CODE OF PRACTICE FOR THE CARE AND HANDLING OF SHEEP:

REVIEW OF SCIENTIFIC RESEARCH ON PRIORITY ISSUES

Sheep Code of Practice Scientific Committee
August 2026

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Excerpt from Scientific Committee Terms of Reference

Background

It is widely accepted that animal welfare codes, guidelines, standards, or legislation should take advantage of the best available knowledge. This knowledge is often generated from the scientific literature.

In re-establishing the Code of Practice development process, NFACC recognized the need for a more formal means of integrating scientific input into the Code of Practice process. A Scientific Committee review of priority animal welfare issues for the species being addressed provides valuable information to the Code Committee in developing or revising the Code of Practice. As the Scientific Committee report is publicly available, the transparency and credibility of the Code is enhanced.

For each Code of Practice being developed or updated, NFACC identifies a Scientific Committee. This committee will consist of a target number of 6 scientists familiar with research on the care and management of the animals under consideration. NFACC will request nominations from 1) Canadian Veterinary Medical Association, 2) Canadian Society of Animal Science, and 3) Canadian Chapter of the International Society for Applied Ethology. At least one representative from each of these professional scientific bodies will be named to the Scientific Committee. Other professional scientific organizations as appropriate may also serve on the Scientific Committee.

Purpose & Goals

The Scientific Committee will develop a report synthesizing the results of research relating to key animal welfare issues, as identified by the Scientific Committee and the Code Committee. The report will be used by the Code Committee in drafting the Code of Practice for the species in question. Some priority issues may not be addressed by the Scientific Committee for any number of reasons (e.g., inadequate available research, existing protocols provide good guidance). Welfare issues that are not addressed by the Scientific Committee should still be addressed in the Code's development.

Note: The Scientific Committee report will not contain recommendations following from any research results. Its purpose is to present a compilation of the scientific findings without bias.

The full Terms of Reference for the Scientific Committee can be found within the NFACC Development Process for Codes of Practice for the Care and Handling of Farm Animals, available at www.nfacc.ca/code-development-process#appendixc.

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Sheep Code of Practice Scientific Committee Report

May 2026

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1 Introduction

1.1 Purpose and Objectives

This report examines priority animal welfare issues relevant to the Canadian sheep industry. The topics and scope were jointly identified by the Code Development Committee and the Scientific Committee through a collaborative prioritization process. That process considered the relevance of each issue to animal welfare, the availability and maturity of the scientific evidence, the potential value of expert synthesis, and alignment with the scope of the Code of Practice, specifically on-farm issues under producer control. The intent was to focus on topics where a structured review of the science would meaningfully support evidence-informed Code development.

The mandate of the Scientific Committee was to review, interpret, and summarize the implications of the available scientific literature for sheep welfare within the identified priority areas, consistent with the National Farm Animal Care Council (NFACC) Code development process. This report was prepared to support the Code Development Committee, whose members bring extensive technical, practical, and sector-specific expertise and are responsible for integrating scientific evidence alongside feasibility, ethical considerations, and industry realities during Code deliberations.

The report reflects a narrative synthesis of the peer-reviewed literature relevant to each priority topic. Where available, systematic reviews, scoping reviews, and meta-analyses were used to draw on higher levels of evidence. However, for many priority issues, the existing body of research does not include enough comparable randomized controlled trials to support robust quantitative synthesis. In these cases, individual primary studies were reviewed and summarized to characterize the current state of knowledge, identify consistent findings, and highlight areas of uncertainty. While formal, systematic review of study design and risk of bias was beyond the scope of this work, the review emphasizes major outcomes, recurring themes, and practical implications relevant to animal welfare. By synthesizing the best available evidence, this report is intended to support transparent, science-informed discussions and decision-making during the development and refinement of the Code of Practice for the care and handling of sheep.

The priority issues addressed in this report include:

- **Pain Control**
    - Main principles
        - Prevention and methods to avoid painful conditions and procedures, evidence-based review of producer perceived negative effects of the use of pain control, sheep-specific social science on barriers to adoption/implementation
    - Painful conditions (lameness, mastitis, infectious diseases)

        - Methods to avoid and mitigate pain and suffering
    - Procedures (lambing, castration, tail docking)
        - Relevant updates to our understanding of the pain associated with lambing
        - Evidence-based strategies to avoid and mitigate pain
- **Endoparasitic and Ectoparasitic Infection**
    - Potential welfare implications of parasites
    - Use of chemicals/drugs to control parasites
    - Genetic selection for resistance to parasites
    - Grazing management strategies and forage species to control parasites
- **Neonatal Care**
    - Ewe–lamb relationship
        - Importance of the bond for the lamb (survival, development, and welfare) and ewe (health and welfare)
    - Fostering, artificial rearing and weaning of lambs
- **Housing and Environment**
    - Key considerations for indoor confinement
        - Social and behavioural deprivation
        - Feed behaviour
        - Effects on health
        - Opportunities for exercise
        - Enrichment
    - Key considerations in extensive systems:
        - Feed quality and access
        - Monitoring and early warning

2 Pain Mitigation

Conclusions:

1. **Strategies to avoid pain include improved management procedures to prevent disease and adoption of management practices to avoid the use of painful procedures.**

2. **When painful procedures are used, adoption of methods that cause least pain and use of analgesia and anesthesia can help mitigate pain. Pre-emptive use of pain mitigation (e.g., local anesthetic before painful procedures) is more effective than the use of analgesics after pain occurs.**

3. **When pain occurs as a consequence of disease, early identification and treatment which reduces severity and/or length of the disease should also mitigate overall pain experience.**

4. **Non-steroidal anti-inflammatory drugs (NSAIDs) have analgesic properties, and, under veterinarian prescription, can be used on sheep.**

5. **A multimodal approach (e.g., combining local anesthetic with NSAID analgesic) has often been shown to be efficacious with respect to pain relief.**

6. **There is a general need for additional research with respect to pain mitigation in sheep, as detailed in section 2.5.**

2.1 Main Principles and Scope

This chapter reviews the scientific literature on pain control in sheep, specifically that related to painful procedures (castration and tail docking), lambing, lameness, mastitis, and infectious disease. The 2012 *Code of practice for the care and handling of sheep: Review of scientific research on priority issues* (Cockram et al.) included chapters on tail docking, castration, and dystocia. As such, the current review provides an update in those areas based on research published since the last report but does not serve to replace the previous review. In the case of dystocia, the current review focuses on pain mitigation in addition to providing information on research conducted since the previous review. The reader is encouraged to read the previous review for a full summary of findings in these areas.

This literature review emphasizes approaches to prevent pain and methods to mitigate it. Avoiding the development of painful conditions should be considered best practice rather than treating them (Guatteo et al., 2012) or mitigating pain once it has occurred. This should include discussions with the flock veterinarian to reduce risk factors for the painful conditions outlined in this chapter. In general, where treatment is needed, that given earlier in the course of disease is preferred, not only to best mitigate the pain response (Lizarraga & Chambers, 2012) but also to increase the chance of cure and reduce disease transmission to other animals. The necessity of painful procedures should be assessed within the context of the individual farm's management system (Guatteo et al., 2012; AWC, 2022). For painful procedures, consideration of alternative management strategies should be given to avoid unnecessary painful procedures, where appropriate (Guatteo et al., 2012). When painful procedures are used and multiple methods exist, the least painful option should be selected (Guatteo et al., 2012). Use of pre-emptive medication is most effective and may include a multimodal approach using both local anesthesia to prevent acute pain and NSAID therapy where inflammatory pain is likely (Lizarraga & Chambers, 2012). Pain mitigation is an underutilized strategy both globally (Lizarraga & Chambers, 2012) and within the Canadian sheep industry (Moon et al., 2010).

2.2 Painful Conditions

2.2.1 Lameness

2.2.1.1 Definition and Causes

"Lameness" is a general term referring to an abnormal gait (Gelasakis et al., 2019). Most lameness in sheep is caused by pain. Lameness can be a serious welfare problem because of its prevalence and the severity of the associated suffering. Sheep that experience pain due to lameness are likely to experience additional welfare issues, such as difficulties in obtaining feed and water and avoiding predators. For example, sheep with footrot often stand on three legs and sometimes eat while resting on their carpi (Zanolari et al., 2021). Lameness is not just a welfare concern: it also impacts productivity and culling risk (Winter, 2011; Lizarraga & Chambers, 2012; Phythian et al., 2013; Green & Clifton, 2017; Small et al., 2021a). Lameness evaluation is often used as a welfare indicator in several animal welfare assurance schemes (Zufferey et al., 2021).

Common causes of lameness include infectious conditions (interdigital dermatitis, also known as foot scald, footrot, contagious digital dermatitis, and septic joint infections) as well as non-infectious causes (white line disease and toe granulomas), although these may put animals at risk of developing further infectious disease (Hodgkinson, 2010; Winter, 2011; Green & Clifton, 2017; Gelasakis et al., 2019). Contagious digital dermatitis is reported in the United Kingdom and regions of continental Europe (Bernhard et al., 2021; Duncan et al., 2021a). However, in North America this has not been described, although the causative agents (*Treponema* species) are common in cattle, as well as wild elk, and bovine isolates have been experimentally shown to cause infection in sheep (Wilson-Welder et al., 2018).

Footrot is a contagious bacterial disease affecting the feet of sheep. Infection of the interdigital skin with the anaerobic bacterium *Dichelobacter nodosus* occurs following physical injury, moist environmental conditions, and infection with other microorganisms. The condition can develop from mild interdigital dermatitis to separation of the hoof (Zanolari et al., 2021). While the causative agents are virulent strains of *D. nodosus*, the bacterial community of the foot is complex, and in affected sheep, Gram-negative anaerobic species predominate, compared to predominantly Gram-positive aerobic species on the feet of healthy sheep (McPherson et al., 2019). As well, *Treponema* species have been found in footrot lesions (Maboni et al., 2017; Duncan et al., 2021b), highlighting the impact of dysbiosis of the bacterial community in the ovine foot.

Laminitis and infective and chronic arthritis are possible causes of lameness in sheep (Boundy, 1983; Li et al., 2017). Bacterial arthritis is a common condition of neonatal lambs (Henderson, 2007), and it can also occur in adult sheep (Scott & Sargison, 2012). Older sheep, such as rams, can develop osteoarthritis in the elbow and other joints (Scott, 2001).

Recent prevalence data on lameness in sheep is lacking for Canada, although antibiotic treatment for lameness was identified in 9% of all on-farm recorded treatments in an Ontario survey (Moon et al., 2010), and several virulent strains of *D. nodosus* (causative agent of footrot) were identified in a sample of lame sheep in Alberta and British Columbia (Olsen et al., 1998). A mail survey of disease occurrence in Canadian sheep flocks in 1982/83 reported “foot problems” in 12% of the flocks. Two percent of ewes were reported to have been culled due to lameness (Dohoo et al., 1985). A study of lameness in one lamb feedlot in southern Alberta in 2017 to 2019 reported that 0.64% were lame and that footrot was considered to be the cause in 23% of the lame lambs (Schwartzkopf-Genswein et al., 2020).

Both naturally occurring lameness and lameness induction models have been shown to decrease nociceptive threshold and withdrawal threshold (Ley et al., 1989; Small et al., 2021a; Simpson et al., 2022), which are subsequently increased with administration of a local anesthetic block (Ley et al., 1989; Simpson et al., 2022). While mild footrot lesions were found to return to normal nociceptive threshold following healing, with more severe lesions it remained elevated for a longer duration (Ley et al., 1989). The facial expressions of sheep that are thought to be responsive to pain can be used to differentiate between sheep with and without footrot (McLennan et al., 2016a). Raised plasma cortisol concentrations have also been associated with footrot, and they may remain elevated for up to 3 months following apparent resolution (Ley et al., 1994).

Automated detection of lameness (such as accelerometers, gyroscope-based sensors, and hoof weight crates) shows some promise at identifying lameness in sheep (Bryne et al., 2019; Kaler et al., 2019) but are not currently at the stage of being commercially tested or available. Several gait scoring systems for sheep lameness can be used to quantify locomotion scores ranging from zero for sheep with normal locomotion to higher scores indicative of severe lameness (Kaler et al., 2009; Angell et al., 2015). Simpler binary systems have also been proposed for ease of use (Phythian et al., 2013; Zufferey et al., 2021).

2.2.1.2 Prevention and Risk Factors

Environment and hygiene. In locations where the predominant cause of lameness is footrot, warm, humid conditions have been associated with an increased prevalence of lameness (Vittis & Kaler, 2019), with prevalence varying according to season in some regions (Hodgkinson, 2010). These conditions favour spread of infectious agents as well as increased risk of damage to the interdigital area, allowing bacteria to colonise the subcutis (Hodgkinson, 2010). Unsanitary handling areas can also promote spread of infectious causes of lameness (Winter, 2011), with higher stocking densities associated with increased lameness prevalence (Kaler & Green, 2009). Housing with poor drainage, insufficient bedding, and poor ventilation can also lead to increased moisture on the ground, creating poorer hoof health (Gelasakis et al., 2019). In neonatal lambs, births occurring later in the lambing period, presumably over more contaminated grounds, had higher risk for developing polyarthritis (Ridler et al., 2019). As well, having a docked tail length of 1 or 2 coccygeal vertebrae (compared to 3 or more) was associated with increased risk of polyarthritis in neonatal lambs (Lloyd et al., 2016).

