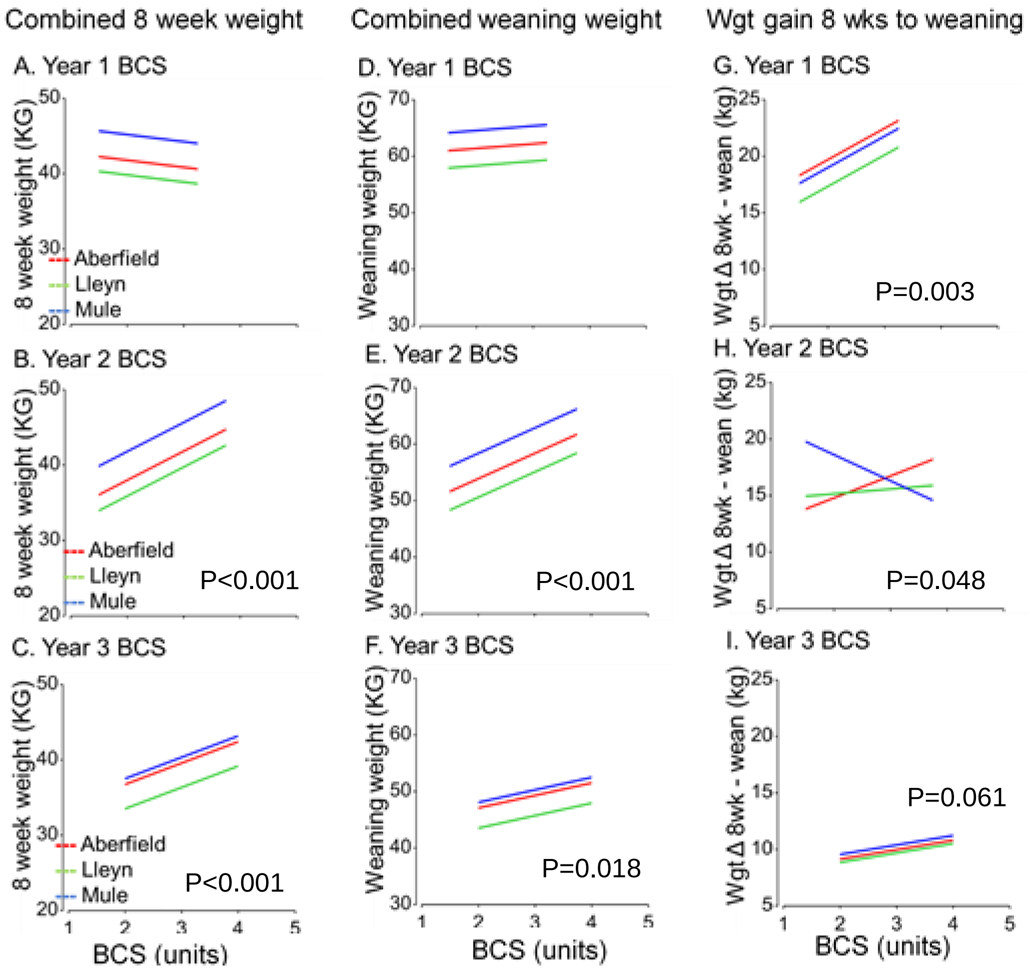


Figure 5.7. Association between ewe BCS **at lambing** on combined lamb 8-week weight (A-C), combined lamb weaning weight (D-F) and lamb weight gain between 8 weeks and weaning (H-J) at the Sussex Farm for Year 1 (A, D, G), Year 2 (B, E, H) and Year 3 (C, F, I).

5.3.1.9 *Ewe BCS change between scanning and lambing*

Combined lamb 8-week weight was negatively associated with ewe BCS gain between scanning and lambing, but in Year 1 only (P=0.008; Figure 5.8. A). Combined lamb weaning weight was not associated with BCS change. Lamb weight gain between 8 weeks and weaning was positively associated with ewe BCS gain between scanning and lambing, again in Year 1 only (P=0.026; Figure 5.8. G).

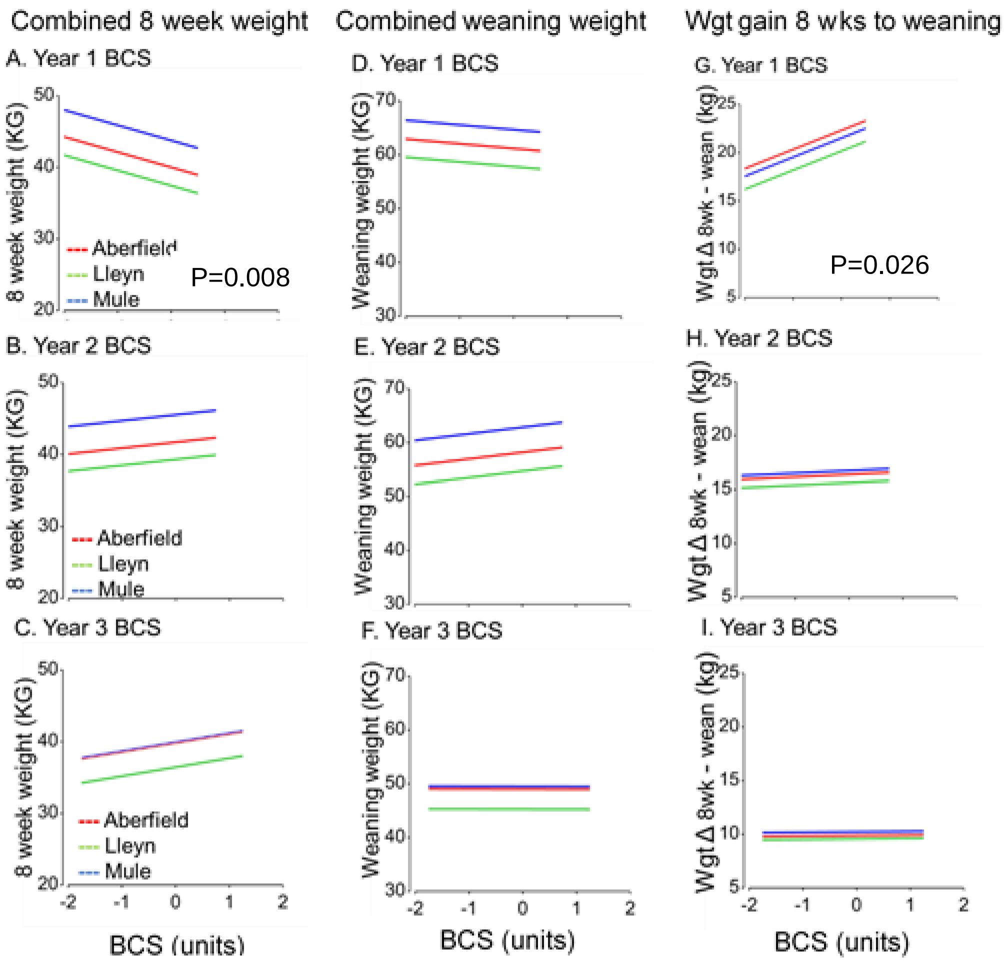


Figure 5.8. Association between ewe BCS change **between scanning and lambing** on combined lamb 8-week weight (A-C), combined lamb weaning weight (D-F) and lamb weight gain between 8 weeks and weaning (H-J) at the Sussex Farm for Year 1 (A, D, G), Year 2 (B, E, H) and Year 3 (C, F, I).

5.3.1.10 *Ewe BCS and liveweight at 8 weeks*

There were ewe genotype x BCS interactions affecting combined lamb 8-week weight (P=0.001; Figure 5.9 B); combined lamb weaning weight (P<0.001; Figure 5.9 H) and lamb weight gain between 8 weeks and weaning (P=0.028; Figure 5.9 N), but in Year 2 only. On all occasions, lamb weight increased as ewe BCS at 8 weeks increased for lambs reared by Aberfield and Lleyn ewes, compared to lambs reared by Mule ewes.

Combined lamb 8-week weight was not associated with ewe liveweight at 8 weeks, other than ewe genotype x liveweight interactions in Years 1 (P<0.001; Figure 5.9 D), 2 (P=0.011; Figure 5.9 E) and 3 (P=0.022; Figure 5.9 F). Similar to ewe genotype x BCS interactions, lamb 8-week weight increased with increasing ewe liveweight at 8 weeks for lambs reared by Aberfield and Lleyn ewes, but not for lambs reared by Mule ewes.

Combined lamb weaning weight was positively associated with ewe liveweight at 8 weeks in Year 2 (P<0.001; Figure 5.9 K); and, to a lesser extent, in Year 3 (P=0.084; Figure 5.9. L). Lamb weight gain between 8 weeks and weaning was positively associated with ewe liveweight at 8 weeks, but in Year 2 only (P=0.004; Figure 5.9. Q).

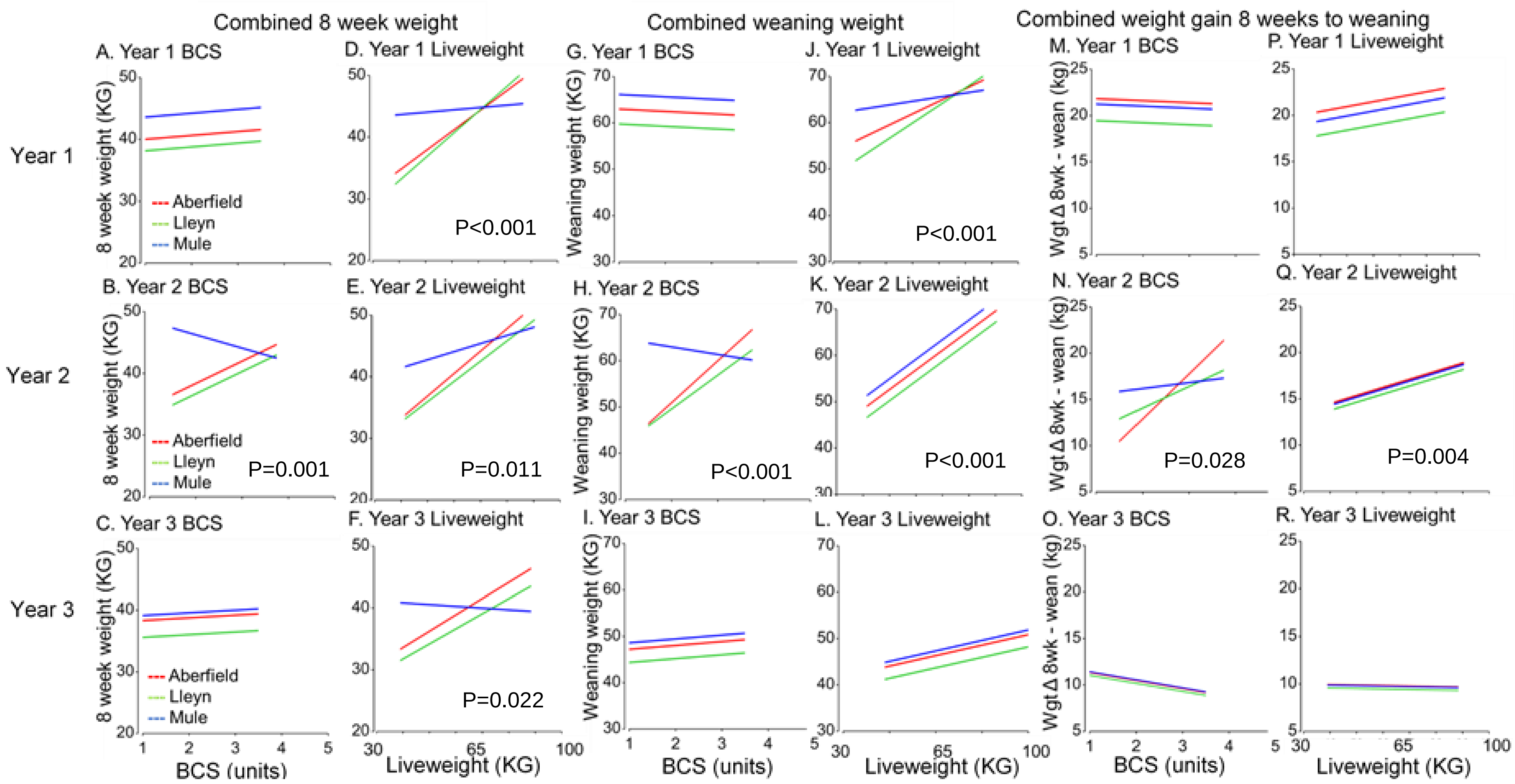


Figure 5.9. Association between ewe BCS (A-C, G-I, M-O) and liveweight (D-F, J-L, P-R) **at 8 weeks** on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) at the Sussex Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

5.3.1.11 *Ewe BCS change between lambing and 8 weeks*

Combined lamb 8-week weight was negatively associated with ewe BCS gain between lambing and 8 weeks in Years 1 (P=0.023), 2 (P=0.020; Figure 5.10 B) and 3 (P=0.006; Figure 5.10 C), with a ewe genotype x BCS interaction also in Year 1 (P=0.025; Figure 5.10 A). Lamb 8-week weight increased with ewe BCS loss for lambs reared by Lleyn ewes, compared to lambs reared by Aberfield and Mule ewes that were heavier when ewes gained BCS.

Lamb weaning weight was not associated with ewe BCS change between lambing and 8 weeks. Lamb weight gain between 8 weeks and weaning was negatively associated with ewe BCS gain in Years 1 (P=0.001; Figure 5.10 G) and 3 (P=0.015; Figure 5.10 I), but positively associated with ewe BCS gain in Year 2 (P<0.001; Figure 5.10 H).

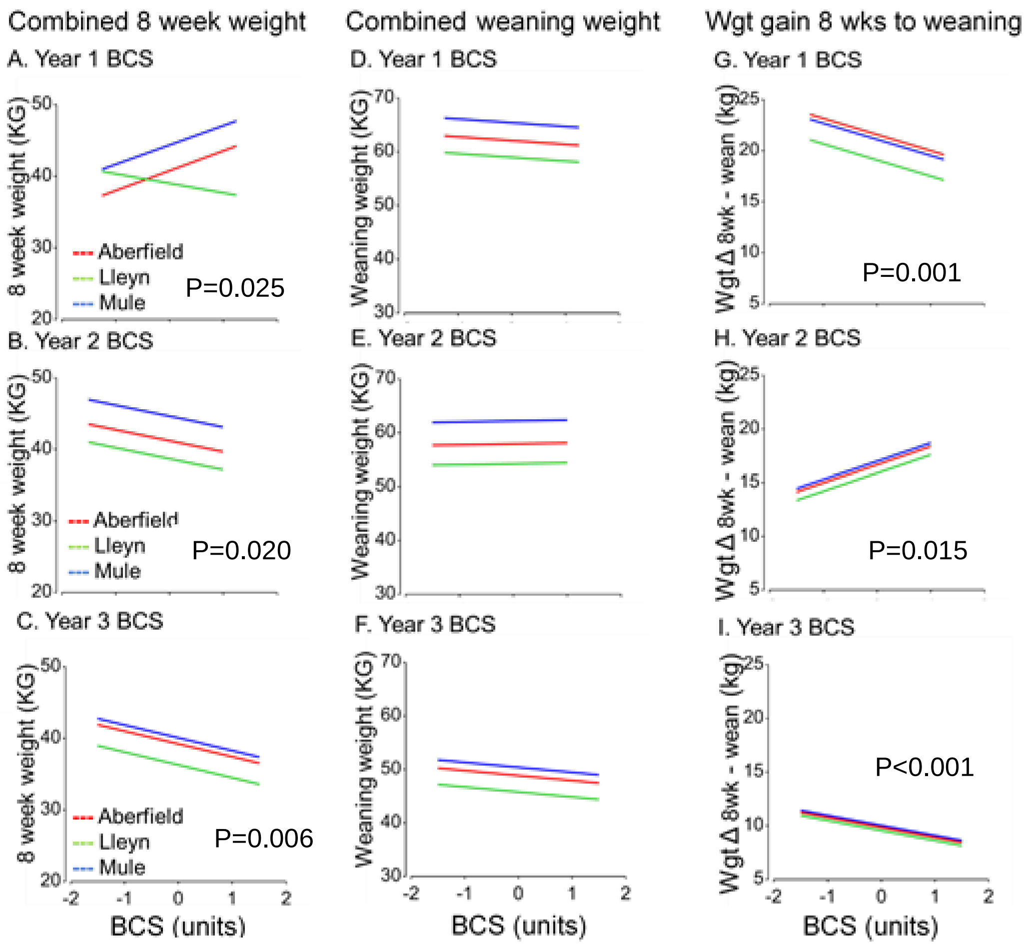


Figure 5.10. Association between ewe BCS change **between lambing and 8 weeks** on combined lamb 8-week weight (A-C), combined lamb weaning weight (D-F) and lamb weight gain between 8 weeks and weaning (G-I) at the Sussex Farm for Year 1 (A, D, G), Year 2 (B, E, H) and Year 3 (C, F, I).

5.3.1.12 *Ewe BCS and liveweight change between scanning and 8 weeks*

Combined lamb 8-week weight was not associated with ewe BCS or liveweight change between scanning and 8 weeks (Figure 5.11 A-F). Neither was combined lamb weaning weight associated with ewe BCS or liveweight change, other than a ewe genotype x BCS interaction, in Year 2 only ($P=0.036$; Figure 5.11 H). Lamb weaning weight increased with ewe BCS gain between scanning and 8 weeks for lambs reared by Aberfield and Lleyn ewes, compared to lambs reared by Mule ewes; which were lighter.

Lamb weight gain between 8 weeks and weaning was positively associated with ewe BCS gain between scanning and 8 weeks in Year 2 ($P<0.001$; Figure 5.11. N), but negatively associated in Year 3 ($P<0.001$; Figure 5.11. O). Lamb weight gain between 8 weeks and weaning was not associated with ewe liveweight gain between scanning and 8 weeks; except for a ewe genotype x liveweight change interaction, in Year 3 only ($P=0.008$; Figure 5.11 R). Lamb weight gain between 8 weeks and weaning increased with ewe liveweight gain for lambs reared by Mule and Lleyn ewes, compared to lambs reared by Aberfield ewes; which were lighter.

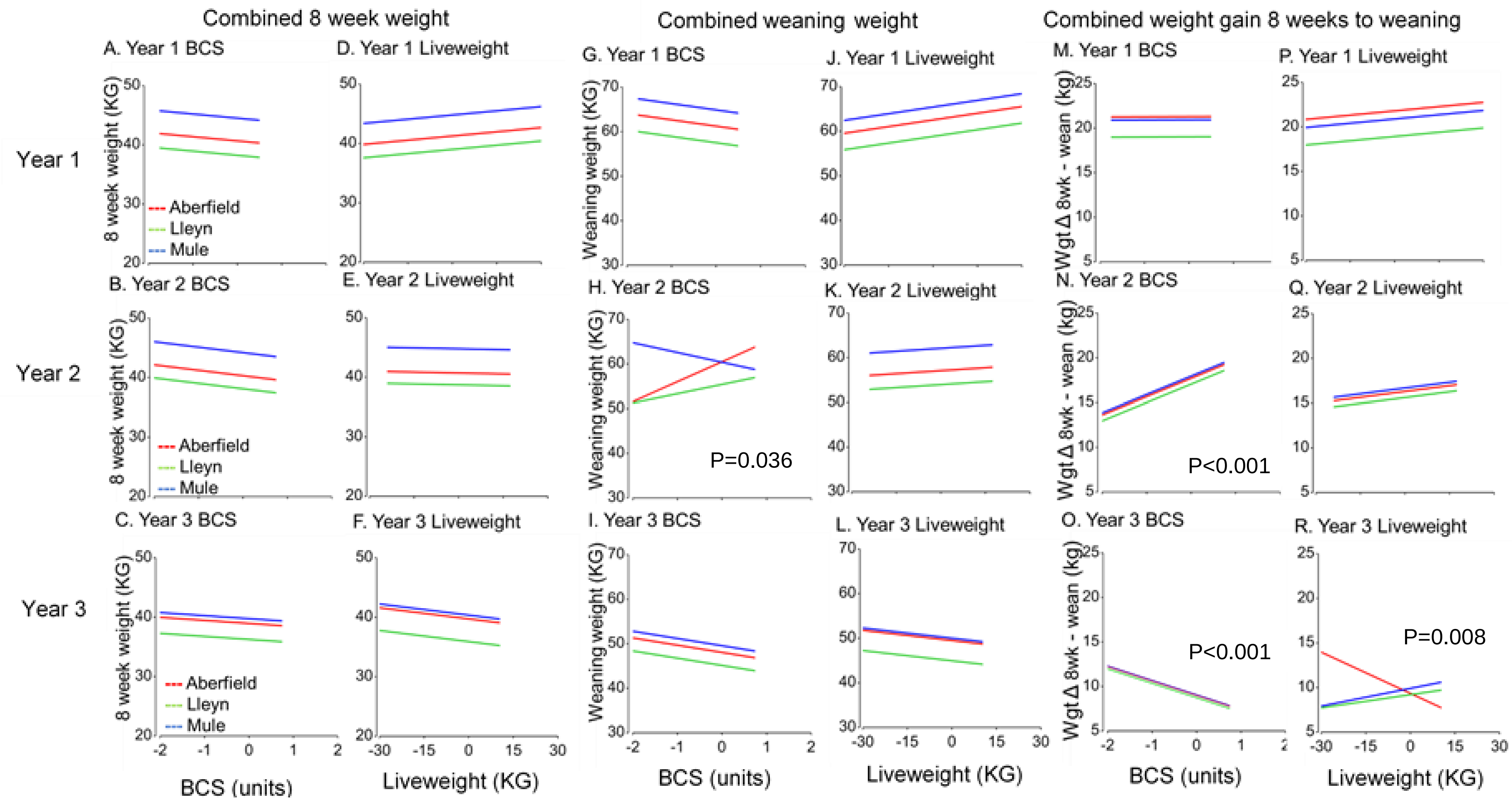


Figure 5.11. Association between ewe BCS change (A-C, G-I, M-O) and liveweight change (D-F, J-L, P-R) **between scanning and 8 weeks** on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) at the Sussex Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

5.3.1.13 *Ewe BCS and liveweight at weaning (current production cycle)*

There were ewe genotype x BCS interactions at weaning for combined lamb weaning weight (P=0.005; Figure 5.12 A) and lamb weight gain between 8 weeks and weaning (P=0.012; Figure 5.12 G), in Year 1 only. Lamb weaning weight and weight gain between 8 weeks and weaning increased as ewe BCS at weaning increased for lambs reared by Aberfield and Lleyn ewes; this was not the case for lamb reared by Mule ewes. The genotype x BCS interaction continued for combined lamb weaning weight in Year 2 (P=0.008; Figure 5.12 B). Lamb weaning weight increased with increasing ewe BCS for lambs reared by Lleyn ewes, compared to lambs reared by Aberfield and Mule ewes. Lamb weight gain between 8 weeks and weaning was positively associated with ewe BCS at weaning, but in Year 2 only (P=0.009; Figure 5.12 H).

Combined lamb weaning weight was positively associated with ewe liveweight at weaning in Years 1, 2 and 3 (P<0.001; Figure 5.12 D-F). Lamb weight gain between 8 weeks and weaning was negatively associated with ewe liveweight at weaning in Year 1 (P=0.021; Figure 5.12 J) but positively associated in Year 2 (P=0.009; Figure 5.12 K).

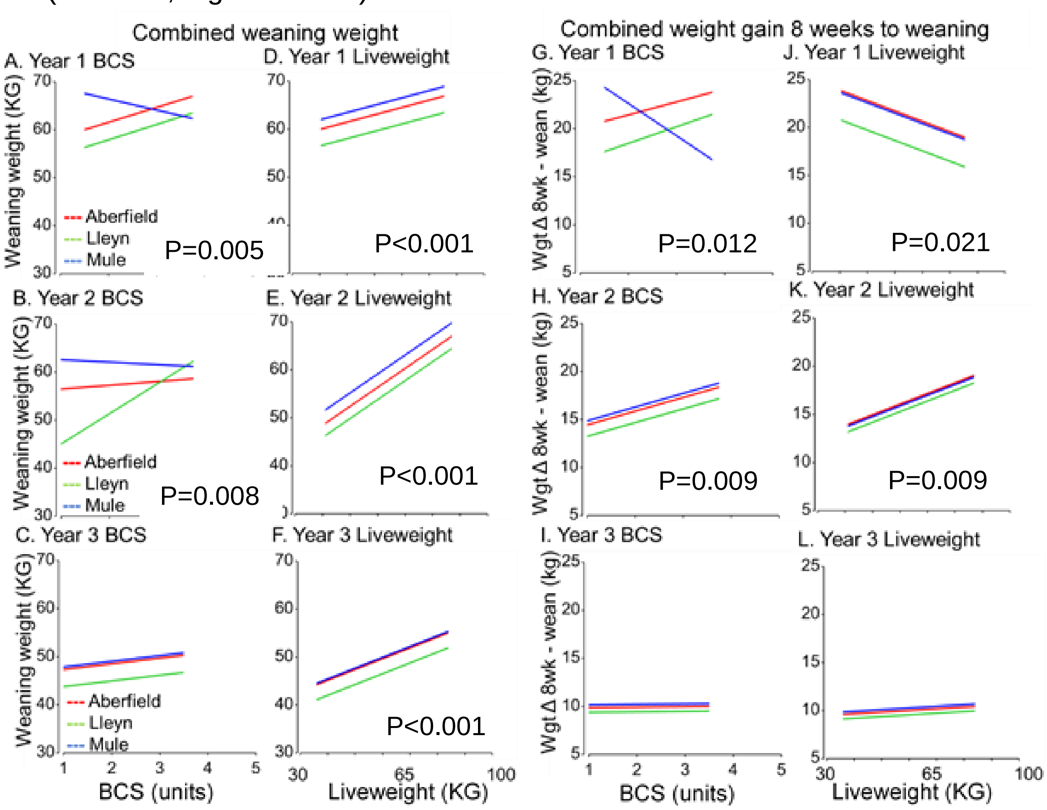


Figure 5.12. Association between ewe BCS (A-C, G-I) and liveweight (D-F, J-L) **at weaning** on combined lamb weaning weight (A-F) and lamb weight gain between 8 weeks and weaning (G-L) at the Sussex Farm for Year 1 (A, D, G), Year 2 (B, E, H) and Year 3 (C, F, I).

5.3.1.14 *Ewe BCS and liveweight change between 8 weeks and weaning*

There were ewe genotype x BCS change interactions for combined lamb weaning weight (P=0.019; Figure 5.13 A) and lamb weight gain between 8 weeks and weaning (P=0.036; Figure 5.13 G), in Year 1 only. Lamb weaning weight and weight gain between 8 weeks and weaning increased with ewe BCS gain for lambs reared by Aberfield ewes, decreased for lambs reared by Mule ewes and was largely unaffected in lambs reared by Lleyn ewes. Combined lamb weaning weight was negatively associated with ewe BCS gain between 8 weeks and weaning, in Year 2 only (P=0.027; Figure 5.13 B).

Lamb weight gain between 8 weeks and weaning was negatively associated with ewe liveweight gain between 8 weeks and weaning in Year 1 (P<0.001; Figure 5.13 J), but positively associated with ewe liveweight gain in Year 2 (P=0.032; Figure 5.13 K).

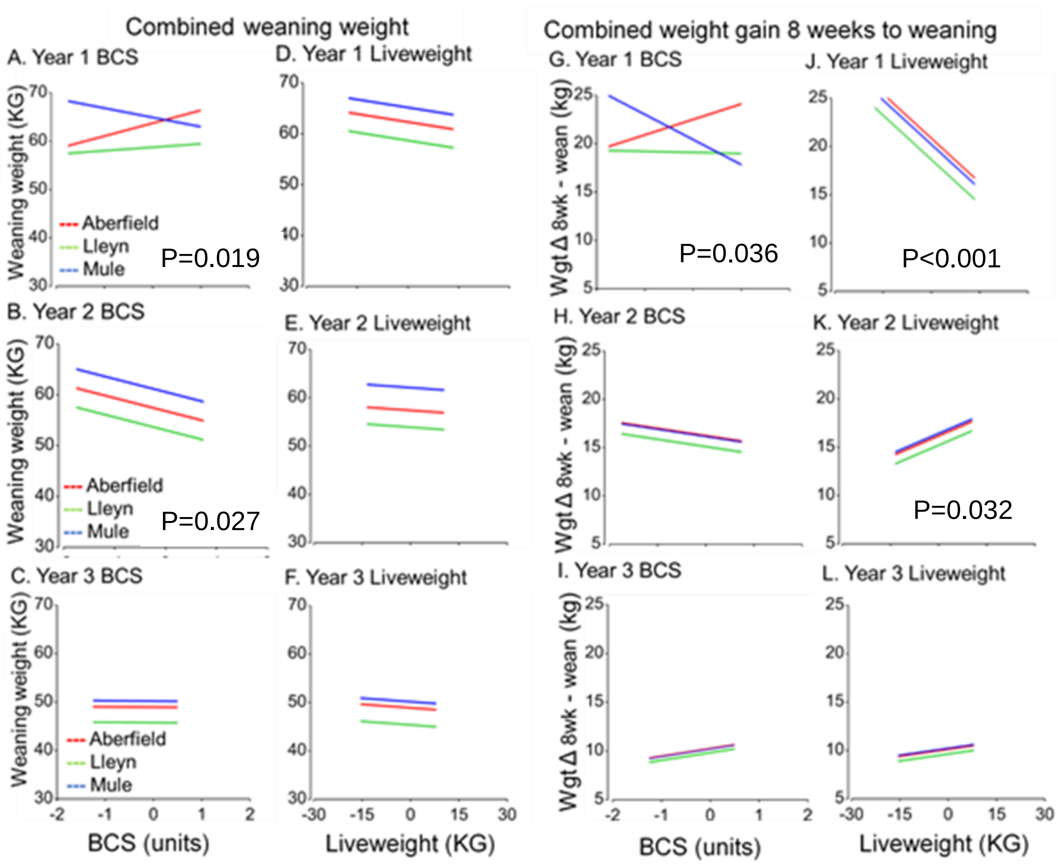


Figure 5.13. Association between ewe BCS change (A-C, G-I) and liveweight change (D-F, J-L) **between 8 weeks and weaning** on combined lamb weaning weight (A-F), and lamb weight gain between 8 weeks and weaning (G-L) at the Sussex Farm for Year 1 (A, D, G, J), Year 2 (B, E, H, K) and Year 3 (C, F, I, L).

5.3.1.15 *Key findings on lamb performance to weaning: Sussex Farm*

The overall factors affecting combined lamb performance to weaning are summarised in Table 5.2 and discussed below.

Table 5.2. Summary of the factors affecting combined twin lamb performance at 8-weeks, at weaning and weight change between 8 weeks and weaning for the Sussex Farm.

	8 weeks	**Weaning**	**Change 8 weeks to weaning**
Genotype	<0.001	<0.001	0.021
Parity	<0.001	<0.001	n/s
Weaning BCS (preceding)	n/s	n/s	n/s
Weaning LWT (preceding)	<0.001	0.007	n/s
Mating BCS	n/s	n/s	0.020
Mating LWT	<0.001	<0.001	n/s
Δ Weaning to mating BCS	n/s	n/s	n/s
Δ Weaning to mating LWT	n/s	n/s	n/s
Scanning BCS	<0.001	0.004	n/s
Scanning LWT	<0.001	<0.001	n/s
Δ Mating to scanning BCS	0.008	n/s	n/s
Δ Mating to scanning LWT	0.017	0.012	n/s
Lambing BCS	<0.001	<0.001	0.003
Δ Scanning to lambing BCS	n/s	n/s	n/s
8-week BCS	<0.001	<0.001	0.028
8-week LWT	<0.001	<0.001	n/s
Δ Lambing to 8 weeks BCS	0.006	n/s	<0.001
Δ Scanning to 8 weeks BCS	n/s	n/s	n/s
Δ Scanning to 8 weeks LWT	n/s	n/s	n/s
Weaning BCS (current)	-	0.008	0.012
Weaning LWT (current)	-	<0.001	0.009
Δ 8 weeks to weaning BCS	-	0.019	n/s
Δ 8 weeks to weaning LWT	-	n/s	<0.001

n/s=not significant

Overall, lamb performance to weaning was associated with ewe genotype, with heavier lambs reared by Mule ewes, compared with lambs reared by Aberfield and Lleyn ewes. Lamb performance to weaning was also positively associated with ewe parity, with parity 1 ewes rearing lighter lambs.

Lamb performance to weaning was associated with ewe liveweight at weaning of the preceding production cycle and ewe liveweight at mating, more so than ewe BCS at either weaning or mating. There were no consistent effects of ewe BCS or weight change between weaning and mating on lamb performance to weaning.

Overall, lamb performance to weaning was positively associated with ewe BCS and liveweight at scanning, ewe BCS and weight gain between mating and scanning and ewe BCS at lambing. However, lamb performance to weaning was not associated with ewe BCS change between scanning and lambing.

Lamb performance to weaning was positively associated with ewe BCS and liveweight at 8 weeks and weaning. However, there were also several ewe genotype x BCS and liveweight interactions, with lamb weight decreasing with increasing ewe BCS for lambs reared by Mule ewes, compared to Aberfield and Lleyn ewes. There was no relationship between lamb performance to weaning with ewe BCS change between scanning and 8 weeks or ewe BCS and liveweight change between 8 weeks and weaning.

5.3.2 Leicestershire Farm: Summary of effects on lamb weight to weaning

5.3.2.1 *Ewe genotype*

Combined lamb 8-week weight and combined lamb weaning weight were associated with ewe genotype in Years 1, 2, and 3 (P<0.001; Table 5.3). Lamb weight gain between 8 weeks and weaning was also associated with ewe genotype (P<0.001, Table 5.3), but in Year 2 only. The heaviest lambs were consistently reared by Mule ewes, compared to lambs reared by Charollais and Aberfield ewes.

Table 5.3. Effect of **ewe genotype** on combined lamb 8-week weight, combined lamb weaning weight and weight gain between 8 weeks and weaning (mean ± SE) for Years 1 to 3 at the Leicestershire Farm. Lamb weights are ranked highest to lowest.

	Year 1	**Year 2**	**Year 3**
8-week weight (KG)	Mule 41.4 ±0.47	Mule 44.5 ±0.28	Mule 39.2 ±0.76
	Charollais 38.8 ±0.20	Charollais 42.4 ±0.70	Aberfield 37.9 ±0.96
		Aberfield 36.3 ±0.83	Charollais 34.2 ±0.13
Weaning weight (KG)	Mule 54.4 ±0.68	Mule 58.9 ±0.34	Mule 53.5 ±1.16
	Charollais 51.8 ±0.28	Charollais 58.1 ±0.79	Aberfield 50.2 ±0.92
		Aberfield 47.8 ±0.01	Charollais 49.3 ±1.56
Weight change 8 weeks to weaning (KG)	Mule 13.0 ±0.36	Mule 14.6 ±0.18	Mule 15.6 ±0.61
	Charollais 13.0 ±0.15	Charollais 14.3 ±0.41	Charollais 15.1 ±0.81
		Aberfield 10.6 ±0.52	Aberfield 14.0 ±0.48

5.3.2.2 *Ewe parity*

Combined lamb 8-week weight and combined lamb weaning weight were positively associated with ewe parity, but in Years 2 and 3 only (P<0.001; Figure 5.14 B-C and P<0.001; Figure 5.14 E-F). Lamb weight gain between 8 weeks and weaning was not associated with ewe parity (Figure 5.14 G-I).