Foot bathing. Foot bathing has historically been used as a method for the treatment and prevention of lameness in sheep. Although it can be an important aspect of treatment, it is no longer recommended as a routine preventative management measure (Kaler & Green, 2009; Lewis & Green, 2020; see 2.2.1.3). Poorly maintained foot baths can damage feet and facilitate disease spread (Winter, 2011). Regular foot bathing as a preventative measure has been associated with higher lameness prevalence (Kaler & Green, 2009).

Foot trimming. Over-trimming (causing bleeding) is associated with increased rates of lameness at the flock level (Winter et al., 2015; Green & Clifton, 2017; Prosser et al., 2019) and can increase risk of development of toe granulomas, which then predispose sheep to footrot (Hodgkinson, 2010; Winter, 2011). In the UK, where pastoral systems predominate, routine trimming has been associated with increased prevalence of lameness (Kaler & Green, 2009) and has been recommended against as a flock management practice (Green & Clifton, 2017; Lewis & Green, 2020). It is also important to note that when sheep are partially or completely confinement housed, hoof overgrowth can occur, and routine trimming may be necessary as part of a lameness management strategy (Gelasakis et al., 2019).

Genetic selection. Genetic testing for susceptibility to footrot has been developed in New Zealand (Bishop & Morris, 2007), and work has been done on other breeds and regions (Mucha et al., 2015; Cinar et al., 2024). Selecting breeding replacements from never-lame ewes has been associated with lower prevalence of lameness compared to farms not conducting such selection (Winter et al., 2015).

Quarantine of new animals. Isolating incoming animals is recommended to prevent introduction of new infections (Winter, 2011; Clements & Stoye, 2014), as well as inspection of the feet and appropriate treatment for any lesions. Farms which report quarantining new sheep for more than 3 weeks had lowered risk of lameness compared to those which did not (Winter et al., 2015).

Vaccination. Vaccination against *D. nodosus* has been shown to be associated with reduced lameness risk (Winter et al., 2015; Cresswell et al., 2023) and is generally recommended as part of a comprehensive lameness prevention strategy (Winter, 2011; Clements & Stoye, 2014; Gelasakis et al., 2019). As of publication date, there are no vaccines for *D. nodosus* licensed for use in Canada.

2.2.1.3 Pain Mitigation Strategies

Prompt identification and treatment. As many types of lameness are painful, rapid identification and treatment both reduces the duration of pain for the individual animal and helps prevent progression of disease to more severe and more painful conditions, as well as reducing risk of spread of infectious causes. Identification of the cause of lameness is also essential to provide effective treatment (Hodgkinson, 2010). Identification of lame sheep and treatment within 3 days of identification are associated with decreased flock prevalence of lameness (Winter et al., 2015; Prosser et al., 2019; Lewis & Green, 2020). Farmers who recognize lameness in sheep with a low locomotion score (less lame) compared with those that only recognize lameness at a higher score (more lame), as well as those who treat as soon as the first lame sheep is seen (compared to waiting until 6 or more are affected), had lower flock level lameness prevalence compared to those with higher treatment thresholds (Winter et al., 2015). Sorting lame sheep from sound sheep at spring turnout after a period of housing was also associated with decreased farm level prevalence of lameness (Kaler & Green, 2009). Prompt treatment also allows cases to be diagnosed early, before progression to more severe conditions (i.e., treatment of interdigital dermatitis before progression to footrot or septic joint infections, or treatment of white line disease before development of secondary infections and abscesses) (Winter, 2011).

Formalin can be used as a pass-through foot bath for interdigital dermatitis (foot scald) (Winter, 2011; Green & Clifton, 2017) or mild toe granulomas (Hodgkinson, 2010), although it is important to note it is an irritant and known carcinogen. Formalin is not recommended for footrot or contagious digital dermatitis, as it is extremely painful on open wounds (Winter, 2011). Zinc sulfate standing foot baths may be used for treatment of interdigital dermatitis (Winter, 2011) but is not recommended for cases of footrot (Winter, 2011; Green & Clifton, 2017). Copper sulfate may be effective in treatment of footrot, but should be used cautiously due to copper sensitivity, particularly in European continental breeds (Winter, 2011). Zinc sulfate foot bathing has been shown to be effective when done for 5 consecutive days (Jackson et al., 2023). Injectable antibiotics have been recommended for the treatment of footrot (Winter, 2011), while more recently, topical treatment (oxytetracycline spray daily for five days) has been shown to be effective (Jackson et al., 2023; Smith & Kreuder, 2024) and may be more suitable considering the importance of reducing overall use of systemic antibiotics. Treatment of contagious digital dermatitis is complex, with poor responses to therapy for severe cases (Winter, 2011).

Pain mitigation. Although NSAIDs have been recommended for inflammatory pain to provide longer lasting analgesia (Lizarraga & Chambers, 2012), few trials have examined their efficacy specific to lameness conditions in sheep. Uptake among farmers is variable in on-farm treatment for lameness (Crawford et al., 2023). In a trial of footrot cases, the administration of a single dose of an NSAID (flunixin meglumine) to eight sheep did not reduce recovery time when given in addition to systemic and topical antibiotics (Kaler et al., 2010). However, the authors considered that their study was underpowered and that the anti-inflammatory, antipyretic, and analgesic properties of the NSAID likely provided some benefit by providing analgesia for up to 24 hours and helping ewes to continue to feed.

Efficacy of meloxicam for pain mitigation has been shown in a lameness model (Colditz et al., 2019). In sheep, in which lameness was induced by the pain caused by the subcutaneous injection of turpentine over the proximal phalanx of a forelimb, the NSAID meloxicam resulted in improved gait, reduced time in which the limb was held in a non-weight bearing posture, and increased tolerance of pressure on the limb (Colditz et al., 2019). Flunixin, carprofen, and ketoprofen were found to reach inferred therapeutic levels following oral administration of double the standard dose, although failing to show efficacy on the lameness model in the same study (Marini et al., 2015).

A combination of topical anesthetic/antiseptic treatment has been shown to provide benefit to open wounds and lesions in sheep, including lameness due to Foot and Mouth Disease (Windsor, 2022), although studies examining topical anesthetic/antiseptic treatment for causes such as interdigital dermatitis, footrot, and contagious digital dermatitis have not been done.

Foot trimming. Trimming is not recommended as part of treatment for foot rot (Winter, 2011; Lewis & Green, 2020), as this is associated with increased healing time for this condition (Kaler et al., 2010). Careful therapeutic trimming has been advised where abscesses occur as a sequela to white line disease, or where white line disease progresses to shelly hoof (Winter, 2011; Green & Clifton, 2017).

Culling. Culling those failing to respond to treatment has been recommended as an important part of lameness control strategies (Winter, 2011; Clements & Stoye, 2014; Green & Clifton, 2017).

Euthanasia. Sheep with chronic lameness and a thickened joint capsule as a consequence of severe septic arthritis should be euthanized (Scott & Sargison, 2012).

2.2.2 Mastitis

2.2.2.1 Definition and Causes

Mastitis in sheep refers to the inflammation of the mammary gland, typically caused by infection, though it can also arise from injury or other less common factors (Menzies & Ramanoon, 2001). Mastitis is a significant welfare concern in the sheep industry (EFSA, 2014), leading to reduced milk production, altered milk composition, and increased risk of ewe morbidity and mortality, as well as reduced lamb performance and welfare (Menzies & Ramanoon, 2001; Alba et al., 2019; Page et al., 2021). Mastitis is a common reason for antimicrobial use among both Canadian meat and dairy sheep producers (Avery et al., 2003).

Clinical Mastitis. Clinical mastitis is characterized by visible signs of inflammation, including swelling, heat, and redness (Menzies & Ramanoon, 2001). This form of mastitis can be acute or peracute, with severe cases leading to high mortality rates due to systemic toxemia (Menzies & Ramanoon, 2001). Common causative agents include *Staphylococcus aureus* and *Mannheimia haemolytica* (Arsenault et al., 2008; Fthenakis, 2019), with *Mannheimia haemolytica* more common in meat sheep than dairy, as transmission from lambs to teats during suckling events increases risk of transmission of this normal inhabitant of the upper respiratory tract to teats (Gelasakis et al., 2015; Fthenakis, 2019). *Mycoplasma* species can also cause clinical mastitis, often also coupled with arthritis, conjunctivitis, or pneumonia (Menzies & Ramanoon, 2001; Fthenakis, 2019). Regardless of cause, affected animals often exhibit signs of discomfort such as restlessness, pain, and anorexia (Gelasakis et al., 2015), and infection can lead to severe damage to the mammary gland and an increased risk of culling (Dohoo et al., 1985).

Subclinical Mastitis. Subclinical mastitis does not present with obvious clinical signs, but it still results in altered milk composition, increased somatic cell count (SCC), and reduced milk quality (Vasileiou et al., 2018). While subclinical ewes experience systemic effects, including elevated inflammatory indicators (Alba et al., 2019), the welfare significance of subclinical mastitis is not clear. It may be detected using diagnostic tools such as the California Mastitis Test (CMT) or milk cultures (Queiroga, 2017). Subclinical mastitis is commonly associated with coagulase negative Staphylococci (CNS) (Queiroga, 2017; Vasileiou et al., 2018; Fthenakis, 2019) and can have long term impacts on both ewe health and flock productivity (Vasileiou et al., 2019).

2.2.2.2 Prevention and Risk Factors

Environmental factors. Environmental conditions play a critical role in the prevalence of mastitis. Poor hygiene, wet conditions, high stocking density, inadequate bedding, and poor ventilation increase bacterial load in the environment and contribute to mastitis risk (Gelasakis et al., 2015). In dairy flocks, lack of post-milking teat disinfection is associated with increased infection risk (Gelasakis et al., 2015; Vasileiou et al., 2018).

Immune function and nutrition. Deficiencies in vitamins and minerals, particularly vitamins A, E, and selenium, can compromise the integrity of the mammary gland and might increase susceptibility to infection (Gelasakis et al., 2015). Clinical pregnancy toxemia, as well as elevated serum beta-hydroxybutyrate, are associated with a higher risk of clinical mastitis (Gelasakis et al., 2015). Furthermore, parasitic infections such as those caused by *Teladorsagia* spp. have been linked to increased mastitis risk, particularly early in lactation, highlighting the need for effective parasite control as part of a broader mastitis prevention strategy (Vasileiou et al., 2019).

Genetic selection. Genetic selection offers a promising avenue for reducing mastitis incidence in sheep. Studies have shown that breeding for resistance to mastitis (lower SCC) can reduce the risk of infection by up to 10% (Conington et al., 2008). While there is some evidence that genetic improvement could be beneficial, further research is needed to identify specific genes associated with mastitis resistance (Conington et al., 2008). In addition, genetic factors related to udder conformation, such as teats that are more prone to injury or difficult to milk, may also influence mastitis susceptibility (Gelasakis et al., 2015).

Milking Management. For dairy sheep, effective milking management is essential in minimizing mastitis risk. Over-milking, under-milking, and improper milking machine settings (e.g., incorrect vacuum, pulsation rate or ratio) can all contribute to teat injury and infection (Gelasakis et al., 2015). Milking should be done according to standard operating procedures (SOPs), ensuring consistency and minimizing the risk of damage to the udder (Vasileiou et al., 2018). Additionally, post-milking teat disinfection reduces disease risk (Gelasakis et al., 2015; Vasileiou et al., 2018). In meat sheep, chapped teats, bites during suckling, lesions from orf, and suckling multiple lambs increases the risk of mastitis (Gelasakis et al., 2015)

Vaccination. Vaccination is another tool that can help prevent mastitis (Gelasakis et al., 2015). Studies have shown that vaccination against *Staphylococcus aureus* during late pregnancy can protect ewes during lambing and the early postpartum period, reducing both clinical and subclinical mastitis (Vasileiou et al., 2022). The development of vaccines targeting biofilm formation in mastitis-causing bacteria may offer additional benefits, particularly in controlling chronic infections (Vasileiou et al., 2022).

2.2.2.3 Pain Mitigation Strategies

Mastitis is a painful condition that can significantly impact ewe welfare. Chronic mastitis has been shown to result in hyperalgesia, where the animal becomes increasingly sensitive to pain (Fitzpatrick et al., 2006; Lizarraga & Chambers, 2012). NSAIDs have been identified as a potential treatment for alleviating pain in affected sheep by reducing the inflammation associated with mastitis (Fitzpatrick et al., 2006). In a study examining facial pain indicators, treatment of ewes with acute clinical mastitis (systemic antibiotics in conjunction with NSAIDs) reduced pain scores in the days following treatment (McLennan et al., 2016b). In ewes with mastitis, the administration of flunixin meglumine can reduce the rectal temperature and the severity of other clinical signs associated with inflammation (Fthenakis, 2000). Early detection and treatment of mastitis are important from many standpoints: to reduce the risk of cases becoming chronic (which further increases pain), to reduce transmission to other animals, to increase efficacy of treatment, and to generally reduce pain associated with prolonged inflammation (Menzies & Ramanoon, 2001; Gelasakis et al., 2015).

2.2.3 Infectious Disease

2.2.3.1 Definition and Causes

Infectious disease is a broad term encompassing disease processes that involve the transmission of pathogens that result in infections that can include acute conditions as well as chronic disease. Diseases may be entirely chronic in nature (e.g., *Maedi visna, Mycobacterium avium* subsp. *paratuburculosis*, caseous lymphadenitis), may be generally acute presenting (e.g., neonatal *E. coli* septicemia), or may be acute disease processes which can progress to chronic conditions (e.g., *Mycoplasma* pneumonia, some causes of clinical mastitis). Infectious disease may be caused by bacterial, viral, fungal, or parasitic infections, and it is beyond the scope of this review to list all relevant disease conditions of all age classes of sheep.

2.2.3.2 Prevention and Risk Factors

The main approaches used to control infectious diseases aim to increase resistance to infection, remove sources of infection, and prevent new contacts that could lead to transmission. Husbandry, hygiene, and management procedures are used to minimize a pathogen's challenge and maximize the host's capacity to resist it (Biggs, 1985). Prevention strategies and risk factors will vary by disease, although in general many causes of infectious disease are common within the Canadian sheep industry and likely warrant discussion and planning of risk mitigation strategies with the flock veterinarian. Several causes of disease in sheep are also zoonotic (such as *Coxiella burnetii*, *Campylobacter* spp., *Chlamydia*, *Toxoplasma gondii*, and contagious ecthyma), further emphasizing the importance of risk mitigation strategies. As an example, *C. burnettii* is increasingly common in Canadian sheep flocks (Lang et al., 1991; Meadows et al., 2015; Turcotte et al., 2021), and both serological positivity for *Coxiella burnetii* and increased risk of clinical Q fever in humans have been associated with sheep exposure in Canada (Dolcé et al., 2003; Meadows et al., 2016; Dolcé et al., 2023). Other infectious diseases are common within the Canadian sheep industry (Dohoo et al., 1985) and include, but certainly are not limited to, Maedi visna (Arsenault et al., 2003; Fournier et al., 2006; Stonos et al., 2017), *Mycobacterium avium* subsp. *paratuberculosis* (Arsenault et al., 2003; Bauman et al., 2016), caseous lymphadenitis (Arsenault et al., 2003), Cache Valley virus (Uehlinger et al., 2018; Bergevin et al., 2023), *Toxoplasma gondii* (Waltner-Towes et al., 1991), and causes of lameness (see 2.2.1.1).

2.2.3.3 Pain Mitigation Strategies

While pain mitigation strategies will differ based on the cause of disease and clinical signs presented, appropriate identification and treatment of animals early in the course of disease are likely to benefit individual animal welfare and reduce disease risk. Preventive strategies are also required to reduce disease risk and incidence within the flock.

Disease can cause a range of negative feelings in animals (including pain), some as a direct consequence of the disease process and some as a consequence of impaired behaviour and physiology (Cockram & Hughes, 2018). The biological mechanisms responsible for many of the adverse effects of disease have their basis in the inflammatory responses to disease and their subsequent effects on the brain. Non-specific behavioural signs of sickness (sickness behaviour) associated with fever, reduced responses to environmental and social stimuli, cognitive impairment, lethargy/increased sleep, and reduced feed and water intake can occur as a consequence of the effects of inflammatory and immune responses (Gregory, 1998). The main aim of treatment of a diseased animal is to achieve rapid and permanent recovery, and this reduces suffering. However, attention must also be given to the alleviation of suffering and feelings associated with sickness during disease states (Gregory, 1998). Some of the unpleasant feelings and discomfort associated with disease can be relieved by medication, such as NSAIDs (Scott, 2011; Ural, 2021; Crawford et al., 2023; Tsekouras et al., 2025) that have anti-inflammatory, anti-exudative, analgesic, and antipyretic properties.

2.2.4 Lambing

Lambing/parturition represents a major event that likely causes pain and discomfort even when it proceeds normally. Ewes that experience dystocia are at increased risk of severe pain and discomfort. Lambing can also cause injury and be followed by the development of clinical conditions such as metritis. Parturition is painful (Martínez-Burnes et al., 2021) as a consequence of cervical dilation, uterine contractions, distention of the birth canal, the expulsion of the fetus, and inflammation of the uterus and vagina. After parturition, pain may be caused by the involution of the uterus and tissue damage. This has the potential to reduce maintenance activities and feeding necessary for lactation and for the degree of maternal care provided to neonatal animals.

2.2.4.1 Definition and Causes of Dystocia

Dystocia in sheep is defined as difficulty during parturition, characterized by the failure to transition from stage I to stage II labour, or when labour progresses inadequately for more than 30 minutes during stage II (Anderson, 2014). This condition can stem from either fetal or maternal causes, though fetal factors are more common (MLA, 2020; Balasopoulou et al., 2022). Fetal causes include malposition, oversized lambs, entangled multiples, emphysematous fetuses, and fetal monsters (Balasopoulou et al., 2022). Maternal causes include ringwomb, narrow pelvic bones, primary and secondary uterine inertia, vaginal prolapse, and uterine torsion (Parkinson et al., 2019). Less common causes include hydroallantosis, hydroamnion, and sciatic nerve paralysis (Jacobson et al., 2020a). The impact of dystocia is substantial, as it leads to increased perinatal mortality in lambs, with a meta-analysis finding 47% (95% CI: 38–55%) of perinatal lamb mortality attributable to dystocia (including stillbirths) (Bruce et al., 2021). Substantial heterogeneity in this metric was seen after accounting for breed (Bruce et al., 2021), highlighting differences across studies which may reflect differences in multiple other factors. Beyond increasing mortality risk, dystocia also significantly impacts welfare for surviving lambs as well as the ewe (Dwyer, 2008; Jacobson et al., 2020a). Lambs affected by dystocia often face additional challenges, such as hypoxia and acidosis, leading to further complications like hemorrhage and congestion of the meninges of the CNS (Jacobson et al., 2020a), reducing lamb vigour and increasing risk of starvation and morbidity (Dwyer, 2008). As well, dystocia often causes pain from injury or trauma to both lamb and ewe, interferes with maternal bonding, and can have longer term impacts on stress reactivity in the lamb (Dwyer, 2008).

2.2.4.2 Prevention and Risk Factors

Adequate nutritional management, including proper protein and energy intake in late gestation, is critical to prevent intrauterine growth restriction and mitigate dystocia risk (Jacobson et al., 2020a). Additionally, hypocalcemia and oxidative stress can impair uterine contractility and predispose ewes to dystocia (Jacobson et al., 2020a).

Although optimal birthweight varies by breed, lambs with either excessively high or low body weights at the time of lambing can increase the risk for dystocia (Jacobson et al., 2020a). Ewes with either a low or an overly high BCS at lambing and those that lose BCS prior to lambing have an increased risk of dystocia (Jacobson et al., 2020a). Terminal sire breeds, which are often selected for traits like muscling and growth, tend to have larger lambs, which increases the likelihood of dystocia, particularly in ewes with smaller pelvic canals, when improper sires are selected, or with primiparous ewes (Dwyer & Bünger, 2012; McHugh et al., 2016). Primiparous ewes as well as ewes over 4.5 years of age have been found to be at higher risk of dystocia, although the risk decreased with age up to 4.5 years (Jacobson et al., 2020a).

Underfeeding during late gestation can lead to intrauterine growth restriction, resulting in lambs that are too small or poorly developed (Jacobson et al., 2020a; Sartori et al., 2020). Ensuring adequate protein and energy intake is critical to ensure that the lamb develops to an appropriate birthweight (MLA, 2020). A meta-analysis found no effect of overfeeding in the second and third trimesters on birthweight, although substantial heterogeneity was seen, suggesting the effect (or lack of effect) may vary based on contextual factors (Sartori et al., 2020).

Hypocalcemia and oxidative stress have both been identified as risk factors for dystocia due to their effects on uterine contractility, highlighting the importance of providing appropriate levels of macrominerals such as calcium, phosphorus, and magnesium, microminerals including selenium, zinc, and copper, as well as vitamins A and E (Jacobson et al., 2020b). Exposure to estrogenic pastures can interfere with uterine function, and has been recommended to be avoided (MLA, 2020). Although the etiology of ringwomb is unclear, it is suggested it may be influenced by hormonal imbalances or nutritional deficiencies (Parkinson et al., 2019). Secondary uterine inertia may result from prolonged labour, metabolic imbalances, or stress (Jacobson et al., 2020a).

Stress and disruption during labour can interfere with uterine function and labour progression, and should be minimized (Jacobson et al., 2020b; MLA, 2020; Balasopoulou et al., 2022). Ensuring adequate feed and shelter and controlling group size has been recommended (MLA, 2020). While appropriate supervision and intervention are needed to reduce complications from dystocia, poor quality intervention can further increase the risk to both the lamb and ewe (Scott, 2005), which highlights the importance of appropriate training in dystocia management for stockpersons.

2.2.4.3 Pain Mitigation Strategies

For both ewe and lamb, dystocia can lead to significant pain and trauma, including damage to the ewe's reproductive tract and inflammation (Dwyer, 2008). Effective pain management following dystocia is critical for minimizing these consequences. Although not well studied in this population, NSAIDs are commonly used to reduce inflammation and pain, as they work by targeting the prostaglandins involved in the inflammatory response (Scott, 2005).

Epidural anesthesia has been shown to provide significant analgesia for manual interventions during dystocia (Scott, 2005). Epidural anesthesia can help by blocking pain pathways during the manual correction of abnormal lamb positions or other complications (Scott, 2005). While vaginal prolapse is often replaced without analgesia with vaginal spoons, it is recommended to use epidural anesthesia when replacement is made with sutures (Scott, 2005).

Supervision during labour (without disturbance to the ewe) is essential to prevent complications from escalating. Proper timing of intervention and the use of analgesics during labour can significantly reduce the level of pain and distress experienced by both the ewe and lamb. Early, appropriate assistance can prevent the onset of severe complications that increase suffering and mortality (Scott, 2005; MLA, 2020).

2.3 Painful Procedures

2.3.1 Castration

2.3.1.1 Necessity of Castration

If management practices are in place that reduce the need for castration, then the rationale for castrating lambs that will be slaughtered before reaching puberty should be considered. All manual methods of castration cause pain. Immunocastration for sheep has been developed, although it is not commercially used or approved for use in Canada (AWC, 2022). While ram lambs have been shown to have higher average daily gain (ADG) than wethers, wethers meat may have small quality advantages based on sensory differences as identified in consumer studies (Gravador et al., 2018; McGrath et al., 2024).

2.3.1.2 Methods and Pain Mitigation Strategies

Rubber ring method. The previous review (Cockram et al., 2012) concluded that rubber ring castration causes acute pain as well as behavioural changes and signs of discomfort for approximately four weeks following the procedure, until the tissue sloughs. The provision of local anesthesia injected into the scrotal neck, spermatic cord, or testis, as well as the administration of the NSAID flunixin, can reduce the acute pain response. Since this publication, research has directly compared rubber ring to rubber ring with clamp, showing decreased behavioural indicators of pain with the addition of the clamp compared to rubber ring alone

(Maslowska et al., 2020). As well, studies have agreed that the administration of local anesthetic blunts the acute pain response (Kells et al., 2020; AWC, 2022; Marini et al., 2025), although when given in conjunction with meloxicam for lambs undergoing ring castration and hot docking of the tail, no additional benefits were seen (Kells et al., 2020). The use of lidocaine impregnated bands is a newer technology which may have benefit compared to traditional bands (Roche et al., 2024), although additional studies examining behavioural and physiologic indicators of pain are needed.

Rubber ring method with clamp (Burdizzo). The previous review (Cockram et al., 2012) concluded that both the clamp method and the combined clamp and rubber ring method cause acute pain, and that local anesthesia injected into the scrotal neck and spermatic chord reduces this response. The pain response to the combined method appears to be less than rubber ring alone but greater than clamp alone. Reviews published since this work agree that there is reduced pain with the clamp and clamp/rubber ring methods compared to rubber ring alone. This is thought to be due to the clamp causing more acute nerve damage (AWC, 2022). Clamp castration requires a skilled operator to ensure both an effective crush as well as avoidance of trauma to the urethra (AWC, 2022). Clamp castration has also been shown to shed necrotic tissue more rapidly, with lower lesion scores, than rubber ring alone (AWC, 2022).

Surgical method. The previous review (Cockram et al., 2012) concluded that surgical castration causes acute pain. The provision of lidocaine and meloxicam for this method provided some signs of effective analgesia but did not consistently reduce indicators of pain compared to sham (Harris et al., 2021). Topical anesthetic provided for surgical castration has shown improved pain mitigation as compared to rubber ring castration (without anesthesia) (AWC, 2022).

2.3.2 Tail Docking

2.3.2.1 Necessity of Tail Docking

Tail docking is commonly used as a preventative measure against flystrike. Docking the tail helps reduce the buildup of feces and urine, especially in long-wool breeds, by keeping the breech area cleaner (Small et al., 2021b; AWC, 2022). However, some studies and expert opinions suggest that breeds that naturally have less fecal soiling or live in low-risk environments may not benefit from this intervention, and that farmers should evaluate individual flock risk factors, including breed, environment, and management practices (Gascoigne et al., 2021; AWC, 2022).

Research by Johnson et al. (2023) showed that tail length and bareness traits are moderately to highly heritable, indicating strong potential for improvement through selection. Lambs with higher genomic breeding values for bareness and shorter tails show reduced dag formation and lower risk of flystrike and may not require tail docking at all under some production conditions (Johnson et al., 2023).