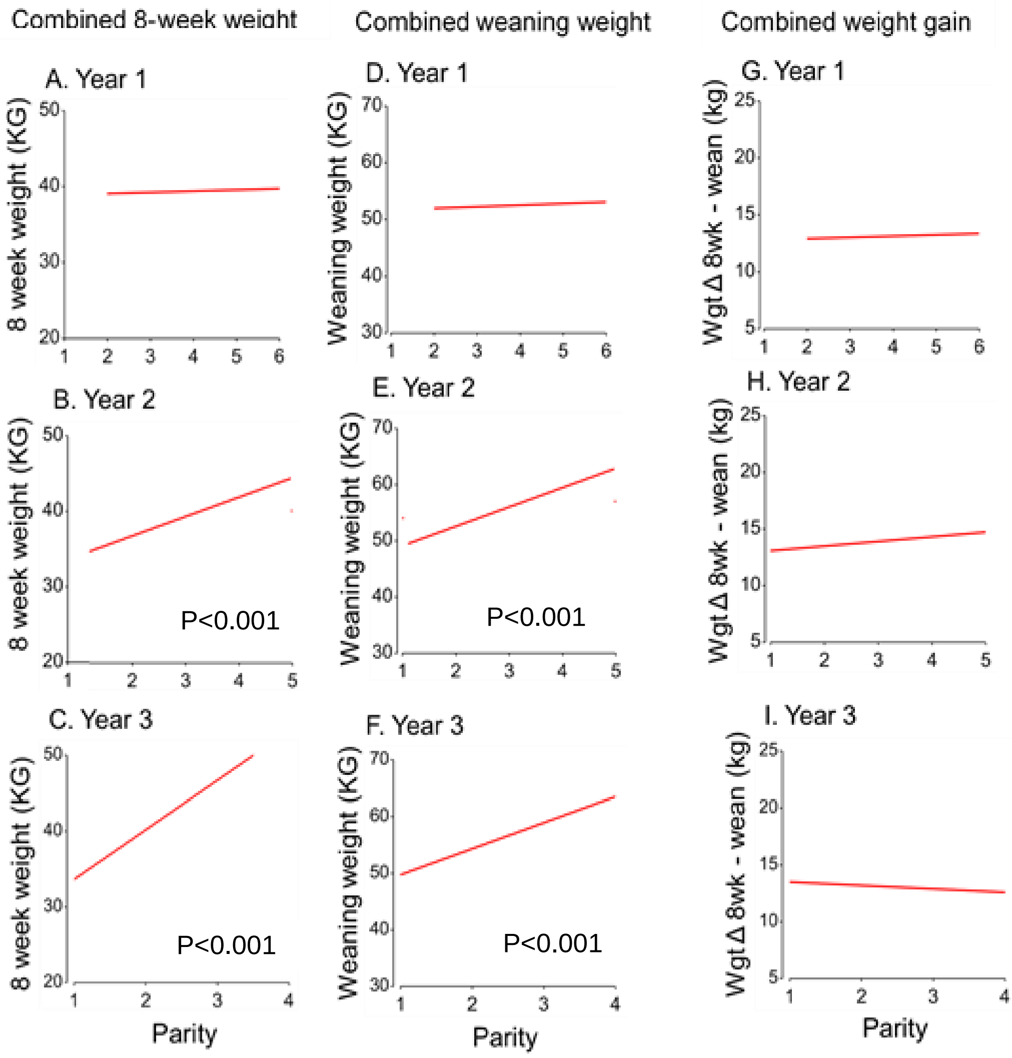


Figure 5.14. Association between **ewe parity** on combined lamb 8-week weight (A-C), combined lamb weaning weight (D-F) and lamb weight gain between 8 weeks and weaning (G-I) in Year 1 (A, D, G), Year 2 (B, E, H) and Year 3 (C, F, I) at the Leicestershire Farm.

5.3.2.3 *Ewe BCS and liveweight at weaning (preceding production cycle)*

Combined lamb 8-week weight was not associated with ewe BCS at weaning of the preceding production cycle. Combined lamb weaning weight (P=0.007; Figure 5.15 H) and lamb weight gain between 8 weeks and weaning (P=0.005; Figure 5.15 N) were negatively associated with ewe BCS at weaning, but in Year 2 only.

Combined lamb 8-week weight was positively associated with ewe liveweight at weaning of the preceding production cycle, but in Year 3 only (P<0.001; Figure 5.15 F). Combined lamb weaning weight and lamb weight gain between 8 weeks and weaning were not associated with ewe BCS at weaning. There were, however, ewe genotype x liveweight interactions affecting combined lamb weaning weight (P=0.001; Figure 5.15 K) and lamb weight gain between 8 weeks and weaning (P=0.002; Figure 5.15 Q), in Year 2 only. On both occasions, combined lamb weaning weight and weight gain between 8 weeks and weaning increased with increasing ewe liveweight for lambs reared by Mule ewes, compared to lambs reared by Charollais ewes.

5.3.2.4 *Ewe BCS and liveweight at mating*

Combined lamb 8-week weight, combined lamb weaning weight and weight gain between 8 weeks and weaning were not associated with ewe BCS at mating, except for ewe genotype x BCS interactions for combined lamb 8-week weight in Year 2 (P=0.025; Figure 5.16 B), combined lamb weaning weight in Year 2 (P<0.001; Figure 5.16 H) and lamb weight gain between 8-weeks and weaning in Year 3 (P=0.002; Figure 5.16 O). On all occasions, lamb weight and weight gain increased with increasing ewe BCS at mating for lambs reared by Aberfield ewes, compared to lambs reared by Charollais and Mule ewes.

Combined lamb 8-week weight was positively associated with ewe liveweight at mating in Years 2 and 3 (P<0.001; Figure 5.16 E-F), with a genotype x liveweight interaction in Year 3 (P=0.003; Figure 5.16 F). Lamb 8-week weight increased with increasing ewe liveweight at mating, but Aberfield ewes had the greatest response. Combined lamb weaning weight was positively associated with ewe liveweight at mating in Years 1 (P=0.002; Figure 5.16 J), 2 (P<0.001; Figure 5.16 K) and 3 (P<0.001; Figure 5.16 L). Lamb weight gain between 8 weeks and weaning was positively associated with ewe liveweight at mating, but in Year 1 only (P<0.001; Figure 5.16 P).

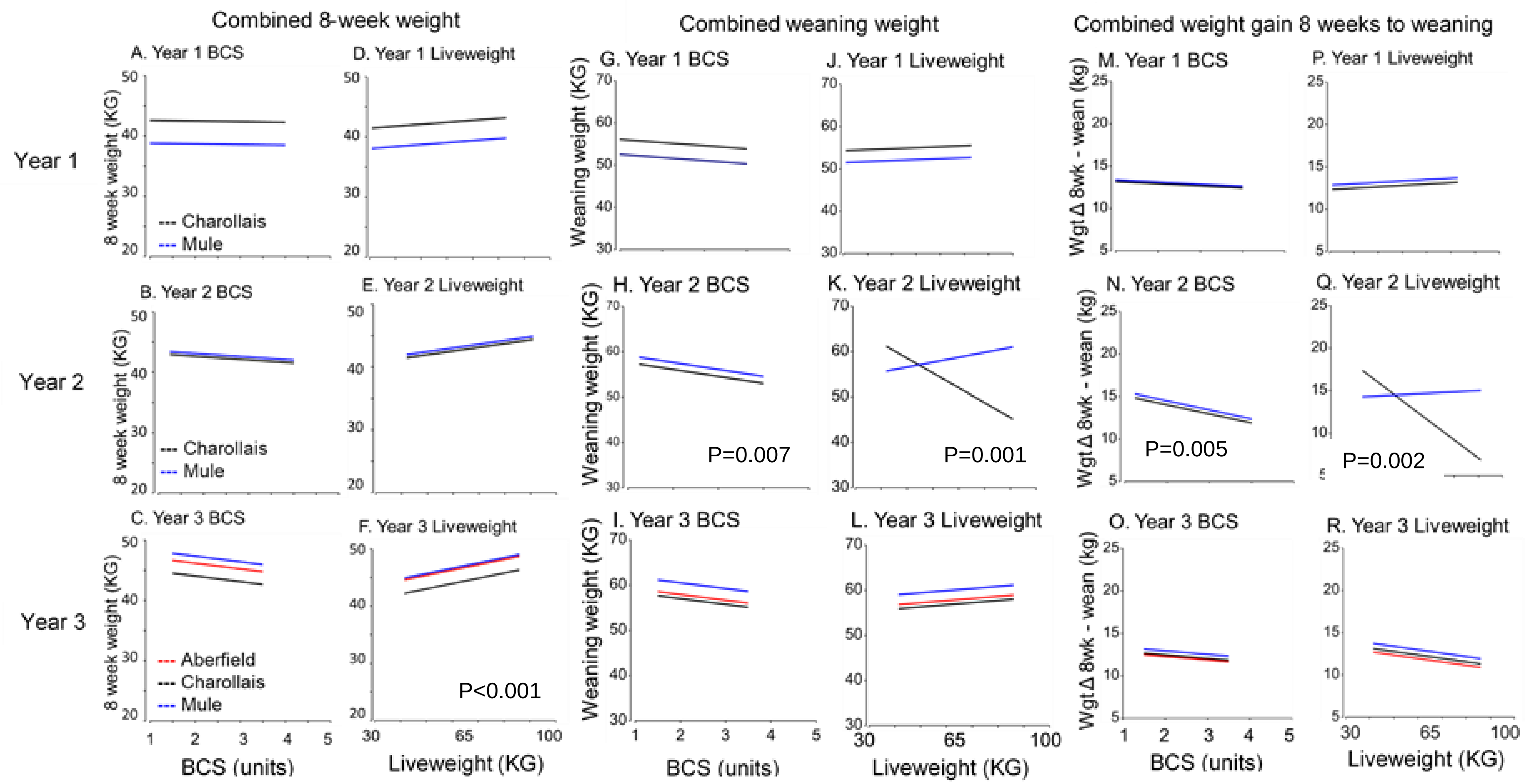


Figure 5.15. Association between ewe BCS (A-C, G-I, M-O) and liveweight (D-F, J-L, P-R) **at weaning** of the preceding production cycle on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) in the subsequent production cycle at the Leicestershire Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

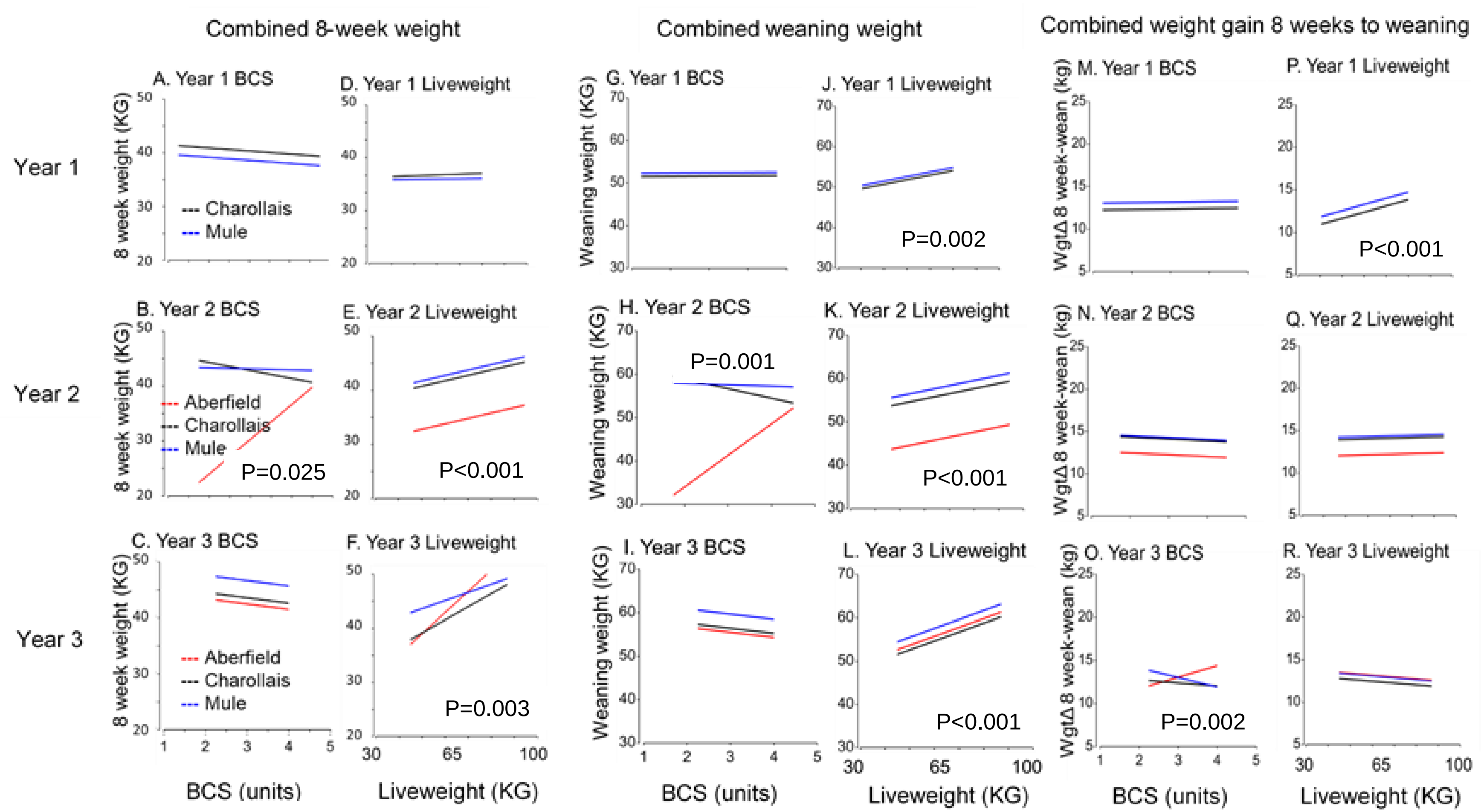


Figure 5.16. Association between ewe BCS (A-C, G-I, M-O) and liveweight (D-F, J-L, P-R) **at mating** on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) at the Leicestershire Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

5.3.2.5 *Ewe BCS and liveweight change between weaning and mating*

Combined lamb 8-week weight was negatively associated with ewe BCS gain between weaning of the preceding production cycle and mating of the subsequent production cycle, but in Year 1 only (P=0.028; Figure 5.17. A). Combined lamb weaning weight (Figure 5.17. G-I) and lamb weight gain between 8 weeks and weaning (Figure 5.17. P-R) were not associated with ewe BCS change between weaning and mating.

There was a suggestion that combined lamb 8-week weight was associated with ewe liveweight change between weaning of the preceding production cycle and mating of the subsequent production cycle, but in Year 1 only (P=0.070; Figure 5.17. D). Combined lamb weaning weight and lamb weight gain between 8 weeks and weaning were not associated with ewe liveweight change. There was a ewe genotype x liveweight interaction for combined lamb weaning weight (P=0.006; Figure 5.17 K) and lamb weight gain between 8 weeks and weaning (P=0.016; Figure 5.17. Q), but in Year 2 only. Lamb weaning weight and weight gain between 8 weeks and weaning increased with ewe liveweight gain for lambs reared by Charollais ewes, compared to lambs reared by Mule ewes.

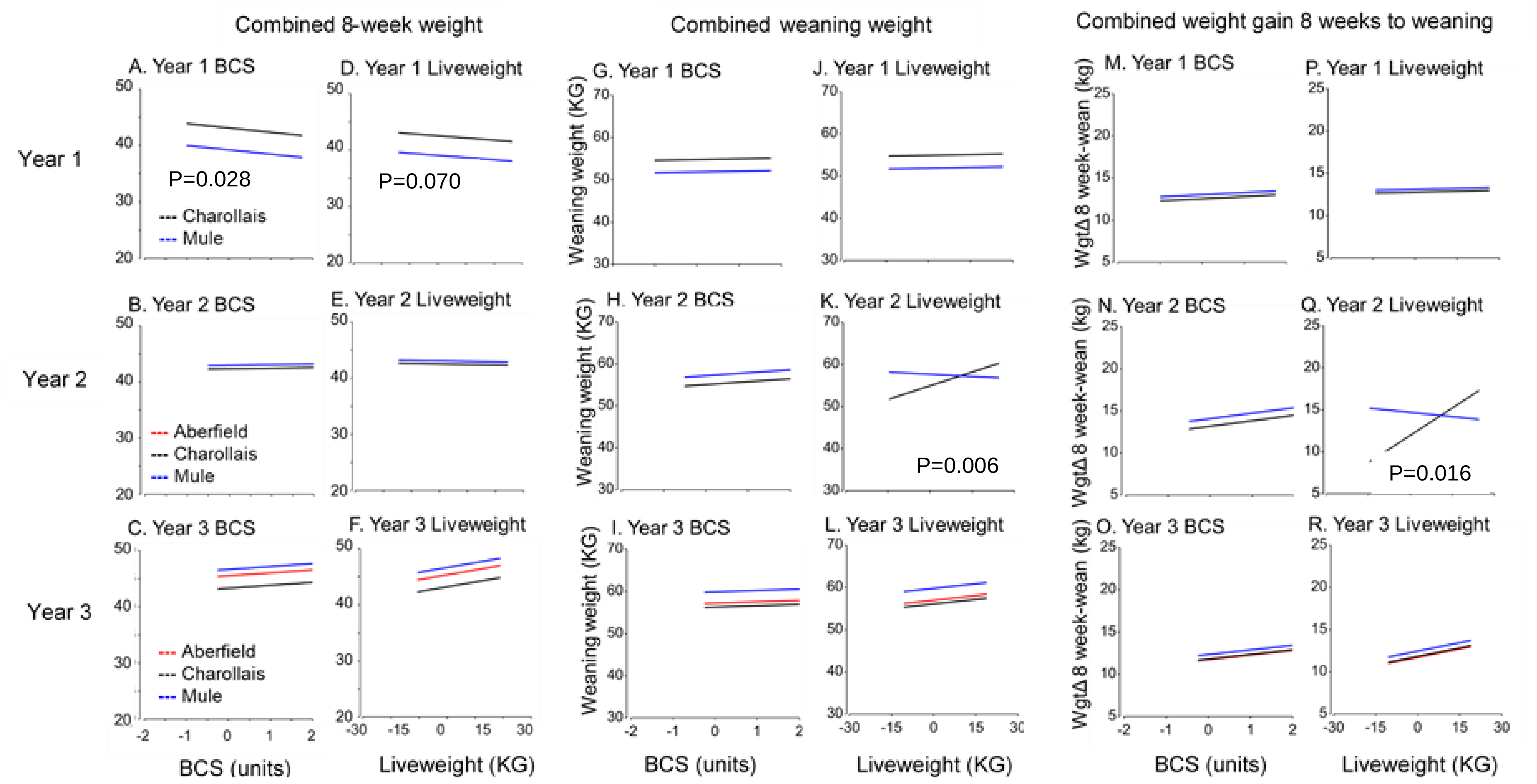


Figure 5.17. Association between BCS change (A-C, G-I, M-O) and liveweight change (D-F, J-L, P-R) **between weaning of the preceding production cycle to mating** of the subsequent production cycle on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) at the Leicestershire Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

5.3.2.6 *Ewe BCS and liveweight at scanning*

Combined lamb 8-week weight was positively associated with ewe BCS at scanning in Years 1 (P=0.036; Figure 5.18 A) and 3 (P=0.003; Figure 5.18 C). Combined lamb weaning weight was positively associated with ewe BCS at scanning, in Year 1 only (P=0.003; Figure 5.18 G). There was a ewe genotype x BCS interaction for combined lamb 8-week weight (P=0.009; Figure 5.18 B) and combined lamb weaning weight (P<0.001; Figure 5.18 H), but in Year 2 only. On both occasions, lamb weight increased with increasing ewe BCS at scanning for lambs reared by Aberfield and Mule ewes, compared to lambs reared by Charollais ewes.

Lamb weight gain between 8 weeks and weaning was positively associated with ewe BCS at scanning in Year 2 (P=0.045; Figure 5.18 N), but negatively associated in Year 3 (P=0.011; Figure 5.18 O).

Combined lamb 8-week weight was positively associated with ewe liveweight at scanning in Years 1, 2 and 3 (P<0.001; Figure 5.18 D-F). Combined lamb weaning weight was positively associated with ewe liveweight at scanning in Years 1 (P<0.001; Figure 5.18 J) and 3 (P<0.001; Figure 5.18 L); with a ewe genotype x liveweight interaction in Year 2 (P=0.006; Figure 5.18 K). Combined lamb 8-week weight increased with increasing ewe liveweight, however, the Aberfield genotype had the greatest response. Lamb weight gain between 8 weeks and weaning was positively associated with ewe liveweight at scanning in Years 1 (P=0.011; Figure 5.18 P) and 2 (P=0.039; Figure 5.18 Q).

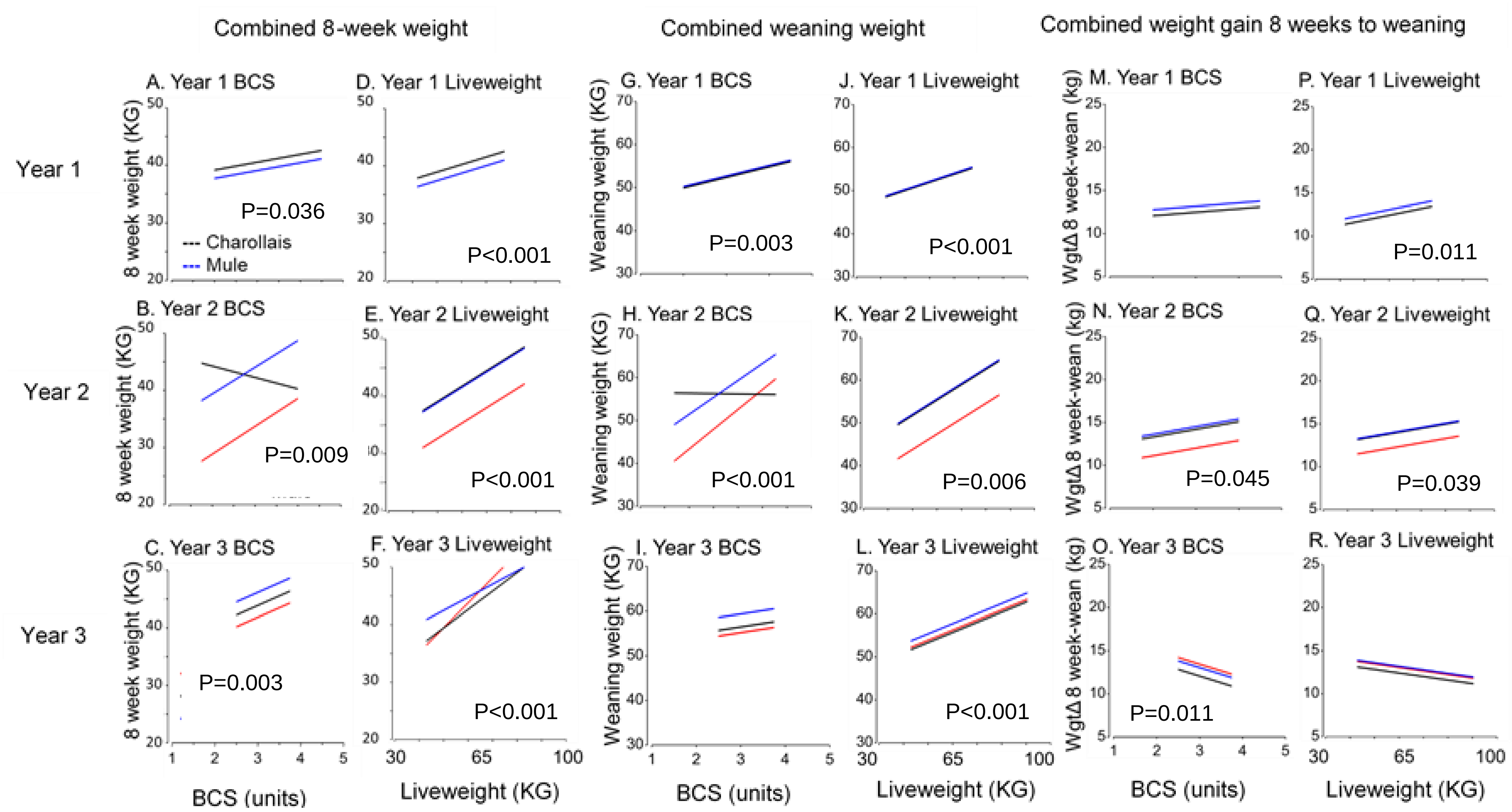


Figure 5.18. Association between ewe BCS (A-C, G-I, M-O) and liveweight (D-F, J-L, P-R) **at scanning** on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) at the Leicestershire Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

5.3.2.7 *Ewe BCS and liveweight change between mating and scanning*

Combined lamb 8-week weight was positively associated with ewe BCS gain between mating and scanning in Years 1, 2 (P<0.001; Figure 5.19 A-B), and 3 (P=0.002; Figure 5.19 C). Combined lamb weaning weight was also positively associated with ewe BCS gain in Years 1 (P=0.019; Figure 5.19 G), 2 (P<0.001; Figure 5.19 H) and 3 (P=0.008; Figure 5.19 I). Lamb weight gain between 8 weeks and weaning was positively associated with ewe BCS gain between mating and scanning in Year 2 (P=0.039; Figure 5.19 N); and to a lesser extent, negatively associated in Year 3 (P=0.052; Figure 5.19 O).

Combined lamb 8-week weight was positively associated with ewe liveweight gain between mating and scanning in Years 1, 2 (P<0.001; Figure 5.19 D-E) and 3 (P=0.008; Figure 5.19 F). Combined lamb weaning weight was positively associated with ewe liveweight gain between mating and scanning in Years 1 (P=0.035; Figure 5.19 J) and 2 (P<0.001; Figure 5.19 K). There were also ewe genotype x liveweight change interactions for combined lamb 8-week weight in Years 2 (P=0.004; Figure 5.19 E) and 3 (P<0.001; Figure 5.19 F); and combined lamb weaning liveweight in Year 2 (P=0.003; Figure 5.19 K). Lamb weights increased with ewe liveweight gain between mating and scanning for lambs reared by Mule ewes, compared to lambs reared by Aberfield and Charollais ewes. Lamb weight gain between 8 weeks and weaning was positively associated with ewe liveweight gain, but in Year 2 only (P=0.024; Figure 5.19 Q).

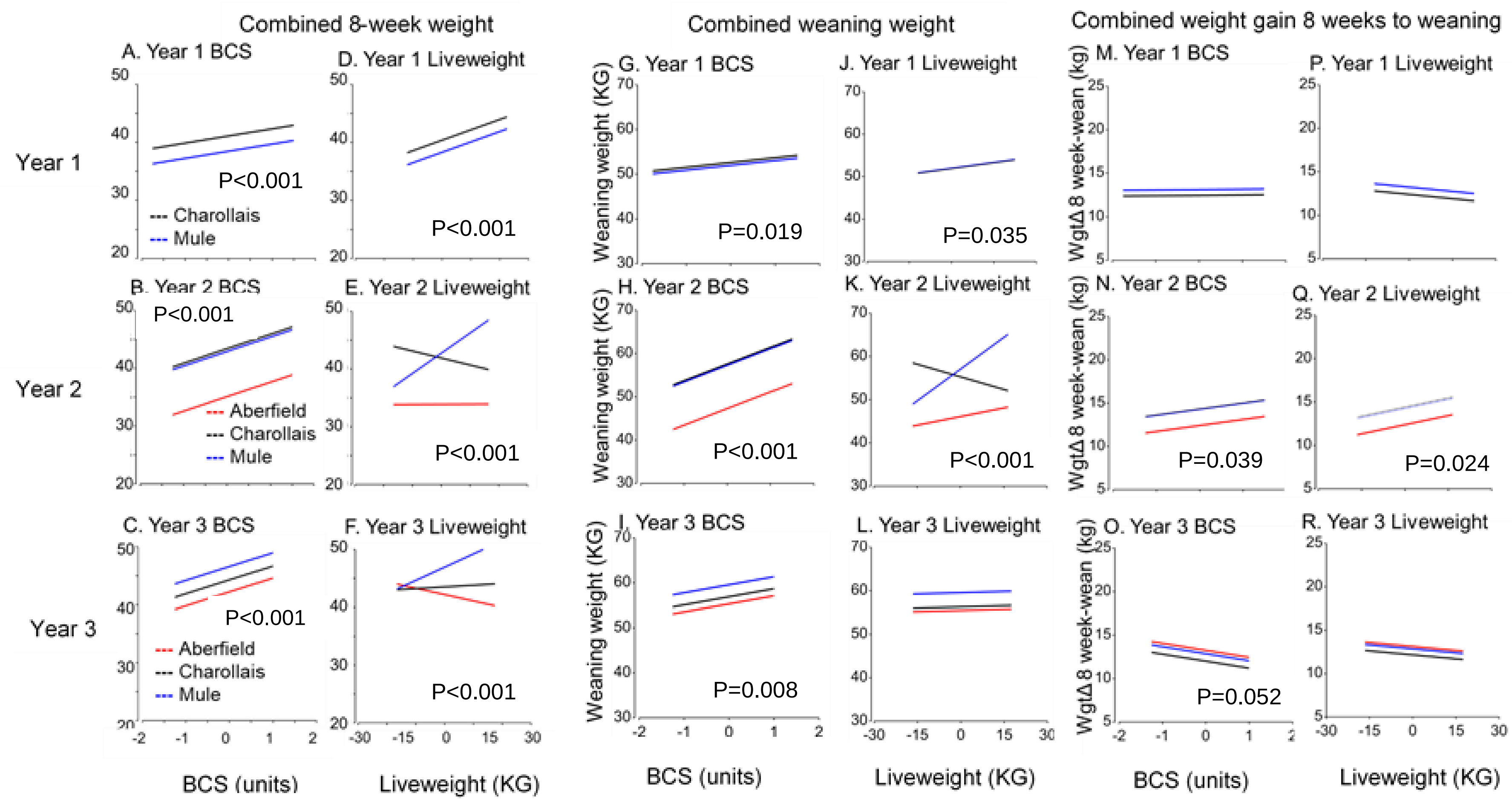


Figure 5.19. Association between ewe BCS change (A-C, G-I, M-O) and liveweight change (D-F, J-L, P-R) **between mating and scanning** on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) at the Leicestershire Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

5.3.2.8 *Ewe BCS at lambing*

Combined lamb 8-week weight was positively associated with ewe BCS at lambing, but in Year 3 only (P<0.001; Figure 5.20 C). Combined lamb weaning weight was positively associated with ewe BCS at lambing in Years 1 (P<0.001; Figure 5.20 D) and 3 (P=0.020; Figure 5.20. F).

There were ewe genotype x BCS interactions with combined lamb 8-week weight and combined lamb weaning weight, in Year 2 (P=0.003; Figure 5.20. B and P=0.002; Figure 5.20 E, respectively) and lamb weight gain between 8 weeks and weaning, in Year 3 (P=0.010; Figure 5.20. I). Lamb weight increased with increasing ewe BCS at lambing for lambs reared by Aberfield and Mule ewes, compared to lambs reared by Charollais ewes. Lamb weight gain increased with increasing ewe BCS at lambing for lambs reared by Aberfield ewes only, compared to lambs reared by Charollais and Mule ewes.

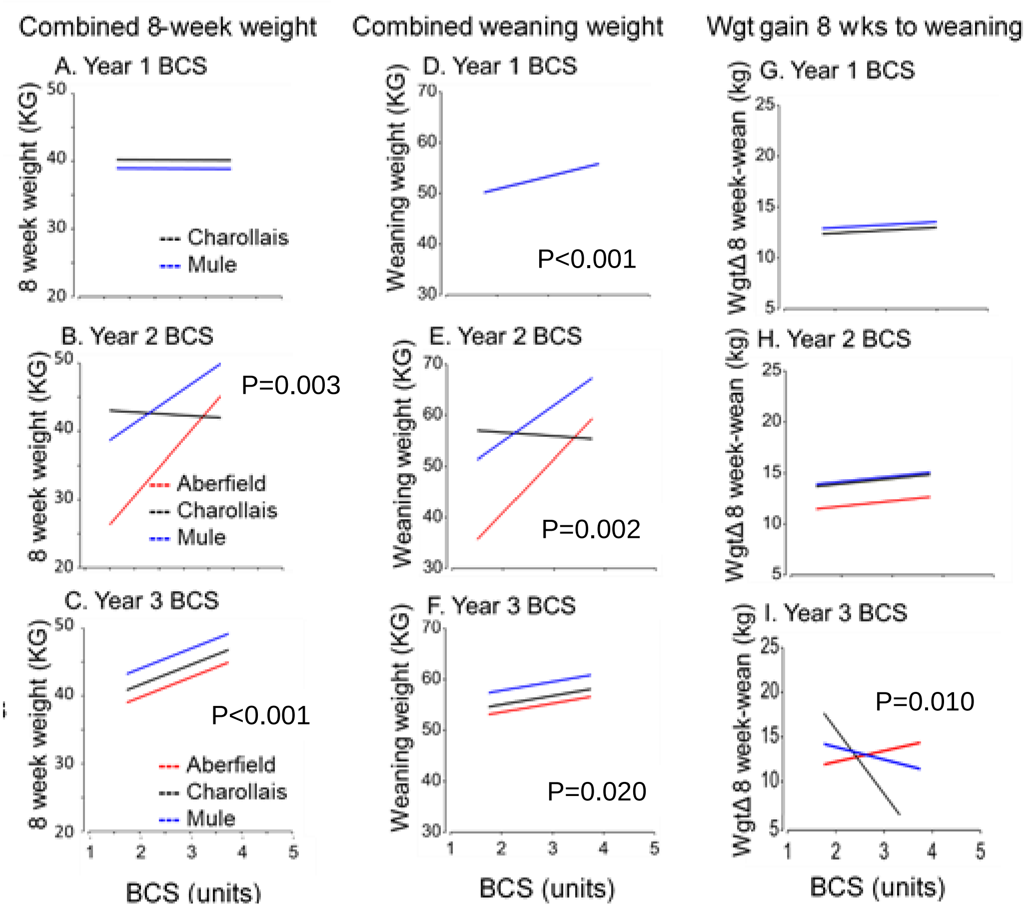


Figure 5.20. Association between ewe **BCS at lambing** on combined lamb 8-week weight (A-C), combined lamb weaning weight (D-F) and lamb weight gain between 8 weeks and weaning (H-J) at the Leicestershire Farm for Year 1 (A, D, G), Year 2 (B, E, H) and Year 3 (C, F, I).

5.3.2.9 *Ewe BCS change between scanning and lambing*

Combined lamb 8-week weight was negatively associated with ewe BCS gain between scanning and lambing, in Year 1 (P=0.024; Figure 5.21 A) and positively associated with BCS gain, in Year 2 (P<0.001; Figure 5.21 B). Combined lamb weaning weight and lamb weight gain between 8 weeks and weaning were not associated with ewe BCS change between scanning and lambing (Figure 5.21 D-F; G-I), neither were there any ewe genotype x interactions.

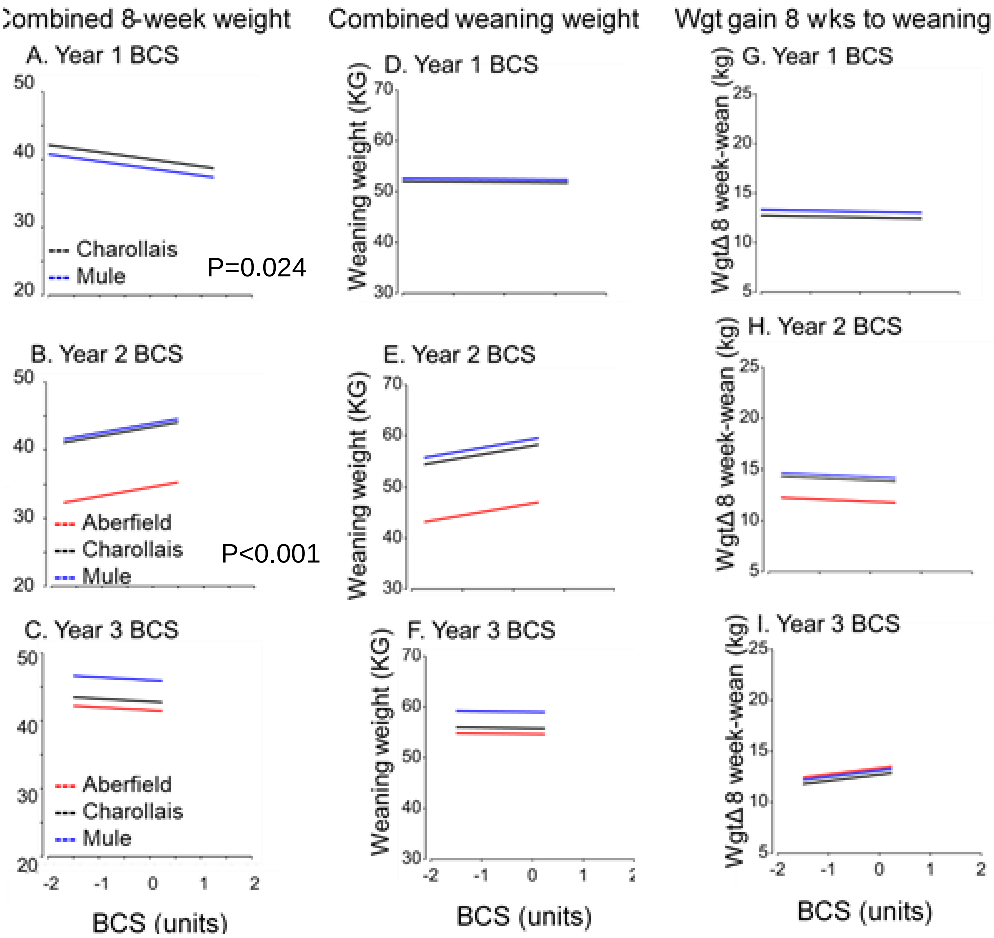


Figure 5.21. Association between ewe BCS change **between scanning and lambing** on combined lamb 8-week weight (A-C), combined lamb weaning weight (D-F) and lamb weight gain between 8 weeks and weaning (H-J) at the Leicestershire Farm for Year 1 (A, D, G), Year 2 (B, E, H) and Year 3 (C, F, I).

5.3.2.10 *Ewe BCS and liveweight at 8 weeks*

Combined lamb 8-week weight and combined lamb weaning weight were positively associated with ewe BCS at 8-weeks, but in Year 1 only ($P<0.001$; Figure 5.22 A, G). There was a ewe genotype x BCS interaction for combined lamb 8-week weight ($P<0.001$; Figure 5.22 B) and combined lamb weaning weight ($P=0.002$; Figure 5.22 H) in Year 2 only. On both occasions, lamb weight at 8-weeks and weaning increased with increasing ewe BCS at 8 weeks for lambs reared by Mule ewes, compared to lambs reared by Aberfield and Charollais ewes that were lighter. Lamb weight gain between 8 weeks and weaning was negatively associated with ewe BCS at 8 weeks, but in Year 2 only ($P<0.001$; Figure 5.22 N).

Combined lamb 8-week weight and combined lamb weaning weight were positively associated with ewe liveweight at 8 weeks in Years 1, 2 and 3 ($P<0.001$; Figure 5.22 D-F; J-L, respectively). There was also a ewe genotype x liveweight interaction for combined lamb 8-week weight and combined lamb weaning weight ($P<0.001$; Figure 5.22 E, K), but in Year 2 only. On both occasions, lamb weight increased with increasing ewe liveweight at 8 weeks for lambs reared by Mule and Aberfield ewes, compared to lambs reared by Charollais ewes.

Lamb weight gain between 8 weeks and weaning was not associated with ewe 8-week weight; except for a ewe genotype x liveweight interaction, in Year 2 only ($P=0.003$; Figure 5.22 Q). Lamb weight gain increased with increasing ewe liveweight at 8 weeks for lambs reared by Aberfield ewes, compared to lambs reared by Mule and Charollais ewes that responded negatively to increasing ewe liveweight.

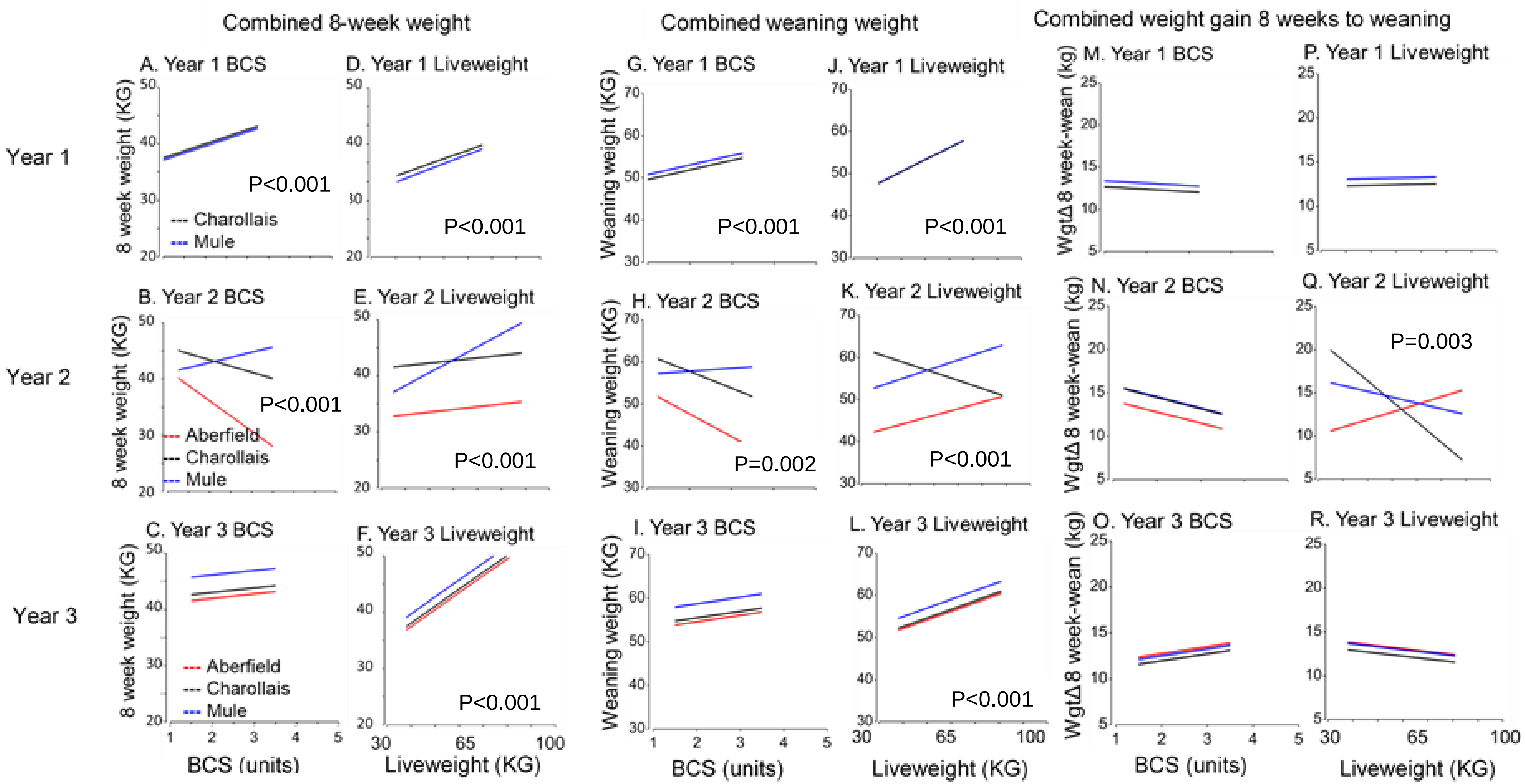


Figure 5.22. Association between ewe BCS (A-C, G-I, M-O) and liveweight (D-F, J-L, P-R) **at 8 weeks** on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) at the Leicestershire Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

5.3.2.11 *Ewe BCS change between lambing and 8 weeks*

Combined lamb 8-week weight was positively associated with ewe BCS change between lambing and 8 weeks in Year 1 (P<0.001; Figure 5.23 A) and negatively associated in Years 2 and 3 (P<0.001; Figure 5.23 B-C). There were ewe genotype x BCS interactions for combined lamb 8-week weight (P<0.001; Figure 5.23 B) and combined lamb weaning weight (P=0.015; Figure 5.23 E), in Year 2 only. Lamb weight decreased with ewe BCS gain between lambing and 8 weeks but the effect was greater for lambs reared by Aberfield ewes, compared to lambs reared by Mule and Charollais ewes.

Lamb weight gain between 8 weeks and weaning was negatively associated with ewe BCS gain between lambing and 8 weeks in Year 2 (P<0.001; Figure 5.23 H) and positively associated with BCS gain in Year 3 (P=0.024; Figure 5.23 I).

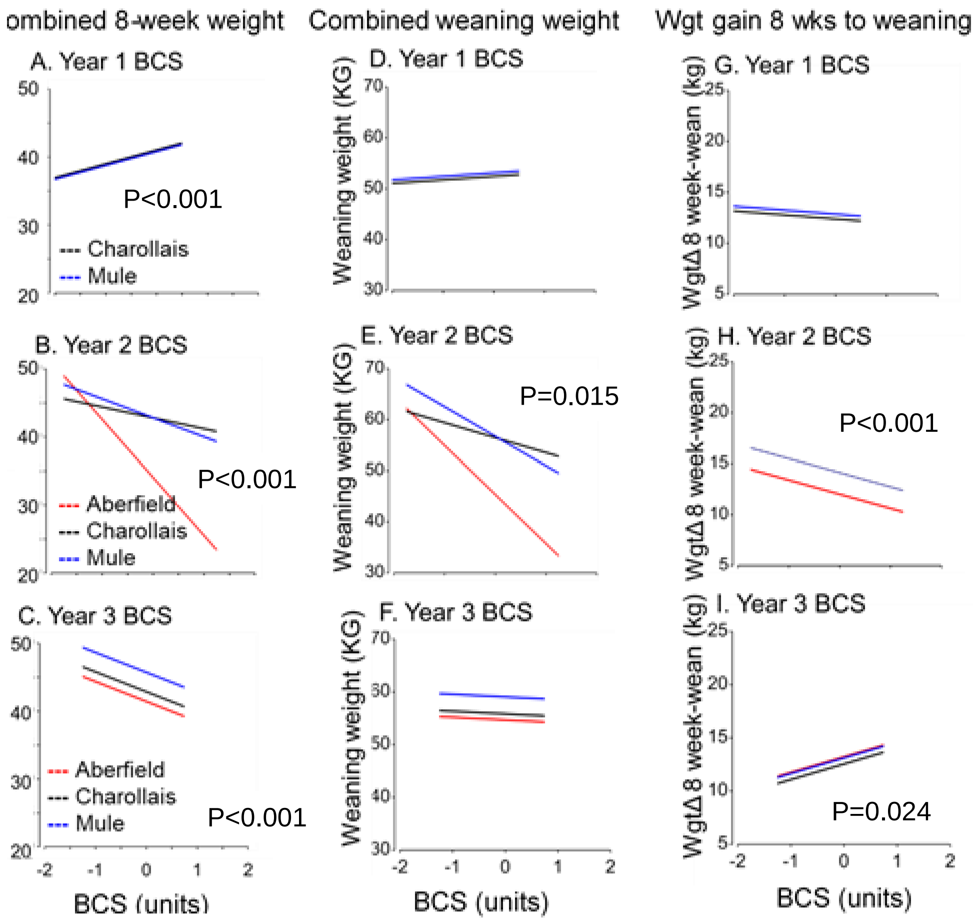


Figure 5.23. Association between ewe BCS change **between lambing and 8 weeks** on combined lamb 8-week weight (A-C), combined lamb weaning weight (D-F) and lamb weight gain between 8 weeks and weaning (G-I) at the Leicestershire Farm for Year 1 (A, D, G), Year 2 (B, E, H) and Year 3 (C, F, I).

5.3.2.12 *Ewe BCS and liveweight change between scanning and 8 weeks*

Combined lamb 8-week weight was positively associated with ewe BCS gain between scanning and 8 weeks in Year 1 (P<0.001; Figure 5.24 A), negatively associated with ewe BCS gain in Year 3 (P=0.014; Figure 5.24 C); with a genotype x BCS interaction in Year 2 (P=0.001; Figure 5.24 B). Lamb weight decreased with ewe BCS gain between scanning and 8 weeks but to a greater extent for lambs reared by Aberfield ewes, compared to lambs reared by Charollais and Mule ewes.

Combined lamb weaning weight was negatively associated with ewe BCS gain between scanning and 8-weeks, but in Year 2 only (P=0.003; Figure 5.24 H). Lamb weight gain between 8 weeks and weaning was negatively associated with ewe BCS gain between scanning and 8 weeks in Year 2 (P<0.001; Figure 5.24 N), but positively associated in Year 3 (P=0.003; Figure 5.24 O).

Combined lamb 8-week weight was positively associated with ewe liveweight gain between scanning and 8 weeks in Year 1 (P<0.001; Figure 5.24 D) and negatively associated in Year 2 (P<0.001; Figure 5.24 E) with a genotype x liveweight interaction in Year 3 (P=0.003; Figure 5.24 F). Lamb 8-week weight decreased with ewe liveweight gain for lambs reared by Aberfield ewes, compared to lambs reared by Charollais and Mule ewes.

Combined lamb weaning weight was positively associated with ewe liveweight gain between scanning and 8-weeks in Year 1 (P=0.003; Figure 5.24 J) and negatively associated in Year 2 (P<0.001; Figure 5.24 K). Lamb weight gain from 8-weeks to weaning was negatively associated with ewe liveweight gain between scanning and 8-weeks in Years 1 (P=0.030; Figure 5.24 P) and 2 (P<0.001; Figure 5.24 Q).

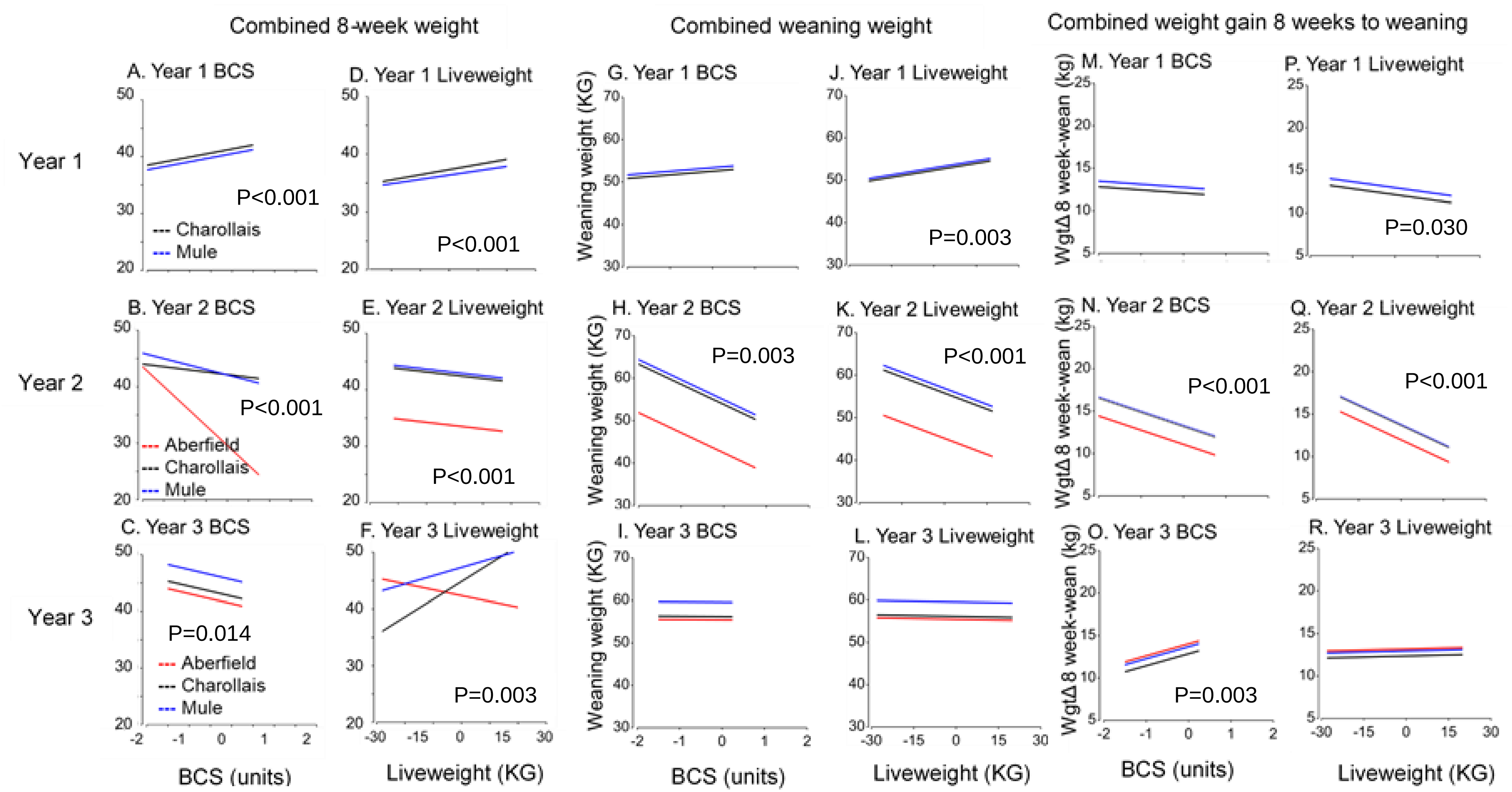


Figure 5.24. Association between ewe BCS change (A-C, G-I, M-O) and liveweight change (D-F, J-L, P-R) **between scanning and 8 weeks** on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) at the Leicestershire Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

5.3.2.13 *Ewe BCS and liveweight at weaning (current production cycle)*

Combined lamb weaning weight and lamb weight gain from 8-weeks to weaning were not associated with ewe BCS at weaning (Figure 5.25 A-C; G-I). However, there were ewe genotype x BCS interactions for combined lamb weaning weight in Years 2 and 3 ($P<0.001$; $P=0.025$; Figure 5.25 B-C, respectively). Lamb weaning weight decreased with increasing ewe BCS at weaning for lambs reared by Aberfield and Charollais ewes, compared to lambs reared by Mule ewes that were heavier with increasing ewe BCS.

Combined lamb weaning weight was positively associated with ewe liveweight at weaning in Years 1, 2 and 3 ($P<0.001$; Figure 5.25 D-F). There were ewe genotype x liveweight interactions for combined lamb weaning weight in Year 2 ($P<0.001$; Figure 5.25 E) and combined lamb weight gain between 8 weeks and weaning, in Years 2 and 3 ($P=0.006$; $P=0.016$; Figure 5.25 K-L, respectively). Combined lamb weaning weight and weight gain between 8 weeks and weaning decreased with increasing ewe liveweight at weaning for lambs reared by Charollais ewes, compared to lambs reared by Mule and Aberfield ewes.

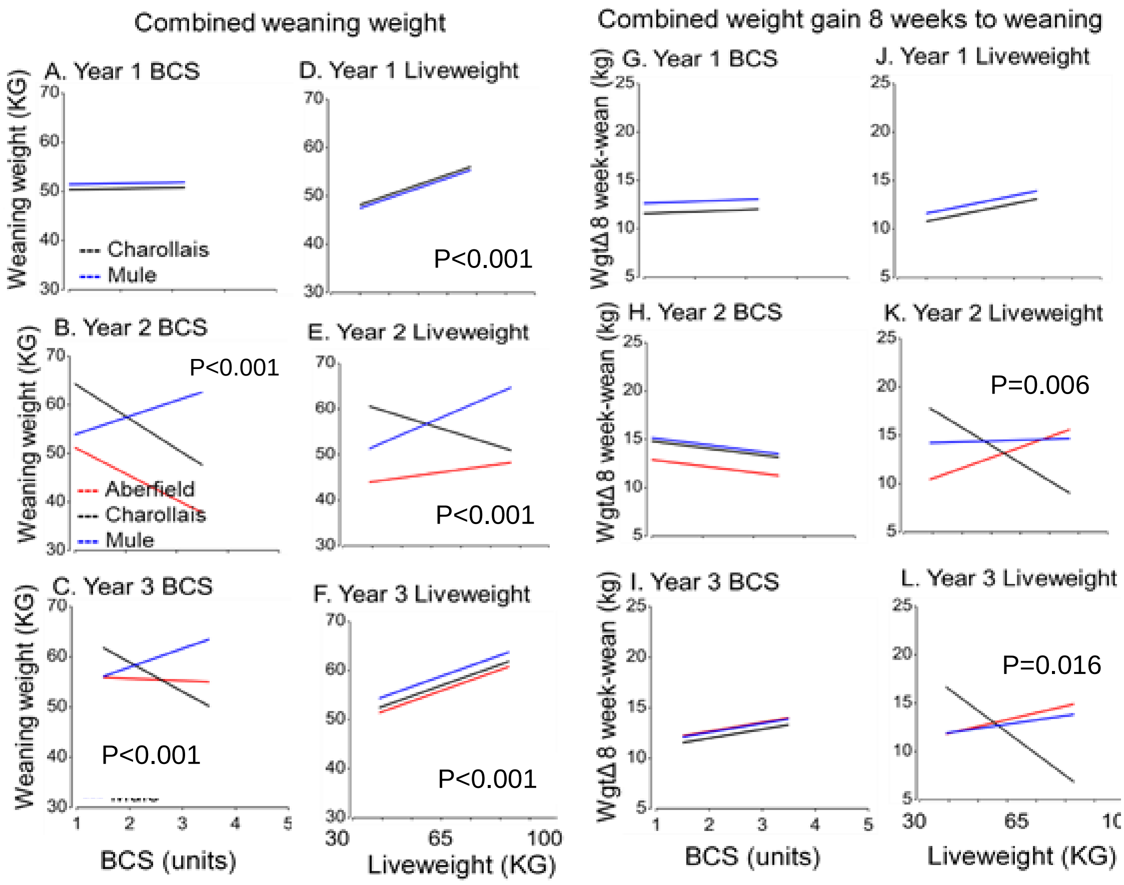


Figure 5.25. Association between ewe BCS (A-C, G-I) and liveweight (D-F, J-L) **at weaning** on combined lamb weaning weight (A-F) and lamb weight gain between 8 weeks and weaning (G-L) at the Leicestershire Farm for Year 1 (A, D, G), Year 2 (B, E, H) and Year 3 (C, F, I).

5.3.2.14 *Ewe BCS and liveweight change between 8 weeks and weaning*

Combined lamb weaning weight (Figure 5.26 A,C) and lamb weight gain between 8 weeks and weaning (Figure 5.25 D-F) were not associated with ewe BCS change between 8 weeks and weaning; except for a ewe genotype x BCS change interaction for combined lamb weaning weight, in Year 2 only (P=0.016; Figure 5.25 B). Lamb weaning weight increased with ewe BCS gain for lambs reared by Aberfield and Mule ewes, compared to lambs reared by Charollais ewes that were lighter with ewe BCS gain.

Combined lamb weaning weight was positively associated with ewe liveweight gain between weeks and weaning, but in Year 2 only (P<0.001; Figure 5.25 E). Lamb weight gain between 8 weeks and weaning was positively associated with ewe liveweight gain between 8 weeks and weaning in Years 1, 2 and 3 (P<0.001; Figure 5.25 J-L).

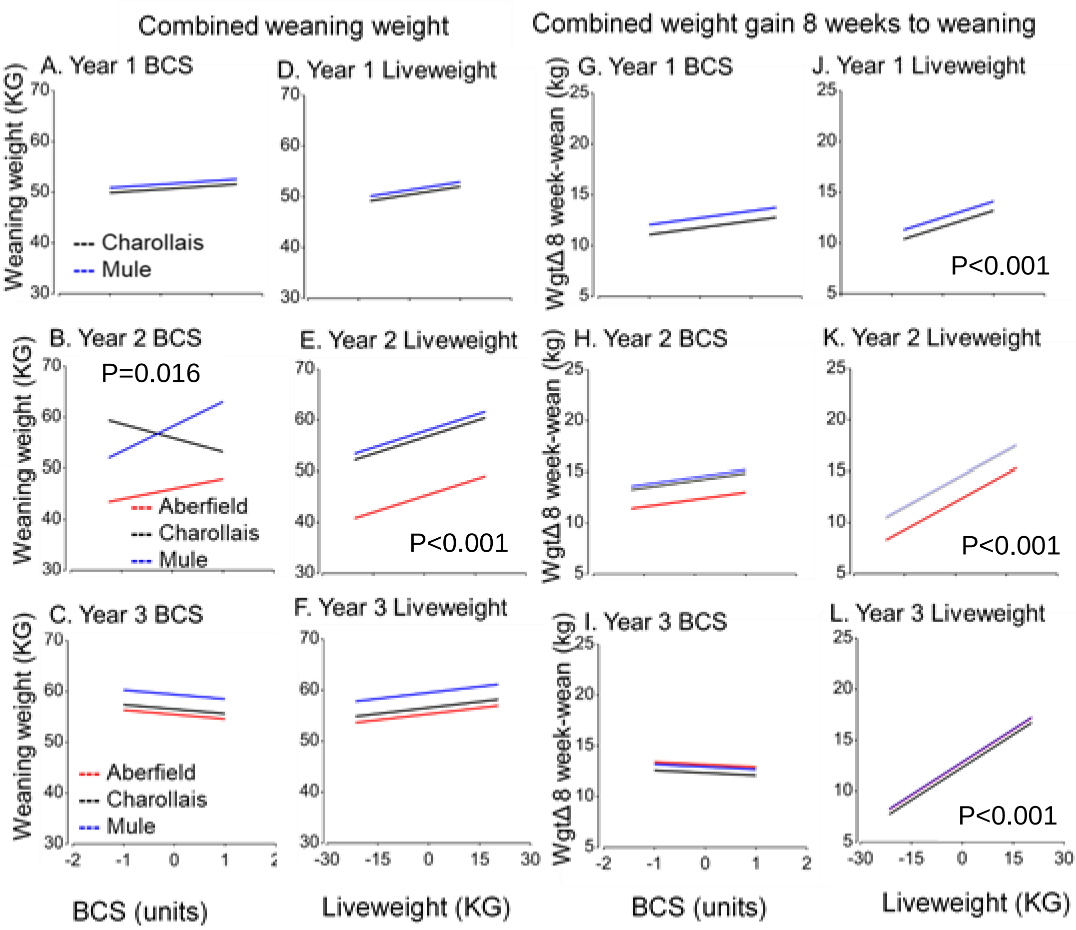


Figure 5.26. Association between ewe BCS change (A-C, G-I) and liveweight change (D-F, J-L) **between 8 weeks and weaning** on combined lamb weaning weight (A-F) and lamb weight gain between 8 weeks and weaning (G-L) at the Leicestershire Farm for Year 1 (A, D, G, J), Year 2 (B, E, H, K) and Year 3 (C, F, I, L).

5.3.2.15 *Key findings for lamb performance to weaning: Leicestershire Farm*

The overall factors affecting combined lamb performance to weaning are summarised in Table 5.4 and discussed below.

Table 5.4. Summary of the factors affecting combined twin lamb performance at 8-weeks, at weaning and weight change between 8 weeks and weaning for the Leicestershire Farm.

	8 weeks	**Weaning**	**Change 8 weeks to weaning**
Genotype	<0.001	<0.001	n/s
Parity	<0.001	<0.001	n/s
Weaning BCS (preceding)	n/s	n/s	n/s
Weaning LWT (preceding)	n/s	n/s	n/s
Mating BCS	0.025	<0.001	n/s
Mating LWT	<0.001	<0.001	n/s
Δ Weaning to mating BCS	n/s	n/s	n/s
Δ Weaning to mating LWT	n/s	n/s	n/s
Scanning BCS	0.003	<0.001	0.011
Scanning LWT	<0.001	<0.001	0.001
Δ Mating to scanning BCS	<0.001	<0.001	0.039
Δ Mating to scanning LWT	<0.001	<0.001	n/s
Lambing BCS	<0.001	<0.001	n/s
Δ Scanning to lambing BCS	n/s	n/s	n/s
8-week BCS	<0.001	<0.001	n/s
8-week LWT	<0.001	<0.001	n/s
Δ Lambing to 8 weeks BCS	<0.001	0.015	0.024
Δ Scanning to 8 weeks BCS	<0.001	0.003	0.003
Δ Scanning to 8 weeks LWT	<0.001	0.011	0.030
Weaning BCS (current)	-	<0.001	n/s
Weaning LWT (current)	-	<0.001	0.016
Δ 8 weeks to weaning BCS	-	0.016	n/s
Δ 8 weeks to weaning LWT	-	n/s	<0.001

n/s=not significant

Lamb performance to weaning was associated with ewe genotype, with heavier lambs reared by Mule ewes.

Lamb performance to weaning was positively associated with ewe parity, in Years 2 and 3, whereby parity 1 ewes reared the lightest lambs. However, the lack of association in Year 1 may be due to the absence of parity 1 ewes in the Leicestershire flock that year.

Overall, lamb performance to weaning was not affected by ewe BCS at weaning of the preceding production cycle, ewe BCS change or liveweight change between weaning and mating. There were, however, ewe genotype interactions for ewe liveweight at weaning and ewe BCS at mating, in Years 2 and 3. Lamb performance to weaning was only consistently, positively associated with ewe liveweight at mating.

Overall, lamb performance to weaning was positively associated with ewe BCS and liveweight at scanning, ewe BCS and weight gain between mating and scanning and ewe BCS at lambing. Lamb performance to weaning was not associated with ewe BCS change between scanning and lambing.

Lamb performance to weaning was positively associated with ewe BCS and liveweight at 8 weeks and ewe liveweight at weaning. The effects on lamb performance to weaning were not consistent for ewe BCS change between lambing and 8 weeks or ewe BCS and liveweight change between scanning and 8 weeks. Lamb performance to weaning was positively associated with ewe liveweight change between 8 weeks and weaning, but not ewe BCS change.

There were several ewe genotype x interactions with BCS and/or liveweight at most production points, in Years 2 and 3. One reason that may account for these genotype interactions is the addition of a new genotype (Aberfield shearlings) in Years 2 and 3. They were younger ewes compared with ageing Mule and Charollais ewes.

5.3.3 *Lancashire Farm: Summary of effects on lamb weight to weaning*

5.3.3.1 *Ewe genotype*

Combined lamb 8-week weight and combined lamb weaning weight were associated with ewe genotype, in Years 2 and 3 (P<0.001; Table 5.5). Lamb weight gain between 8 weeks and weaning was also associated with ewe genotype, but in Years 1 and 2 (P<0.001; Table 5.5). For all significant associations, lambs reared by Mule ewes were heavier, compared to lambs reared by Texel ewes. Both genotypes were present at every parity at the Lancashire Farm (Table 2.8).

Table 5.5. Effect of **ewe genotype** on combined lamb 8-week weight, combined lamb weaning weight and weight gain between 8 weeks and weaning (mean ± SE) for Years 1 to 3 at the Lancashire Farm. Lamb weights are ranked highest to lowest. * indicates significance P<0.001.

	Year 1	**Year 2**	**Year 3**
8-week weight (KG)	Texel 40.4 ±0.65 Mule 40.2 ±0.41	Mule 45.4 ±0.58 * Texel 43.1 ±0.72	Mule 48.9 ±0.72 * Texel 42.5 ±0.82
Weaning weight (KG)	Mule 61.5 ±0.52 Texel 60.3 ±0.83	Mule 73.5 ±0.68 * Texel 68.4 ±0.85	Mule 63.9 ±0.87 * Texel 58.7± 0.99
Weight change 8 weeks to weaning (KG)	Mule 21.3 ±0.35 * Texel 19.9 ±0.56	Mule 28.1 ±0.36 * Texel 25.3 ±0.45	Mule 17.5 ±0.70 Texel 16.3 ±0.79

5.3.3.2 *Ewe parity*

Combined lamb 8-week weight and combined lamb weaning weight were associated with ewe parity in Years 1 (P=0.017; P=0.001; Table 5.6), 2 (P<0.001; Table 5.6) and 3 (P=0.004; P=0.039; Table 5.6). Lamb weight gain between 8 weeks and weaning was not associated with ewe parity. Lamb performance to weaning was lowest for parity 1 ewes, each year (Table 5.6).

Table 5.6. Effect of **ewe parity** on combined lamb 8-week weight, combined lamb weaning weight and weight gain between 8 weeks and weaning (mean ± SE) for Years 1 to 3 at the Lancashire Farm. Lamb weights are ranked highest to lowest. * indicates significance P<0.001.

	Year 1	**Year 2**	**Year 3**
8-week weight (KG)*	Parity 3 41.99 ± 0.886	Parity 3 46.30 ± 1.018	Parity 2 46.82± 1.409
	Parity 4 41.12 ± 0.887	Parity 4 45.48 ± 1.051	Parity 3 45.60 ± 0.904
	Parity 2 40.30 ± 0.845	Parity 5 45.47 ± 1.060	Parity 4 45.40 ± 1.233
	Parity 1 39.45 ± 0.475	Parity 2 45.29 ± 0.659	Parity 5 42.07 ±0.929
		Parity 1 38.18 ± 1.221	Parity 1 41.85± 1.484
Weaning weight (KG)*	Parity 3 59.80 ± 1.120	Parity 3 74.37 ± 1.272	Parity 2 64.60± 1.702
	Parity 4 59.09 ± 1.121	Parity 4 72.39 ± 1.240	Parity 4 62.61 ± 1.489
	Parity 2 59.02 ± 1.068	Parity 5 72.27 ± 1.250	Parity 3 61.81 ± 1.092
	Parity 1 58.20 ± 0.601	Parity 2 72.19 ± 0.777	Parity 5 59.50 ±1.123
		Parity 1 64.15 ± 1.440	Parity 1 58.44 ± 1.792
Weight change 8 weeks to weaning (KG)	Parity 2 18.72 ± 0.728	Parity 3 17.07 ± 0.670	Parity 2 17.78± 1.369
	Parity 4 17.97 ± 0.764	Parity 4 16.91 ± 0.653	Parity 3 17.43 ± 0.903
	Parity 3 17.80 ± 0.733	Parity 2 16.90 ± 0.409	Parity 4 17.21 ± 1.198
	Parity 1 17.35 ± 0.410	Parity 5 16.96 ± 0.653	Parity 5 16.59 ±1.442
		Parity 1 16.80 ± 0.759	Parity 1 16.21 ± 0.879

5.3.3.3 *Ewe BCS and liveweight at weaning (preceding production cycle)*

There was a suggestion that combined lamb 8-week and combined lamb weaning weight were negatively associated with ewe BCS at weaning of the preceding production cycle, but in Year 2 only (P=0.094; P=0.066; Figure 5.27 B, G, respectively). Combined lamb 8-week weight and combined lamb weaning weight were not associated with ewe liveweight at weaning. Lamb weight gain from 8-weeks to weaning was not associated with ewe BCS or liveweight at weaning of the preceding season.

5.3.3.4 *Ewe BCS and liveweight at mating*

There was a suggestion that combined lamb 8-week weight was positively associated with ewe BCS at mating in Year 1 (P=0.061; Figure 5.28 A); with a significant ewe genotype x BCS interaction in Year 2 (P=0.045; Figure 5.28 B). Lamb 8-week weight increased with increasing ewe BCS at mating for lambs reared by Texel ewes, compared to lambs reared by Mule ewes. Combined lamb weaning weight and lamb weight gain between 8 weeks and weaning were not associated with ewe BCS at mating.

Combined lamb 8-week weight and combined lamb weaning weight were positively associated with ewe liveweight at mating, but in Year 1 only (P<0.001; Figure 5.28 D, J, respectively). There was a suggestion that lamb weight gain between 8 weeks and weaning was positively associated with ewe liveweight at mating in Year 1 (P=0.082; Figure 5.28 P), with a ewe genotype x BCS interaction in Year 3 (P=0.008; Figure 5.28 R). Lamb weight gain between 8 weeks and weaning increased with increasing ewe liveweight at mating for lambs reared by Mule ewes, compared to lambs reared by Texel ewes that gained less weight with increasing ewe liveweight.

5.3.3.5 *Ewe BCS and liveweight change between weaning and mating*

Combined lamb 8-week weight was positively associated with ewe BCS gain between weaning of the preceding production cycle and mating of the subsequent production cycle, but in Year 2 only (P=0.032; Figure 5.29 B). There was a suggestion that lamb 8-week weight was positively associated with ewe liveweight gain, but in Year 3 only (P=0.094; Figure 5.29 E).

Combined lamb weaning weight (Figure 5.29 F-J) and lamb weight gain between 8 weeks and weaning (Figure 5.29 K-O) were not associated with ewe BCS or liveweight change between weaning and mating.