2.3.2.2 Methods and Pain Mitigation Strategies

Rubber ring method. The previous review (Cockram et al., 2012) concluded that this method is acutely painful, with evidence showing increased pain compared to using a hot knife or using a combination of rubber ring and clamp, and with some evidence suggesting it is more painful than surgical docking. The review found that local anesthesia provided at the site prior to ring application can reduce signs of acute pain, and that the NSAID diclofenac reduced the cortisol response but not behavioural signs of pain and was not as effective as local anesthesia (Cockram et al., 2012). Studies published since the previous review support the claim that rubber ring tail docking may be more painful than hot or cold knife (Orihuela & Ungerfeld, 2019). Behavioural studies have also shown that female lambs may exhibit more intense responses than males, indicating possible sex differences in pain sensitivity (Marini et al., 2023). Tail wounds from rubber ring docking took a range of 30–60 days to heal, with infection present in at least 89% of tails (Woods & Adcock, 2025).

Local anesthesia appears to be efficacious in helping mitigate acute pain (Small et al., 2020; 2021b; 2021c). While NSAID administration is not as effective as local anesthesia with regards to acute pain reduction (Schllemer et al., 2021; AWC, 2022), there is some evidence meloxicam provides additional pain mitigation when given in conjunction with local anesthesia (Dunthorne, 2021). The use of lidocaine impregnated bands is a newer technology which may have benefit compared to traditional bands (Roche et al., 2024), although additional studies examining behavioural and physiological indicators of pain are needed.

Rubber ring with clamp (Burdizzo) method. The previous review (Cockram et al., 2012) concluded that when rubber ring tail docking is combined with a clamp method, it appears less painful than use of a rubber ring alone and may be more painful that surgical methods. Reviews published since the previous work support this conclusion (Orihuela & Ungerfeld, 2019; AWC, 2022), highlighting earlier wound healing compared to rubber ring alone (AWC, 2022). However, this method is still painful, and providing pain mitigation of both anaesthesia and analgesia reduces levels of pain (AWC, 2022).

Surgical (cold knife) method. The previous review (Cockram et al., 2012) concluded that surgical tail docking is acutely painful but may be less painful than rubber ring tail docking, although evidence was mixed. Reviews published since the previous suggest the cold knife method may be more painful than hot knife, as the cauterisation causes third-degree burns, damaging nociceptors and reducing sensitivity in the area, while also suggesting it may be more painful than rubber ring docking based on differences in cortisol increase (Orihuela & Ungerfeld, 2019). Provision of topical anesthesia for this method may help reduce behavioural signs of pain (Ferrer et al., 2020).

Hot iron (hot knife) method. The previous review (Cockram et al., 2012) found that hot iron/hot knife docking had decreased acute physiological and behavioural responses compared to other methods, such as rubber ring or surgery. While studies published since the previous review support the claim that hot knife docking causes less pain response compared to rubber ring or cold knife (Orihuela & Ungerfeld, 2019), it is clear this method is painful when no pain mitigation is given (AWC, 2022; Teubes et al., 2025). Local anesthetic and meloxicam showed improvements in behavioural indicators of pain when hot docking was done in conjunction with ring castration (Kells et al., 2020).

2.4 Producer Barriers Against the Use of Pain Mitigation in Sheep

Strategies to reduce pain include improved management procedures to prevent injury and disease, adoption of alternative management procedures to avoid the use of painful procedures, and increased use of analgesia and anaesthesia (Weary et al., 2006). There is a range of analgesic drugs that could provide some level of analgesia to sheep (Lizarraga & Chambers, 2012; Cohen et al., 2024). Surveys in other countries have identified that many sheep producers do not use NSAIDs (Crawford et al., 2023; Tsekouras et al., 2025)

There are several factors that can limit the use of analgesics in animals:

1. Lack of recognition of behavioural signs of pain (sheep often mask their signs of pain as an antipredator mechanism)
2. Withdrawal periods before slaughter or use of milk are required because of concern over human food safety due to residues in the food
3. Lack of availability of suitable drugs for sheep
4. Treatment costs (in addition to drug costs there are labour costs associated with administration) versus benefits (uncertain production benefits and too few studies that suggest a reduction in suffering)
5. Risk of misuse of drugs by humans, regulation of controlled drugs, and increased administrative requirements restrict the availability of analgesics to producers
6. Lack of approved drugs for use in sheep, thereby requiring extra-label use of analgesics
7. Route and frequency of administration of some drugs require trained personnel
8. Delay between the time of drug administration and the onset of analgesic activity
9. Adverse effects of some analgesics
10. Concern that reduced pain will result in further damage to an injured area

(Anil et al., 2005; Coetzee, 2013).

There are major regulatory and cost implications associated with the authorization of drugs, such as analgesics for use specifically in sheep (McKellar, 2006). Under the Cascade system, drugs authorised for use in other food-producing animals may be prescribed for sheep by a veterinarian, on a case-by-case basis for the protection of animal welfare. When veterinarians use off-label drugs they need to obtain conservative information on withdrawal periods to avoid residues in human food and be satisfied that the toxicity risks are acceptable. These concerns may limit the quantities of analgesics that a veterinarian would prescribe for use at any one time by a producer (Cook, 2011). The potential toxic effects of an overdose of an NSAID can include renal and gastrointestinal toxicity and inhibition of blood clotting (Lees et al., 2004).

A lack of treatment guidance and industry promotion was found to be a major limitation on the use of analgesics in a survey of Northern Irish sheep producers (Crawford et al., 2023). In some countries there is information in a format suitable for use by producers on pain control in sheep (Scott, 2012; Manteca et al., 2017; MLA, 2020). Discussion between producers and veterinarians on the best methods for providing pain mitigation in sheep is reported to be an essential component of the use of analgesics in sheep (Crawford et al., 2023). In Canada, the existing requirements in the sheep Code of Practice do not require the use of analgesia for all painful procedures on sheep. The absence of strict animal welfare legislation that requires the use of analgesics on sheep farms together with inadequate enforcement may also affect analgesic use.

2.5 Future Research Needs

- **Management strategies to prevent the need for painful procedures warrant further research to determine the impact of these practices, as well as to identify their generalizability to varying populations (i.e., commodity/animal production sector, breed, climate).**

- **Further research (i.e., clinical trials) surrounding use of NSAIDs in sheep is needed, particularly for painful conditions including lameness, mastitis, infectious diseases, and dystocia. While some research has explored the impact of dystocia on pain in the ewe as well as mothering behaviour and bonding, further research could also explore pain in lambs born to ewes that experienced dystocia.**

- **For painful procedures and conditions, strategies in addition to the use of anaesthesia and analgesia for reducing pain should be explored, including the impact of mothering and social dynamics and other environmental stressors.**

- **More practical delivery methods for pain relief (e.g., needleless injectors, oral or transdermal administration) should be investigated, as well as a better understanding of barriers to pain control use within the Canadian sheep industry. There is a need for research on how to overcome barriers to the use of pain mitigation on sheep farms.**

- **Research exploring best management practices to control lameness in total or partial confinement housing is warranted, including identifying best practices for preventative practices in these flocks.**

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3 Endoparasitic and Ectoparasitic Infection

Conclusions:

1. **Endoparasites can cause disease and injury that affect the physiological function and the affective state of sheep.**

2. **Ectoparasites can transmit a variety of pathogens, and cause injury, toxic effects, irritation, and anemia.**

3. **Both ecto and endoparasites can cause a loss of condition and reduced vigour.**

4. **Selective treatment strategies and consideration of refugia (the population of parasites not exposed to dewormers) are important aspects of parasite management for gastrointestinal nematode (GIN) infection.**

5. **Ensuring appropriate dosing, storage of drugs, and calibration of dosing guns and avoiding long-acting therapies are important to slow the development of anthelmintic resistance.**

6. **As risk factors vary between farms, selection of antiparasitic drugs and strategies of use should be developed individually with the flock's veterinarian.**

7. **GIN resistance is moderately heritable with potential for genetic selection both through clinical parameters (e.g., fecal egg counts [FECs], FAMACHA) and salivary IgA testing (CarLA® Saliva Test).**

8. **Integrated parasite management combining genetics with proper prevention and treatment strategies is essential for sustainable control.**

9. **Ensuring adequate dietary protein is protective against the effects of *Haemonchus* infections in lambs.**

10. **Grazing strategies should consider level of contamination, animal risk, and environmental conditions.**

3.1 Potential Welfare Implications of Parasites

Some parasites can cause disease, illness, and injury that affect the physiological function and the affective state of sheep. Illness in sheep can cause a range of negative feelings, such as pain, suffering, sickness, and discomfort. Understanding the pathophysiological mechanisms of parasitic disease provides a biological basis for interpreting potential impacts of the parasites on the welfare of sheep. The pathophysiology of a disease describes the alterations in normal function that occur as a consequence of disease. When cells are injured due to a disease, there are changes in the structure and function of tissues that are responsible for the development of clinical signs and feelings of illness (Cockram & Hughes, 2018).

Some pathophysiological changes due to parasites may not be severe enough to cause (a) recognizable impairment of function, (b) clinical signs, and/or (c) changes in affective states associated with illness. Some diseases resolve, are repaired, or are otherwise combated before they develop into recognizable impairment and severe negative mental states. Other diseases are latent and may remain in the body without overt signs (subclinical disease), or they may develop into clinical disease at a later date. Some parasitic diseases are negligible in their consequences and the sheep might not be aware of the presence of the parasites. Whether parasitic infestation causes disease and injury depends on factors such as the type of parasite, the severity of the infestation, and the immunity, genotype, health, nutrition, and physiological condition of the sheep (Stear et al., 2003).

The biological mechanisms responsible for many of the adverse effects of parasitic disease on an animal have their basis in the inflammatory responses to disease and their subsequent effects on the brain. Parasites can cause varying degrees of tissue damage, inflammation, immune responses, an acute phase response, sickness, discomfort, anorexia, weight loss, and weakness (Kyriazakis et al., 1998; Colditz, 2003; Williams, 2011; McRae et al., 2015).

3.1.1 Endoparasites

- Protozoa, such as cryptosporidia and coccidia, can damage intestinal epithelial cells in young lambs and cause diarrhea, anorexia, and abdominal pain (Fresán & Pliego, 2021)

- Enteric parasitic roundworms or nematodes, such as *Haemonchus*, *Teladorsagia* and *Trichostrongylus* species, can cause disease and affect welfare by:
  - mechanical obstruction of ducts and the gastrointestinal tract
  - sucking blood and causing anemia, e.g., *Haemonchus contortus* (Baker et al., 1959)
  - damaging the lining of the abomasum and reducing the secretion of acid and enzymes (Holmes, 1987)
  - causing parasitic gastroenteritis. The diarrhea is caused by a combination of malabsorption of digesta, water and electrolyte secretion due to damaged villi in the small intestine, reduced digesta transit time, mucosal immune responses and inflammation that increase gut permeability to fluids, plasma and mucins, and from changes in the composition of the gut microflora (Stear et al., 2003; Cortés et al., 2020; Jacobson et al., 2020)
  - debilitating sheep by consuming digesta and the lining of the digestive tract, and sometimes hemorrhage of the gastrointestinal tract. In addition, the nematodes can cause inappetence and protein loss (from leakage of plasma protein and damage to the lining of the gastrointestinal tract). This reduced nutrient energy intake can lead to weight loss (Holmes, 1987). If anemia develops, this can cause weakness (Flay et al., 2022). If sheep have a heavy parasite burden, they have to allocate energy to tissue repair and an immune response. The overall effect of this reduced availability of energy is that sheep parasitized by nematodes can show less complex behavioural activity and reduced activity compared with those treated with an anthelmintic (Burgunder et al., 2018; Ikurior et al., 2020; Reeves et al., 2024; Hempstead et al., 2023; Högberg et al., 2021).

- Lungworms (*Dictyocaulus* and *Muellerius* species) can be present in the bronchi of the lungs. They can cause coughing, weakness, loss of condition, and difficulty breathing (Panuska, 2006)

- Liver fluke (*Fasciola hepatica*) can cause disease as a consequence of migrating flukes damaging liver structure and function. This can result in weight loss, anemia, and hypoproteinemia (Stuen & Ersdal, 2022)

- Tapeworms (*Moniezia* or *Thysanosoma*) do not normally cause serious problems unless they are present in large numbers, when they can cause weight loss and intestinal obstruction (Elliott, 1986).

3.1.2 Ectoparasites

External parasites can transmit a variety of different types of pathogens, cause direct damage, toxic effects, irritation, anemia, allergy, and a general loss of condition.

- Sheep infested with ked (*Melophagus* sp.) can lose condition and become anemic as a consequence of the insect sucking blood through the skin and causing irritation (Small, 2005; Plant, 2006)

- Ticks (Ixodidae) can attach to sheep to obtain blood. They can cause irritation, infection, anemia, and potentially transmit a variety of viral, bacterial, and protozoal pathogens (Cortinas & Jones, 2006; Torina & Caracappa, 2012)

- Mosquitoes, black flies, biting midges, sandflies, horse flies, deer flies, and stable flies can cause bites and irritation. Some transmit viruses. The common house fly, *Musca domestica*, can transmit bacteria such as *Salmonella* species (Cortinas & Jones, 2006)

- Biting (*Damalinia* species) and sucking (*Linognathus* species) lice can cause irritation that can result in rubbing, scratching and biting, anemia, and reduced rest and eating (Cortinas & Jones, 2006)

- The sheep nasal fly (*Oestrus* species) deposits its larvae directly on or near the nostrils of sheep. The larvae then move into the nasal passages and sinuses, causing irritation (Cortinas & Jones, 2006)

- Blowflies (*Lucilia* and *Calliphora* species) can lay their eggs on sheep, and the larvae burrow into the flesh and can cause a toxic effect due to ammonia secretion. Sheep fly strike (myiasis) is a painful condition associated with inflammation, irritation, and sometimes death (Wall & Lovatt, 2015). Sheep can experience fever, reduced feed intake, and have raised plasma concentrations of cortisol, cytokines, and acute phase proteins (Colditz et al., 2005; Shutt et al., 1988). Surgical procedures, such as tail docking and mulesing, that have been used to reduce the risk of fly strike, can themselves cause pain (Plant, 2006)

- Mites can cause an allergic, exudative dermatitis. Mange (sheep scab) caused by *Psoroptes* species is not present in Canada but has the potential to cause intense irritation. Other species of mites can occasionally affect sheep in Canada (Cortinas & Jones, 2006). Irritation from mites causes rubbing that increases in severity as the condition spreads. In sheep, reduced feeding and resting can occur with subsequent emaciation and systemic bacterial infections (Berriatua et al., 2001; Corke & Broom, 1999; Milne et al., 2008).