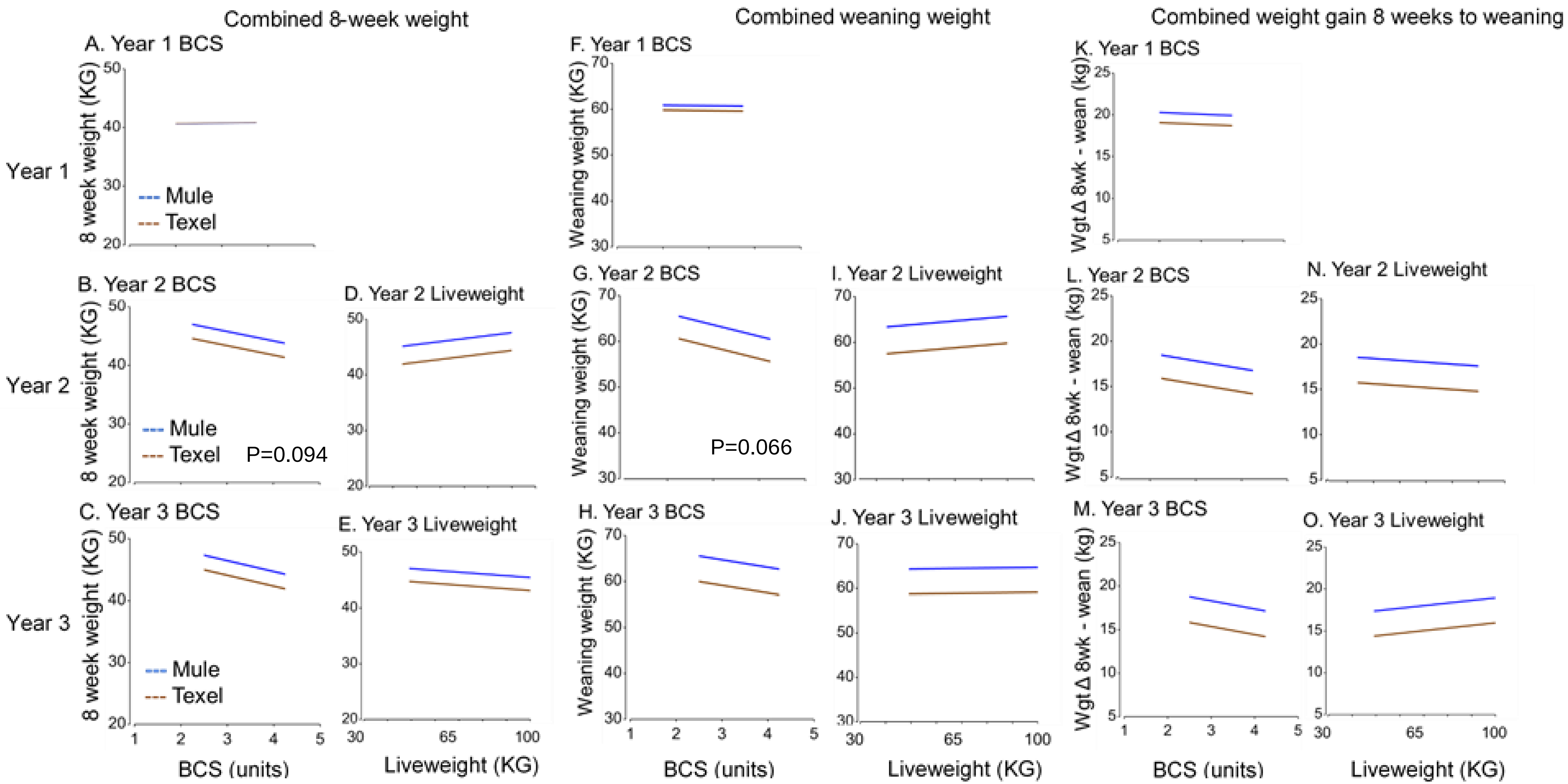


Figure 5.27. Association between ewe BCS (A-C, F-H, K-M) and liveweight (D-E, I-J, N-O) **at weaning** of the preceding production cycle on combined lamb 8-week weight (A-E), combined lamb weaning weight (F-J) and lamb weight gain between 8 weeks and weaning (K-O) in the subsequent production cycle at the Lancashire Farm for Year 1 (A, F, K), Year 2 (B, D, G, I, L, N) and Year 3 (C, E, H, J, M, O).

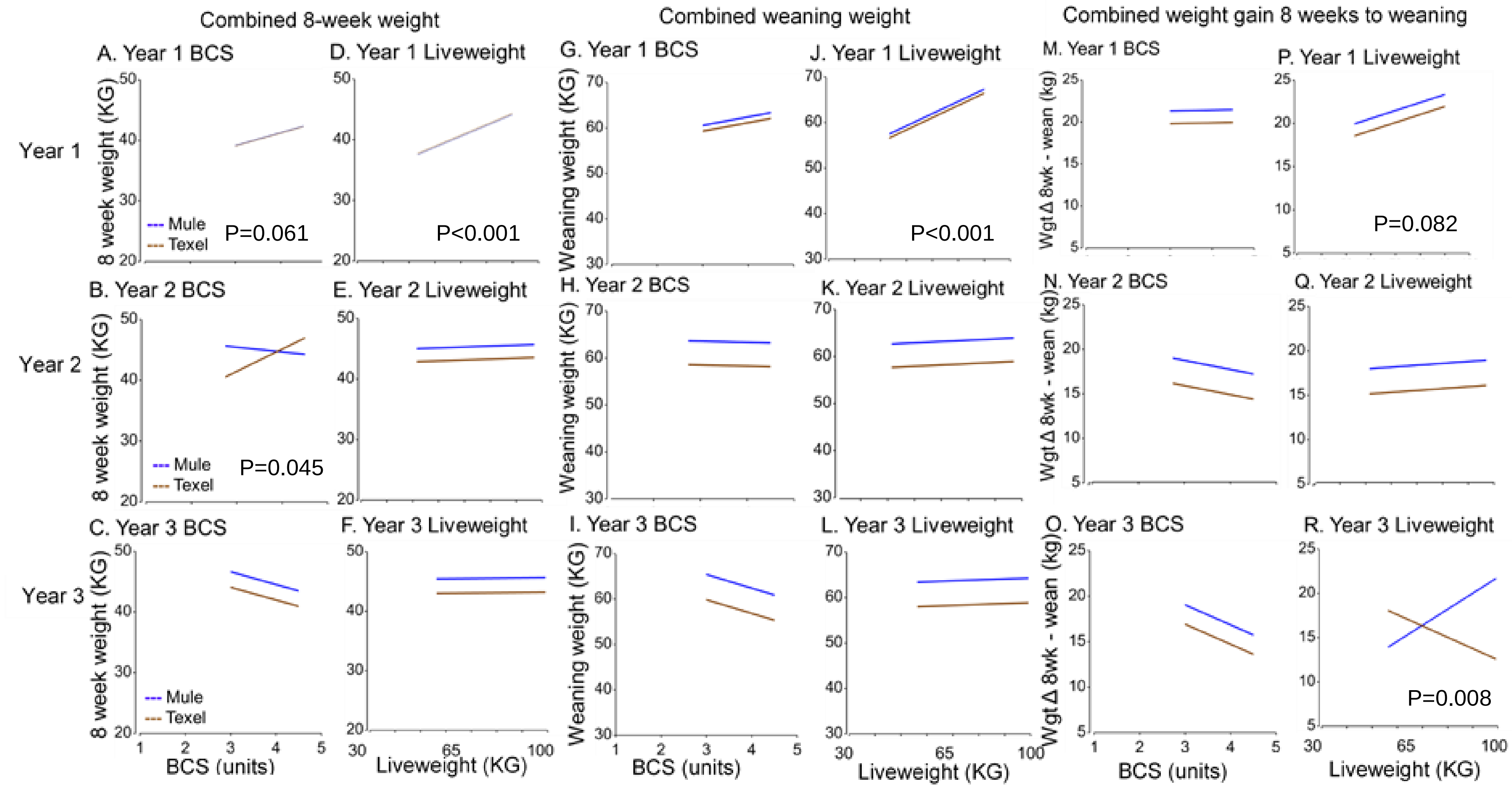


Figure 5.28. Association between ewe BCS (A-C, G-I, M-O) and liveweight (D-F, J-L, P-R) **at mating** on combined lamb 8-week weight (A-F), combined lamb weaning weight (G-L) and lamb weight gain between 8 weeks and weaning (M-R) at the Lancashire Farm for Year 1 (A, D, G, J, M, P), Year 2 (B, E, H, K, N, Q) and Year 3 (C, F, I, L, O, R).

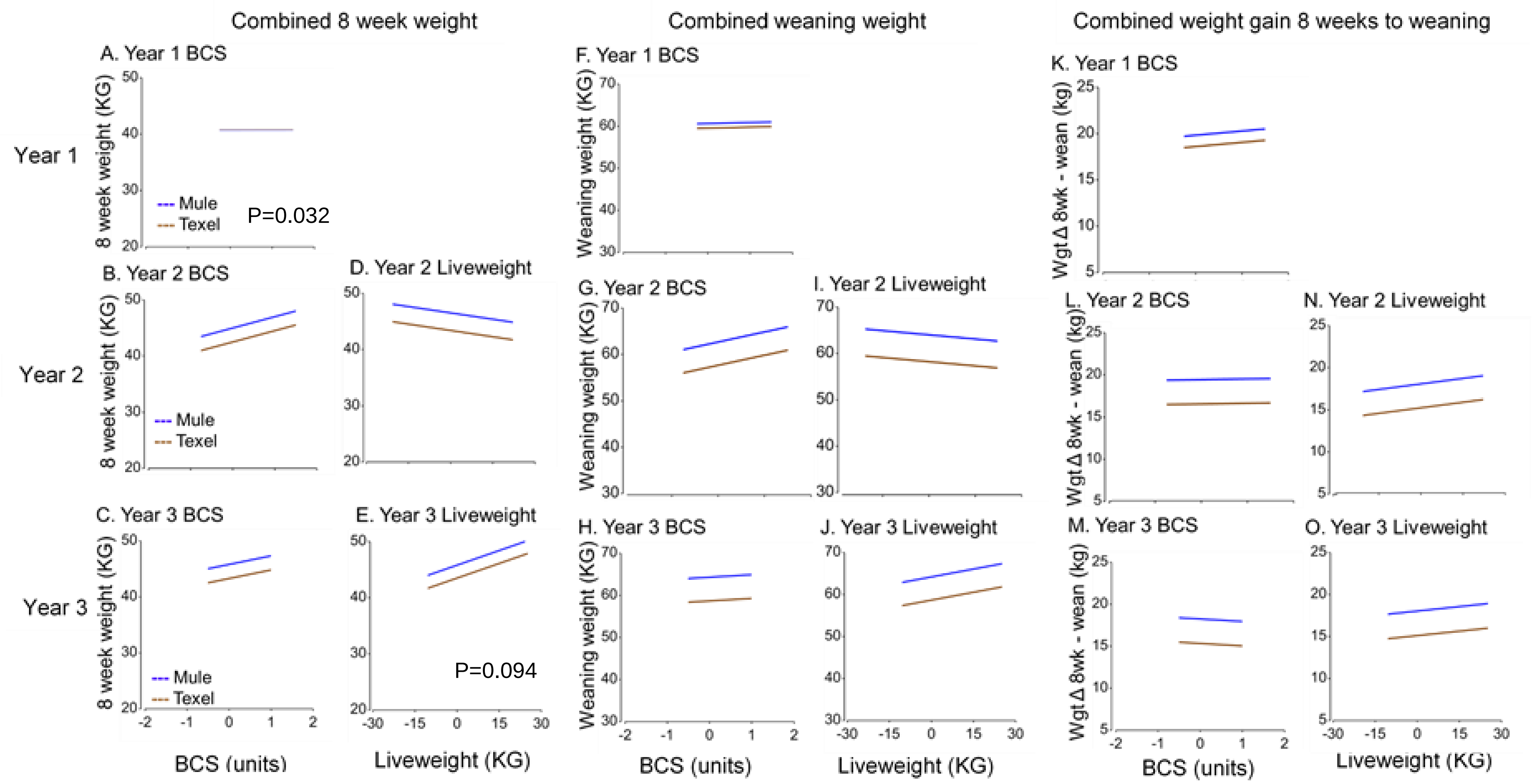


Figure 5.29. Association between ewe BCS change (A-C, F-H, K-M) and liveweight change (D-E, I-J,N-O) **between weaning of the preceding production cycle and mating** of the subsequent production cycle on combined lamb 8-week weight (A-E), combined lamb weaning weight (F-J) and lamb weight gain between 8 weeks and weaning (K-O) at the Lancashire Farm for Year 1 (A, F, K), Year 2 (B, D, G, I, L, N) and Year 3 (C, E, H, J, M, O).

5.3.3.6 *Ewe BCS and liveweight at scanning*

Ewe liveweight data at scanning in Years 1 and 2 and ewe BCS data at scanning in Year 2 were not available.

For the years where data was provided, combined lamb 8-week weight (Figure 5.30 A-B), combined lamb weaning weight (Figure 5.30 D-E) and lamb weight gain between 8 weeks and weaning (Figure 5.30 G-H) were not associated with ewe BCS or liveweight at scanning. However, there was a ewe genotype x liveweight interaction for lamb weight gain between 8 weeks and weaning (data only available in Year 3) (P=0.019; Figure 5.30 I). Lamb weight gain increased with increasing ewe liveweight at scanning for lambs reared by Mule ewes, compared to lambs reared by Texel ewes that were lighter with increasing ewe liveweight.

5.3.3.7 *Ewe BCS and liveweight change between mating and scanning*

Ewe liveweight data at scanning in Years 1 and 2 and ewe BCS data at scanning in Year 2 were not available.

For the years where data was provided, combined lamb 8-week weight (Figure 5.31 A-C), combined lamb weaning weight (Figure 5.31 D-F) and lamb weight gain between 8 weeks and weaning (Figure 5.31 G-I) were not associated with ewe BCS or liveweight change between mating and scanning.

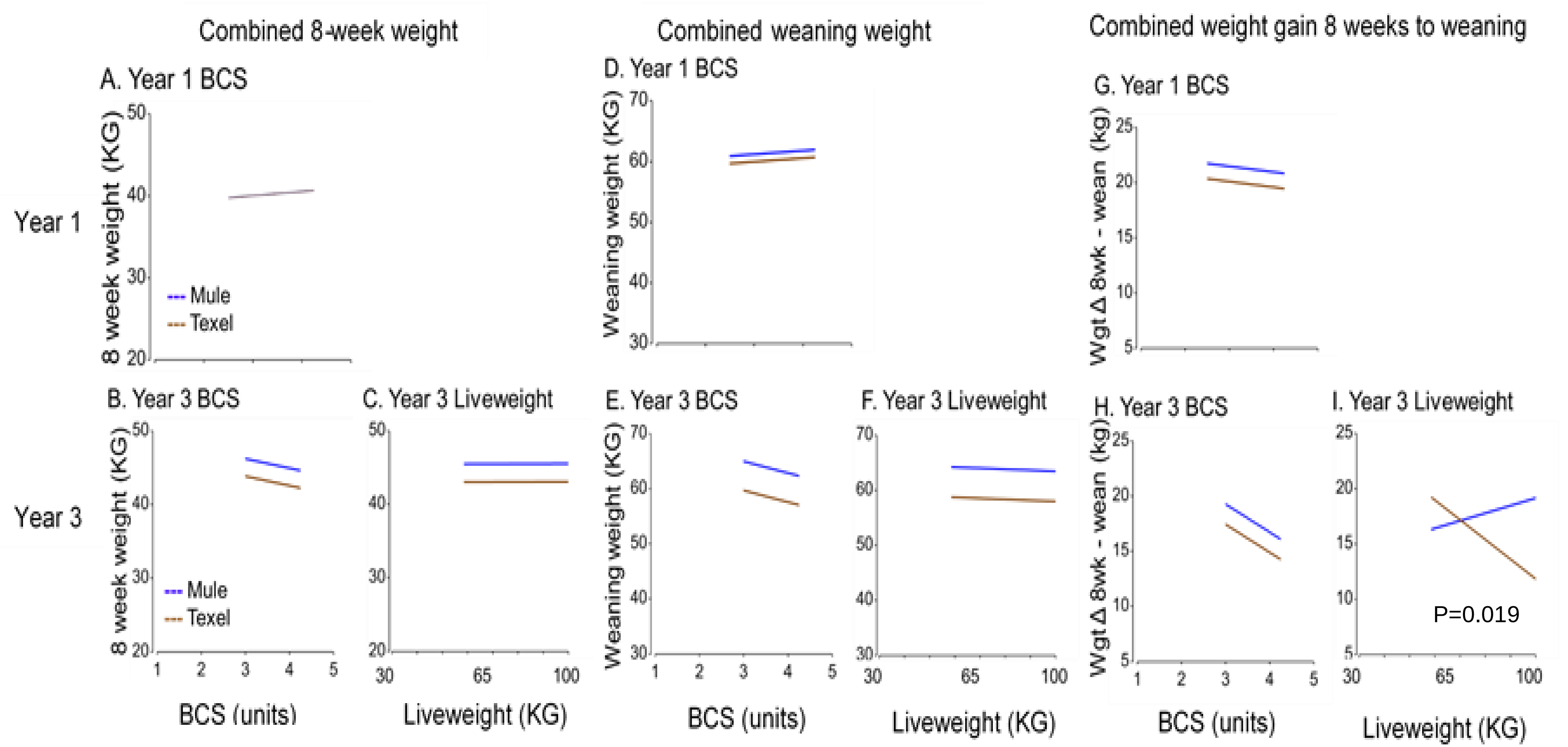


Figure 5.30. Association between ewe BCS (A-B, D-E, G-H) and liveweight (C, F, I) **at scanning** on combined lamb 8-week weight (A-C), combined lamb weaning weight (D-F) and lamb weight gain between 8 weeks and weaning (G-I) at the Lancashire Farm for Year 1 (A, D, G) and Year 3 (B, C, E, F, H, I).

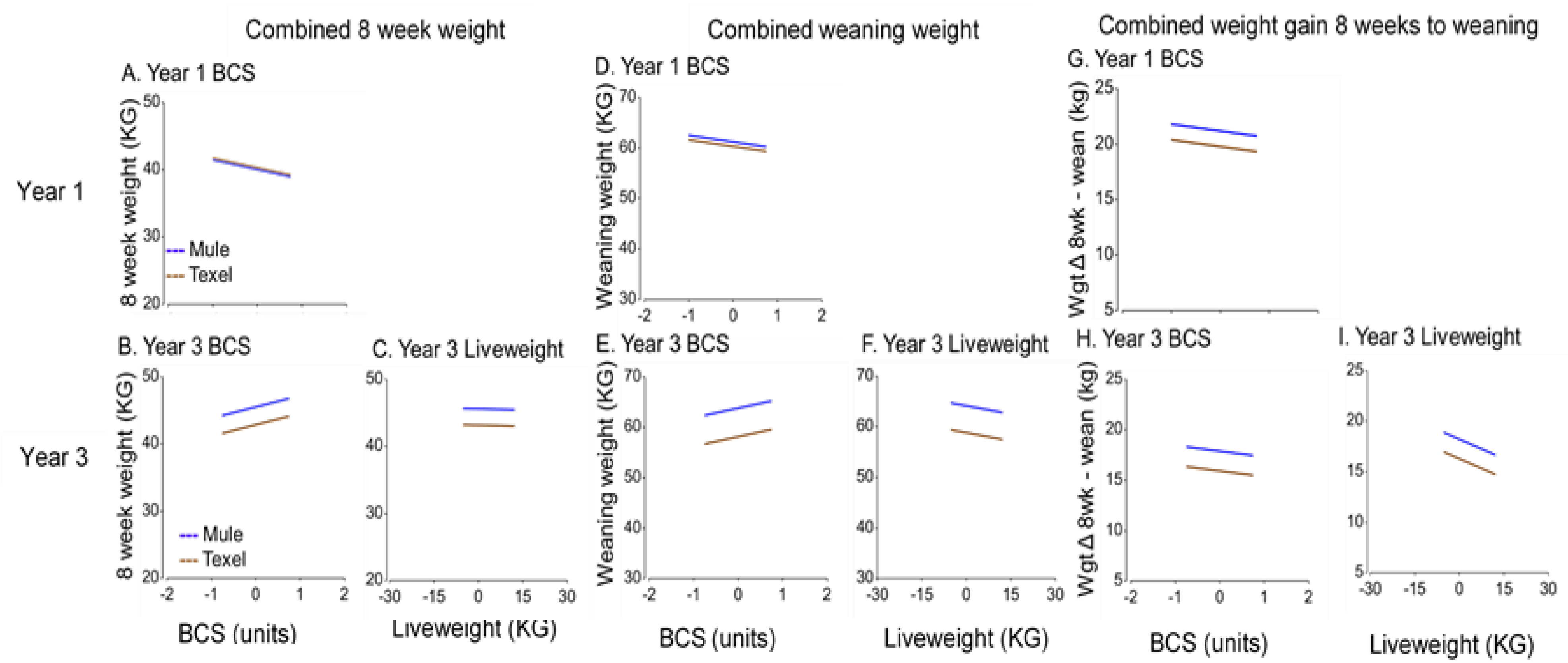


Figure 5.31. Association between ewe BCS change (A-B, D-E, G-H) and liveweight change (C, F, I) **between mating and scanning** on combined lamb 8-week weight (A-C), combined lamb weaning weight (D-F) and lamb weight gain between 8 weeks and weaning (G-I) at the Lancashire Farm for Year 1 (A, D, G) and Year 3 (B, C, E, F,H, I). No figures were significant.

5.3.3.8 *Ewe BCS at lambing*

Combined lamb 8-week weight was positively associated with ewe BCS at lambing, but in Year 1 only (P=0.040; Figure 5.32 A). Combined lamb weaning weight (Figure 5.32 D-F) and lamb weight gain between 8 weeks and weaning (Figure 5.32 G-I) were not associated with ewe BCS at lambing.

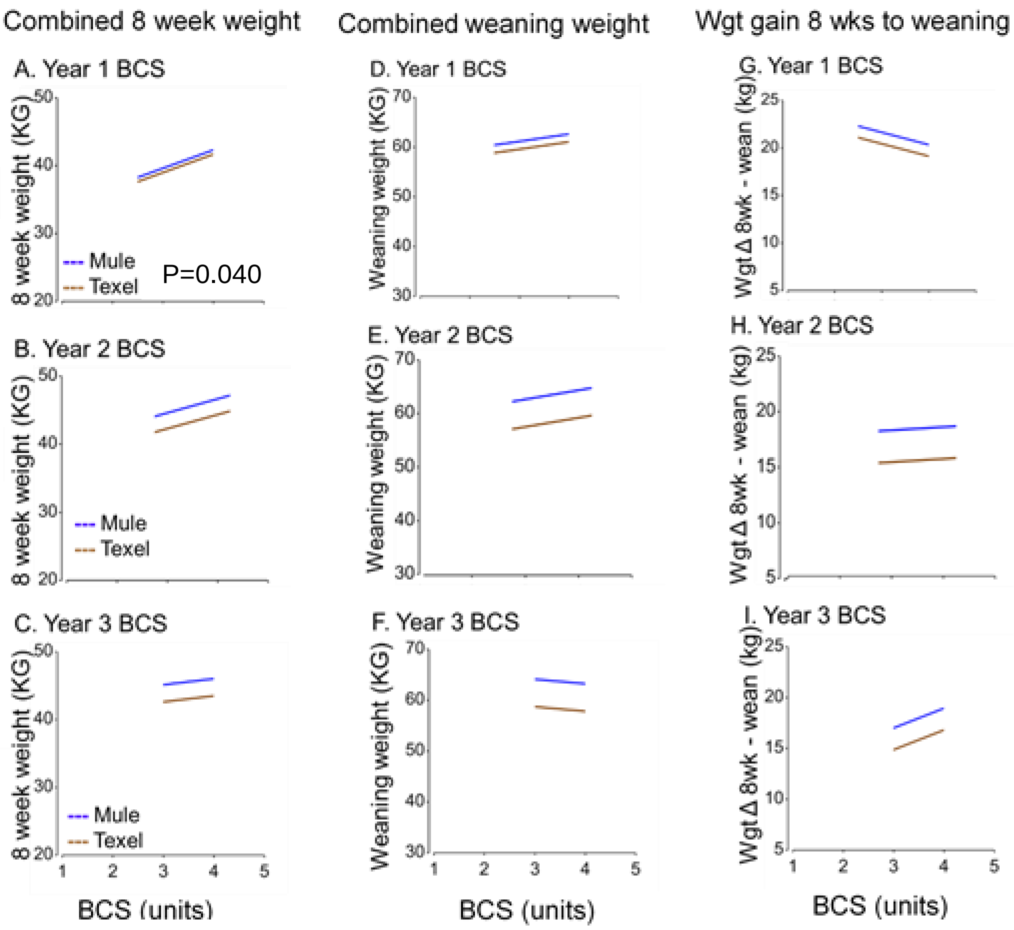


Figure 5.32. Association between ewe BCS **at lambing** on combined lamb 8-week weight (A-C), combined lamb weaning weight (D-F) and lamb weight gain between 8 weeks and weaning (G-I) at the Lancashire Farm for Year 1 (A, D, G), Year 2 (B, E, H) and Year 3 (C, F, I).

5.3.3.9 *Ewe BCS change between scanning and lambing*

Combined lamb 8-week weight (Figure 5.33; A-B) and combined lamb weaning weight (Figure 5.33; C-D) were not associated with ewe BCS change between scanning and lambing. Lamb weight gain between 8 weeks and weaning was positively associated with ewe BCS gain, but in Year 3 only (Figure 5.33; F).

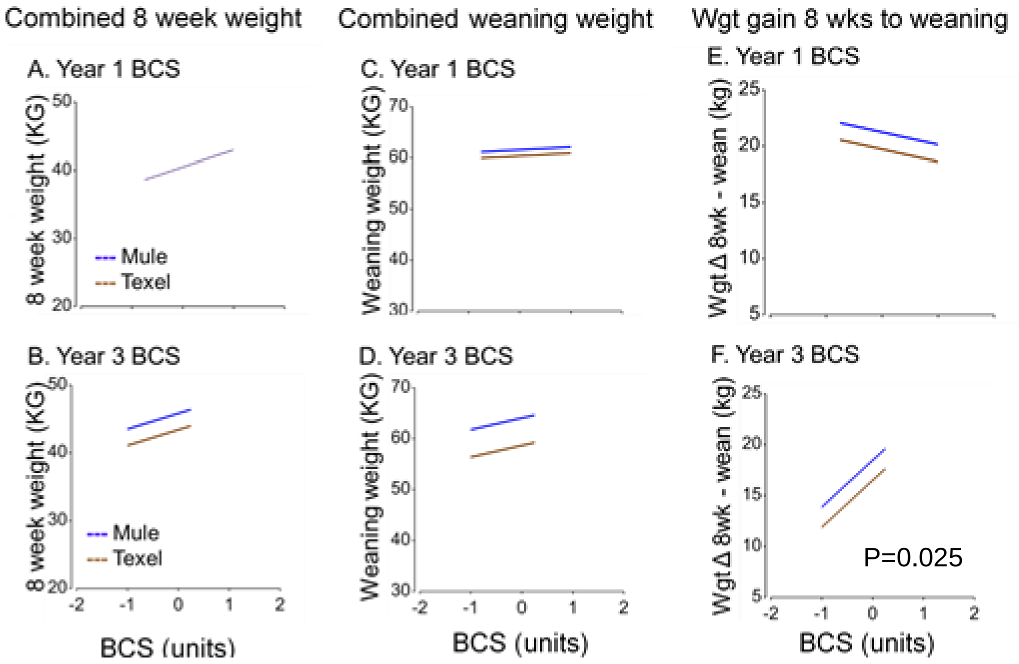


Figure 5.33. Association between ewe BCS change **between scanning and lambing** on combined lamb 8-week weight (A-B), combined lamb weaning weight (C-D) and lamb weight gain between 8 weeks and weaning (E-F) at the Lancashire Farm for Year 1 (A, C, E) and Year 3 (B, D, F).

5.3.3.10 *Ewe BCS at 8 weeks*

Ewe liveweight data at 8 weeks was not available.

Combined lamb 8-week weight was negatively associated with ewe BCS at 8 weeks in Year 2 (P=0.011; Figure 5.34 B); and, to a lesser extent, in Year 3 (P=0.081; Figure 5.34 C), with a ewe genotype x BCS interaction in Year 1 (P=0.049; Figure 5.34 A). Combined lamb 8-week weight increased with increasing ewe BCS at 8 weeks for lambs reared by Texel ewes, compared with lambs reared by Mule ewes that were lighter with increasing ewe BCS.

There was a suggestion that combined lamb weaning weight was negatively associated with ewe BCS at 8 weeks in Year 1 (P=0.097; Figure 5.34 D); this relationship was significant in Year 2 (P=0.025; Figure 5.34 E).

Lamb weight gain between 8 weeks and weaning was negatively associated with ewe BCS at 8 weeks in Years 1 (P=0.028; Figure 5.34 G), 2 (P=0.010; Figure 5.34 H) and 3 (P=0.016; Figure 5.34 I).

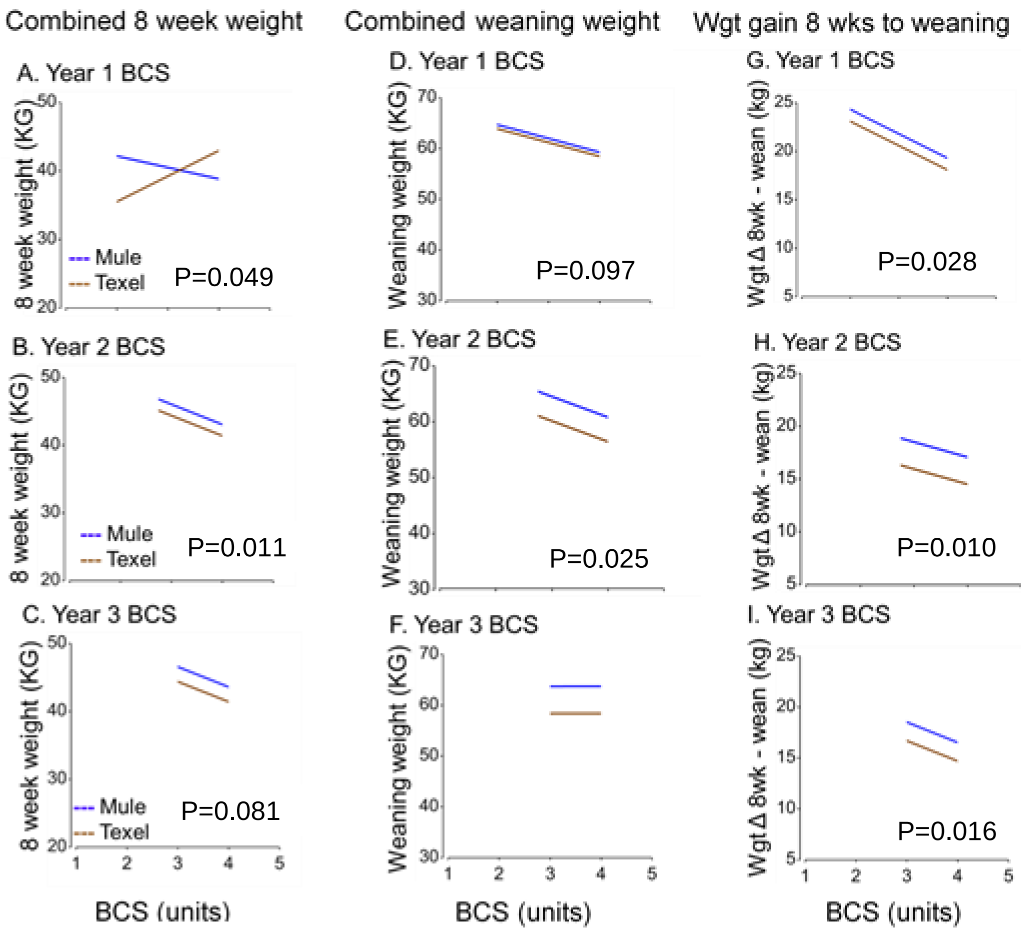


Figure 5.34. Association between ewe BCS **at 8 weeks** on combined lamb 8-week weight (A-C), combined lamb weaning weight (D-F) and lamb weight gain between 8 weeks and weaning (G-I) at the Lancashire Farm for Year 1 (A, D, G), Year 2 (B, E, H) and Year 3 (C, F, I).

5.3.3.11 *Ewe BCS change between lambing and 8 weeks*

There was a suggestion that combined lamb 8-week weight was negatively associated with ewe BCS gain between lambing and 8 weeks in Year 1 (P=0.059; Figure 5.35 A); this relationship was significant in Years 2 (P<0.001; B) and 3 (P=0.043; Figure 5.35 C).

Combined lamb weaning weight was negatively associated with ewe BCS gain in Years 1 and 2 (P=0.028; P=0.004; Figure 5.35 D-E). Lamb weight gain between 8 weeks and weaning was negatively associated with ewe BCS gain between lambing and 8 weeks in Years 1, 2 and 3 (P=0.015; P=0.018; P=0.001; Figure 5.35 G-I).

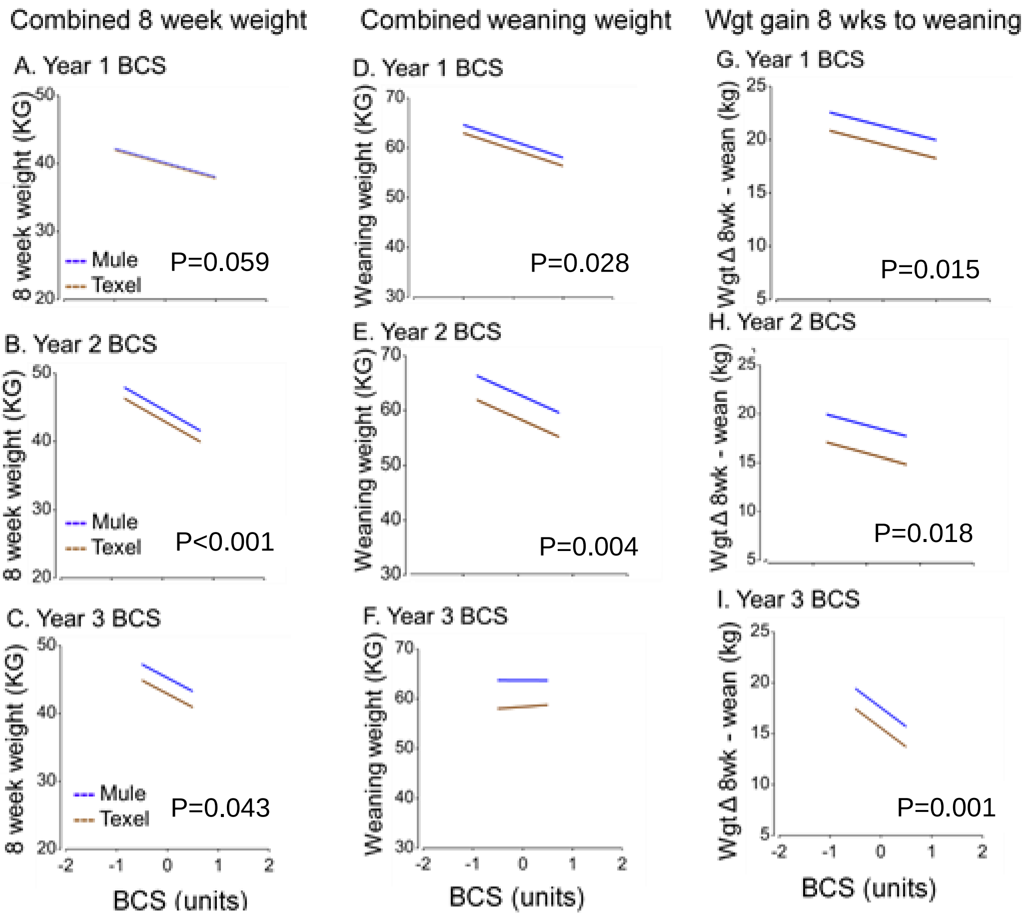


Figure 5.35. Association between ewe BCS change **between lambing and 8 weeks** on combined lamb 8-week weight (A-C), combined lamb weaning weight (D-F) and lamb weight gain between 8 weeks and weaning (G-I) at the Lancashire Farm for Year 1 (A, D, G), Year 2 (B, E, H) and Year 3 (C, F, I).

5.3.3.12 *Ewe BCS change between scanning and 8 weeks*

Combined lamb 8-week weight (Figure 5.36 A-B), combined lamb weaning weight (Figure 5.36 C-D) and lamb weight gain between 8 weeks and weaning were not associated with ewe BCS change between scanning and 8 weeks (Figure 5.36 E-F).

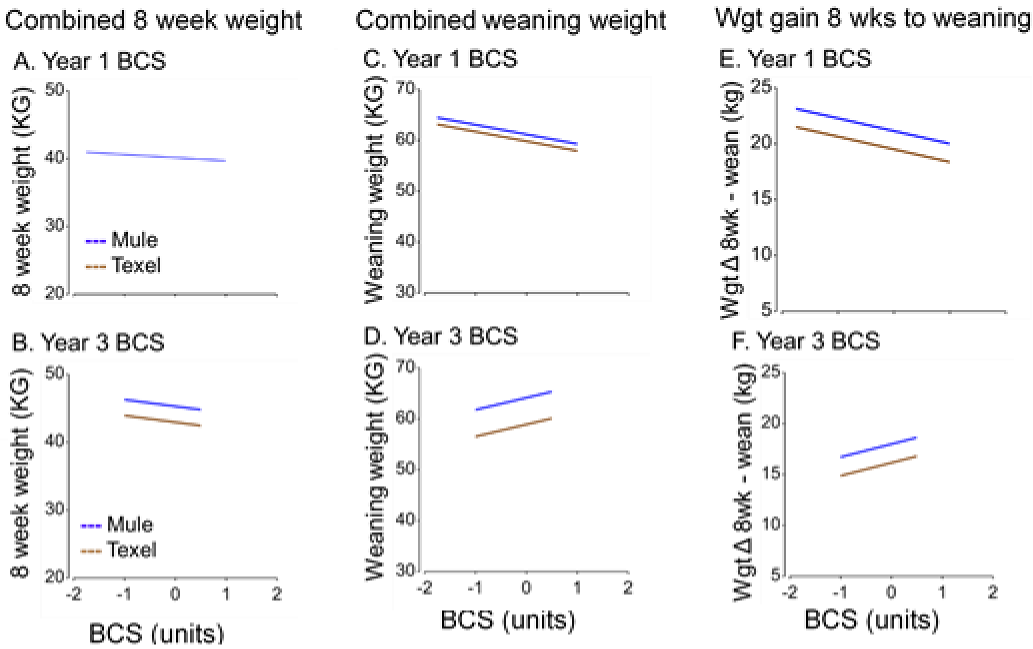


Figure 5.36. Association between ewe BCS change **between scanning and 8 weeks** on combined lamb 8-week weight (A-B), combined lamb weaning weight (C-D) and lamb weight gain between 8 weeks and weaning (E-F) at the Lancashire Farm for Year 1 (A, C, E) and Year 3 (B, D, F). No figures were significant.

Ewe BCS and liveweight at weaning (current production cycle)

Combined lamb weaning weight was negatively associated with ewe BCS at weaning, in Years 1 and 2 (P=0.027; P=0.003; Figure 5.37 A-B). Lamb weight gain between 8 weeks and weaning was negatively associated with ewe BCS at weaning in Years 2 and 3 (P<0.001; P=0.036; Figure 5.37 G-H).

Combined lamb weaning weight (Figure 5.37 D-E) and lamb weight gain between 8 weeks and weaning (Figure 5.37 I-J) were not associated with ewe liveweight at weaning.

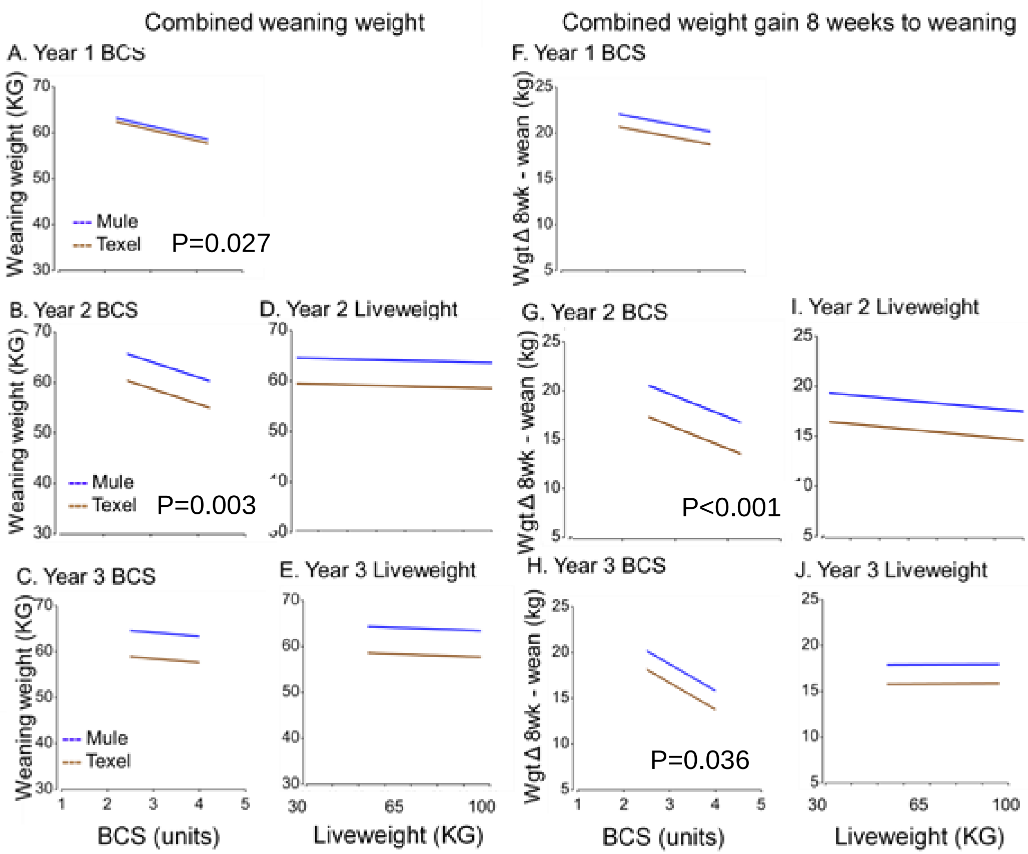


Figure 5.37. Association between ewe BCS (A-C, F-H) and liveweight (D, E, I, J) **at weaning** of current production cycle on combined lamb weaning weight (A-E) and lamb weight gain between 8-weeks and weaning (F-J) at the Lancashire Farm for Year 1 (A, F), Year 2 (B, D, G, I) and Year 3 (C, E, H, J).

5.3.3.13 *Ewe BCS change between 8 weeks and weaning*

Combined lamb weaning weight was not associated with ewe BCS change between 8 weeks and weaning (Figure 5.38 A-C). Lamb weight gain between 8 weeks and weaning was negatively associated with ewe BCS gain between 8 weeks and weaning, in Years 2 and 3 (P=0.008; P=0.015; Figure 5.38 E-F).

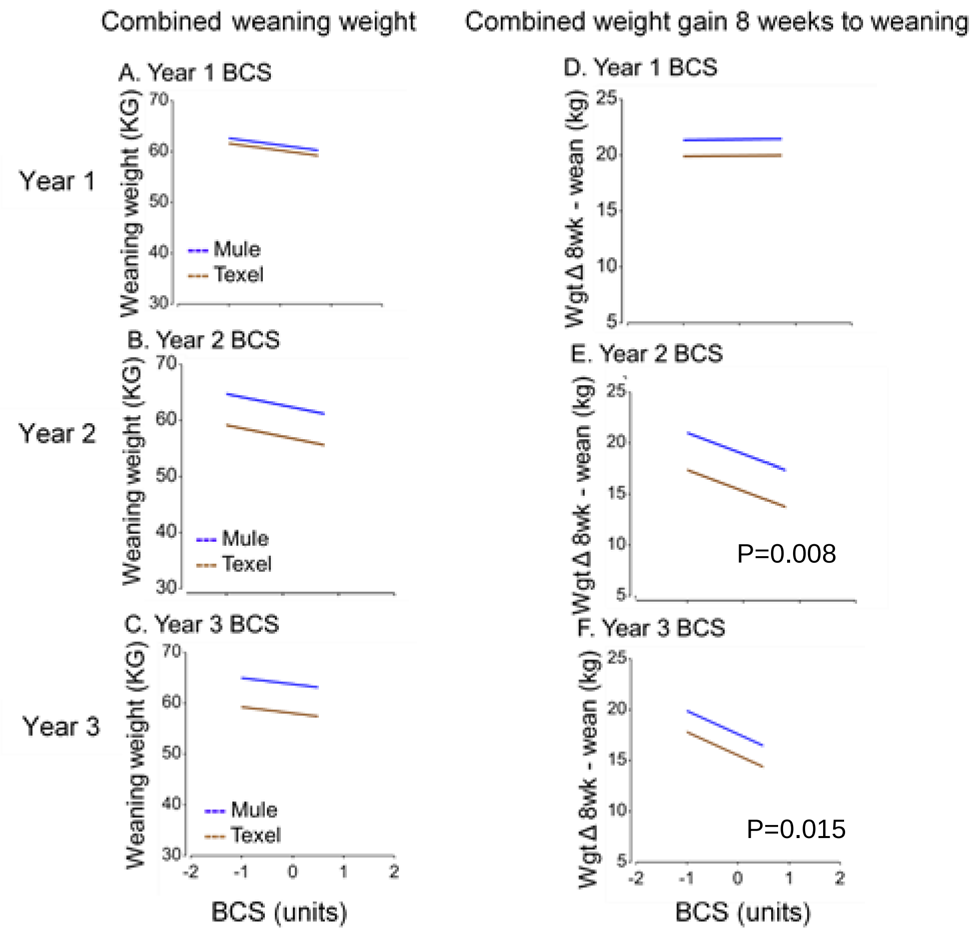


Figure 5.38. Association between ewe BCS change **between 8 weeks and weaning** on combined lamb weaning weight (A-C), and lamb weight gain between 8 weeks and weaning (D-F) at the Lancashire Farm for Year 1 (A, D), Year 2 (B, E) and Year 3 (C, F).

5.3.3.14 *Key findings lamb performance to weaning: Lancashire Farm*

The overall factors affecting combined twin lamb performance to weaning are summarised in Table 5.7 and discussed below.

Table 5.7. Summary of the factors affecting combined twin lamb performance at 8-weeks, at weaning and weight change between 8 weeks and weaning for the Lancashire Farm.

	8 weeks	Weaning	Change 8 weeks to weaning
Genotype	<0.001	<0.001	<0.001
Parity	<0.001	<0.001	n/s
Weaning BCS (preceding)	n/s	n/s	n/s
Weaning LWT (preceding)	n/s	n/s	n/s
Mating BCS	n/s	n/s	n/s
Mating LWT	n/s	n/s	n/s
Δ Weaning to mating BCS	n/s	n/s	n/s
Δ Weaning to mating LWT	n/s	n/s	n/s
Scanning BCS	n/s	n/s	n/s
Scanning LWT	n/s	n/s	n/s
Δ Mating to scanning BCS	n/s	n/s	n/s
Δ Mating to scanning LWT	n/s	n/s	n/s
Lambing BCS	n/s	n/s	n/s
Δ Scanning to lambing BCS	n/s	n/s	n/s
8-week BCS	0.011	0.025	0.010
Δ Lambing to 8 weeks BCS	<0.001	0.004	0.015
Δ Scanning to 8 weeks BCS	n/s	n/s	n/s
Weaning BCS (current)	-	0.003	<0.001
Weaning LWT (current)	-	n/s	n/s
Δ 8 weeks to weaning BCS	-	n/s	0.008

n/s=not significant -

Similar to the observations at the Sussex and Leicestershire Farms, the heaviest lambs were reared by Mule ewes. The effect of ewe parity was also consistent with the Sussex and Leicestershire Farms, whereby combined lamb 8-week weight and combined lamb weaning weight were associated with ewe parity. Parity 1 ewes rearing twin lambs consistently had the lightest lambs at weaning.

Overall, lamb performance to weaning was not associated with ewe BCS and liveweight at weaning of the preceding production cycle, ewe BCS and liveweight at mating or ewe BCS and liveweight at scanning. These observations differ from those at the Sussex and Leicestershire Farms. This is likely to be as a result of ewes being in better condition (and at target BCS) at weaning, mating and scanning at the Lancashire Farm, compared with the Sussex and Leicestershire Farms.

Overall, lamb performance to weaning was not associated with ewe BCS and liveweight change between weaning and mating. This observation is broadly consistent with the Sussex and Leicestershire Farms, despite the difference in ewe condition at the three farms. This suggests that the performance of a production cycle is already determined by weaning of the preceding production cycle, regardless of condition.

There were no effects on lamb performance to weaning as a result of ewe BCS and liveweight change between mating and scanning, ewe BCS at lambing, ewe BCS change between scanning and lambing or ewe BCS change between scanning and 8 weeks. These observations, again, differ to the Sussex and Leicestershire Farms and are attributed to the difference in flock condition between the farms.

Overall, lamb performance to weaning was negatively associated with ewe BCS at 8 weeks, ewe BCS at weaning, ewe BCS gain between lambing and 8 weeks and ewe BCS gain between 8 weeks and weaning. Ewes at lower BCS, and ewes mobilising BCS, had heavier combined lamb 8-week weight, heavier combined lamb weaning weight and greater lamb weight gain between 8 weeks and weaning. These observations differ to those of the Sussex and Leicestershire Farms. Again, this is likely due to the difference in ewe condition between the farms. It is also worth noting that the Lancashire Farm was the only farm to achieve a mean flock 8-week weight of 20 kg every year and a mean flock weaning weight of 30 kg in two out of the three years (Table 2.17; Table 2.20).

5.3.4 Pooled data across all three farms (twin lamb performance to weaning)

Overall, combined lamb 8-week weight and combined lamb weaning weight were more frequently associated with ewe BCS and liveweight (actual and change). Lamb weight gain between 8 weeks and weaning was less affected by ewe BCS and liveweight.

When comparing key observations of lamb performance to weaning from the individual farm by year analyses, some similar observations emerge. Firstly, the consistent effect of ewe genotype and ewe parity across the three farms. The heaviest lambs are reared by Mule ewes and the lightest lambs are reared by parity 1 ewes. However, it is worth noting the potential confounding effects of genotype x parity observed at both the Sussex and Leicestershire Farms (Table 2.6; Table 2.7). Secondly, the absence of an effect of ewe BCS at weaning (of the preceding production cycle), ewe BCS or liveweight change between weaning and mating, and ewe BCS change between scanning and lambing were consistent across the three farms.

Additional trends observed at the Sussex and Leicestershire Farms are not supported by observations at the Lancashire Farm. Lamb performance to weaning was positively associated with ewe liveweight at weaning and mating, ewe BCS and liveweight at scanning, and ewe BCS and liveweight change between mating and scanning at the Sussex and Leicestershire Farms, but it was not associated with lamb performance at the Lancashire Farm. Regarding ewe condition (BCS and liveweight) at 8 weeks and weaning, whilst significant for all three farms, the direction of the associations differed. Positive associations were observed at the Sussex and Leicestershire Farms together with ewe genotype x interactions, compared to the Lancashire Farm that observed negative associations. In addition, lamb performance to weaning was significantly associated with ewe condition change between 8 weeks and weaning at the three farms. However, associations were positive (with ewe genotype x interactions) at the Sussex and Leicestershire Farms, and negative at the Lancashire Farm.

To assess the overall impact of ewe BCS and liveweight at key stages of the production cycle on twin lamb performance to weaning, data across the three production cycles from the three farms were combined and analysed (Table 5.8).

Table 5.8. Summary of effect of ewe BCS and Liveweight (LWT) and change (Δ) on performance of twin lambs to weaning (lamb 8-week weight, lamb weaning weight and lamb weight gain between 8 weeks and weaning). Data pooled across the three study farms over three production cycles.

	Combined 8-week weight	**Combined weaning weight**	**Weight gain 8 weeks to weaning**
Weaning BCS (Preceding)	n/s	n/s	n/s
Weaning LWT (Preceding)	<0.001 (+)	<0.001 (+)	n/s
Mating BCS	<0.001 (+)	<0.001 (+)	n/s
Mating LWT	<0.001 (+)	<0.001 (+)	n/s
Δ BCS weaning - mating	n/s	n/s	n/s
Δ LWT weaning - mating	n/s	n/s	n/s
Scanning BCS	<0.001 (+)	<0.001 (+)	n/s
Scanning LWT	<0.001 (+)	<0.001 (+)	=0.051 (+)
Δ BCS mating - scanning	<0.001 (+)	<0.001 (+)	n/s
Δ LWT mating - scanning	<0.001 (+)	<0.001 (+)	n/s
Lambing BCS	<0.001 (+)	<0.001 (+)	n/s
Δ BCS scanning - lambing	n/s	n/s	n/s
8-week BCS	<0.001 (+)	<0.001 (+)	<0.001 (+)
8-week LWT	<0.001 (+)	<0.001 (+)	<0.001 (+)
Δ BCS lambing - 8 weeks	=0.002 (-)	<0.001 (-)	<0.001 (-)
Δ BCS scanning - 8 weeks	n/s	n/s	n/s
Δ LWT scanning - 8 weeks	n/s	n/s	n/s
Weaning BCS (current)	-	<0.001 (+)	<0.001 (+)
Weaning LWT (current)	-	<0.001 (+)	<0.001 (+)
Δ BCS 8 weeks - weaning	-	n/s	n/s
Δ LWT 8 weeks - weaning	-	n/s	n/s

n/s not significant - no data (-) negative association (+) positive association

All significant relationships between ewe BCS and liveweight on combined lamb 8-week weight, combined lamb weaning weight and lamb weight gain between 8 weeks and weaning were positive. However, there were both positive and negative significant relationships relating to change in BCS and liveweight between various production points.

5.3.4.1 *BCS and liveweight at weaning (preceding production cycle)*

In the merged analyses, combined lamb 8-week weight, combined lamb weaning weight and lamb weight gain between 8 weeks and weaning were not associated with ewe BCS at weaning of the preceding production cycle (Figure 5.39 A, C, E). These observations are consistent with the individual farm by year analysis. Combined lamb 8-week weight and combined lamb weaning weight were each positively associated with ewe liveweight at weaning (P<0.001; Figure 5.39 B, D), but lamb weight gain between 8 weeks and weaning was not associated with ewe liveweight at weaning (Figure 5.39 F). There were farm x year interactions (P<0.001) for ewe liveweight at weaning which would support the variation reported in the individual farm by year analysis. Lamb performance to weaning was not associated with ewe liveweight at weaning at the Lancashire Farm but positive associations were observed at the Sussex and Leicestershire Farms as well as ewe genotype x liveweight interactions (Appendix III. Table 1).

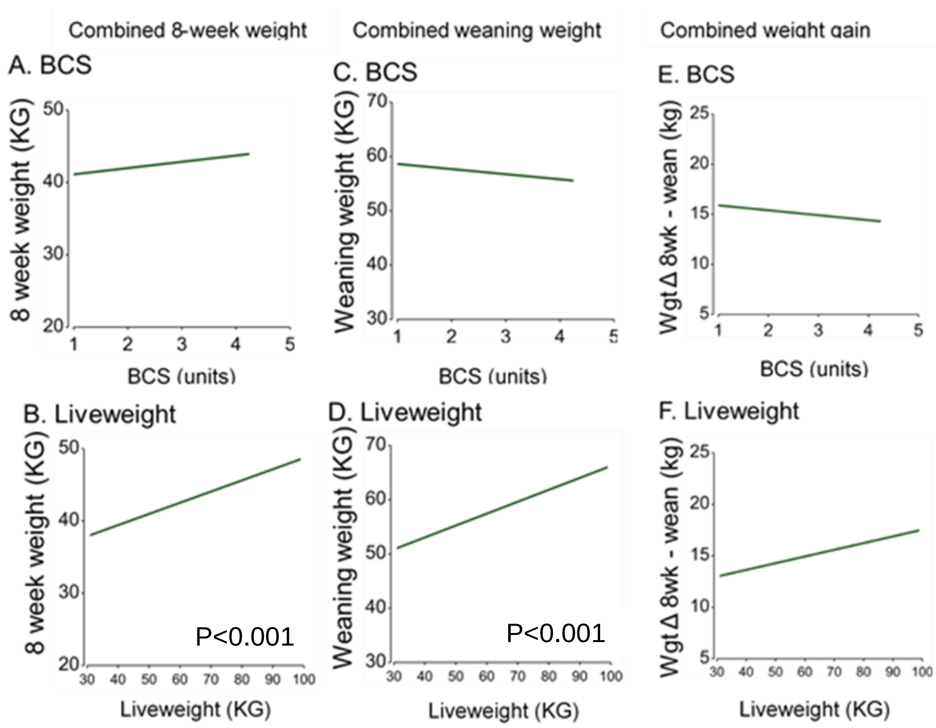


Figure 5.39. Association between ewe BCS (A, C, E) and liveweight (B, D, F**) at weaning** of the preceding production cycle on lamb 8-week weight (A-B), lamb weaning weight (C-D) and lamb weight gain between 8 weeks and weaning (E-F) for the combined analyses.

5.3.4.2 *Ewe BCS and liveweight at mating*

In the merged analyses, combined lamb 8-week weight and combined lamb weaning weight were positively associated with ewe BCS and liveweight at mating ($P<0.001$; Figure 5.40 A-D). As with weaning, there were farm x year interactions which are consistent with the variations observed when each farm was analysed separately (Appendix III. Table 2). The Lancashire Farm, again, reported fewer associations compared to the Sussex and Leicestershire Farms.

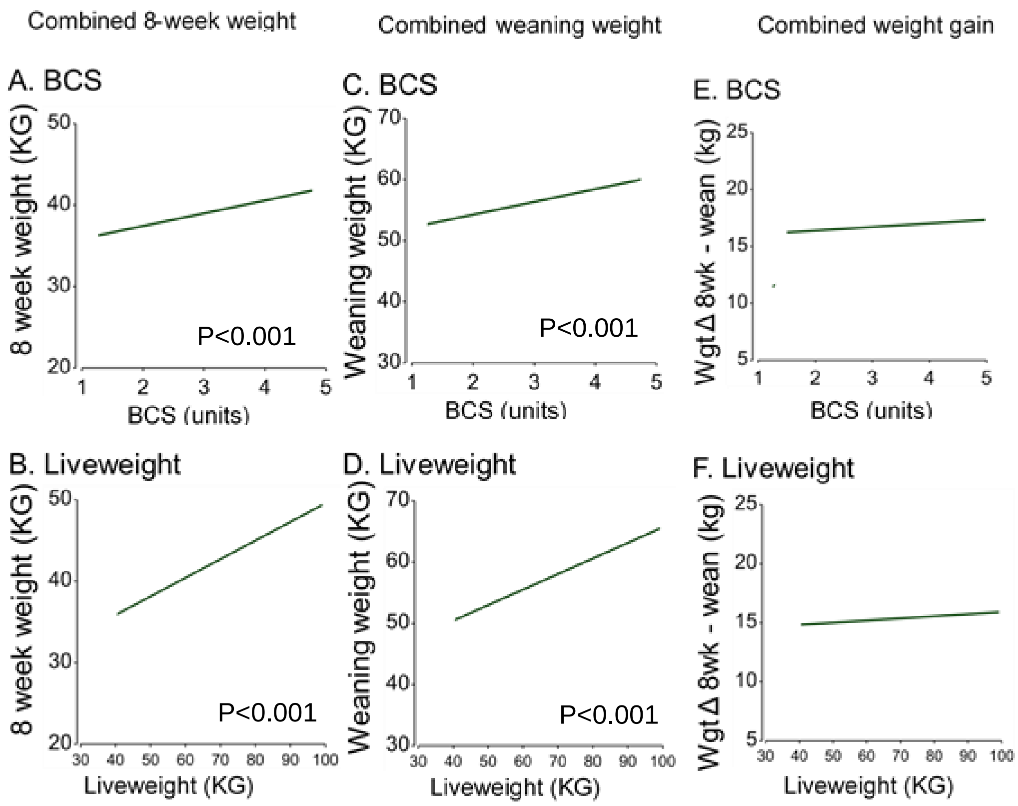


Figure 5.40. Association between ewe BCS (A, C, E) and liveweight (B, D, F) **at mating** on lamb 8-week weight (A-B), lamb weaning weight (C-D) and lamb weight gain between 8 weeks and weaning (E-F) for the combined analyses.

5.3.4.3 *Ewe BCS and liveweight change between weaning and mating*

In the merged analyses, lamb performance to weaning was not associated with ewe BCS or liveweight change between weaning of the preceding production cycle and mating of the subsequent cycle (Figure 5.41 A-F). These observations support the individual farm by year analysis (Appendix III. Table 3).

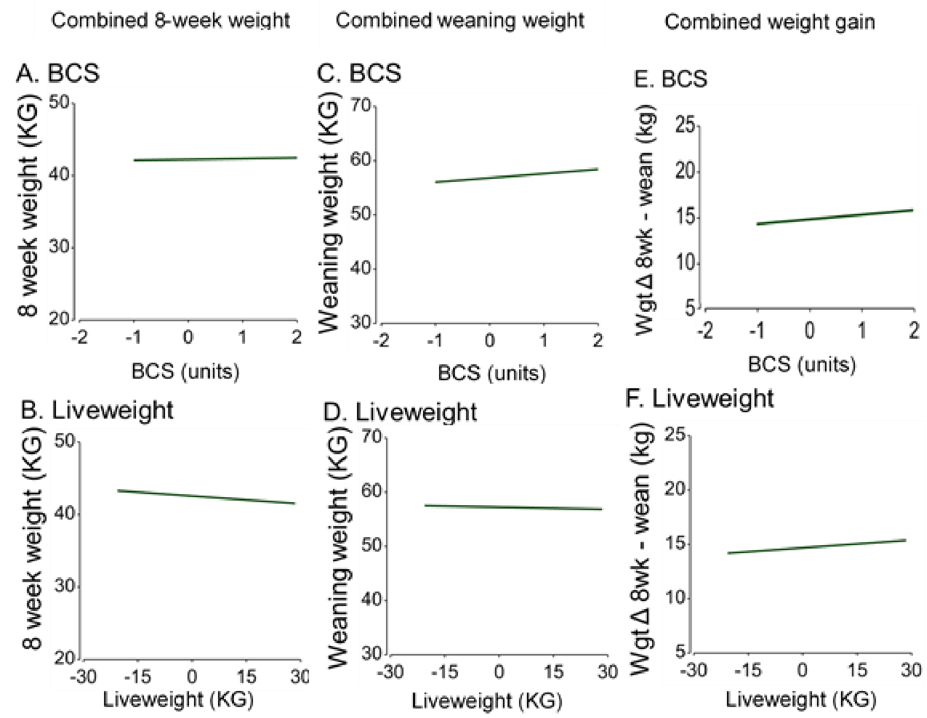


Figure 5.41. Association between ewe BCS change (A, C, E) and liveweight (B, D, F) change **between weaning and mating** on lamb 8-week weight (A-B), lamb weaning weight (C-D) and lamb weight gain between 8 weeks and weaning (E-F) for the combined analyses.

5.3.4.4 *Ewe BCS and liveweight at scanning*

In the merged analyses, combined lamb 8-week weight and combined lamb weaning weight were both positively associated with ewe BCS and liveweight at scanning (P<0.001; Figure 5.42 A-B; C-D). Lamb weight gain between 8 weeks and weaning was not associated with ewe BCS at scanning (Figure 5.42 E) but there was a suggestion of an association with ewe liveweight (P=0.051; Figure 5.42 F). Again, there were farm x year interactions in the merged analyses which would account for observations between individual farms. Lamb performance to weaning at the Lancashire Farm was not associated with ewe BCS or liveweight at scanning, compared with the Sussex and Leicestershire Farms, where positive associations were observed (Appendix III. Table 4).

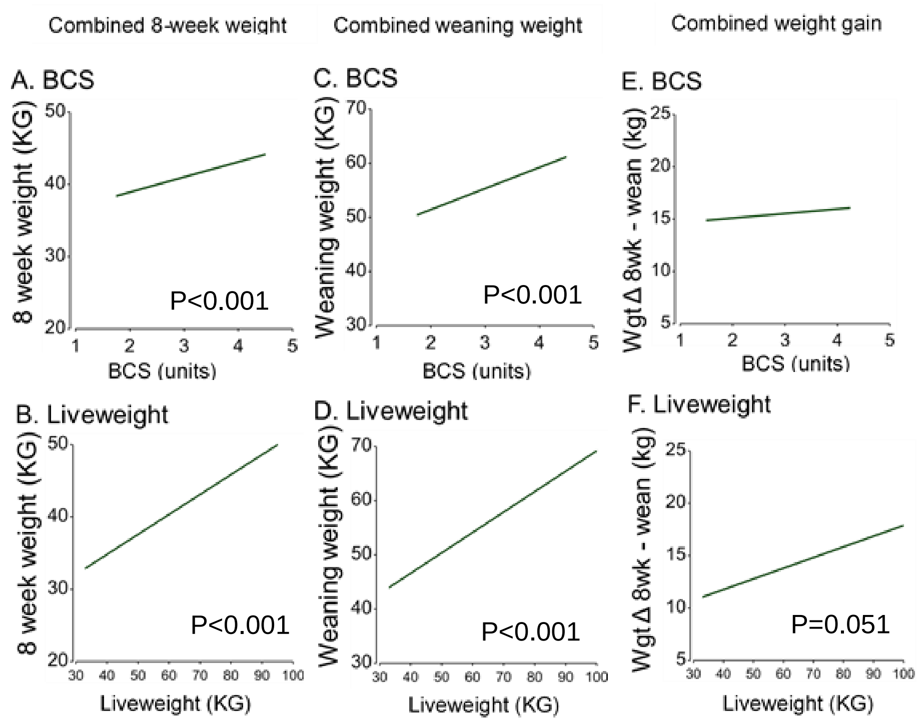


Figure 5.42. Association between ewe BCS (A, C, E) and liveweight (B, D, F) **at scanning** on lamb 8-week weight (A-B), lamb weaning weight (C-D) and lamb weight gain between 8 weeks and weaning (E-F) for the combined analyses.

5.3.4.5 *Ewe BCS and liveweight change between mating and scanning*

In the merged analyses, combined lamb 8-week weight and combined lamb weaning weight were both positively associated with ewe BCS and liveweight gain between mating and scanning (P<0.001; Figure 5.43 A-B; C-D). Lamb weight gain between 8 weeks and weaning was not associated with ewe BCS or liveweight change between mating and scanning (Figure 5.43 E-F). Again, there were farm x year interactions which would explain the variation seen between farms (Appendix III. Table 5). Ewe BCS and liveweight change between mating and scanning were not associated with lamb performance to weaning at the Lancashire Farm, compared to the positive associations at the Sussex and Leicestershire Farms.

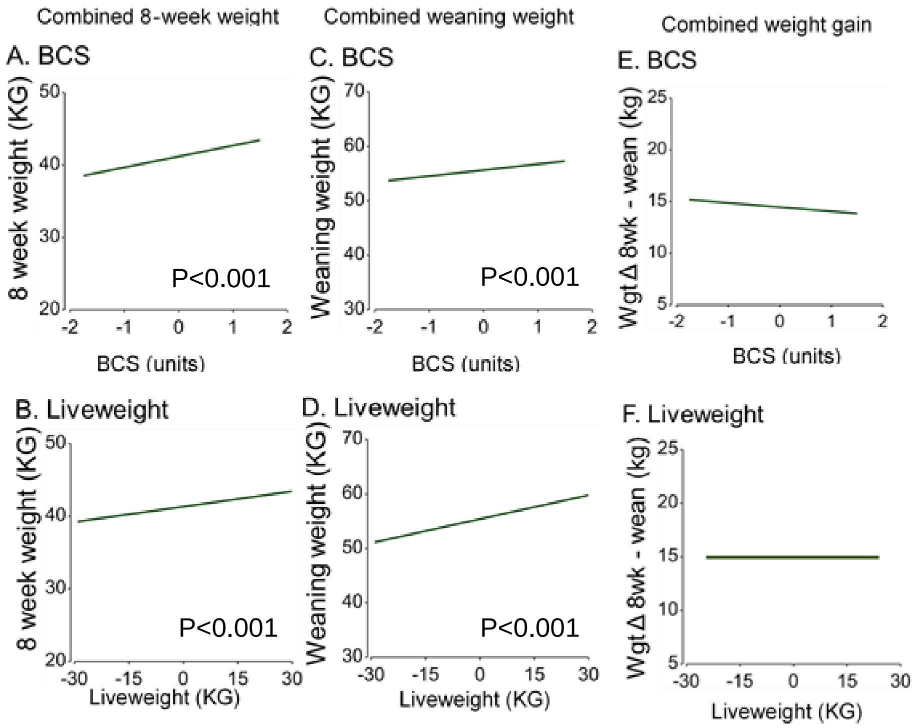


Figure 5.43. Association between ewe BCS change (A, C, E) and liveweight (B, D, F**)** change **between mating and scanning** on lamb 8-week weight (A-B), lamb weaning weight (C-D) and lamb weight gain between 8 weeks and weaning (E-F) for the combined analyses.

5.3.4.6 *Ewe BCS at lambing*

In the merged analyses, combined lamb 8-week weight and combined lamb weaning weight (P<0.001; Figure 5.44 A-B) were positively associated with ewe BCS at lambing, but lamb weight gain between 8 weeks and weaning was not (Figure 5.44 C). There was, once again, variation in the individual farm by year analyses (Appendix III. Table 6). No associations between lamb performance to weaning and ewe BCS at lambing were observed at the Lancashire farm, compared to the Sussex and Leicestershire Farms that reported positive associations, albeit not every year.

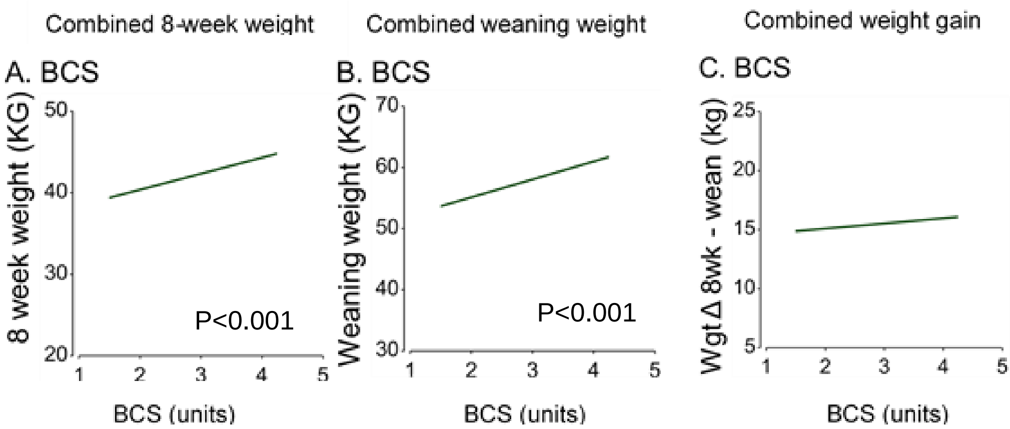


Figure 5.44. Association between ewe BCS **at lambing** on lamb 8-week weight (A), lamb weaning weight (B) and lamb weight gain between 8 weeks and weaning (C) for the combined analyses.

5.3.4.7 *Ewe BCS change between scanning and lambing*

In the merged analyses, combined lamb 8-week weight, combined lamb weaning weight and lamb weight gain between 8 weeks and weaning were not associated with ewe BCS change between scanning and lambing (Figure 5.45 A-C). These observations are consistent with the individual farm by year analysis (Appendix III. Table 7).

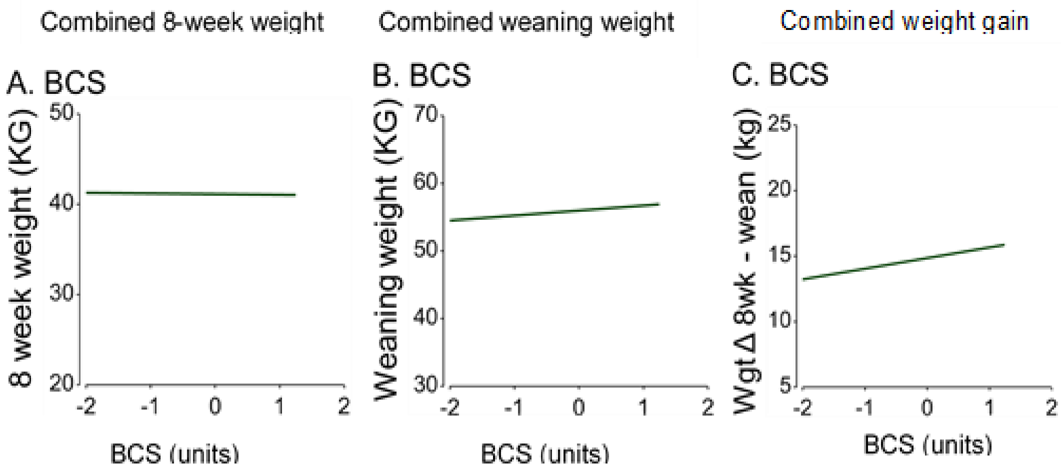


Figure 5.45. Association between ewe BCS change **between scanning and lambing** on lamb 8-week weight (A), lamb weaning weight (B) and lamb weight gain between 8 weeks and weaning (C) for the combined analyses.

5.3.4.8 *Ewe BCS and liveweight at 8 weeks*

In the merged analyses, combined lamb 8-week weight, combined lamb weaning weight and weight gain between 8 weeks and weaning were positively associated with ewe BCS and liveweight at 8 weeks (P<0.001; Figure 5.44 A-F). These observations were consistent with the individual farm by year analyses for the Sussex and Leicestershire Farms. However, at the Lancashire Farm, whilst there were associations between lamb performance to weaning and ewe BCS at 8 weeks, these associations were negative (Appendix III. Table 8).