If the control of external parasites requires the sheep to be handled, dipped, or sprayed, this can cause stress, and dipping can result in bacterial infections (Plant, 2006; Hargreaves & Hutson, 1990).

3.2 Use of Chemicals/Drugs to Control Parasites

In general, parasite control programs include appropriate use of anthelmintic drugs, but it is important to note that all control programs also require other aspects of control, including monitoring and selective treatment, quarantining of new introductions, investigation of treatment failure, and pasture management to control the level of contamination (Menzies, 2019).

3.2.1 Gastrointestinal Nematodes (GIN)

Low levels of parasite challenge may have little impact on productivity or welfare and enable the animals to develop immunity; thus, the goal is to have limited exposure of naive animals to infective larvae, allowing low-level challenge to occur (Sargison, 2011). Exposure to higher numbers of infective larvae can cause clinical disease and mortality in both lambs and mature sheep, although naive lambs are at higher risk (Menzies, 2019).

While seasonal GIN burdens will somewhat vary depending on temperature and humidity, a study done in Ontario and Quebec showed GIN FECs peaking in spring for ewes and summer for lambs, with pasture larval counts peaking between summer and fall, depending on specific area weather conditions (Mederos et al., 2010). Winter kill of *Haemonchus* has historically been seen in Canada (Swales, 1939; Falzon et al., 2014); climate change has impacted this occurrence in many areas and should be taken into account when developing parasite control plans.

3.2.1.1 Chemicals and Drugs Used to Control GIN

Anthelmintics used to treat GIN consist of the broad spectrum categories of macrocyclic lactones, benzimidazoles, imidazothiazoles, spiroindoles, and amino-acetonitrile derivatives, and the narrow spectrum anthelmintics closantel (effective against *Haemonchus contortus* and *Fasciola hepatica*) (Menzies, 2019). The oldest of these categories has only existed since the 1960s (benzimidazoles), and due to the length of time related to the process of anthelmintic drug discovery, it is unlikely many new categories will be discovered (Sargison, 2012). This is of note, as there is widespread resistance of GIN to many different anthelmintic classes throughout the world (Sayers & Sweeney, 2005; Sargison, 2011; Arsenopoulos et al., 2021; Höglund & Gustaffson, 2023), as well as within the Canadian sheep flock, with several studies showing high levels of anthelmintic resistance (Mederos et al., 2010; Barrere et al., 2013; Falzon et al., 2013a; Westers et al., 2017).

Copper oxide wire particles as a treatment have been studied for efficacy against GIN, and while some efficacy has been seen for *Haemonchus*, the results are less consistent for other GIN. However, the utility of this product is questioned as sheep are very susceptible to copper toxicity (Torres-Acosta & Hoste, 2008). Additionally, while numerous herbal remedies have undergone several studies assessing their efficacy, scientific evidence is lacking, and concerns exist regarding the variability in biochemical content and the lack of standardization of these products (Torres-Acosta & Hoste, 2008).

Barbervax vaccination (not available in Canada) has been shown to reduce the risk of haemonchosis in lambs, although not of other GIN species (Andronicos et al., 2025).

3.2.1.2 Targeted (Selective) Treatment and Refugia

It is estimated that 80% of a farm's GIN burden occurs in 20–30% of animals (Arsenopoulos et al., 2021). If alleles for resistance are within the parasite population, increased exposure of GIN to anthelmintics speeds the development of resistance (Sargison, 2011). Therefore, selective treatment (rather than blanket treatment) helps focus therapeutic dosing on individual animals likely to have a larger worm burden and/or that are clinically impacted, while preserving refugia in the untreated animals. At least 10% of a group should be left untreated (Arsenopoulos et al., 2021), although higher percentages, if possible, will further slow resistance development (Höglund & Gustaffson, 2023). Selective treatment (only treating animals likely to be clinically affected) at lambing, based on age, BCS, and FAMACHA (Faffa Malan Chart) score, compared to blanket treatment, reduced the number of animals treated in an Ontario study by 47% (Westers et al., 2017). These animals (poor BCS, higher FAMACHA, as well as those carrying multiples) are more likely to have higher periparturient egg rises (Högberg et al., 2021; González-Warleta et al., 2025). In the Ontario study, no differences were seen in the percentage of treatments needed during the grazing season, or percentage of parasitism deaths (Westers et al., 2017). Therefore, refugia can be maintained in the population while still achieving the same clinical outcomes, as well as reducing the cost of treatments. During the grazing season, using FAMACHA scoring can help ensure only sheep clinically affected by *haemonchus* are treated, to help preserve refugia and identify flock level problems prior to severe disease or death loss (Torres-Acosta & Hoste, 2008; Menzies, 2019; Zajac & Garza, 2020). Similarly, for other GIN infections, treating lambs based on growth rate (Crilly, 2023) or dag score (Menzies, 2019) can help select treatment for animals more likely to have larger parasite burdens.

Consideration of the pasture contamination is also needed, as dosing and moving to sterile pasture increases the speed of resistance development in the parasite population, compared to dosing and moving to contaminated pasture, or moving then dosing (Torres-Acosta & Hoste, 2008; Höglund & Gustaffson, 2023). By allowing animals to become reinfected with low numbers of parasites susceptible to anthelmintics (dosing and moving to contaminated pasture) or moving and then dosing (allowing pasture to be contaminated by susceptible parasites ahead of treatment) increases the proportion of susceptible parasites in the population. Planning strategies with the flock veterinarian is essential to help control farm level burdens and preserve refugia.

Record keeping is also essential, as animals who repeatedly require anthelmintic treatment (e.g., score 4 or 5 on FAMACHA) should be culled, which will help reduce the environmental burden from these animals (Menzies, 2019).

3.2.1.3 Drug Selection and Use Strategies to Avoid Resistance

When anthelmintics are given, resistance risk can be reduced by also avoiding under dosing animals. Weighing animals (or weighing the heaviest in a group), calibration of the drench gun, proper calculation of drug dosage, and appropriate drug administration and storage are recommended (Menzies, 2019; Höglund & Gustaffson, 2023). Long-acting anthelmintics are associated with increased resistance risk, and should be avoided (Sargison, 2011; Menzies, 2019). Use of narrow-spectrum anthelmintics where possible is recommended to slow resistance (Sargison, 2011). Holding off feed for 24 hours prior to drenching can slow the rate of passage which can allow for better absorption of the drug (Sargison, 2011; Menzies, 2019), although some studies have shown this may not occur if sheep were fasted after grazing lush pastures (Sargison, 2011), emphasizing the need for individual farm-based development of parasite control plans in consultation with the flock veterinarian. A 2010 study in Ontario found that blanket treatments were common, as well as failure to calibrate drench guns prior to use (Falzon et al., 2013b). While use of multiple anthelmintic classes at once may increase efficacy if there is resistance to either drug alone (Zajac & Garza, 2020), this practice can also speed the development of multi-drug class resistance (Menzies, 2019). As there are multiple factors influencing drug selection and use which vary by farm, a specific parasite control program for an individual farm should be developed with the flock's veterinarian.

3.2.2 Trematodes (e.g., Liver Flukes)

Part of liver fluke control includes the use of anthelmintics to suppress egg output and control pasture contamination, but it also should involve grazing management to avoid contact of the infectious organisms with susceptible hosts, as well as drainage of pasture to reduce egg hatching and survival of free-living stages (Sargison, 2011). While all anthelmintics effective against liver flukes will work against adults in the bile ducts, they differ in efficacy for immature flukes within the liver (Sargison, 2011). Resistance to anthelmintics has been seen, and so using a holistic approach, including environmental management, feedback from slaughter plants (to identify liver damage), and targeted treatments appropriate for the estimated stage of infection are important to consider (Colston & Mearns, 2023).

3.2.3 Coccidiosis

Clinical coccidiosis is typically a disease only of youngstock and is related to the level of environmental contamination with oocysts as well as host immune function (Menzies, 2019). Coccidiostats may be used to control infection, but require adequate intake prior to infection (Menzies, 2019). Toltrazuril can be used metaphylactically, that is, administered to a group of animals that do not show any evidence of disease but are at risk of developing the disease (Mundt et al., 2009; Menzies, 2019), with some evidence for therapeutic use (Mundt et al., 2009). Metaphylactic use of toltrazuril requires knowledge of the epidemiology of the infection on a given farm (Odden et al., 2018; Menzies, 2019). Amprolium and sulfonamides may be used as treatment for coccidiosis (Menzies, 2019).

3.2.4 Cysticercus ovis/Taenia ovis

Treatment of farm dogs every 4–6 weeks with cestocides and proper disposal of deadstock have been part of a program in New Zealand which has reduced condemnation rates due to *C. ovis* in lambs (DeWolf et al., 2014). An Ontario study has shown associations between farms which allow dogs to scavenge deadstock, as well as those failing to dispose of deadstock, and increased condemnations in lambs due to *C. ovis* (DeWolf et al., 2012).

3.2.5 Ectoparasites

For chorioptic mange, keds, and lice, the goal of treatment should be eradication of the parasite from the flock, as the parasites will only survive a short time off the host (Plant & Lewis, 2011). Topical application of synthetic pyrethroids or insect growth regulators for lice can be effective when done along the backline within 24 hours of shearing (Plant & Lewis, 2011). Formulations made for long wool application can help control infestations but will not eradicate lice in sheep with long wool (Plant & Lewis, 2011). Dusting is not considered effective for lice, and dipping may not be effective if sheep are not wet to the skin (Plant & Lewis, 2011). Macrocyclic lactones can be effective against ectoparasites (Plant & Lewis, 2011), but there is a risk that use of this drug for ectoparasites will speed the development of GIN anthelmintic resistance.

3.3 Genetic Selection for Resistance to Parasites

Multiple studies demonstrate that gastrointestinal nematode (GIN) resistance is heritable and influenced by multiple genomic regions (reviewed by Sayers & Sweeney, 2005; Karlsson & Greeff, 2012; Cunha et al., 2024). For example, Willoughby et al. (2024) found liver transcriptome changes linked to infection, identifying candidate genes (e.g., ALAS1, TAT) tied to metabolic and immune responses. Genome-wide studies further pinpoint specific loci: Karrow et al. (2014) identified chromosome 20 as strongly associated with worm resistance in Canadian sheep, while Pickering et al. (2015) detected a major signal on chromosome 26 (candidate gene SGCZ) and a dagginess-associated locus on chromosome 15 in New Zealand sheep ("dagginess" referring to fecal soiling in the crutch area).

A meta-analysis estimated a global heritability of approximately 0.25 (95% CI = 0.22–0.27) for GIN resistance, which was stable across breeds and environments (Hayward, 2022). A narrative review also reported heritabilities in individual studies ranging from 0.00–0.46 for fecal egg count (FEC) and 0.07–0.37 for hematological and immune traits related to GIN resistance (Cunha et al., 2024). Karlsson & Greeff (2012) emphasized moderate heritability for both fecal egg counts and dagginess. In a meta-analysis, Hayward (2022) also showed a positive correlation (+0.10) with resistance to GIN and performance (which included studies assessing impact on weight, weight gain, BCS, wool traits, lambs born, lamb weights, or lamb growth), although specifically selecting for immune markers (as opposed to FECs and FAMACHA) can sometimes trade off with productivity.

Although selection for resistance to parasites is beneficial, some trade-offs with productivity exist. Douhard et al. (2022) found that resistance carried a small cost, with these ewes having lower body weight during the first gestation. These costs appear minor when nutritional needs are met and are likely outweighed by long-term benefits. Hayward (2022) also found that adaptive immune markers were unfavourably related to performance traits, whereas lowered FEC and FAMACHA scores were positively correlated with productivity.

In addition to selection on clinical parameters (e.g., FECs, FAMACHA), other tools for selection have been proposed. The CarLA Saliva Test (which measures salivary IgA against GIN larvae) has been shown to predict future FECs under Canadian grazing conditions (DeWolf et al., 2025a). In a follow-up study, DeWolf et al. (2025b) showed that dam salivary IgA concentrations were positively associated with lamb growth and negatively with FEC, suggesting potential as a heritable biomarker for selection. Genomic selection is also promising: Pickering et al. (2015) showed accuracy using a 50K SNP chip to predict future FEC within Coopworth sheep, while Karrow et al. (2014) also found genetic variants suitable for DNA-based selection programs in Canadian sheep.