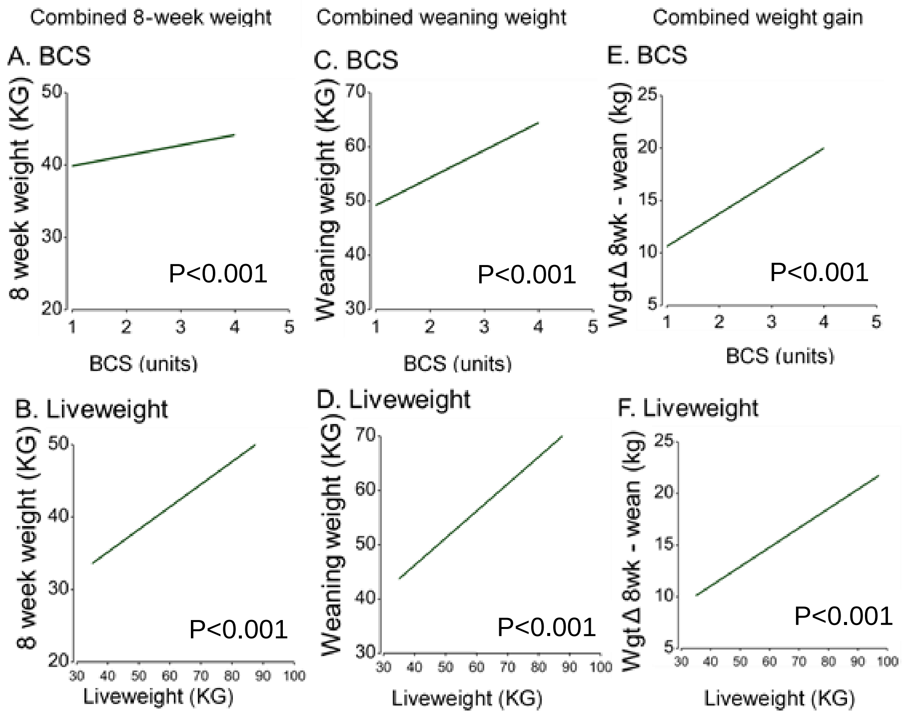


Figure 5.46. Association between ewe BCS (A, C, E) and liveweight (B, D, F) **at 8 weeks** on lamb 8-week weight (A-B), lamb weaning weight (C-D) and lamb weight gain between 8 weeks and weaning (E-F) for the combined analyses.

5.3.4.9 *Ewe BCS and liveweight change between scanning and 8 weeks*

In the merged analyses, combined lamb 8-week weight, combined lamb weaning weight and lamb weight gain between 8 weeks and weaning were not associated with ewe BCS and liveweight change between scanning and 8 weeks (Figure 5.48 A-F). These observations were supported by the Lancashire Farm data in the individual farm by year analyses (Appendix III. Table 9). However, for the Sussex and Leicestershire Farms, positive associations between lamb performance to weaning and change in ewe BCS and weight between scanning and 8 weeks were observed, albeit not every year.

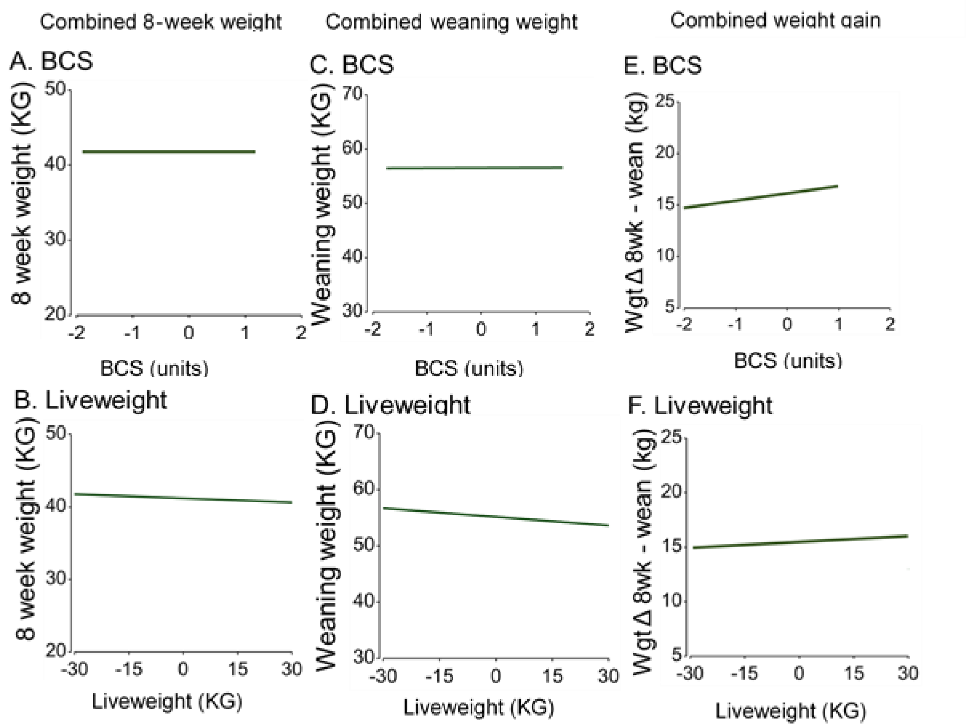


Figure 5.47. Association between ewe BCS change (A, C, E) and liveweight change (B, D, F) **between scanning and 8 weeks** on lamb 8-week weight (A-B), lamb weaning weight (C-D) and lamb weight gain between 8 weeks and weaning (E-F) for the combined analyses.

5.3.4.10 *Ewe BCS change between lambing and 8 weeks*

In the merged analyses, combined lamb 8-week weight, combined lamb weaning weight and lamb weight gain between 8 weeks and weaning (P=0.002; P<0.001, P<0.001; Figure 5.48 A-C) were all positively associated with ewe BCS loss between lambing and 8-weeks. These observations were broadly consistent with the individual farm by year analyses for the Sussex and Lancashire Farms, but negative and positive associations between the years were observed at the Lancashire Farm (Appendix III. Table 10).

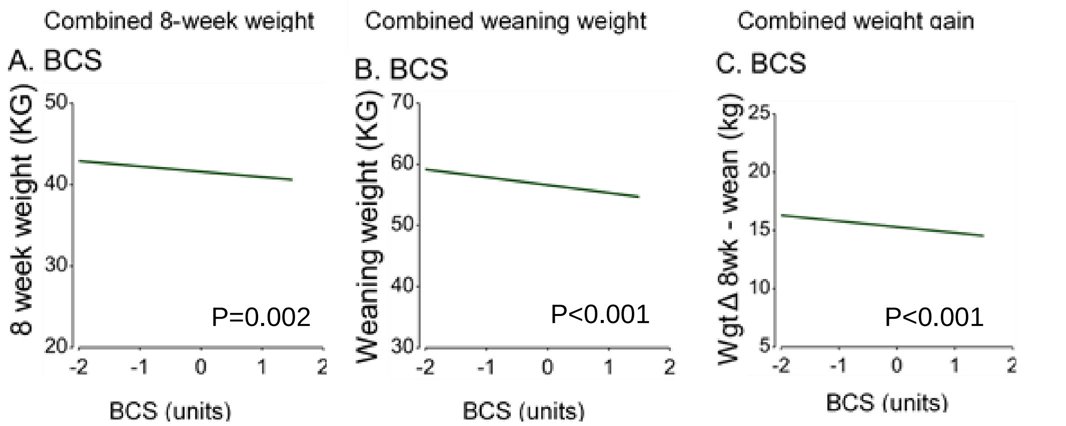


Figure 5.48. Association between ewe BCS change **between lambing and 8 weeks** on lamb 8-week weight (A), lamb weaning weight (B) and lamb weight gain between 8 weeks and weaning (C) for the combined analyses.

5.3.4.11 *Ewe BCS and liveweight at weaning (current production cycle)*

In the merged analyses, combined lamb weaning weight and weight gain between 8 weeks and weaning were positively associated with ewe BCS and liveweight at weaning (P<0.001; Figure 5.49 A-D). These observations support the individual farm by year analyses, with the exception of the Lancashire Farm where negative associations with ewe BCS at weaning were observed (Appendix III. Table 11).

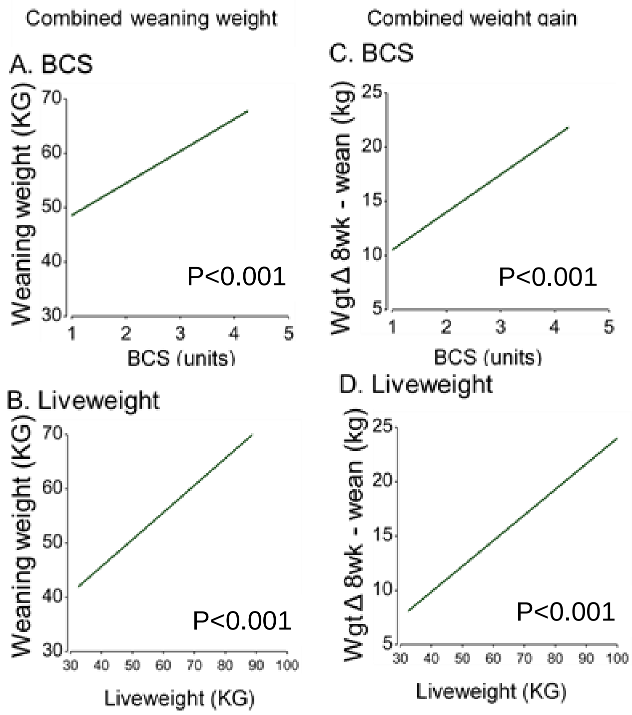


Figure 5.49. Association between ewe BCS (A, C) and liveweight (B, D) **at weaning** of the current production cycle on lamb weaning weight (A-B) and lamb weight gain between 8 weeks and weaning (C-D) for the combined analyses.

5.3.4.12 *Ewe BCS and liveweight change between 8 weeks and weaning*

In the merged analyses, combined lamb weaning weight and lamb weight gain between 8 weeks and weaning were not associated with ewe BCS and liveweight change between 8 weeks and weaning (Figure 5.50; A-D). These observations broadly support the individual farm by year analysis for the Sussex and Lancashire Farms. However, there were associations at the Leicestershire Farm for lamb weaning weight and lamb weight gain between 8 weeks and weaning with ewe liveweight loss between 8 weeks and weaning (Appendix III. Table 12).

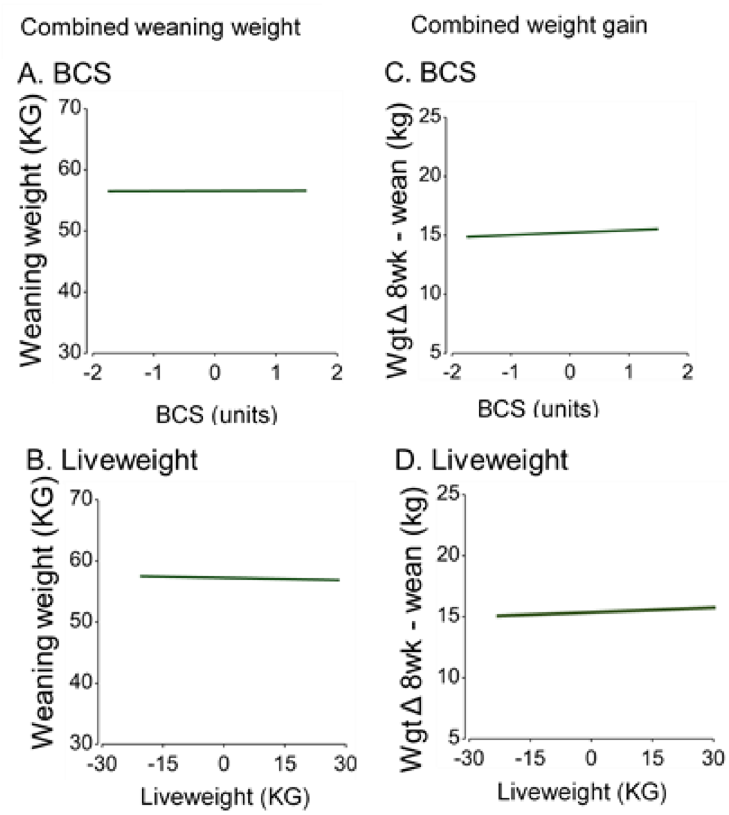


Figure 5.50. Association between ewe BCS change (A, C, E) and liveweight change (B, D, F) **between 8 weeks and weaning** on lamb weaning weight (A-B) and lamb weight gain between 8 weeks and weaning (C-D) for the combined analyses.

5.3.4.13 *Lamb factors associated with performance to weaning*

When analysing the effects on combined lamb 8-week weight and combined lamb weaning weight, lamb age was included in the model alongside unadjusted lamb weight data. This was to account for the small variation in lamb age. At all production points, lamb age was significantly associated with combined 8-week weight and combined weaning weight ($P<0.001$). Older lambs were heavier than younger lambs.

When analysing the effects on lamb weight gain between 8 weeks and weaning, combined unadjusted 8-week lamb weight was included in the model. At all production points, lamb weight at 8 weeks was significantly associated ($P<0.001$) with lamb weight gain between 8 weeks and weaning. Heavier lambs at 8 weeks gained more weight to weaning, compared to lighter lambs at 8 weeks.

Lamb sex was also included in the model. Twins were either Male/Male (MM), Male/Female (MF) or Female/Female (FF). Twin sex was significantly associated with both combined lamb 8-week weight and combined lamb weaning weight ($P<0.001$), but was not associated with lamb weight gain between 8 weeks and weaning. On all occasions the order (heaviest to lightest) was MM>MF>FF.

5.4 Discussion

Overall, twin lamb performance to weaning was associated with ewe BCS and liveweight, and change in ewe BCS and liveweight from weaning of one production cycle to weaning of the subsequent production cycle. Combined lamb 8-week weight and combined lamb weaning weight were more frequently associated with ewe BCS and weight (actual and change) than was the case for lamb weight gain between 8 weeks and weaning.

5.4.1 Pooled data across all three farms: Performance of singles to weaning

To determine if the performance of twin lambs differed to single lambs, data for ewes rearing one lamb (from birth to weaning) across all datasets were pooled and analysed (Table 5.9). Performance of single lambs to weaning was less affected by ewe BCS and liveweight, compared to lambs reared as twins. However, ewe condition during the lactation period (lambing to weaning) was associated with both single and twin lamb performance to weaning. BCS and liveweight change were not associated with the performance of single lambs to weaning between any two production points.

Table 5.9. Summary of factors affecting performance of **single lambs** to weaning (lamb 8-week weight, lamb weaning weight and lamb weight gain between 8 weeks and weaning). Data pooled across the three study farms over three production cycles.

	Combined 8-week weight	**Combined weaning weight**	**Weight gain 8 weeks to weaning**
Weaning BCS	n/s	n/s	n/s
Weaning LWT	n/s	n/s	n/s
Mating BCS	n/s	n/s	n/s
Mating LWT	0.003 (+)	0.015 (+)	n/s
Δ BCS weaning - mating	n/s	n/s	n/s
Δ LWT weaning - mating	n/s	n/s	n/s
Scanning BCS	n/s	n/s	n/s
Scanning LWT	n/s	n/s	n/s
Δ BCS mating - scanning	n/s	n/s	n/s
Δ LWT mating - scanning	n/s	n/s	n/s
Lambing BCS	<0.001 (+)	=0.002 (+)	n/s
Δ BCS scanning - lambing	n/s	n/s	n/s
8-week BCS	<0.001 (+)	<0.001 (+)	n/s
8-week LWT	<0.001 (+)	<0.001 (+)	n/s
Δ BCS lambing - 8 weeks	n/s	n/s	n/s
Δ BCS scanning - 8 weeks	n/s	n/s	n/s
Δ LWT scanning - 8 weeks	n/s	n/s	n/s
Weaning BCS	-	0.026 (+)	n/s
Weaning LWT	-	<0.001 (+)	n/s
Δ BCS 8 weeks - weaning	-	n/s	n/s
Δ LWT 8 weeks - weaning	-	n/s	n/s

5.4.2 Ewe parity and genotype

As discussed in Chapters 3 and 4, across all three farms, the heaviest lambs at 8 weeks and weaning were reared by Mule ewes, compared with other genotypes.

Combined lamb 8-week weight and combined lamb weaning weight were associated with ewe parity. Across all farms, parity 1 ewes (lambing as two-year olds) reared lighter twin lambs to weaning. The only exception to this was the Leicestershire Farm in Year 1, where there was no association. The likely reason for a lack of association is the absence of parity 1 ewes in Year 1 at the Leicestershire Farm. This finding is supported by research that reported preferential nutrition was required for younger ewes (Gonzalez *et al.,* 1997), two-year-old ewes should be managed as a separate management group (Morris *et al.,* 2000) and ewes aged two (and six) years at the time of lambing have reduced lamb weight at 100 days of age (Ptáček *et al.,* 2017).

5.4.3 Weaning of one production cycle to one-month post-mating of subsequent production cycle

Overall, twin lamb performance to weaning was associated with ewe liveweight at weaning of the preceding production cycle, more so than ewe BCS. This association between lamb performance and liveweight at weaning supports the observations in Chapters 3 and 4 (ewe fertility). The reasons are not fully understood but one suggestion is the mobilisation of additional fat reserves once subcutaneous fat reserves (assessed by BCS) have been mobilised. The partition of fat varies between different breeds in cattle (Wright and Russel, 1984). The variation of fat within the adipose depots influences the body fat and condition score relationship. The most extreme example would be the difference between dairy breeds that deposit a higher proportion of fat intra-abdominally and the lowest proportion of subcutaneous fat compared with Hereford cross Friesian cows who had the highest proportion of subcutaneous fat. This study also found that there is little difference between subcutaneous fat between breeds when cows are thin. Such studies have not been performed in sheep.

This current chapter indicates that ewe liveweight at weaning of the preceding production cycle affects lamb performance to weaning in the subsequent production cycles for twin lambs but not for lambs reared as singles (Table 5.9). This suggests that the impact of weaning liveweight is greater for ewes rearing twins than singles. This is likely due to the additional energy requirements of lactation for ewes rearing more than one lamb. Ewes rearing twins produce between 20 and 40% more milk in the first 4 weeks post-partum compared to ewes rearing singletons (Hatfield *et al.,* 1995; NRC, 1985).

Both combined lamb 8-week weight and combined lamb weaning weight were positively associated with ewe BCS and liveweight at mating. Interestingly, there were associations between 8-week weight and weaning weight of single lambs and ewe liveweight at mating, but no association with ewe BCS at mating (Table 5.9). The fact that ewe BCS at mating can affect the growth rate of twins, but not that of singles, is supported by Alvarez *et al.,* (2007). A greater reliance on mobilising reserves to meet the increased requirements of lactation to rear two lambs is a conceivable explanation for the difference between ewes rearing single and twin lambs. This observation is supported by our findings.

The individual farm by year analyses and farm interactions reported in the pooled analysis highlights differences between the three farms. The Sussex and Leicestershire Farms differed in their observations at both weaning and mating compared with the Lancashire Farm. The most likely explanation for the different observations is the BCS and weight of the ewes at the respective farms. As discussed in Chapter 2, the Lancashire Farm was the only farm to achieve the BCS and lamb weight targets at each stage year-on-year. This suggests that the impact of ewe condition on lamb performance to weaning is determined by the starting condition of the flock. Ewe milk production and lamb growth to weaning is greatest for ewes that have more body fat to mobilise (McNeill *et al.,* 1997; Brand & Franck, 2000; Lambe *et al.,* 2005).

Overall, lamb performance to weaning was not associated with ewe BCS or liveweight change between weaning and mating. These observations were consistent for lambs reared as singles (Table 5.9) and twins (Table 5.8) and consistent with the effects on ewe fertility, as discussed in Chapters 3 and 4. These observations support the suggestion that flock performance is already determined by ewe condition at weaning of the preceding production cycle.

5.4.4 One-month post-mating to scanning (mid-pregnancy)

Combined lamb 8-week weight and combined lamb weaning weight were positively associated with ewe BCS and liveweight at scanning and ewe BCS and liveweight gain between mating and scanning. However, these observations were not fully supported in the individual farm by year analysis with the Lancashire Farm reporting no associations between lamb performance to weaning and ewe condition to scanning. There are two possible reasons for this. Firstly, there were data gaps at the Lancashire Farm; scanning BCS was not available in Years 1 and 2 and liveweight were not available in Year 2 resulting in no analysis of these production points and therefore no comparisons. Secondly, the Lancashire Farm had the highest BCS of the three flocks with mean flock BCS at scanning of 3.5 units, compared to the other two farms (Appendix I.), suggesting there is less effect when ewes are at target BCS. The Lancashire Farm also achieved the highest lamb 8-week and weaning weight each year. Overall, these analyses support the findings from Chapters 3 and 4 relating to ewe fertility and continues to challenge the recommendation to lose 0.5 unit BCS between mating and scanning, especially when mating BCS is not on target. However, the majority of evidence for this loss in condition was based on the compensatory blood supply to the placenta resulting in improved placenta development and subsequently lamb birthweight (Robinson, 1992). Our findings suggest that maintenance or gain in ewe condition during this period positively affects ewe fertility and growth rate of twin lambs to weaning. This is supported by Paganoni *et al.*, (2014) who reported that, irrespective of breed, for every 1 kg increase in liveweight change during early and late pregnancy, lamb weaning weights increased. However, data from the Lancashire Farm suggests that condition gain in ewes already at target condition may not improve lamb performance further; therefore, recommendations may vary between farms based on flock condition.

5.4.5 Scanning (mid-pregnancy) to lambing

The metabolisable energy (ME) requirement of a 70 kg ewe carrying two fetuses increases from 11 MJ/day 8 weeks pre-lambing to 18 MJ/day 1 week pre-lambing (AFRC, 1993). The additional requirements are required to meet the demands of the growing conceptus (Mellor, 1983) and for udder development (Henderson, 2002). Nutrition in late pregnancy is crucial for good quality colostrum and milk yield during lactation (Fthenakis *et al.*, 2012). Ewes not receiving their energy requirements in late pregnancy via the diet will mobilise body fat resulting in less being available during lactation. This may impact overall milk yield and therefore lamb performance to weaning. Lambs born to ewes at BCS 2 units were lighter throughout lactation compared with lambs born to ewes at BCS 2.5 or 3 units (Corner-Thomas *et al.*, 2015). Overall, lamb 8-week weight and lamb weaning weight, for both single and twin lambs, were positively associated with ewe BCS at lambing. The positive effect of lambing BCS on weaning weight is supported by (Hossamo et al. 1986; Cranston *et al.*, 2017). However, there was a farm interaction in our studies, whereby the Lancashire Farm reported no association of twin lamb performance to weaning with ewe BCS at lambing. The most likely explanation for this difference is the

Lancashire flock BCS at lambing of 3 units, compared to 2.2 and 2.5 units for Sussex and Leicestershire, respectively (Appendix I.).

5.4.6 Lactation period (lambing to weaning)

Overall, twin lamb performance to weaning was positively associated with ewe BCS loss between lambing and 8 weeks. Lamb weight at 8 weeks and weaning increased when ewes mobilised BCS during this period. Energy requirements of a 70 kg twin bearing ewe increases from 18 MJ/day in late pregnancy to ~33 MJ/day in lactation (AFRC, 1993). Peak milk yield occurs 3-4 weeks post-partum, producing 40-50% of total milk production in the first four weeks of lactation (AFRC, 1993). If nutrition post-lambing does not meet the increased requirements, this will result in a decrease in milk yield, unless the ewe has sufficient body reserves (Gibb & Treacher, 1980; Vernon & Finley, 1985; Treacher & Caja, 2002).

Lamb 8-week weight, lamb weaning weight and weight gain between 8 weeks and weaning for lambs reared as singles and twins were all positively associated with ewe BCS and liveweight at 8 weeks and weaning. However, it is important to document the differences observed between farms. Whilst the positive associations are consistent with individual farm by year analyses at the Sussex and Leicestershire Farms, the associations at the Lancashire Farm were negative. Similar to other production points already reported, the most likely explanation for this is the difference in ewe BCS and liveweight between the three flocks. The Lancashire Farm is the only farm achieving target BCS throughout the year (Appendix I.), the only farm to feed ewes for 3-4 weeks post-lambing (2.2.2.3) and the only farm to achieve the lamb weight targets at 8 weeks and weaning. Lamb growth was significantly higher in the first 8 weeks for lambs suckling fitter ewes compared to thin ewes (Gibb & Treacher, 1980). This would support the observations at the Lancashire Farm.

Interestingly, weight of single lambs at 8 weeks and weaning were also positively associated with ewe BCS and liveweight at 8-weeks and weaning (Table 5.9) suggesting that the effect of ewe condition during lactation also affects the ability of ewes to rear a single lamb.

Is it important to emphasise that in our studies, weaning occurred 90 days post-lambing, in-line with the current recommendations (AHDB, 2014a). However, the age of lambs at weaning, in practice, is not gathered in any centralised system and is therefore unknown. This is considered further in Chapter 6.

5.4.7 Lamb factors affecting lamb performance to weaning

Overall, lamb performance at 8 weeks and weaning were both positively associated with lamb age. Older lambs were heavier because they had more opportunity to gain weight compared with younger lambs.

Lamb performance at 8 weeks was positively associated with lamb performance at weaning. Heavier lambs at 8 weeks were heavier at weaning. The reason for this is likely to be due to milk production in early lactation. Lamb growth to weaning is largely determined by milk intake (Doney & Peart, 1976; Snowder & Glimp, 1991) with almost half of total milk production occurring in the first four weeks of lactation (AFRC, 1993). This early lactation period is also important for rumen development (Gibb *et al.,* 1981) which subsequently affects performance to weaning (B&LNZ, 2014).

Lamb performance at 8 weeks and weaning were associated with lamb sex. Male/Male (MM) were heavier than Male/Female (MF) who were heavier than Female/Female (FF). This finding supports other studies that reported male lambs have a higher pre-weaning growth rate compared to females (Rhodes, 1969; Fourie *et al.,* 1970; Butler-Hogg *et al.,* 1984).

5.5 Conclusion

Our findings suggest that ewe condition at weaning in the preceding production cycle, in particular ewe liveweight, influences lamb performance up to and including weaning of the subsequent production cycle. Greater emphasis is required at this stage of production to reduce the long-term effect of poor flock condition at weaning on future flock performance.

These analyses support the findings from Chapters 3 and 4 and challenges the current advice to allow 0.5 unit condition loss (or 5 percent liveweight loss) between mating and scanning. Ewes should at least maintain condition between mating and scanning in relation to lamb performance to weaning.

The overall performance of ewes during lactation suggests heavier lambs are reared by ewes in better condition at 8 weeks and weaning. However, the differing observations between farms suggests that performance to weaning is dependent on ewe BCS at lambing and the reserves available during lactation.

Lamb weight at 8 weeks is an indicator of lamb performance to weaning. Heavier lambs at 8 weeks are heavier at weaning and gain more weight between 8 weeks and weaning. Measurements at 8 weeks (i.e. lamb weight, ewe BCS and ewe liveweight) should become a management tool on commercial sheep farms to aid decision making; for example by determining weaning date to avoid poor ewe condition affecting subsequent production cycles.

6 CHAPTER 6: Surveying sheep farmer's practice and opinion on assessing ewe condition and barriers to assessing condition by BCS

6.1 Introduction

DEFRA's UK Farm Business Survey reports year-on-year that livestock farmers would not be profitable in the absence of subsidy and environmental payments (DEFRA, 2020). The introduction of the Basic Payment Scheme (BPS) subsidy which replaced the headage scheme (whereby farmers were paid for every ewe in the flock), contributed to a decline of 20% of the UK sheep flock between 2005 and 2018, amounting to a decrease of 4.2 million breeding ewes (DEFRA, 2019). The improvement in the national flock performance, in terms of number of lambs reared per ewe, during this time was marginal from 1.12 in 2005 to 1.15 in 2018 (DEFRA/AHDB/LAA/IAAS, 2018). In comparison, as a result of agricultural subsidy removal in New Zealand during the mid-1980s (Vitalis, 2007), the national sheep flock decreased by 55%, from 57.9 million ewes in 1990/91 to 27.6 million in 2016/17. However, lamb production only decreased by 8% (B&LNZ, 2019) because the proportion lambs reared per ewe increased from 0.98 to 1.25, and lamb carcass weights increased from 14kg to 17kg. The decline and subsequent loss of farming subsidy expected after the UK leaves the EU may have a significant effect on the UK sheep flock (NFU, 2019). Farmers will need to improve profitability to remain financially viable as a result of the loss of subsidy payments. Previous chapters (chapters 3 to 5) of this thesis identified the positive effects that ewe BCS and liveweight have on flock production. There may be a requirement to increase the use of ewe BCS as a management tool to optimise production and enable sheep farms to be financially viable businesses post-Brexit.

There is limited UK-based research on the number of farmers using BCS as a management tool to assess ewe condition, or the importance that farmers attribute to the impact of BCS on flock performance throughout the production cycle. The only UK published research on the number of farmers using BCS, that is known to the author, is a small survey of sheep producers (n=105). The survey reported farmers had heard of BCS and used it as a management tool but BCS was not done through palpation, for the majority, with the suggestion that farmers confused the term BCS with selecting lambs for slaughter (Owen *et al.*, 2017). A UK farmer focus group (n=25 farmers) rated ewe BCS as the second most important factor influencing ewe reproduction (second to nutrition and grassland management) (SheepNet, 2017).

The relationship between farmer behaviour and the adoption of best practice or new technology often assumes that farmers are only driven by economic factors. However, farmer decision making has, for a long time, been driven by factors other than profit alone, such as perceived availability of time and a general reluctance to change (Garforth et al., 2006; Wilson *et al.,* 2013). Other factors that affect change implementation are age, gender, farm size and business succession (Aubert *et al.,* 2012). Many of the practices in sheep farming are passed down from one generation to the next (Wójcik *et al.,* 2019) and based on experience (Irwin, 1995). Knowledge, in isolation, is not sufficient to change behaviour when the information or advice provided contradicts farmers experience on sheep farms, with practical experience dominating over classroom learning (Clifton *et al.,* 2019). When a behaviour change is required, it is important to understand the factors that influence and drive farmers, and the barriers preventing that behaviour change, whether it is adopting of best practice or implementing new technology.

6.1.1 Aims and objectives

The overarching aim of this chapter was to determine the use of and importance attributed to assessing ewe condition using ewe BCS by English sheep producers.

The specific objectives were to determine:

- How and when sheep farmers assess ewe condition
- The importance farmers attribute to the impact of ewe condition on flock performance across different production points during the year
- Means by which ewe condition is recorded and utilised
- Whether farmers correctly apply the BCS technique (by palpation)
- The barriers preventing BCS from being used as a management tool.

6.2 Materials and methods

An online survey comprising of 20 questions (Appendix IV) was designed using Microsoft Forms software. Draft surveys were piloted with five sheep farmers and two industry consultants. Pilot responses suggested the survey would take approximately 10 minutes to complete.

The survey can be found in Appendix IV. Below is a summary of the questions:

- Farm information: enterprises represented, location (county and country)
- Flock information: number of breeding ewes, rams, replacements and lambs reared per year
- Questions relating to ewe condition: do you believe ewe condition is important; which ewes do you assess to determine flock condition; how condition is assessed at different production points (tupping, scanning, lambing, 8 weeks and weaning); describe how you body condition score; how do you categorise ewe condition and how do you record information
- Questions relating to lamb production: how and when do you assess lamb condition at different production points (birth, 8 weeks, weaning and slaughter/sale); describe how you assess lamb condition and age at weaning
- Questions relating to barriers to assessing ewe condition: time required to handle ewes, prefer to weigh ewes, cannot split management groups, lack of confidence in the concept of BCS, handling facilities make BCS difficult and lack of confidence how to BCS.

The six barriers in the questionnaire were based on the author's knowledge of the industry, together with feedback and comments from sheep farmers. There was an opportunity for farmers to provide examples of other barriers specific to them.

The survey was sent via email on 8th October 2019 to 3,460 producers registered to receive sheep information from AHDB using the AHDB Customer Relationship Manager (CRM) system. The survey was open for 45 days. A reminder was sent on 22nd October 2019 and the survey closed on 20th November 2019.

Results were exported into, and data was managed within, Microsoft Excel 2017, with contingency tables produced using pivot table functions. Statistical analysis was undertaken using chi-square and chi-square test for trend using a spreadsheet developed within Microsoft Excel 2017 (N R Kendall, Personal communication) based on equations from (Daya, 2001). Graphs were also produced in Microsoft Excel 2017. Probabilities <0.05 was deemed significant.

Flock size was categorised by breeding ewe numbers 1 to 99, 100 to 199, 200 to 499, 500 to 999 and 1000+. This was reflecting data in Figure 1.1 (AHDB, 2020a), to enable comparisons to national data.

Data generated will be kept electronically, password protected and will be used purely for the purposes of the research project (including dissemination of findings). No-one other than research colleagues or examiners will have access to any of the data collected. The only personal data to be collected is the first half of the post code (eg LE12) for approximate geographical location. There will be no name, email address, address or other contact information or personal demographic information collected. Ethical review number 1022 131119.

The number of responses analysed differ between questions, depending on the enterprises on the farm (i.e. breeding ewes and/or finishing lamb enterprises) and whether respondents assessed condition using BCS. For example, answers provided by respondents who did not record a breeding ewe enterprise were excluded from questions relating to assessments of breeding ewe condition. Generic reference to assessing ewe condition included all options for assessing condition (e.g. BCS, weight and visual assessment). It is clearly defined in the question whether it is specifically asking about BCS by palpation as a method of assessing ewe condition.

6.3 Results

6.3.1 Response rate

Of the 3,460 people the survey was distributed to, 34% (1,176) opened the email (email open rate). A total of 326 sheep producers completed and submitted the questionnaire, a response rate of 9.4%. The average time taken to complete the survey was 13 minutes and 48 seconds. The percentage of respondents that completed the survey within 10, 15 and 20 minutes were 60% (195/326), 81% (264/326) and 93% (303/326), respectively.

6.3.2 Exclusions

Responses outside England (n=42) were excluded from the analysis, resulting in a total of 284 responses available for analysis. Submitted surveys were reasonably complete, with no further general exclusions applied.

6.3.3 *Farm enterprises*

The majority of respondents 98% (278/284) had a breeding ewe enterprise on their farm, 2% (6/284) had a lamb finishing enterprise only (no breeding ewes) and 66% (187/284) had both breeding ewe and lamb finishing enterprises.

6.3.4 *Farm locations*

The geographical representation of the England respondents are mapped using the first half of their postcode, which would take us to their nearest postal town (Figure 6.1).

Figure 6.1. Geographical representation of survey respondents from England representing postal town (n=284).

6.3.5 *Farmer's perception of the importance of ewe condition*

Only farmers who had a breeding ewe enterprise were included in this analysis (n=278). When asked whether, overall, ewe condition in general was important, 97% of respondents (271/278) said 'yes' it was important and 3% (7/278) said it was 'sometimes' important. Nobody said ewe condition was 'not' important or 'not sure' if important. There was no significant effect of flock size category or the number of business enterprises (P>0.05) on farmer's perception of the importance of ewe condition.

Respondents were asked their opinion on the importance of ewe BCS for flock productivity at various stages of the production cycle (mating, scanning, lambing, 8-weeks and weaning) using a 5-point Likert scale (not at all important, not very important, unsure, quite important and very important) (Figure 6.2). Only farmers who had a breeding-ewe flock were included in this analysis (n=278). Ewe BCS was deemed 'very' or 'quite' important by 99% (275/277) at mating, 89% (236/266), at scanning 97% (269/276), at lambing, 76% (208/275) at 8 weeks and 70% (193/274) at weaning (Figure 6.2). Only 9% (25/278) of respondents thought ewe BCS was very important at all five production points. There was no significant effect of flock size category or the number of business enterprises (P>0.05) on respondents opinion on the importance of ewe BCS at different production stages.

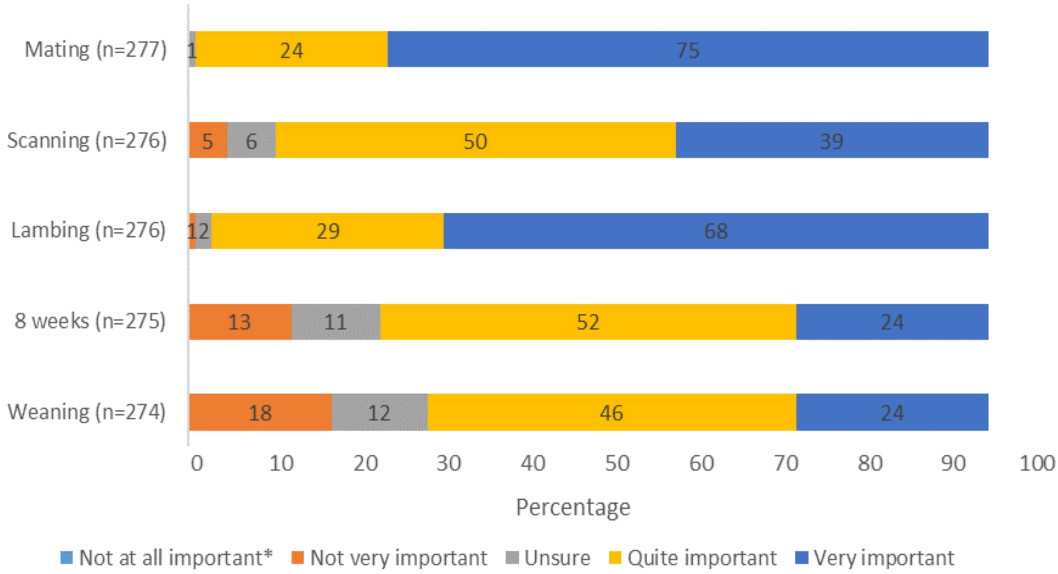


Figure 6.2. Importance of ewe BCS on flock productivity at mating, scanning, lambing, 8 weeks and weaning. Number of respondents per production point in brackets. *= no respondents agreed that BCS was "not at all important".

6.3.6 *Means by which farmers assess ewe condition*

Respondents were asked if they assessed ewe condition at mating, scanning, lambing, 8 weeks and weaning and means by which condition was assessed at each production point (BCS and weight, BCS, weight only, visual or do not assess condition). Only farmers that had a breeding ewe enterprise were included in this analysis (n=278). Overall, >99% (276/277) of respondents assessed ewe condition at mating, 87% (234/268) at scanning, 94% (261/276) at lambing, 76% (216/275) at 8 weeks and 92% (253/276) at weaning (Figure 6.3).

Means by which farmers assessed ewe condition changed between production points (Figure 6.3). Respondents assessing ewe condition using BCS and weight or BCS only were 77% (213/277) at mating, 61% (170/278) at scanning, 61% (169/276) at lambing, 34% (93/275) at 8 weeks and 65% (180/276) at weaning (Figure 6.3). Visual assessment to determine ewe condition was commonly used at every production point, accounting for 22% (61/277) at mating, 25% (68/268) at scanning, 33% (92/276) at lambing, 44% (120/275) at 8 weeks and 24% (67/276) at weaning (Figure 6.3). Visual assessment was significantly associated with smaller flocks (P=0.003). Assessing ewe condition by weight accounted for less than 2% (5/278) of responses at each production stage (Figure 6.3).

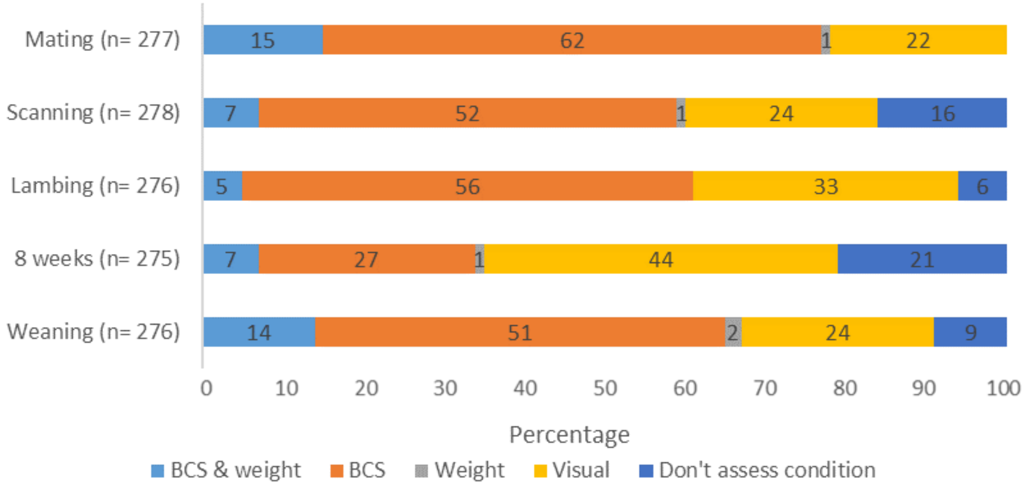


Figure 6.3. Means by which farmers assess ewe condition at each production point. Number of respondents per production point in brackets.

6.3.7 Which ewes are assessed to determining flock condition

Only farmers that assessed ewe condition using BCS at least once a year were included in this analysis (n=231). The majority of respondents (71%; 164/231) assessed every ewe in the flock to determine overall flock condition, 17% (39/231) assessed the fattest or thinnest within a management group and 7% (16/231) assessed certain management groups only. There was no significant effect of flock size category or the number of farm enterprises (P>0.05).

Over half of respondents who assessed condition using BCS (59%; 136/231) categorised their ewes as “fat, fit or thin”, and 40% (92/231) allocated either a 5 point or a 9 point score, with no significant effect of flock size category or the number of farm enterprises (P>0.05). There was no significant relationship (P>0.05) between the number of ewes assessed to determine condition (whole flock, fattest or thinnest in a group or certain management groups) with how condition was assigned (“fat, fit, thin” or a number score).

6.3.8 Methods by which farmers capture ewe BCS data

Many respondents did not record the information (46%; 105/231), with no effect of flock size category or the number of farm enterprises. Paper records and EID were used by 20% (46/231) of respondents. However, there was a significant effect of flock size category (P=0.003), with smaller flocks more likely to use paper records and larger flocks more likely to use EID technology (Figure 6.4). Physically identifying the ewes (e.g. spray paint or mark) was a tool used by 5% (14/231) of respondents, separate management of ewes (for being thin or fat) was used by 4% (12/231), and 3% (11/231) used their smartphone (Figure 6.4).

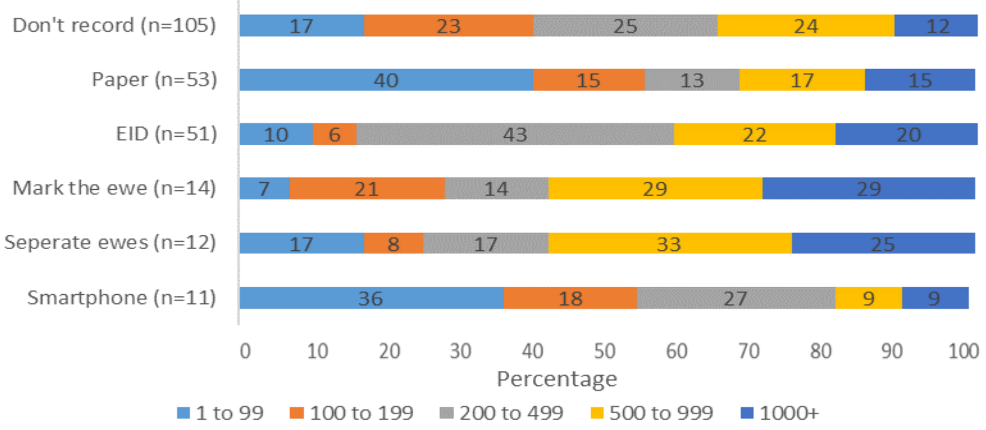


Figure 6.4. Methods by which farmers capture ewe BCS data, by flock size category. Number of respondents in brackets. Percentages are rounded to nearest 1%.

6.3.9 Understanding the term BCS and the technique used by farmers

Respondents were asked “if you handle EWES to assess condition, please describe HOW you assess condition”. The correct answer would be “palpation of the lumbar region, to assess level of fat cover over the transverse processes”. We accepted “handle the loin to feel for the sharpness of the spinous processes” The following descriptions were accepted instead of “transverse/spinous processes”: spine, loin, back, above pelvis, after ribs, backbone, short ribs and mid-back.

Only respondents that assessed ewe condition by BCS were included in this analysis (n=231). A correct answer was provided by 45% of respondents (103/231); with 55% (128/231) providing an incorrect answer. The most common reasons for an incorrect answer were stating secondary locations for assessing condition (in addition to the loin) (53%; 68/128) and not referring to the loin but naming other locations (e.g. dock and ribs (18%; 23/128). A further 29% (37/128) provided insufficient information on the location and/or technique used.

6.3.10 Means by which farmers assess lamb condition

Respondents were asked "if you handle LAMBS, please describe HOW you assess condition". Finished lamb classification falls into two categories:

1. Fat class: five main classes ranging from 1 to 5 (very lean to excessively fat), with classes 3 and 4 sub-divided into L (leaner) and H (fatter). Farmers palpate the animal at the dock (tail), tips of transvers processes (loin) and ribs (AHDB, 2018c) Experienced assessors suggest that the loin and dock would be the key two areas, with ribs secondary (personal communication).
2. Conformation: (EUROP grid) visual shape of the carcass, taking into account carcass profile and fullness of legs (AHDB, 2018c).

Only respondents with a finishing lamb enterprise were included in this analysis (n=193). A correct answer was provided by 57% (110/193) of respondents with 43% (83/193) providing an incorrect answer. Reasons for an incorrect answer included providing insufficient detail on where they assessed condition (e.g. "feel and assess cover", "general fitness" or "thin, ok, fat" (39%; 32/83); naming only one site for handling instead of two or three, mostly only mentioning the loin (34%; 28/83); or generic referencing "e.g. same as ewes" (10%; 8/83).

6.3.11 Comparing ewe BCS and assessing lamb condition

Only respondents with both breeding ewe and lamb finishing enterprises were included in this analysis (n=187). When comparing responses for assessing breeding ewe condition and lamb condition, 15% (28/187) assessed breeding ewes in the same way as finished lambs. In total, 38% (71/187) either made reference to similarities between ewe BCS and lamb selection in their response or wrote the same answer for both questions.

6.3.12 Barriers to assessing ewe condition using BCS

Respondents were asked whether they agreed or disagreed with six previously identified barriers to assessing ewe condition by BCS using a 5-point Likert scale (disagree strongly, disagree, neither agree nor disagree, agree, agree strongly) (Figure 6.5). Responses were combined, with disagree strongly and disagree combined as a negative response, neither agree nor disagree regarded as a neutral response and agree and strongly agree combined as a positive response. Only farmers who had a breeding ewe flock were included in this analysis (n=278). Time required to handle ewes to assess condition by BCS was a barrier for 43% (119/278) of respondents. However, 35% (98/278) disagreed that time was a barrier. The ability to separate ewes into different management groups based on BCS was the second most supported barrier (31%; 86/278). Overall, 14% (39/278) of farmers agreed they would prefer to weigh ewes than assess condition by BCS and 14% (38/278) agreed their handling facilities made assessing condition by BCS difficult. Lack of confidence in how to BCS (10%; 28/278) and lack of confidence in the concept of BCS (5%; 14/275) were the least supported barriers (Figure 6.5).

Respondents' opinion on time, preference to weigh sheep, lack of confidence in the BCS concept and lacking confidence in how to assess using BCS were not statistically significant for flock size category or the number of farm enterprises (P>0.05). However, the ability to manage groups separately and handling facilities were both significantly affected by flock size (P<0.001), with smaller flocks citing these as barriers, more so than larger flocks.

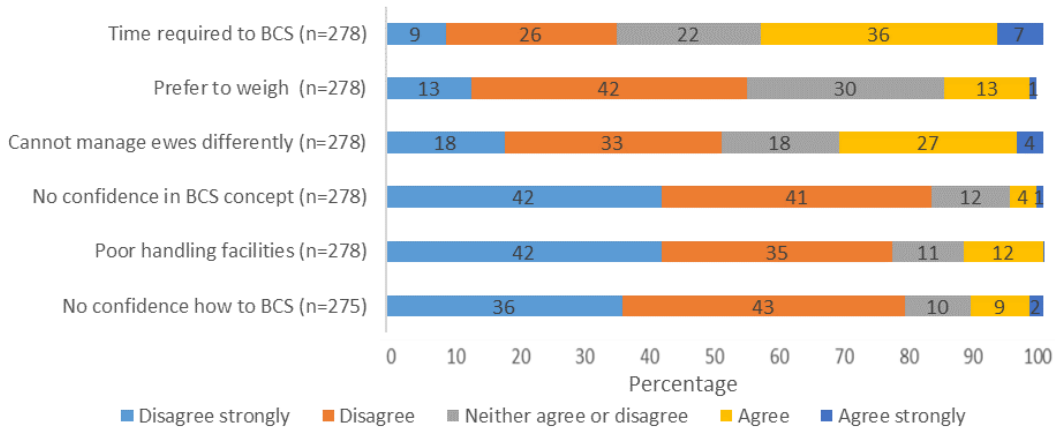


Figure 6.5. Respondents' agreement of barriers to using BCS as a method of assessing ewe condition

6.3.13 Additional barriers to assessing ewe condition using BCS

Respondents were asked if there were additional barriers affecting their ability or willingness to assess ewe condition using BCS. The most common additional comments received, which were not listed in the six pre-determined barriers, were:

- The cost of EID and handling/weighing equipment (n=4)
- The ability to gather the information using EID software (n=4) and lack of confidence analysing or utilising the information once gathered (n=5)
- Regular, visual assessment of ewe condition is sufficient (n=3)
- Reluctance to handle ewes with young lambs at lambing (n=2).

6.4 Discussion

6.4.1 Respondent representation

Some 34% (1176/3460) of recipients opened the email containing the link to the survey (open rate) and 9.4% submitted a response (326/3460). The open rate is greater than the AHDB average of 30% (range for 2019 emails was 19.6 to 34.5%). However, 20% opened the email but did not submit a response. Registrations on the AHDB CRM system are not restricted to sheep producers, with many consultants, vets and lecturers with an interest in sheep able to register. One explanation for the difference in open rate and response rate is that respondents did not have a breeding ewe or finishing lamb enterprise.

An online survey has a potential bias towards respondents who are competent and confident users of technology. Despite DEFRA (2020) indicating that 87% of farmers own a laptop or PC, poor internet connection (39%) and poor computer skills (31%) were cited as barriers to their use on farms. Respondents are also more likely to complete a survey because they have strong opinions (either positively or negatively) about a subject, in this case ewe condition or BCS (Goldberg, 2003).

There was overall, good survey coverage with responses from most regions (Figure 6.1). However, there were potential gaps in the upland and hill areas. One explanation for this is the data provided on farm location, with respondents providing the first half of their postcode, which takes us to the nearest postal town. Poor internet signal in some upland and hill areas (Farrington *et al.*, 2015) coupled with an online survey could also have been a contributing factor. Finally, the extensive nature of upland and hill farming could mean the survey was bias towards lowland farming systems. Extensive hill sheep farmers have varied conditions on their farms and have different levels of input and management practices, compared to lowland farms (Morgan Davies *et al.,* 2006). Skilled labour required for hill farm management practices is less available and the lack of regular labour might explain why hill farmers gather ewes and lambs less frequently (Morgan Davies *et al.,* 2006; Waterhouse, 1996). For these reasons, hill farmers are less likely to gather ewes and assess ewe condition using BCS as frequently as lowland farmers, and could account for a lower response rate from these farms.

Our survey response rate of 9.4% is below the typical agriculture response rate of 12 to 35% suggested by Pennings *et al.,* (2002). However, their figures are based on both postal and online distribution, whereas ours was email distribution only. Many factors affect a survey response rate. For example, distribution method (where, how and when), target industry (responses vary between different industries), brand recognition and the respondent relationship with the brand, demographics (age and sex), survey simplicity and size, and the presence of an incentive (e.g. prize draw or financial reward) (Surveys, 2020). Our survey was completed with no incentive or prize offered. Email only distribution was the most practical and cost effective method for this thesis.

6.4.2 Flock size

Respondents to the survey had a mean flock size of 506 ewes (standard error ± 37.8), which is higher than the national average flock size of 220 ewes (AHDB, 2018a). Each flock size category was represented in our survey, however there were significantly fewer small flocks represented in our survey compared to the national flock distribution ($P<0.001$; Figure 6.6).

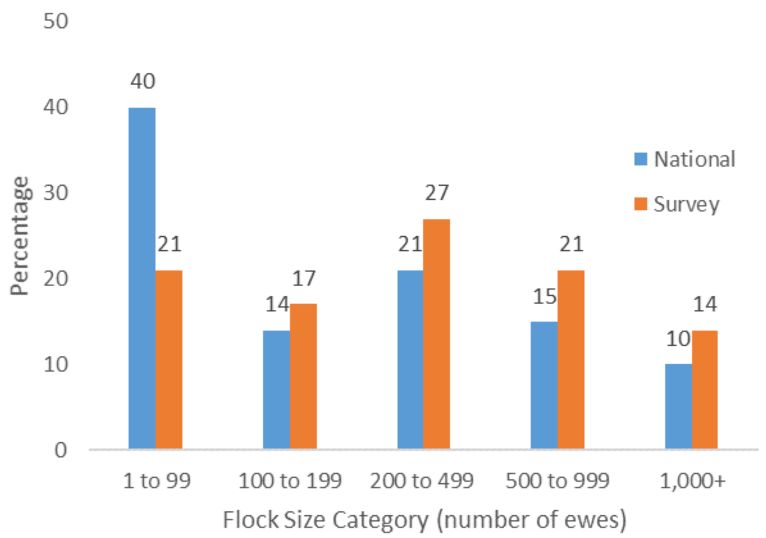


Figure 6.6. Percentage of farms per flock size category in the national sheep flock (blue) and survey respondents (orange).

6.4.3 Farmer's perception of the importance of BCS, when and how ewe condition is assessed

Our survey found that 98% of English respondents agree that ewe condition is important. This finding supports the SheepNet, (2017) study, that reported a small UK farmer focus groups rated ewe BCS the second most important factor influencing ewe reproduction. BCS was second to nutrition and grassland management, both of which can influence ewe BCS, which is an indicator of current and historical nutritional status (Caldeira *et al.,* 2007).

The importance farmers placed on ewe BCS throughout the year differed to when and how farmers assessed condition throughout the year (Table 6.1). Farmers identified mating as the most important production point. Mating was also the production point when most ewes were assessed by BCS and when ewes were least likely to be assessed visually. The message relating to the importance of ewe condition at mating for optimising performance (Gunn *et al.,* 1991; Robinson *et al.,* 2002; Annett & Carson, 2006; Fthenakis, et al., 2012; Rooke *et al.,* 2015) appears to have been adopted by the respondents of this survey.

Farmers identified weaning as the time point least likely to affect flock productivity. Findings from the preceding chapters of this thesis (chapters 3 to 5) linked poor ewe condition (BCS and liveweight) at weaning to reduced litter size at scanning and lambing, and reduced lamb growth rates to weaning in the subsequent production cycle. Whilst farmers identified ewe BCS at weaning as least likely to affect productivity (70%), more farmers (91%) assessed condition at weaning, and did so by BCS (65%) compared to weight or visual assessment (Table 6.1). One explanation for this discrepancy between the level of importance attached to BCS and the number of respondents that assessed condition at weaning could be that farmers assess ewe condition at weaning as part of a routine checklist alongside checking udders for mastitis (AHDB, 2018d) and poor dentition (AHDB, 2016b). Many farmers provide preferential feed to thin ewes at weaning to regain condition prior to mating in the subsequent production cycle with many ewes likely to be required to gain up to 1 unit of BCS between weaning and mating (Kenyon *et al.,* 2014). The data from this thesis (chapters 3 to 5) suggests the implications of poor condition at weaning is long term, and this survey provides an insight into farmer's opinions, providing an opportunity for knowledge exchange on the importance of ewe condition at weaning on subsequent production cycles.

Assessing ewe condition at 8 weeks is a relatively new concept for commercial sheep farmers and could account for the lack of importance assigned to this production point. Chapter 5 of this thesis demonstrated the importance of lamb performance at 8 weeks on lamb performance to weaning, and indicated that 8 weeks post-lambing is an important time point to assess flock performance; representing an additional knowledge exchange opportunity.

At least 20% of respondents assessed ewe condition visually at every production point (Table 6.1). Farmers are encouraged to assess ewe condition using palpation, due to the shortcomings of assessing condition by eye, in particularly in the presence of a full fleece (Fernandez, 2020), however visual assessment still appears to be commonly done in practice. Our research is supported by Jones *et al.,* (2011) who surveyed 2,032 New Zealand farmers via a telephone questionnaire lasting 10 minutes. They reported that from the 96% of farms who assessed ewe condition, 37% assessed condition visually. It is not possible to determine from our survey responses whether farmers gathered ewes and visually assessed them running through a race or whether they visually assessed condition from a distance (e.g. in the field as part of daily husbandry as part of fulfilling the sheep welfare code (DEFRA, 2003).

More respondents assessed ewe condition at mating, lambing and weaning (despite identifying weaning as least likely to affect productivity), than at scanning (Table 6.1). Fewer farmers assessing condition at scanning is supported by Jones *et al.,* (2011) who reported that scanning was the least common time for ewe condition to be assessed (in New Zealand) with only 30% assessing condition at scanning. However, only 36% of our survey respondents scanned their ewes. It has not been possible to decipher if flocks represented in our English survey were scanned for pregnancy diagnosis. Whilst ewes are gathered and individually handled for pregnancy scanning, scanning operators work at speed (up to 150 ewes per hour; personal communication) which does not allow farmers to assess ewe condition simultaneously. Ewes would need to be handled separately to assess condition which could be one explanation for why this is lower than expected. Limited farm labour is another reason why ewe condition may not be assessed at scanning. Based on Nix, (2013), mean labour time of 4 h per ewe per year would require one person to manage a flock of at least 600 ewes. However, based on Defra, (2018) flock size data, 75% of sheep holdings have fewer than 500 breeding ewes, suggesting many sheep flocks operate on a part-time basis.

Table 6.1. A comparison of farmer opinion on the importance attributed to ewe BCS, when farmers assess condition and whether condition was assessed using BCS at each production point, in descending order (5 - most to 1 - least).

	Descending order				
	1 (most)	2	3	4	5 (least)
Importance of ewe	Mating	Lambing	Scanning	8 weeks	Weaning
BCS, %	99	97	87	76	70
Farms assessing ewe	Mating	Lambing	Weaning	Scanning	8 weeks
condition, %	99	94	91	84	78
Farms assessing by	Mating	Weaning	Lambing	Scanning	8 weeks
BCS, %	77	65	61	59	33
Farms assessing	8 weeks	Lambing	Scanning	Weaning	Mating
visually, %	43	33	24	24	22

6.4.4 Capturing information on ewe condition

Farmers were asked how they assigned ewe BCS to their ewes, with 59% assigning a “fit, fat, thin” scale and 40% assigning a number score (5 or 9 point scale). The score assigned bares little importance as long as management practice reflects the score and that the same person scores the flock, to avoid assessor variation (Phythian *et al.,* 2012). Assessor reliability and repeatability in our research is discussed in (1.4.1). However, the current survey found that only 50% of respondents record any data on ewe condition. Lima *et al.,* (2018) found that, whilst 99% of the respondents in their survey used EID tags and 52% had an EID reader, only 21% used EID for stock management purposes. Our survey supports these findings, with only 20% using EID to collect BCS data, suggesting that the benefits of EID technology are not being fully realised and that compliance is merely a result of legislation. The financial commitment of purchasing a reader has already occurred on over half of sheep farms (Lima *et al.,* 2018), providing an opportunity to promote the use and benefits of collecting and analysing data for improved flock performance. However, our survey found that flock size played an important role in the use of EID for ewe BCS data collection, with the cost of handling equipment and EID software a greater barrier for smaller flocks compared to larger flocks which are more likely to utilise EID as a management tool.

6.4.5 Understanding and implementing BCS

The findings from a survey of UK farmers (Owen *et al.,* 2017), when asked to indicate where farmers feel or handle ewes to assess condition by placing a "X" on a photograph of a sheep, suggested confusion between the term BCS in breeding ewes and lamb selection, with many opting for assessing ewes at additional sites to the loin. The findings from our survey, despite asking the same question albeit in a different format (e.g. describe how you assess condition), agrees with those of Owen *et al.,* (2017). The lumbar region is the best site to assess BCS because it is the last part of the growing animal to develop, and the location where fat is deposited last and mobilised first (Casey & Stevens, 2016). There is no evidence to suggest that assessing ewe condition using more than one site determines condition incorrectly. However, additional sites increases the time taken to assess condition, with access to those additional sites often restricted, for example, when ewes are in a weigh crate or race. Additional time taken to assess ewe condition has been identified in our survey as the most common barrier to assessing condition using BCS.

6.4.6 Barriers to assessing ewe condition using BCS

To the author's knowledge, this is the first study to investigate barriers specific to assessing ewe condition by BCS in England. Overall, the main barrier to assessing ewe condition by BCS was time, despite the acceptance that ewe condition was important. The barrier of time is mentioned by sheep farmers in other aspects of sheep production. For example, the time taken to catch each individual lame ewe is a barrier to prompt treatment of lameness (O'Kane *et al.,* 2017; Green *et al.,* 2020). Time to collect faecal samples and wait for the results to determine the need to administer an anthelmintic is also a barrier to the adoption of sustainable worm control strategies (SCOPS, 2013).

It is not possible to decipher from this survey how time operates as a barrier. Farmers may perceive assessing ewe condition by BCS as a management practice requiring additional gathering and handling; the time taken to assess condition by palpation is too time consuming; or the additional time required to manage ewes post-assessment. There are no published data available relating to the amount of time it takes to BCS a flock of ewes. However, data captured at one of the study farms indicated that assessing condition by BCS varied depending on the number of staff available and how the data is recorded. With one labour unit, the mean number of ewes assessed by BCS per minute was 2 when BCS data was entered into a stick reader, 4 ewes per minute when data was entered into a weigh head in a weigh crate and 9 ewes per minute when ewes were weighed only. If there was an additional labour unit to help ewes into the weigh crate, the mean number of ewes per minute increased to 4, 5 and 11 respectively (Unpublished data; Blyth, M personal communication). A farmer-based video on the practical application of BCS demonstrated that once the ewes are gathered in a race, it is possible to BCS and physically mark ewes below the target BCS for that production point, in this case weaning, with a temporary colour crayon at a speed of 5 seconds per ewe (B&LNZ, 2013b). For comparison purposes, administration times of mineral supplementation options were 30 seconds per sheep for a drench, 34 seconds per sheep for an injection and between 75 and 98 seconds per sheep to administer a bolus (Williams *et al.,* 2017). The time taken to gather a flock of ewes and apply ectoparasite treatments takes 1.24 min per animal on average (Morgan Davies *et al.,* 2006) with (Nix, 2002) quoting 1.29 min per ewe.

The second most supported barrier was the ability to manage ewes in separate management groups after assessing condition, more so for smaller flocks than larger flocks. Managing multiple management groups is also a barrier mentioned in the treatment and isolation of lame ewes (O'Kane *et al.,* 2017).

It is encouraging that only 10% of respondents agreed that their ability to assess condition by BCS was a barrier to its adoption, with only 5% agreeing that the concept of BCS was a barrier. However, when asked how they applied the BCS technique, less than half correctly described the method. This suggests that KE activity relating to how farmers assess condition would need to be incorporated into other messages because 90% consider they are able to assess condition using BCS.

6.5 Conclusion

Overall, respondents agree that ewe condition is important. However, the importance ascribed to BCS varies during the production cycle with mating considered important by most time to assess ewe condition and weaning considered to have the least impact on flock performance. With the exception of 8 weeks post lambing, the majority of respondents assessed ewe condition by BCS, but visual assessment still accounted for greater than 20% at each production point. Despite assessing condition, almost half do not record any information, implying individual ewe condition and performance is not monitored over time.

Farmers confuse the term BCS for breeding ewes with lamb selection for slaughter with less than half identifying the correct location to handle ewes by palpation. Finally, time was the biggest barrier to assessing ewe condition by BCS followed by the difficulty of managing ewes after assessing condition. However, barriers differed by flock size, with smaller flocks identifying more barriers than larger flocks.

7 CHAPTER 7: General discussion and conclusions

7.1 General discussion

A number of key performance indicators (KPIs) are proposed from analyses of data pooled across the three study farms over three consecutive production cycles. A summary of the effects of ewe BCS and liveweight, and change in ewe BCS and liveweight for each of the several production points during the annual production cycle, on ewe fertility and combined lamb weight (of twins) to weaning can be found in Table 7.1. Each recommended KPI is discussed, in chronological order.

7.1.1 KPI 1: Ewe condition at weaning (preceding production cycle)

Ewe condition at weaning of the preceding production cycle is emerging as an important KPI for sheep flocks. Ewe BCS at weaning of the preceding production cycle was positively associated with litter size at scanning in the subsequent production cycle. However, ewe liveweight at weaning was more closely associated with ewe fertility and lamb weight than ewe BCS (Table 7.1), with lighter ewes resulting in smaller litter sizes and lighter lambs at weaning. These data suggest that ewe liveweight at weaning can affect ewe performance at weaning of the subsequent production cycle, 12 months later, with liveweight being more important than BCS. Ewes in poor condition (i.e. around 1.5 units) need to replace body protein in addition to adipose tissue (Robinson *et al.,* 2002); perhaps indicating that intra-abdominal fat reserves, rather than subcutaneous body fat *per se* (as determined by BCS), may be a more important limiting factor at weaning. Caldeira and Portugal. (2007) found that intermuscular fat represented the largest fat depot in ewes at BCS scores below 3 units, and Russel *et al.,* (1969) observed that intermuscular fat is mobilised by ewes between BCS 2 and 1 units.

Table 7.1. Summary of the effects of ewe BCS and liveweight (LWT), and change (Δ) in ewe BCS and liveweight between the several production points during the annual production cycle, on ewe fertility and combined lamb weight of twins to weaning. Data are pooled across the three study farms over three production cycles.

A. Weaning to Lambing	Proportion pregnant	Litter size at scanning	Proportion lambed	Litter size at lambing	Combined 8-week weight	Combined weaning weight	Lamb weight gain 8 wks to weaning
Weaning BCS (preceding)	n/s	<0.001 (+)	n/s	n/s	n/s	n/s	n/s
Weaning LWT (preceding)	n/s	<0.001 (+)	n/s	<0.001 (+)	<0.001 (+)	<0.001 (+)	n/s
Mating BCS	n/s	0.002 (+)	n/s	n/s	<0.001 (+)	<0.001 (+)	n/s
Mating LWT	n/s	<0.001 (+)	n/s	<0.001 (+)	<0.001 (+)	<0.001 (+)	n/s
Δ BCS weaning – mating	n/s	n/s	n/s	n/s	n/s	n/s	n/s
Δ LWT weaning – mating	n/s	n/s	n/s	n/s	n/s	n/s	n/s
Scanning BCS	<0.001 (+)	<0.001 (+)	<0.001 (+)	<0.001 (+)	<0.001 (+)	<0.001 (+)	n/s
Scanning LWT	<0.001 (+)	<0.001 (+)	<0.001 (+)	<0.001 (+)	<0.001 (+)	<0.001 (+)	0.051 (+)
Δ BCS mating – scanning	<0.001 (+)	<0.001 (+)	<0.001 (+)	<0.001 (+)	<0.001 (+)	<0.001 (+)	n/s
Δ LWT mating – scanning	<0.001 (+)	<0.001 (+)	<0.001 (+)	<0.001 (+)	<0.001 (+)	<0.001 (+)	n/s
Lambing BCS	-	-	n/s	0.002 (-)	<0.001 (+)	<0.001 (+)	n/s
Δ BCS scanning - lambing	-	-	n/s	<0.001 (-)	n/s	n/s	n/s

- data absent   n/s not significant   (+) positive association   (-) negative association   Δ change   LWT liveweight

B. Lambing to weaning	Proportion pregnant	Litter size at scanning	Proportion lambed	Litter size at lambing	Combined 8-week weight	Combined weaning weight	Lamb weight gain 8 wks to weaning
8-week BCS	-	-	-	-	<0.001 (+)	<0.001 (+)	<0.001 (+)
8-week LWT	-	-	-	-	<0.001 (+)	<0.001 (+)	<0.001 (+)
Δ BCS lambing - 8 weeks	-	-	-	-	0.002 (-)	<0.001 (-)	<0.001 (-)
Δ BCS scanning - 8 weeks	-	-	-	-	n/s	n/s	n/s
Δ LWT scanning - 8 weeks	-	-	-	-	n/s	n/s	n/s
Weaning BCS (current)	-	-	-	-	-	<0.001 (+)	<0.001 (+)
Weaning LWT (current)	-	-	-	-	-	<0.001 (+)	<0.001 (+)
Δ BCS 8 weeks - weaning	-	-	-	-	-	n/s	n/s
Δ LWT 8 weeks - weaning	-	-	-	-	-	n/s	n/s

- data absent   n/s not significant   (+) positive association   (-) negative association

Change in ewe BCS and liveweight between weaning of the preceding production cycle and mating of the subsequent production cycle was not associated with ewe fertility or lamb weight gain to weaning (Table 7.1). This suggests that ewe BCS and weight change between weaning and mating has no impact on the subsequent production cycle. Studies undertaken by Hickson *et al.,* (2012) found that ewe liveweight gain between weaning and mating had no effect on the number of fetuses scanned or lambs born, which supports our findings. One explanation for the lack of association is that historical ewe condition has pre-determined a ewe's fertility for the subsequent production cycle, with Robinson *et al.,* (2005) reporting a ewe's ovulation rate is sensitive to her nutritional status in the six months leading up to ovulation.

Farmers agree that ewe condition at mating is important, with 99% assessing body condition at mating. Fewer farmers (70%) agree that ewe condition at weaning is important for flock productivity. Most farmers utilise the period between weaning and mating to regain ewe condition for the next production cycle, believing that gaining condition lost during lactation is sufficient for subsequent flock productivity. Our data does not support this strategy.

Is it important to emphasise that in our studies, weaning occurred 12 weeks post-lambing, in-line with the current recommendations (AHDB, 2014a). However, unpublished data (Appendix IV) suggests the mean and median age of lambs at weaning in England is 14 weeks, with the majority of sheep farms (66%) weaning their lambs between 14 and 20 weeks of age. Further research and knowledge exchange is required on the long-term effects of ewe condition at weaning and the importance of weaning lambs at 12 weeks.

7.1.2 KPI 2: One-month post mating to scanning (mid-pregnancy)

Ewe condition at scanning, but more specifically condition change between mating and scanning, is emerging as a KPI for sheep flocks. Ewe BCS and liveweight at scanning, and ewes gaining BCS and weight between mating and scanning, were each positively associated with ewe fertility (proportion pregnant and litter size at scanning, proportion lambed and litter size at lambing) and lamb weight to weaning (combined 8-week weight and combined weaning weight) (Table 7.1). These findings challenge the current advice to allow 0.5 units BCS loss (or 5% liveweight loss) between mating and scanning (Gunn et al., 1991). Whilst our research does not investigate the effects on placental development, lamb birthweight or lamb survival, which forms the basis for most research in this area (Clarke *et al.,* 1988; Munoz *et al.,* 2007; Addah *et al.,* 2012), the positive association with maintaining or gaining condition between mating and scanning relating to ewe fertility and lamb performance to weaning are consistent. Ewes should, at least, maintain condition between mating and scanning. Furthermore, farmers agree that ewe condition at scanning is important for flock productivity, with 89% agreeing it was very or quite important and 87% assessing condition at scanning time.

7.1.3 KPI 3: Barren ewes at lambing

Annually, between 5 and 8% of ewes in the study flocks did not rear a lamb at tagging (48 h post-lambing). Ewes not rearing a lamb included ewe and lamb mortalities or the absence of a record. This figure is inclusive of ewes barren at scanning, meaning that between 2 and 4% of ewes scanned pregnant did not rear a lamb at tagging. There are no figures to compare this to industry benchmarks.

7.1.4 KPI 4: Ewe BCS at lambing

Ewe BCS at lambing is emerging as an important KPI for sheep flocks. Ewe BCS at lambing was negatively associated with litter size at lambing (Table 7.1). No other study has reported positive associations between lower ewe BCS at lambing and litter size at lambing, with most studies indicating that lower BCS at lambing has a detrimental effect (Robinson *et al.,* 2002; Kenyon *et al.,* 2012; Dwyer, 2014; Corner-Thomas *et al.,* 2015). Our analyses does not establish cause and effect but associations between two variables (i.e. litter size and BCS at lambing). These data indicate that, on the whole, ewes lost BCS between scanning and lambing, with twin bearing ewes losing more condition than single bearing ewes. This would explain why these effects are observed.

In contrast, lamb 8-week weight and lamb weaning weight, for both single and twin lambs, were positively associated with ewe BCS at lambing (Table 7.1). The positive effect of lambing BCS on weaning weight is supported by (Hossamo et al. 1986; Robinson *et al.,* 2002; Kenyon *et al.,* 2012; Dwyer, 2014; Corner-Thomas *et al.,* 2015; Cranston *et al.,* 2017). All reported that lambs born to ewes at BCS 2 units were lighter throughout lactation compared with lambs born to ewes at BCS 2.5 or 3 units. Nutrition leading up to lambing is crucial for good quality colostrum and milk yield during lactation (Fthenakis *et al.,* 2012). Ewes not receiving their energy requirements through diet will mobilise body fat, resulting in less being available during lactation, which may impact overall milk yield and therefore lamb weight at weaning. However, there was a farm interaction in our studies, whereby the Lancashire Farm reported no association between twin lamb weight to weaning and ewe BCS at lambing. The most likely explanation for this is the difference in flock BCS at lambing between farms. Body condition score at the Lancashire farm averaged 3 units, compared to 2.2 and 2.5 units for the Sussex and Leicestershire farms respectively (Appendix I.). The data from the Lancashire Farm also suggests there is no additional benefit to ewes being above BCS 3 units at lambing time.