Karlsson & Greeff (2012) reviewed the evidence for genetic influences on coccidiosis, infestation with lice, dagginess, and flystrike, suggesting all may have heritable traits amenable to selection, although more research is needed.

3.4 Grazing Management Strategies and Forage Species to Control Parasites

3.4.1 Grazing Management Strategies

Grazing strategies specifically in relation to timing of antiparasitic drug use is covered in section 3.2.1.2. Pasture contamination with GIN is typically highest for lambs by mid to late grazing season, and adult females in late gestation and lactation (Menzies, 2019). Frequent monitoring and selective treatment both prior to lambing and during the grazing season are important aspects to control, as outlined in 3.1.2. Lambing ewes on pasture is particularly challenging with respect to managing the periparturient egg rise, as well as increased risk of exposing young lambs to high pasture burdens (Menzies, 2019). Consideration of indoor or non-grass-based lambing should be given when space is limited or if there are challenges with respect to parasite management.

Exposing ground to sunlight increases the chance the infectious third larval stage (L3) will be subject to heat and drying (Menzies, 2019; Delmilho & Dias da Costa, 2023). This may be accomplished by dethatching or ploughing and replanting older pastures. Breaking up fecal pellets increases the chance of killing L1 and L2, but facilitates the release of L3 (Menzies, 2019); in a North American study, harrowing did not impact GIN parasitism of grazing lambs (Harris, 2021).

It has been recommended that maintaining higher sward height (> 5 cm) improves safety with respect to L3 migration (Menzies, 2019); however, different heights of higher swards (20 cm vs. 10 cm) have not shown a difference in L3 *Haemonchus* migration (Gasparina et al., 2021). Areas which favour L3 survival include low lying and wet areas (e.g., around water troughs), and these are recommended to be graveled to improve drainage, or fenced off (Menzies, 2019).

Rotating pastures with cattle or horses, or co-grazing can decrease pasture infectivity to sheep (Torres-Acosta & Hoste, 2008; Grace et al., 2018; Menzies, 2019; Joly et al., 2022). Llamas and goats, for the purpose of GIN, should be considered the same species as sheep, as they share these parasites (Torres-Acosta & Hoste, 2008; Menzies, 2019).

If available, low-risk pastures should be used for the most susceptible animals (newly weaned lambs), which include newly seeded or rested pasture or hayfields, or annual pastures ploughed under at the end of each season (Menzies, 2019).

Almost all rotational grazing systems require flocks to return repeatedly to the same pasture in the same grazing season. As such, consideration of L3 survival time with respect to temperature and humidity should be given (Torres-Acosta & Hoste, 2008; Menzies, 2019). Animals should be moved before eggs hatch into L3 and should not return until L3 have died (Torres-Acosta & Hoste, 2008; Menzies, 2019). L3 may survive for weeks or months in moist, warm conditions. As such, it is challenging to predict when a pasture is lower risk. Specific evasive grazing strategies (those developed with knowledge of larval development given local conditions) exist in other countries, but local models of Canadian regional geography and weather to predict L3 burdens do not exist.

Heavily contaminated pastures should be considered for ploughing and reseeding, used for hay, or grazed with another species (Menzies, 2019). Stored manure also reflects a risk if not well-composted and is recommended to only be spread onto fields prior to ploughing or cropping (Menzies, 2019). If heavily contaminated pastures are to be grazed, there is a reduced risk if non-lactating ewes not in late pregnancy are used at a lower stocking density and with rapid rotation, although routine monitoring should be done (Menzies, 2019).

3.4.2 Impact of Nutrition on Parasitism

Ensuring dietary needs are met can directly impact parasitism: increasing protein (by either supplemental feed or grazing lambs on newly sown pasture) can improve *Haemonchus* resilience in lambs (lower FAMACHA score and higher PCV) compared to not supplementing or grazing older pastures (Campbell et al., 2021). Increased protein intake around parturition can alleviate the periparturient egg rise and therefore help reduce spring pasture contamination (Marley et al., 2005; Torres-Acosta & Hoste, 2008). Indeed, ewes grazing a higher protein sward showed reduced FEC and increased PCV during lactation (López-Leyva et al., 2022). Poor nutrition, including trace mineral deficiencies, reduces immune function and increases susceptibility to disease (Crilly, 2023). This impact of nutrition on immune function may be indirect, related to the nutritional modulation of the sheep immune response, or may be direct from intake of plant secondary metabolites (see section 3.4.4) (Ishaq et al., 2023).

3.4.3 Nematophagous Fungi

Nematophagous fungi are microorganisms adapted to live in various soils, feeding on parasitic larvae through numerous mechanisms (predatory, ovicidal, endoparasites of larvae, or producers of toxic metabolites) (Delmilho & Dias da Costa, 2023). While these fungi have potential application in small ruminant parasite management, environmental temperature and humidity can cause challenges with implantation in the environment (Delmilho & Dias da Costa, 2023). To our knowledge, these have not been investigated in the peer-reviewed literature for sheep production in Canada.

3.4.4 Bioactive Forages

Bioactive forages include chicory, sulla, sainfoin, and birdsfoot trefoil, which contain condensed tannins (Crilly, 2023). These condensed tannins may act directly on GIN in the gastrointestinal tract to damage the cuticle and reduce egg hatching or may act secondarily impacting the immune response to GIN infection (Crilly, 2023). Additionally, the structure of these plants may inhibit larval migration (Crilly, 2023). Grazed lotus (birdsfoot trefoil) showed restricted migration of L3 to the upper stratum of the plant, potentially decreasing infection risk (Garcia-Méndez et al., 2002). The use of these species has been studied in both monocultures and multispecies mixes (herbal leys).

When compared to a clover/grass mix, use of an herbal ley (which has a higher macro and micronutrient content, specifically selenium and cobalt) showed 78% lower FECs in a UK study on grazing lambs (Cooledge et al., 2024). Several studies have evaluated chicory (at 50–90% of total sward dry matter), which appears to reduce GIN counts, although some studies show mixed results between GIN species (Ishaq et al., 2023). A narrative review concluded that in in vivo studies in sheep, goats, and deer, plants containing condensed tannins need to be fed at a minimum of 3–4% total dry matter to observe antiparasitic activity (reduced FECs) (Rodríguez-Hernández et al., 2023).

3.5 Future Research Needs

- **Models for Canadian regional climate conditions used to predict L3 burdens in real time could help inform specific evasive grazing strategies for Canadian sheep farmers.**
- **Surveillance data on parasite burdens and resistance across Canadian sheep farms could help monitor changes in profiles and/or response to improved practices.**

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4 Neonatal Care

Conclusions:

1. **Lamb mortality can be associated with significant welfare impacts on the lamb prior to death: it indicates that surviving lambs may also have been exposed to aversive conditions and that mortality could impact ewe welfare. A reduction in the lamb mortality rate remains an important goal to improve sheep welfare. Uptake of existing scientific knowledge in farm would help to improve survival.**

2. **The bond between the ewe and her lamb is vital for ensuring early ingestion of colostrum in the lamb. Colostrum intake is the single most important factor in ensuring lamb survival.**

3. **The factors underlying the development of a successful bond are well known: ensuring good ewe nutrition in pregnancy and providing a safe and quiet lambing environment that allows the appropriate maternal behaviours to be expressed.**

4. **Although early weaning and artificial rearing of lambs may be unavoidable in some systems, early weaned young lambs show deficits in immune function, development, and growth, which are not seen when lambs are weaned at later ages.**

5. **Further research to understand improved weaning methods in sheep and whether the impacts of mother separation can be mitigated by improved nutrition or other husbandry actions are required.**

4.1 Scope

The previous Scientific Committee report (Cockram et al., 2012) on neonatal care covered dystocia in some detail, neonatal lamb survival with consideration of the development of the Starvation, Mismothering, Exposure Complex (SME), and the impact on the welfare of the lamb of artificial rearing and weaning. This review will update those areas with research conducted since 2012 and provide a more detailed overview of the development of the ewe–lamb relationship and its importance for ewe and lamb welfare. Fostering methods and their success in achieving good outcomes for lamb welfare will also be discussed. Dystocia and its impact on pain in the ewe and lamb is covered elsewhere (see section 2) and will be considered here only as a contributory factor in lamb mortality or ewe–lamb bonding.

4.2 Lamb Survival

Rates of lamb mortality have been presented in many studies, and there is good agreement that average lamb mortality of 15% is common in most sheep producing countries (Dwyer et al., 2016). This figure has remained largely unchanged, at least in the scientific literature, over many decades, despite improved understanding of the causes of mortality, ewe–lamb relationship formation, and genetic studies of lamb survival (e.g., Dwyer, 2008a; Brien et al., 2010; Hølmoy et al., 2017; Shiels et al., 2021; Nel et al., 2021; Bunter et al., 2023). However, there is significant variation between farms, with survival of lambs reportedly as high as 100% on some Canadian farms or as low as 70% on others (Ratanapob et al., 2020). Similarly, between farm variation in lamb survival have been reported in the UK (Gascoigne et al., 2017), New Zealand (Forrest et al., 2006), and Australia (Refshauge et al., 2015). Thus, although it is possible to achieve high levels of survival in practice, most farms still fall within the range of 10–25%. Analysis of lamb mortality related to disease led Fragkou et al. (2010) to suggest that lamb mortality should be as low as 3% with an upper acceptable limit of 5%, although very few farms currently achieve this. Elsewhere, achievable targets for lamb mortality are considered to be less than 14% from scanning to sale (Gascoigne & Davies, 2019). A reduction in the percentage of lamb mortality is an important welfare goal. Depending on the cause of death, lambs that die likely experience a range of unpleasant states, including hunger, sickness, and pain before they die. Some lambs will also experience breathlessness and hypothermia (Mellor & Stafford, 2003; 2004).

Newborn lambs are at risk of hypothermia when exposed to cold, wet, and windy conditions, which rapidly deplete body reserves (Slee et al., 1980), and the risk is reduced if they are provided with shelter (Gregory et al., 1999). In some countries which experience very cold winters (e.g., Scandinavia, Canada), sheep may almost exclusively be housed at lambing time. In other countries, some sheep may be housed at lambing (e.g., about 50% of sheep flocks in the UK are housed for lambing), or this may occur very infrequently (e.g., New Zealand, Australia). In milder climates where outdoor lambing is common, although housing of ewes at lambing time is often considered to be beneficial in improving lamb survival, data on lamb survival figures do not show a large increase in survival of lambs born in more intensive, indoor, lambing systems compared to extensive systems lambing outdoors (e.g., studies in outdoor lambing flocks report mortality rates of 8–15% in the UK, Australia, and New Zealand: Everett-Hincks et al., 2005; Sawalha et al., 2007; Brien et al., 2010; Hay et al., 2025a; studies in indoor lambing flocks in UK and Ireland report rates of 9–19%: Binns et al., 2002; Keady et al., 2009; Shiels et al., 2025). However, these studies are not directly comparable as different breeds are used and more vulnerable animals may be housed. Comparison of the same breeds lambed indoors and outdoors suggested improved neonatal survival in indoor systems compared to outdoor, but this difference had disappeared by weaning (Hay et al., 2026). Lambs are, however, more likely to die of different causes outdoors compared to indoors. In a meta-analysis of 11 studies in Australia and New Zealand (Bruce et al., 2021), proportionately most lambs died from dystocia (47%, 95% Confidence Interval [CI]: 38, 55) as either the primary or secondary cause of mortality (including stillbirths and postnatal births with evidence of hypoxia as related to dystocia). The rate of dystocia as the main cause of lamb death was 53% (95% CI: 47, 60) in Australia and 35% (95% CI: 19, 51) in New Zealand, perhaps related to the selection pressure against lambing difficulty in the latter country. In studies using postmortem data to allocate cause of death, infectious disease has been found to be an important cause in indoor lambing flocks (e.g., 36% in Norwegian flocks: Hølmoy et al., 2017; 22–34% in Irish flocks: Shiels et al., 2025), with 12–50% of lamb deaths attributed to dystocia (Hølmoy et al., 2017; Shiels et al., 2025). However, for outdoor lambing flocks, the starvation–mismothering–exposure complex (SME) becomes more important (accounting for 25–34% of lamb deaths in Australia and UK: Refshauge et al., 2015; Clune et al., 2021; Hay et al., 2025a), with stillbirth, birth injury, and dystocia also considered important causes.

Many studies have attempted to assess the genetic components of lamb survival as a means of reducing lamb mortality. Overall, the heritability of lamb survival is very low (ranging from 0.01–0.18 across different studies (Brien et al., 2010; Sawalha et al., 2007; Hay et al., 2025a), perhaps because the trait is made up of a number of factors that may be genetically antagonistic for survival (e.g., heavier lambs have higher risks of dystocia but improved ability to resist the cold; Bunter et al., 2023). Selection for individual causes of lamb mortality suggest that there may be some scope in selecting for related traits (such as optimal birthweight: Bunter et al., 2023; deaths from dystocia or lambing ease: MacFarlane et al., 2010; Matheson et al., 2012; Hay et al., 2025a; lamb vigour: MacFarlane et al., 2010; Matheson et al., 2012) but heritability of death from SME does not have a heritability significantly above 0 in several studies (Everett-Hincks et al., 2014; Hay et al., 2025b). Deaths from SME appear to have a large environmental component, with the weather on the day of birth and lamb body reserves being important (Pollard, 2006; Plush et al., 2016; Horton et al., 2018; Cloete et al., 2023) as well as the quality of the ewe–lamb relationship.

4.3 Ewe–Lamb Relationship

Lambing and the onset of maternal care is a crucial period in the life of the lamb and has a significant impact on the success of the lambing period. Prior to the birth of a lamb, most ewes are indifferent to other lambs, and some may be aggressive towards them. However, at birth, even naive ewes which have not given birth before are capable of showing complex and complete expression of maternal care, which appears as the ewe delivers her lamb. The behavioural, physiological, and neuroendocrinological mechanisms underlying the development of the relationship between the ewe and lamb have been well studied (e.g., reviewed by Dwyer 2008b; 2014), and there is now a good understanding of the important factors contributing to a successful bond formation. At birth, the ewe carries out two key functions which contribute to the survival of her lambs (Poindron et al., 2007): firstly she shows nurturing responses towards the lamb that lead to a successful sucking interaction (Dwyer, 2008a), and, secondly, she forms an exclusive olfactory memory for the smell and taste of the amniotic fluids in the coat of her lamb (Keller et al., 2003). Over time the ewe then develops an ability to recognize her lamb through a range of sensory modalities (smell, sight, sound: Alexander & Shillito, 1977). These twin functions of maternal care are of vital importance for lamb survival—the lamb needs to suckle to avoid starvation, prevent hypothermia, and to develop a bond with its mother; the ewe needs to develop an olfactory recognition for her own lamb to maintain maternal care and to avoid lamb rejection. As ewes form exclusive relationships with their lambs, failure of bonding responses means the lamb will die from starvation and hypothermia as no other ewe will look after it. The behaviours associated with these two functions and the underlying physiological triggers are similar but stimulate different neuroendocrinological outputs (Dwyer, 2008b). The onset of maternal care is critically dependent on changes in the circulating concentrations of the steroid hormones progesterone and estradiol in late pregnancy, the neurological signals transmitted to the ewe's brain during labour, and the presence of amniotic fluids in the coat of the lamb.

4.3.1 Endogenous Steroid Hormones

During pregnancy, the ewe produces progesterone and estrogen which work together to maintain pregnancy. Over the second half of pregnancy, circulating estradiol increases exponentially and stimulates the mRNA expression of oxytocin (Broad et al., 1993) and its receptors (Broad et al., 1999) in key tissues in the periphery (mammary glands, uterus) and centrally (e.g., hypothalamic neurones, amygdala). Approximately 48 hours before giving birth, in response to signals from the fetus (e.g., increasing fetal glucocorticoids which interact with the production of prostaglandins from the placenta: Schuler et al., 2018), the concentration of circulating progesterone begins to decline (Dwyer et al., 1999; Dwyer, 2008b), which results in an upregulation of estrogen and an increase in oxytocin receptor numbers. These changes are considered to be "priming" responses, as these are permissive for the expression of maternal care. On their own, changes in the ratio of estrogen to progesterone are not normally sufficient for short-latency maternal care to be shown in ewes (Keverne et al., 1983; Kendrick et al., 1991). However, studies manipulating these hormones demonstrate that maternal care cannot be elicited in non-pregnant ewes if they have not first been pre-treated with progesterone and estrogen (Kendrick & Keverne, 1991). This demonstrates that these changes in endogenous hormone concentration in late gestation are essential for maternal care to be expressed at birth, but they require additional physiological mechanisms for maternal care to be elicited.

4.3.2 Neurological Inputs

As the ewe begins labour and the lamb moves through the birth canal, the walls of the vagina and cervix are stretched and neural inputs via the vagal nerve signal the process to the ewe's brain (known as the Ferguson Reflex). This stimulates the release of oxytocin from the centrally projecting neurones of the paraventricular nucleus of the hypothalamus (Da Costa et al., 1996), which is communicated to different centres in the brain: particularly to the amygdala and the olfactory bulb. Stimulation by oxytocin, binding to the receptors produced by changes in the steroid hormone levels in late pregnancy, acts as a "switch" for the onset of maternal behaviour (Kendrick et al., 1987; Lévy et al., 1992). The importance of this part of the sequence has been demonstrated by studies which gave ewes an epidural, which prevents this signal reaching the brain, where ewes showed no interest in their lambs (Krehbiel et al., 1987; Lévy et al., 1992). In addition, non-pregnant ewes, appropriately primed with estrogen and progesterone, can show maternal behaviour when given artificial stimulation of the birth canal to mimic the stretching that occurs during birth (Kendrick & Keverne, 1991). Finally, intracerebroventricular infusion of oxytocin will induce maternal behaviour in non-parturient ewes (Kendrick et al., 1987).

4.3.3 Amniotic Fluid

Ewes normally find amniotic fluids repulsive and will avoid eating from troughs where these have been placed (Lévy et al., 1983) and the birth sites and lambs of other ewes (Poindron et al., 2010). However, under the control of the mechanisms described above, during labour the ewe becomes increasingly attracted to the smell and taste of amniotic fluids—her own when the amnion breaks and fluids are spilt, and sometimes also those of other ewes that may be lambing nearby. The amniotic fluids carry olfactory information about the lamb, and when the lamb is born the ewe transfers her attraction from the fluids spilt on the ground to the coat of her lamb (Dwyer, 2014). This gives specificity to the behaviour, as it is directed only towards her own lamb (Nowak et al., 2007) but can also disrupt the bonding process if the ewe is anosmic (unable to smell) or if the olfactory signal from her own lamb becomes contaminated with that of other lambs (Poindron et al., 2010). It is important, therefore, to allow the ewe time at the birth site to transfer her attraction for the birth fluids to her lamb, and to avoid contaminating the lamb with the amniotic fluids of other lambs. Ewes that spend less time at the birth site or leave the birth site too early have reduced ewe–lamb bonding and a higher risk of lamb death, especially in twin-bearing ewes (Nowak & Poindron, 2006).

4.3.4 Neuroendocrinology

When the lamb is born, following the signalling and oxytocin release caused by stretching of the birth canal, the ewe enters a period of intensive learning where neurotransmitter changes in the olfactory bulb allow her to form an exclusive olfactory memory for her lamb (Lévy et al., 1993; 1995; Keverne et al., 1993). This period is relatively short, lasting only 20–60 minutes after delivery, and if the ewe is not able to interact with her lamb at this time, then she may fail to recognize her own lamb (Poindron et al., 2010). This process is called maternal "selectivity" and is defined as the ewe allowing her own lamb to suckle but rejecting the attempts of other lambs to reach the udder (Poindron et al., 2007). As ewes form exclusive relationships with lambs and then reject all other lambs and prevent them from suckling, this is an important cause of mismothering or lamb abandonment. Studies investigating the time course of maternal bonding suggest that most ewes form an exclusive attachment within 6–12 hours of lambing and all other lambs will then be rejected (Nowak et al., 2011). Ewes need to form a new relationship with each lamb in their litter: lambs are nearly always fraternal (Romeyer et al., 1993) rather than identical twins, and their individual genetic and olfactory signatures needs to be learned by the ewe. Thus, any management actions or interference by other ewes that lead to separation of ewes from their lambs soon after birth are a risk factor for bonding failure. These responses may result in lambs dying from starvation and hypothermia, as the selectivity of the ewe will prevent other ewes from caring for a rejected lamb, or require management actions to deal with the un-mothered lamb.

4.4 Ewe–Lamb Behaviour

4.4.1 Behaviour at Parturition

After birth, the first responses of the ewe to the presence of the lamb are to an intensive period of licking and grooming, which can last up to 2–4 hours after delivery, accompanied by the expression of frequent low-pitched bleats or "rumbles" towards the lamb (Dwyer, 2008a). Licking and grooming behaviour serves several important functions: it helps to clean and dry the lamb, which can be very important in outdoor lambing ewes where wind chill can cause the body temperature of wet newborn lambs to plummet (Pollard, 2006; Plush et al., 2016). Ewes may also remove membranes and fluids from the mouth and nose of the lamb which can help to stimulate breathing. Additionally, the licking and grooming behaviour is the main mechanism by which the ewe learns to recognize the smell of her own lambs. Ewe vocal responses may function to provide reassurance and strengthen the developing relationship between ewe and lamb (Sèbe et al., 2008; Dwyer et al., 1998). The ewe also facilitates the udder-seeking and first sucking responses of her lamb to enable it to find its way to the udder and to suck the first colostrum. Disturbances to the normal onset of maternal behaviour may be expressed by the ewe as a reluctance to allow the lamb to access the udder, through circling or backing movements as the lamb approaches the udder, and aggression or rejection responses (butting and threats), often accompanied by high-pitched vocalisations indicative of distress (Dwyer & Lawrence, 1998; Dwyer et al., 1998).

The behaviour of the newborn lamb is also important to ensure its survival. Lambs are precocious, mobile and active at birth, and able to regulate their own body temperature and so actively contribute to their own survival. Lambs have brown fat reserves located around the major organs and in the scapular region, which possess a unique uncoupling protein that allows the lamb to rapidly generate large amounts of heat by a process called non-shivering thermogenesis (Clarke & Symonds, 1998). This can provide the lamb with sufficient heat to maintain body temperature immediately after birth but requires nutrient energy to keep up the levels of heat production. The newborn lamb needs to replenish those reserves by suckling, so in cold temperatures (particularly if it is also windy or wet) where lambs are rapidly losing heat to the environment, the interval in which the lambs can maintain body temperature before suckling will be very short (Plush et al., 2015; 2016). Behaviourally, the lamb has a sequence of righting, attempting to stand, and standing that can typically be accomplished within 5–15 minutes after birth, although some lambs may take much longer (Dwyer, 2003; Dwyer & Lawrence, 2000a; Dwyer & Morgan, 2006). Once standing, the lamb needs to be sufficiently active to stand, orient towards the ewe, integrate the sources of sensory information from the ewe (such as the differences in texture between the woolly belly of the ewe and the smooth feel of the udder, the smell of the wax produced by the udder), and attach to a teat (Nowak et al., 1997).

Ingestion of colostrum serves a number of vital functions for the lamb. Suckling provides the lamb with nutrition, in particular to fuel the requirements to generate heat and maintain body temperature (Clarke & Symonds, 1998). Suckling also provides the lamb with transfer of passive immunity through absorption of IgG from colostrum. Ewe placentas do not allow for the passage of macromolecules, such as immunoglobulins, thus the newborn lamb is immunologically naive (Nowak & Poindron, 2006). Newborn lambs therefore must acquire immunological protection from their mothers by ingesting immunoglobulins in the first milk or colostrum. For a short period after birth the gut is permeable to the passage of immunoglobulins (and also to other large molecules such as bacteria), and rapid suckling can provide immunological protection. Colostrum also contains growth factors that encourage the gut to close and thus limit the passage of pathogens, such as *E. coli*, which can cause disease in newborn lambs. Finally, suckling also plays a key role in ewe–lamb bonding, helping the lamb learn to recognize its mother (Nowak et al., 2007). Just as the ewe needs to learn to recognize her own lambs, so the lamb also needs to learn to recognize its mother, to be able to stay with her and avoid attempting to suck from other ewes which can lead to lamb injury from the vigorous rejection responses of maternal ewes. Lambs have been shown to be able to discriminate their mother at close quarters using visual and olfactory cues at 12 hours old (Nowak & Lindsay, 1992) or by vocal cues from 48 hours old (Sèbe et al., 2007). Lambs can also distinguish their mothers from another ewe at a distance by 3 days of age, although it took longer for them to discriminate their sibling lambs (Nowak, 1990). In twin lambs, those lambs that spent less time with the dam in the tests at 12 hours old had poorer survival to 7 days of age (Nowak & Lindsay, 1992). Therefore, suckling behaviours and early ingestion of colostrum are vital to lamb survival. Lambs that are slow to stand and suck after birth are vulnerable to the development of hypothermia and starvation, at risk of infectious disease, and may be susceptible to injury or predation if they are poorly bonded to their mothers.

4.4.2 Ewe–Lamb Bond During Lactation

Once the bond between ewe and lamb has been formed, it remains relatively durable and consistent throughout lactation, where short periods of ewe–lamb separation do not cause the bond to fail. Studies of the time course of maternal bonding suggest that ewe–lamb separation of 4 hours at birth will result in only 50% of ewes showing maternal care, and this decreases to only 10% with 24 hours of separation (Poindron et al., 2007). However, ewes which have had 24 hours of contact with their lamb still show maternal responsiveness when separated from their lambs for 24 hours. Ewes are attentive to the presence of their lambs and show greater vigilance (particularly through the expression of the "head up" alert posture where the head is held rigidly above the level of the shoulders) than non-lactating ewes. Ewe and lamb maintain a close spatial relationship, reinforced by frequent suckling interactions, and both partners become distressed when separated, even if visual contact is maintained (Dwyer & Lawrence, 2000a). During the first few weeks of lactation, the ewe allows the lamb to suckle whenever it approaches. Over time, the lamb may spend more time away from the ewe, for example, when playing, although it maintains close contact when grazing, resting, or moving. Around 4 weeks of age the ewe begins to restrict lamb access to the udder to times when she has indicated to the lamb (by vocalisation and/or use of the head up posture) that it may come and suckle (Pickup & Dwyer, 2011). With twin-bearing ewes, the ewe will typically only allow the lambs to suckle when both are present. The ewe then continues to control the dynamics of the relationship although responsibility for maintaining contact shifts to the lamb for the rest of the lactation period.