Farmers agree that ewe condition at lambing time is important for flock productivity, with 97% agreeing it was important and 94% assessing condition at lambing. However, 33% of respondents assessed condition visually, not by BCS. Unless ewes are shorn pre-lambing, fleece cover is likely to mask ewe condition at this time of year and may result in an inaccurate assessment of ewe condition (B&LNZ, 2016), especially if ewe condition is visually assessed from a distance (e.g. outdoor lambing ewes).

7.1.5 KPI 5: Ewe condition during lactation (lambing to weaning)

Ewe condition during lactation is also emerging as an important KPI for sheep flocks. In the pooled analyses, ewe BCS loss between lambing and 8 weeks and ewe BCS and liveweight at 8 weeks and weaning were all positively associated with lamb performance to weaning (Table 7.1). The positive associations in the pooled analyses are consistent with the individual farm analyses for the Sussex and Leicestershire Farms, but the individual farm associations at the Lancashire Farm were negative. Ewe BCS at lambing and ewe BCS and liveweight throughout lactation was higher at the Lancashire Farm, compared to the Leicestershire and Sussex Farms, and may explain the difference between the study farms. There is sufficient research to support this theory. If nutrition post-lambing does not meet the increased requirements of lactation, this will result in a decrease in milk yield, unless the ewe has sufficient body reserves (Gibb & Treacher, 1980; Vernon & Finley, 1985; Treacher & Caja, 2002). Under these conditions, ewe milk production and lamb growth to weaning is greatest for ewes with more fat to mobilise (McNeill *et al.,* 1997; Brand & Franck, 2000; Lambe *et al.,* 2005).

Assessing ewe condition at 8-weeks post-lambing was not considered as important by farmers, with 76% agreeing it was very or quite important. While 76% assessed condition at 8 weeks, 43% did so visually, not by BCS. The inclusion of 8 weeks post-lambing as a measure of flock performance is a new concept to most commercial sheep farmers and may explain why many think it is less important. However, the findings from this study suggest that ewe performance at 8 weeks is key to flock performance to weaning.

7.1.6 KPI 6: Lamb weight at 8-weeks and weaning

Prior to our research, there were no industry targets for lamb 8-week weight or lamb weaning weight (at 12 weeks). The study farms were provided with a weight target of 20 kg at 8 weeks and 30 kg at weaning. These figures were calculated based on mean lamb birthweight of 5 kg (Thompson *et al.,* 2004; Gardner, 2007; Gubbins, 2016) and mean DLWG of 280 g/day from birth to weaning (Muir, Smith, & Lane, 2003; B&LNZ, 2014). Our findings suggest that lamb 8-week weight is an important KPI for sheep farms, with lamb performance at 8 weeks key to performance at weaning. Lambs that are heavier at 8 weeks are heavier at weaning and gain more weight between 8 weeks and weaning. With almost half of total milk production occurring in the first four weeks of lactation (AFRC, 1993), the early lactation period determines lamb growth as a result of milk intake (Doney & Peart, 1976; Snowder & Glimp, 1991). The early lactation period is also important for rumen development (Gibb *et al.,* 1981) which subsequently affects performance to weaning (B&LNZ, 2014).

It is recommended that lamb 8-week weight be a KPI for sheep farms, with a target of 20 kg (adjusted for lamb age) for lowland/upland flocks. Lamb weaning weight is also a recommended KPI. However, the Lancashire Farm was the only one of our study farms to achieve the 30 kg target at weaning. Sheep producers in Australia wean lambs at 45% of their mature bodyweight, or greater than 20 kg and Thompson, et al., (2011); Gascoigne & Lovatt, (2015) recommend lambs should exceed 25 kg at weaning. Our research suggests 25 to 28 kg is a more realistic target weight for the KPI of lamb weaning weight, dependant on weight at 8 weeks.

Lambs weighing less than 17 kg at 8 weeks (15% less than the target of 20 kg) were classed as ‘light’ lambs in our study. The percentage of light lambs that fell into this category varied by year and across farms, with a range of 7 to 35%. There are no national targets to compare these observations and determine good, average or poor performance. However, this data would suggest that a realistic target is for fewer than 15% of lambs to be below 17 kg at 8 weeks post-lambing (when the target is 20kg). Further research is required to establish the robustness of this target, to investigate the causes behind light lambs and the best management options for them.

Lamb age and lamb sex were both positively associated with lamb performance at 8 weeks and at weaning. Older lambs were heavier because they had more opportunity to gain weight compared to younger lambs. Male/Male (MM) were heavier than Male/Female (MF) which, in turn, were heavier than Female/Female (FF) lambs. This finding supports other studies that reported male lambs have a higher pre-weaning growth rate compared to females (Rhodes, 1969; Fourie *et al.,* 1970; Butler-Hogg *et al.,* 1984).

7.1.7 Uptake of BCS and barriers to assessing ewe condition by BCS

Overall, farmers agree that ewe condition is important, with the emphasis changing during the production cycle. Mating and lambing were ranked the two production points most farmers agreed had an effect on flock performance, with 8 weeks and weaning considered the two production points farmers agreed were less likely to affect flock performance. This thesis highlights that performance at 8 weeks is a key indicator of lamb performance to weaning and that ewe condition at weaning has a long-term effect on ewe fertility and lamb performance to weaning in the subsequent production cycle. In addition, greater than 20% of farmers report that they assess ewe condition visually at each production point. Owen *et al.,* (2017) also reported that farmers assess ewe condition visually. Of the farmers who assess ewe condition, 46% did not record the data in any format, suggesting the progress of individual ewe condition is not monitored over time.

There is evidence from our research, also supported by findings from Owen *et al.,* (2017), that farmers confuse the term BCS for breeding ewes with assessing lamb selection for slaughter. Whilst only 10% agreed that confidence in applying the BCS technique was a barrier to using BCS in their flocks, only 45% provided a correct answer when asked to describe how and where they assess ewe condition using BCS. Most incorrect answers were as a result of farmers naming the dock/tail, ribs and shoulders as locations used to determine ewe condition.

The key messages arising from this research will be incorporated into the AHDB Beef and Lamb Knowledge Exchange (KE) activity plan. Alongside other AHDB funded research, these findings will be disseminated to English levy payers through various channels. These include face to face farmer events, podcast and online events as well as written publications.

7.2 General conclusions

The outcomes of this thesis confirm that ewe BCS and liveweight, and change in ewe BCS and liveweight between key production points are associated with flock fertility (proportion ewes pregnant and litter size), lambing outcomes (proportion ewes lambed and litter size) and the weight of lambs through to weaning; and reveal a number of key performance indicators (KPIs) for sheep producers.

Ewe condition, in particular ewe liveweight at weaning has a long-term effect (at least twelve months) on flock performance (ewe fertility and lamb weight to weaning). However, there is no effect of ewe BCS and liveweight change between weaning and mating on flock performance. Farmers relying on ewes 'milking off their backs' and regaining that condition for mating will likely see a negative impact on ewe productivity in subsequent production cycles. However, farmers do not recognise the importance of ewe condition at weaning on current or future flock productivity, with the majority weaning lambs 14 weeks and older.

Findings from our study challenges the current advice to allow 0.5 unit condition loss (or 5% liveweight loss) between mating and scanning. A new recommendation is for ewes to, at least, maintain condition between mating and scanning.

The association between lamb weight to weaning with ewe BCS and liveweight is dependent on ewe condition at lambing. Ewes at target condition at lambing will mobilise condition during lactation and rear heavier lambs to weaning. Ewe condition at 8 weeks should be used as a management tool to determine the time of weaning.

This thesis confirms that lamb weight at 8 weeks is a good indicator of lamb weight to weaning and suggests that both lamb 8-week weight and lamb weaning weight are recommended as flock KPIs. A target 8-week weight of 20 kg at 8 weeks is realistic for lowland/upland sheep flocks. However, a target weaning weight of between 25 and 28 kg is more achievable. Producers should aim for fewer than 15% of their lamb crop to be below 17 kg at 8 weeks (15% lighter than the flock target of 20 kg).

Two of the three study flocks failed to achieve the recommended BCS targets, suggesting many farms in England could improve flock BCS and subsequently flock performance. The flock that achieved target BCS had the largest litter sizes at scanning, the heaviest lambs at 8 weeks (and the lowest percentage of light lambs at 8 weeks) and the heaviest lambs at weaning.

Farmers agree that ewe condition is important but its importance declines during the year, with ewe condition at mating was the point where most farmers agreed that condition had an effect on flock productivity. Ewe condition at weaning was the point when least farmers agreed that condition had an effect on flock productivity. However, farmers confuse the term BCS for breeding ewes with selecting lambs for slaughter. Many still assess ewe condition visually and fail to record any information to monitor individual ewe condition over time. The main barriers to assessing condition are time and the ability to manage ewes separately.

7.3 Future research

Future research priorities arising from the findings of this thesis are summarised below.

7.3.1 Relationship between ewe BCS and liveweight

The importance of ewe liveweight as a measure of ewe 'fitness' was demonstrated in Chapters 3 to 5. Ewe liveweight was associated with flock performance at times when ewe BCS was not, for example, at weaning. The underlying causes for this are not fully understood and have yet to be explored in sheep. Research in cattle (Wright *et al.,* 1984) suggests differences relating to the location of adipose tissue, other than subcutaneous (as measured by BCS), would affect ewe liveweight. A possible future research project, outside the scope of this thesis, would be to explore the location and amount of adipose tissue through post mortem assessment of mature ewes (three years or older) at different BCS (range 1.5 to 4 units) for different ewe genotypes. Aberfield, Texel and Mule ewes would provide a good comparison and would be representative of sheep genotypes in England.

A second opportunity relating to ewe BCS and liveweight would be the ability to predict BCS from a known liveweight and liveweight change for English farming systems and ewe genotypes. Two published papers, from outside the UK, have achieved this (Cannas & Boe, 2003; van Burgel *et al.,* 2011). Cannas & Boe, (2003) analysed data from ten separate experiments and formulated an equation to predict ewe BCS using liveweight change. It concluded that their equation could predict liveweight with good accuracy if the liveweight at BCS

2.5 units (mid-point of the 0 to 5 scale) was known for the breed or population. van Burgel *et al.,* (2011) established ewe condition score relative to the SRW Standard Reference Weight (SRW) system, whereby a gain or loss of 10% of a ewe's SRW was equal to one unit BCS. For example, a ewe at BCS 3 units and liveweight of 70 kg would gain or lose 7 kg to attain BCS 4 BCS 2 respectively. The limitation of applying this study in the UK is its genotype specificity (Merino ewes). The UK has a larger number of ewe genotypes across farming systems but also within farms.

Both these research projects have demonstrated that it is possible to predict ewe condition from ewe liveweight and change in liveweight during production points based on individual ewe liveweight. If it is possible to replicate this in the UK, ewes would still need to be condition scored at least once a year. This constraint is not necessarily prohibitive because it would reduce the number of times ewes are currently condition scored, based on the parameters of this research project (mating, scanning, lambing, 8 weeks and weaning).

7.3.2 Impact of ewe parity and age at mating on flock performance

The current series of studies observed that Parity 1 ewes (mated to lamb as two year-old shearlings) consistently had the smallest litter sizes at scanning (Chapter 3) and lightest twin lambs at 8 weeks and weaning (Chapter 5). However, some of the effects of ewe parity are confounded by the lack of ewe genotype at the same parity. Further research looking at the performance of Parity 1 ewes to understand differences in performance would be beneficial to the sheep industry. A second aspect of this could be to determine the difference between ewes mated to lamb as ewe lambs (one-year olds) and ewes mated to lamb as shearlings (two-year olds).

7.3.3 Light lambs at 8 weeks

Further research to understand the reasons for light lamb at 8 weeks, determine the cause(s) and understand management practices that affect the number of light lambs, is recommended. Furthermore, investigating the best course of action for these lambs is merited. For example, early weaning and preferential feeding, and determining whether compensatory growth is possible and cost-effective.

8 References

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9 Appendices

9.1 Appendix I.

Table 1. Mean flock body condition score (BCS), liveweight (LWT) and change (∆) in BCS and liveweight (mean ± SE) for the Sussex Farm.

	Year 1	Year 2	Year 3
A. Ewe BCS (units)			
Weaning	2.55 ± 0.06	2.50 ± 0.02	2.49 ± 0.02
Mating	3.24 ± 0.02	3.36 ± 0.01	3.35 ± 0.02
Scanning	3.14 ± 0.01	3.35 ± 0.01	3.26 ± 0.03
Lambing	2.59 ± 0.01	2.84 ± 0.01	2.83 ± 0.05
8 weeks	2.69 ± 0.02	2.75 ± 0.02	2.93 ± 0.05
Weaning	2.47 ± 0.02	2.45 ± 0.02	2.52 ± 0.04
B. Ewe BCS change* (units)			
∆ BCS weaning - mating	0.63 ± 0.02	0.82 ± 0.02	0.79 ± 0.02
∆ BCS mating - scanning	-0.11 ± 0.01	-0.02 ± 0.01	-0.09 ± 0.01
∆ BCS scanning - lambing	-0.55 ± 0.02	-0.51 ± 0.02	-0.44 ± 0.02
∆ BCS lambing - 8 weeks	0.11 ± 0.01	-0.04 ± 0.02	0.06 ± 0.01
∆ BCS 8 weeks - weaning	-0.23 ± 0.02	-0.36 ± 0.02	-0.42 ± 0.01
C. Ewe liveweight (kg)			
Weaning	55.3 ± 0.35	59.4 ± 0.33	63.5 ± 0.33
Mating	61.8 ± 0.30	62.4 ± 0.29	65.1 ± 0.36
Scanning	64.6 ± 0.33	64.1 ± 0.33	61.5 ± 0.72
8 weeks	61.0 ± 0.34	61.5 ± 0.32	60.6 ± 0.85
Weaning	58.9 ± 0.33	62.9 ± 0.33	57.6 ± 0.81
D. Ewe liveweight change* (kg)			
∆ Weaning - mating	11.0 ± 0.33	4.4 ± 0.24	2.8 ± 0.18
∆ Mating - scanning	2.8 ± 0.36	1.6 ± 0.20	-3.6 ± 0.20
∆ Scanning - 8 weeks	-3.5 ± 0.39	-2.7 ± 0.24	-1.1 ± 0.22
∆ 8 weeks - weaning	-2.4 ± 0.17	1.1 ± 0.12	-3.3 ± 0.14

*mean change (BCS and liveweight) calculated as the mean change of individual ewes between two production points

Table 2. Mean flock body condition score (BCS), liveweight (LWT) and change (Δ) in BCS and liveweight (mean ± SE) for the Leicestershire Farm.

	Year 1	Year 2	Year 3
A. Ewe BCS (units)			
Weaning	1.83 ± 0.04	1.99 ± 0.04	2.32 ± 0.04
Mating	2.70 ± 0.02	3.01 ± 0.01	3.09 ± 0.01
Scanning	2.81 ± 0.01	2.83 ± 0.01	3.12 ± 0.01
Lambing	2.61 ± 0.02	2.39 ± 0.03	2.70 ± 0.03
8 weeks	1.91 ± 0.02	2.34 ± 0.02	2.57 ± 0.02
Weaning	1.94 ± 0.03	2.21 ± 0.03	2.54 ± 0.02
B. Ewe BCS change* (units)			
Δ BCS weaning - mating	0.64 ± 0.02	0.75 ± 0.02	0.75 ± 0.02
Δ BCS mating - scanning	0.11 ± 0.02	-0.18 ± 0.01	0.03 ± 0.01
Δ BCS scanning - lambing	-0.21 ± 0.01	-0.45 ± 0.01	-0.43 ± 0.01
Δ BCS lambing - 8 weeks	-0.71 ± 0.02	-0.07 ± 0.01	-0.14 ± 0.01
Δ BCS 8 weeks - weaning	0.06 ± 0.01	-0.13 ± 0.01	-0.03 ± 0.01
C. Ewe liveweight (kg)			
Weaning	48.9 ± 0.84	60.1 ± 1.01	60.3 ± 1.00
Mating	58.1 ± 0.18	62.7 ± 0.18	62.1 ± 0.22
Scanning	60.1 ± 0.19	60.1 ± 0.24	59.9 ± 0.21
8 weeks	57.8 ± 0.41	59.9 ± 0.59	60.2 ± 0.46
Weaning	59.6 ± 0.69	60.1 ± 0.63	61.0 ± 0.59
D. Ewe liveweight change* (kg)			
Δ Weaning - mating	8.6 ± 0.29	4.5 ± 0.15	5.4 ± 0.14
Δ Mating - scanning	1.9 ± 0.15	-2.6 ± 0.15	-2.2 ± 0.12
Δ Scanning - 8 weeks	-2.4 ± 0.20	-0.7 ± 0.17	0.2 ± 0.17
Δ 8 weeks - weaning	2.1 ± 0.12	0.1 ± 0.10	0.7 ± 0.08

*mean change (BCS and liveweight) calculated as the mean change of individual ewes between two production points

Table 3. Mean flock body condition score (BCS), liveweight (LWT) and change (∆) in BCS and liveweight (mean ± SE) for the Lancashire Farm.

	Year 1	Year 2	Year 3
A. Ewe BCS (units)			
Weaning	2.84 ± 0.03	2.83 ± 0.08	3.03 ± 0.08
Mating	3.51± 0.02	3.49 ± 0.06	3.50 ± 0.02
Scanning	3.41 ± 0.02	-	3.58 ± 0.02
Lambing	3.30 ± 0.02	3.41 ± 0.05	3.44 ± 0.05
8 weeks	3.21± 0.02	3.31 ± 0.05	3.39 ± 0.06
Weaning	3.00 ± 0.03	3.23 ± 0.05	3.32 ± 0.06
B. Ewe BCS change* (units)			
∆ BCS weaning - mating	0.60 ± 0.02	0.54 ± 0.02	0.40 ± 0.02
∆ BCS mating - scanning	-0.09 ± 0.02	-	0.07 ± 0.01
∆ BCS scanning - lambing	-0.21 ± 0.03	-	-0.15 ± 0.01
∆ BCS lambing - 8 weeks	-0.09 ± 0.02	-0.09 ± 0.01	-0.05 ± 0.01
∆ BCS 8 weeks - weaning	-0.22 ± 0.02	-0.08 ± 0.02	-0.07 ± 0.01
C. Ewe liveweight (kg)			
Weaning	-	67.44 ± 2.14	71.09 ± 1.29
Mating	68.82 ± 0.39	72.34 ± 1.30	77.07 ± 1.01
Scanning	-	-	80.13 ± 0.87
8 weeks	-	-	-
Weaning	-	78.92 ± 1.27	71.05 ± 0.56
D. Ewe liveweight change* (kg)			
∆ Weaning - mating	-	2.72 ± 0.44	5.86 ± 0.32
∆ Mating - scanning	-	-	3.06 ± 0.22
∆ Scanning - 8 weeks	-	-	-
∆ 8 weeks - weaning	-	-	-

*mean change (BCS and liveweight) calculated as the mean change of individual ewes between two production points; - data absent

9.2 Appendix II.

Table 1. Summary of data analyses on effects of BCS and liveweight (LWT) at **weaning of preceding production cycle** on proportion pregnant and litter size at scanning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			**Leicestershire**			**Lancashire**		
		Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
Proportion pregnant	**BCS Weaning**	N/S	N/S *	N/S	N/S	N/S	N/S	N/S	N/S	N/S
	LWT Weaning	A^{+VE}	+VE	N/S *	N/S	N/S	N/S	-	A^{+VE}	N/S
Litter size	**BCS Weaning**	+VE	N/S	N/S	+VE	+VE	+VE	N/S	+VE	N/S
	LWT Weaning	+VE	N/S	A^{+VE}	+VE	+VE	+VE	-	+VE	N/S

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction only; A approaching association; - data absent

Table 2. Summary of data analyses on the effects of BCS and liveweight (LWT) **at mating** on proportion pregnant and litter size at scanning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			**Leicestershire**			**Lancashire**		
		Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
Proportion pregnant	**BCS Mating**	N/S	N/S*	N/S	N/S	N/S*	N/S	N/S	N/S	N/S
	LWT Mating	N/S	N/S	N/S *	N/S	N/S*	N/S	N/S	N/S	A^{+VE}
Litter size	**BCS Mating**	N/S	N/S	N/S	+VE	+VE	+VE	N/S	N/S	N/S
	LWT Mating	+VE	+VE	+VE	+VE*	+VE	+VE	+VE	+VE	A^{+VE}

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction; A approaching association

Table 3. Summary of data analyses on the effects of BCS and liveweight (LWT) change (Δ) **between weaning and mating** on proportion pregnant and litter size at scanning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			Leicestershire			Lancashire		
		Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
Proportion pregnant	**Δ BCS Weaning to mating**	N/S	N/S	+VE	N/S	N/S	N/S	N/S	N/S	N/S
	Δ LWT Weaning to mating	N/S	A^{+VE}	N/S	N/S	N/S	N/S	-	N/S	A^{+VE}
Litter size	**Δ BCS Weaning to mating**	N/S*	N/S	N/S	-VE	N/S	A^{+VE}	N/S	N/S	N/S
	Δ LWT Weaning to mating	N/S	+VE	N/S	-VE	N/S	A^{+VE}	-	N/S	N/S

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction; A approaching association; - data absent

Table 4. Summary of data analyses on the effects of BCS and liveweight (LWT) **at scanning** on proportion pregnant and litter size at scanning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			Leicestershire			Lancashire		
		Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
Proportion pregnant	**BCS Scanning**	N/S	+VE	N/S	N/S*	+VE	+VE	N/S	-	+VE
	LWT Scanning	N/S	+VE	+VE	+VE	N/S *	N/S	-	-	+VE
Litter size	**BCS Scanning**	N/S	N/S	N/S	+VE	+VE *	A^{+VE}	N/S	-	N/S
	LWT Scanning	N/S	+VE	+VE	+VE	+VE *	+VE	-	-	+VE

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction; A approaching association; - data absent

Table 5. Summary of data analyses on the effects of BCS and liveweight (LWT) change (Δ) **between mating and scanning** on proportion pregnant and litter size at scanning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			Leicestershire			Lancashire		
		Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
Proportion pregnant	**Δ BCS Mating to scanning**	N/S	+VE	N/S	N/S	N/S	+VE	N/S	-	+VE
	Δ LWT Mating to scanning	N/S	+VE	+VE	+VE	N/S	+VE	-	-	+VE
Litter size	**Δ BCS Mating to scanning**	N/S	N/S	+VE	N/S	N/S	-VE	+VE [A]	-	A[+VE]
	Δ LWT Mating to scanning	N/S	+VE *	+VE	+VE *	+VE *	+VE *	-	-	+VE

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction only; A approaching association; - data absent

9.3 *Appendix III.*

Table 1. Summary of data analyses on the effects of ewe BCS and liveweight (LWT) **at weaning** of preceding production cycle on lamb 8-week weight, lamb weaning weight and lamb weight gain 8 weeks to weaning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			Leicestershire			Lancashire		
		Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
8 weeks	**BCS Weaning**	A^{+VE}	N/S	N/S	N/S	N/S	N/S	N/S	A^{-VE}	N/S
	LWT Weaning	N/S	+VE	+VE	A^{+VE}	A^{+VE}	+VE	-	N/S	N/S
Weaning	**BCS Weaning**	N/S	N/S	*	A^{-VE}	-VE	N/S	N/S	A^{-VE}	N/S
	LWT Weaning	A^{+VE}	+VE	+VE	N/S	*	N/S	-	N/S	N/S
Weight gain	**BCS Weaning**	N/S	N/S	*	N/S	-VE	N/S	N/S	N/S	N/S
	LWT Weaning	N/S	A^{+VE}	N/S	N/S	*	N/S	-	N/S	N/S

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction only; A approaching association; - data absent

Table 2. Summary of data analyses on the effects of ewe BCS and liveweight (LWT) **at mating** on lamb 8-week weight, lamb weaning weight and lamb weight gain 8 weeks to weaning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			Leicestershire			Lancashire		
		Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
8 weeks	**BCS Mating**	N/S	A^{+VE}	N/S	N/S	*	N/S	A^{+VE}	*	N/S
	LWT Mating	+VE	+VE	+VE	N/S	+VE	*	+VE	N/S	N/S
Weaning	**BCS Mating**	N/S	N/S	N/S	N/S	*	N/S	N/S	N/S	N/S
	LWT Mating	+VE	+VE	+VE	+VE	+VE	+VE	+VE	N/S	N/S
Weight gain	**BCS Mating**	+VE	N/S	+VE	N/S	N/S	*	N/S	N/S	N/S
	LWT Mating	N/S	N/S	N/S	+VE	N/S	N/S	A^{+VE}	N/S	*

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction only; A approaching association

Table 3. Summary of data analyses on the effects of ewe BCS and liveweight (LWT) change (Δ) **between weaning of the preceding production cycle and mating** on lamb 8-week weight, lamb weaning weight and lamb weight gain 8 weeks to weaning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			Leicestershire			Lancashire		
		Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
8 weeks	**Δ BCS Weaning to mating**	N/S	+VE	N/S	+VE	N/S	N/S	N/S	+VE	N/S
	Δ LWT Weaning to mating	N/S	+VE	N/S	N/S	N/S	N/S	-	N/S	+VE
Weaning	**Δ BCS Weaning to mating**	N/S	A^{+VE}	*	N/S	N/S	N/S	N/S	N/S	N/S
	Δ LWT Weaning to mating	A^{+VE}	N/S	A^{+VE}	N/S	*	N/S	-	N/S	N/S
Weight gain	**Δ BCS Weaning to mating**	N/S	N/S	*	N/S	N/S	N/S	N/S	N/S	N/S
	Δ LWT Weaning to mating	N/S	N/S	N/S	N/S	*	N/S	-	N/S	N/S

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction only; A approaching association; - data absent

Table 4. Summary of data analyses on the effects of ewe BCS and liveweight (LWT) **at scanning** on lamb 8-week weight, lamb weaning weight and lamb weight gain 8 weeks to weaning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			Leicestershire			Lancashire		
		Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
8 weeks	**BCS Scanning**	+VE	+VE	+VE	+VE	*	+VE	N/S	-	N/S
	LWT Scanning	A+VE	+VE	+VE	+VE	+VE	+VE	-	-	N/S
Weaning	**BCS Scanning**	+VE	+VE	+VE	+VE	*	N/S	N/S	-	N/S
	LWT Scanning	N/S	+VE	+VE	+VE	*	+VE	-	-	N/S
Weight gain	**BCS Scanning**	N/S	N/S	N/S	N/S	+VE	-VE	N/S	-	N/S
	LWT Scanning	N/S	+VE	N/S	+VE	+VE	N/S	-	-	*

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction only; A approaching association; - data absent

Table 5. Summary of data analyses on the effects of ewe BCS and liveweight (LWT) change (Δ) **between mating and scanning** on lamb 8-week weight, lamb weaning weight and lamb weight gain 8 weeks to weaning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			**Leicestershire**			**Lancashire**		
		Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
8 weeks	**Δ BCS Mating to scanning**	+VE	N/S	N/S	+VE	+VE	+VE	N/S	-	N/S
	Δ LWT Mating to scanning	A^{-VE}	+VE	N/S	+VE	*	*	-	-	N/S
Weaning	**Δ BCS Mating to scanning**	N/S	N/S	A^{+ve}	+VE	+VE	+VE	N/S	-	N/S
	Δ LWT Mating to scanning	-VE	+VE	N/S	+VE	+VE		-	-	N/S
Weight gain	**Δ BCS Mating to scanning**	A^{-VE}	N/S	N/S	N/S	+VE	-VE	N/S	-	N/S
	Δ LWT Mating to scanning	N/S	N/S	N/S	N/S	+VE	N/S	-	-	N/S

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction only; A approaching association; - data absent

Table 6. Summary of data analyses on the effects of ewe BCS **at lambing** on lamb 8-week weight, lamb weaning weight and lamb weight gain 8 weeks to weaning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			Leicestershire			Lancashire		
		Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
8 weeks	**BCS Lambing**	N/S	+VE	+VE	N/S	*	+VE	+VE	N/S	N/S
Weaning	**BCS Lambing**	N/S	+VE	+VE	+VE	*	N/S	N/S	N/S	N/S
Weight gain	**BCS Lambing**	+VE	*	A^{+VE}	N/S	N/S	*	N/S	N/S	N/S

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction only; A approaching association

Table 7. Summary of data analyses on the effects of ewe BCS change (Δ) **between scanning and lambing** on lamb 8-week weight, lamb weaning weight and lamb weight gain 8 weeks to weaning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			Leicestershire			Lancashire		
		Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
8 weeks	**Δ BCS Scanning to lambing**	-VE	N/S	N/S	-VE	+VE	N/S	+VE	-	N/S
Weaning	**Δ BCS Scanning to lambing**	N/S	N/S	N/S	N/S	N/S	N/S	N/S	-	N/S
Weight gain	**Δ BCS Scanning to lambing**	+VE	N/S	N/S	N/S	N/S	N/S	N/S	-	+VE

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction only; A approaching association; - data absent

Table 8. Summary of data analyses on the effects of ewe BCS and liveweight (LWT) **at 8 weeks** on lamb 8-week weight, lamb weaning weight and lamb weight gain 8 weeks to weaning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			Leicestershire			Lancashire		
		Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
8 weeks	**BCS 8 weeks**	N/S	*	*	+VE	*	N/S	A^-VE	-VE	-VE
	LWT 8 weeks	*	*	*	+VE	+VE	+VE	-	-	-
Weaning	**BCS 8 weeks**	N/S	*	N/S	+VE	*	N/S	A^-VE	-VE	N/S
	LWT 8 weeks	*	+VE	A^+VE	+VE	*	+VE	-	-	-
Weight gain	**BCS 8 weeks**	N/S	*	N/S	N/S	-VE	N/S	-VE	-VE	-VE
	LWT 8 weeks	N/S	+VE	N/S	N/S	*	N/S	-	-	-

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction only; A approaching association; - data absent

Table 9. Summary of data analyses on the effects of ewe BCS change (Δ) **between lambing and 8 weeks** on lamb 8-week weight, lamb weaning weight and lamb weight gain 8 weeks to weaning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			Leicestershire			Lancashire		
		Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
8 weeks	**Δ BCS Lambing to 8 weeks**	*	-VE	-VE	-VE	-VE	-VE	A^{-VE}	-VE	-VE
Weaning	**Δ BCS Lambing to 8 weeks**	N/S	N/S	N/S	N/S	*	N/S	-VE	-VE	N/S
Weight gain	**Δ BCS Lambing to 8 weeks**	-VE	+VE	-VE	N/S	-VE	+VE	N/S	N/S	A^{-VE}

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction only; A approaching association

Table 10. Summary of data analyses on the effects of ewe BCS and liveweight (LWT) change (Δ) **between scanning and 8 weeks** on lamb 8-week weight, lamb weaning weight and lamb weight gain 8 weeks to weaning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			Leicestershire			Lancashire		
		Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
8 weeks	**Δ BCS Scanning to 8 weeks**	N/S	N/S	N/S	+VE	-VE	-VE	N/S	-	N/S
	Δ LWT Scanning to 8 weeks	A^{+VE}	N/S	N/S	+VE	-VE	*	-	-	-
Weaning	**Δ BCS Scanning to 8 weeks**	A^{+VE}	*	N/S	A^{+VE}	-VE	N/S	N/S	-	N/S
	Δ LWT Scanning to 8 weeks	A^{+VE}	N/S	N/S	+VE	-VE	N/S	-	-	-
Weight gain	**Δ BCS Scanning to 8 weeks**	N/S	+VE	-VE	N/S	-VE	+VE	N/S	-	N/S
	Δ LWT Scanning to 8 weeks	N/S	N/S	*	-VE	-VE	N/S	-	-	-

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction only; A approaching association; - data absent

Table 11. Summary of data analyses on effects of ewe BCS and liveweight (LWT) **at weaning** on lamb 8-week weight, lamb weaning weight and lamb weight gain 8 weeks to weaning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			Leicestershire			Lancashire		
		Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Weaning	BCS weaning	*	*	N/S	N/S	*	*	-VE	-VE	N/S
	LWT weaning	+VE	+VE	+VE	+VE	*	+VE	-	N/S	N/S
Weight gain	BCS weaning	*	+VE	N/S	N/S	N/S	N/S	N/S	-VE	-VE
	LWT weaning	-VE	+VE	N/S	N/S	*	*	-	N/S	*

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction only; A approaching association; - data absent

Table 12. Summary of data analyses on the effects of ewe BCS and liveweight (LWT) change (Δ) **between 8 weeks and weaning** on lamb weaning weight and lamb weight gain 8 weeks to weaning for the Sussex, Leicestershire and Lancashire Farms across the three years.

		Sussex			Leicestershire			Lancashire		
		Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Weaning	**Δ BCS 8 weeks to weaning**	*	N/S	N/S	-VE	*	N/S	N/S	N/S	N/S
	Δ LWT 8 weeks to weaning	A*	-VE	N/S	-VE	+VE	N/S	-	-	-
Weight gain	**Δ BCS 8 weeks to weaning**	*	N/S	N/S	+VE	N/S	N/S	N/S	-VE	N/S
	Δ LWT 8 weeks to weaning	N/S	+VE	N/S	+VE	+VE	+VE	-	-	-

+VE significant positive association; -VE significant negative association; N/S not significant; * breed interaction only; A approaching association; - data absent

9.4 ***Appendix IV.***

Farmer Survey: Assessing condition in sheep

AHDB Beef & Lamb and The University of Nottingham are researching how and when sheep producers assess breeding ewe condition. We would also like to gain insight into the main barriers to the assessment of ewe condition. Please complete this survey as accurately as possible for all breeding sheep on your farm. Thank you.

1. Which enterprise(s) do you have on your farm? Tick all that apply

Sheep - breeding ewes; Sheep – finishing lambs; Beef - suckler herd; Beef – finishing; Dairy - milking cows; Dairy – heifer rearing; Arable; Poultry; Pigs; Other

2. Where is your main flock based?

England; Wales; Scotland; Northern Ireland; Republic of Ireland; Other

3. What is the location of your farm? Please provide the first half of your postcode e.g. LE12

This information will only be used to map the responses. It will not be possible to identify individual farms by partial postcode.

4. What is the typical number of BREEDING EWES in your flock?

5. What is the typical number of BREEDING RAMS in your flock?

6. What is the typical number of REPLACEMENTS retained/purchased in your flock?

7. What is the typical number of LAMBS REARED in your flock?

8. Do you believe ewe condition is important?

Yes; No; Sometimes; Not sure; Other

9. When assessing ewe condition, do you assess;

Every ewe in the flock; Certain management group(s); Fattest or thinnest in a group; Other

10. For each time point below, how and when do you assess EWE condition? Please select one answer per row

	Visual	Handle (condition score)	Weight	Condition score & weight	Don't assess condition	Don't have sheep
Tupping						
Scanning						
Lambing						
8 weeks						
Weaning						

11. If you body condition score (handle) EWES, please describe how you condition score.

12. If you body condition score (handle) ewes, how do you categorise their condition?

Fat, fit, thin; 5 point scale; Do not categorise; Do not body condition score; Other

13. If you body condition score (handle) ewes, how do you record the information?

EID software or device; Smartphone; Paper; Do not record; Do not body condition score; Other

14. For each time point below, how and when do you assess LAMB condition? Please select one answer per row

	Visual	Handling	Weight	Handling & weight	Don't assess condition	Don't have lambs
Birth/dry pen						
8 weeks						
Weaning						
Drafting for slaughter/sale						

15. If you handle LAMBS, please describe how you assess condition.

16. At what age do you typically wean your lambs? Please select one

8 weeks; 10 weeks; 12 weeks; 14 weeks; 16 weeks; 18 weeks; 20+ weeks; Other

17. For each statement below, please indicate the extent to which you agree or disagree that it is a barrier to doing more body condition scoring.

	Disagree strongly	Disagree	Neither agree or disagree	Agree	Agree strongly
Time required to handle the ewes					
Prefer to weigh ewes					
Cannot split groups based on body condition score					
I don't have confidence in the concept of body condition scoring					
My handling facilities make body condition scoring difficult					
I am not confident how to body condition score					

18. Are there other barriers not listed in the previous question?

19. How important do you think ewe body condition score is for whole flock productivity at the stages of production below?

	Not at all important	Not very important	Unsure	Quite important	Very important
Tupping					
Scanning					
Lambing					
8 weeks					
Weaning					

20. If you have any comments regarding ewe body condition scoring, please write them below.

Thank you very much for your participation.