The natural lactation period in sheep is relatively long, up to 12 months, and this allows for a protracted period of learning by the lamb from the ewe. In a natural situation, the ewe lambs would remain in the natal flock for life, with their mothers and grandmothers. Lambs learn about the social signals used by the flock (such as the "head up" posture which is used to signal possible threats between flock members), social distances (Dwyer & Lawrence, 2000a), food preferences (Mirza & Provenza, 1990; Saint-Dizier et al., 2006), and reactivity to novelty (Coulon et al., 2015). In some farming systems, this transfer of knowledge is used in a system called "hefting," where sheep are kept on unfenced pastures in the UK and information about food, water, and the "home-range" are transferred from mothers to daughters.

4.5 Factors Influencing the Expression of Maternal Care

As described above, the process of ewe–lamb bonding is under maternal physiological control with a cascade of responses occurring in response to different signals which allow the ewe to express the appropriate behaviour at the right time to achieve a strong bond. In addition to expressing behaviours that allow the lamb to suckle, it is also crucial that the ewe learns to recognize her own offspring. However, these responses can be affected by both internal and external factors that can reduce the success of the bond and therefore increase the probability of lamb mortality.

4.5.1 Maternal Parity

It is well known that ewes lambing for the first time are more vulnerable to losing lambs and can show behavioural disturbances (Dwyer, 2008a; Dwyer & Lawrence, 2000b). In ewes, this is characterized by a slower onset of maternal licking and grooming, a high frequency of moving away as the lamb attempts to suckle, leading to prolonged intervals between birth and first ingestion of colostrum, and a high propensity to show maternal aggression and rejection, at least initially. Primiparous ewes are also less efficient in their pregnancies, typically producing smaller and lighter lambs attached to less efficient placentas, smaller litters, and less milk and colostrum (Dwyer et al., 2005). In terms of their neurobiology, primiparous ewes have a lower density of estrogen receptor-α in the hypothalamic and limbic regions of the brain (Meurisse et al., 2005), although circulating concentrations of estrogens are not affected (Dwyer & Smith, 2008), and thus are less responsive to the priming effects of estrogen and progesterone. Inexperienced ewes need the experience of interacting with a lamb in the first pregnancy for their neurotransmitter responses to become mature. Taken together with the behavioural responses, this results in higher mortality and slower growth of the offspring of primiparous mothers. Inexperienced ewes are more dependent on the precise sequence of hormonal events and lamb stimuli to show maternal care than experienced ewes, thus they are also more susceptible to any environmental disturbances (see below). In addition, as most sheep management systems maintain young ewes in peer groups, inexperienced ewes will not have encountered young lambs before, thus fear of novelty may also contribute to their disturbed behaviour. Primiparous ewes will often show similar grooming and bleating responses to multiparous ewes but are more likely to move away as the lamb attempts to suckle after birth, until they become more familiar with the presence of a lamb.

4.5.2 Maternal Genetics

Many studies have demonstrated breed differences in the quantity and quality of maternal care expressed by ewes at birth, which in some cases is also reflected in breed differences in lamb mortality. Overall, the consensus suggests that ewes that are more "rustic," or less selected for production characteristics, are more maternal and show higher and more focused maternal care than those more highly selected for production (Dwyer & Lawrence, 2005). These studies clearly support genetic variation in the ability of the ewe to provide high levels of maternal care for her offspring. Attempts to derive heritability indices for maternal care have been hampered by the lack of good records that accurately reflect the behaviour of the ewes, and in many cases have relied on indirect measures such as Maternal Behaviour Score (O'Connor et al., 1985) or Maternal Assistance Score (Hay et al., 2025b) or the ability of the ewe to rear her lambs to weaning (Cloete & Scholtz, 1998). Some of the indirect measures cannot separate different motivations of the ewe—for example, the Maternal Behaviour Score assesses the willingness of a ewe to approach a human holding her lamb (O'Connor et al., 1985). However, this titrates fearfulness of humans against maternal motivation to remain with her lamb and a highly fearful but very maternal ewe may score more poorly than a confident ewe that is less maternal, and studies suggest poor association with lamb survival (Lambe et al., 2001; Everett-Hincks & Cullen, 2009). Other scores cannot clearly separate the behaviour of the lamb from that of the ewe (e.g., Maternal Assistance Score). This may have contributed to often low levels of heritability of maternal behaviour (e.g., 0.05 for Maternal Assistance Score: Hay et al., 2025b; 0.09–0.20 for Maternal Behaviour Score: Brien et al., 2010; Everett-Hincks & Cullen, 2009; Everett-Hincks et al., 2005; Lambe et al., 2001). However, despite these issues, selection for maternal rearing ability has been associated with altered maternal behavioural responses (Cloete et al., 2002) suggesting there is some genetic control of this trait.

4.5.3 Pregnancy Nutrition

Undernutrition in early pregnancy influences the establishment of pregnancy and maternal recognition of pregnancy through its impact on progesterone secretion and placental development (Abecia et al., 2006; Toschi & Baratta, 2021). The impact on maternal behaviour, however, is mainly related to reduced nutrition in late gestation and does not appear to be influenced by moderate undernutrition earlier in pregnancy. Undernutrition of late-pregnant ewes is associated with impaired udder development and reduced milk and colostrum production (Mellor & Murray, 1985; Mellor et al., 1987; Charismiadou et al., 2000; Bizelis et al., 2000). Undernutrition is also known to cause impairments in maternal behaviour—ewes take longer to interact with their lambs than well fed ewes, spend less time grooming or licking and bleating at their lambs after birth, and appear to be more weakly bonded to their lambs (Dwyer et al., 2003). They also spend less time on the birth site (Putu et al., 1988) and are quicker to return to feeding after birth (Dwyer et al., 2003).

4.5.4 Environment

In a natural setting, ewes will typically move away from the flock in late pregnancy and move to a secluded and isolated part of their home range to give birth (Dwyer & Lawrence, 2005). Even in a paddock with boundaries or with indoor housing, ewes will choose to move to higher ground to lamb or along the fence lines, or in cubicles if offered the opportunity (Gonyou & Stookey, 1985). Clearly, they prefer to lamb in a quiet and secluded place where they will not be disturbed, and there is some evidence that ewes will choose to lamb at times when humans are not present if lambing supervision is intermittent. If disturbed during labour, ewes may delay parturition, which can lead to a prolonged labour with consequences of dystocia and stillbirth (Fisher & Mellor, 2002). As described above, once the ewe is lambing in an indoor system they can be at risk of being moved away from the birth site too early (by other ewes or by management actions), which can disturb the normal process of bonding and lamb recognition. If many ewes are lambing in close proximity, there can also be risks of mismothering as ewes will be attracted to any newborn lamb and may form an olfactory memory for a lamb that is not their own.

In rodent species, psychological stress in pregnancy reduces or abolishes the expression of maternal care, with less maternal grooming accompanying heightened anxiety responses (Patin et al., 2002; Champagne & Meaney, 2006). In sheep, only a few studies have investigated these effects, and the data are rather inconclusive. In a study where sheep were either gentled or handled aversively during pregnancy, an increase in maternal grooming of the lamb was reported in the aversively handled group (Hild et al., 2011). However, other studies looking at transport, social isolation, yarding, mid-pregnancy shearing, or a series of unpredictable chronic mild stressors have shown an increase in anxiety behaviours in some situations (Roussel et al., 2006), but little or no effect on the onset of ewe maternal care (Coulon et al., 2014; Corner et al., 2006) and a small negative effect on maternal bonding responses (Coulon et al., 2014). Social stress induced by restricted space or high stocking for lactating ewes is associated with increased maternal cortisol release and reduced maternal grooming behaviour and suckling durations (Lv et al., 2015). Thus, overall, in most situations, stress in pregnancy, at the levels experienced by ewes in these studies, tends to have only a small direct negative impact on the onset of expression of maternal care.

4.5.5 Dystocia

A difficult birth leads to slower times to stand and lick their lambs in ewes (Dwyer & Lawrence, 2000a), related to exhaustion and potentially the pain associated with assisted deliveries or protracted labour. Ewes that are recumbent for a long time after delivery may not lick their lambs at all during the time period that an olfactory memory might be formed and are thus more likely to fail to bond successfully with their own lambs (Dwyer & Lawrence, 1998). If ewes are delivered by caesarean section, there is a potential risk that the Ferguson reflex may be disrupted (Flint et al., 1978) and the onset of maternal care impaired (Krehbiel et al., 1987). This is, however, unlikely to be the case if the ewe is given a caesarean section following a period of labour when the lamb will have moved into the birth canal.

4.5.6 Ewe Health

Painful conditions, or ill health can have a significant effect on the behaviour of the ewe (Gougoulis et al., 2010), including changing her position in any movement order (Doughty et al., 2018). Few studies have focused on the impact of maternal ill health on the expression of maternal care in sheep, with most studies assessing the impact of maternal care on offspring pain responses. However, patterns of ewe–lamb behaviour are altered by subclinical mastitis (Gougoulis et al., 2010) and lameness. Lambs remained closer to lame ewes, as assessed using proximity sensors (Reeves, 2024). There is some evidence that these observations may reflect changes in lamb rather than ewe behaviour, perhaps indicating hunger in the lamb (Peckler & Adcock, 2025).

4.6 Factors Influencing the Expression of Lamb Behaviour

The coordinated and active expression of lamb standing, udder-seeking, and suckling are critical for lamb survival. The lamb needs to ingest sufficient colostrum to maintain body temperature, as well as the other benefits of colostrum, and early suckling is associated with improved survivability. Even ewes showing high levels of maternal care cannot ensure the survival of a low vigour lamb, and maternal care will start to wane if she does not receive appropriate stimulation from the suckling behaviour of the lamb. Suckling responses and contact between the ewe and lamb lead to oxytocin release and contribute to the continuing expression of bonding behaviours. Lamb behaviour can be affected by intrinsic factors, events occurring during pregnancy in the prenatal period and at birth.

4.6.1 Lamb Genetics

Similar to the studies of breed differences in maternal care, breed, line, and sire differences in lamb behaviour have also been shown (Dwyer & Lawrence, 2000a; Dwyer, 2003). These also demonstrate that the more rustic, less selected lamb breeds are typically quicker to stand and find the udder than lamb breeds that have been more selected for production traits. A study using embryo transfer between breeds demonstrated that this was independent of maternal behaviour and reflected the lambs' behaviour immediately postpartum (Dwyer & Lawrence, 1998). Heritability estimates of lamb behaviours have shown that standing and suckling are under significant control of the lambs' own genetics (MacFarlane et al., 2010; Matheson et al., 2012), suggesting that improved lamb vigour could be a target for genetic selection programs.

4.6.2 Litter Size

Lambs born into larger litters (triplets or more) have significantly higher mortality than singles or twins (Hinch et al., 1985; Dwyer, 2003), and the causes of mortality are different (singles are more likely to die from dystocia and stillbirth, twins from birth injury and SME, and triplets from SME or in utero prematurity: Refshauge et al., 2015). The lower birthweight of lambs born as multiples undoubtedly contributes to their higher mortality, as they will have a larger surface-area to volume ratio and so will lose body temperature more quickly than larger lambs and have lower brown fat reserves (Stott & Slee, 1987; Dwyer & Morgan, 2006). However, triplet lambs are also compromised by their placental insufficiency (Dwyer et al., 2005) and have impaired behavioural and physiological responses compared to single or twin lambs that is in addition to birth weight effects. Further, the ewe typically has only two functional teats and needs to divide her maternal care between three or more lambs. Although the ewe does increase maternal licking with each additional lamb born, later born lambs receive less licking and grooming than earlier lambs (Dwyer & Lawrence, 1998). In studies of mutual recognition, triplet-bearing ewes are capable of discriminating between each of their lambs (Chniter et al., 2017), whereas triplet lambs show deficits in their maternal recognition abilities.

4.6.3 Lamb Sex

Typically, male lambs have been shown to be larger, more likely to experience lambing difficulty, and slower to stand and suckle than ewe lambs (Dwyer, 2003). In tests of separation and reunion with the mother, female lambs were more vocal at separation and left the holding pen to reunite with their mothers more quickly than male lambs (Hernandez et al., 2009). These behavioural differences are reflected in a higher mortality rate in male lambs compared to ewe lambs (Huffman et al., 1985; Southey et al., 2004; McHugh et al., 2015).

4.6.4 Lambing Ease

Lambs born following a short and uncomplicated delivery are quicker to stand and suckle than lambs born following a longer birth process (Dwyer, 2003). Birth difficulty is a significant risk factor for increased lamb mortality (e.g., McHugh et al., 2015), and the impact of a prolonged delivery on behavioural traits undoubtedly contributes to this. Lambs can suffer a range of impacts when experiencing a difficult birth, including hemorrhage around the brain and spinal cord, subcutaneous edema, or rupture of the liver. Assistance to deliver dystocic lambs can also cause limb fractures, broken ribs, and other trauma. A prolonged labour and difficult delivery can cause hypoxia and traumatic injury in the lamb, with over 80% of lambs dying during the course of delivery reportedly having some form of birth injury, and up to 57% of lambs dying from SME (Haughey et al., 1993). An investigation in Uruguay of the central nervous system of 96 single and twin Corriedale lambs dying in the first 6 days of life found that hemorrhages in meninges, brain congestion and edema, neuronal ischemic necrosis, intraparenchymal hemorrhages in medulla oblongata and cervical spinal cord, parasagittal cerebral necrosis, and periventricular leukomalacia were associated with early death (Dutra et al., 2007). No significant lesions were found in anteparturient deaths or in those aged between 7 and 16 days. These authors conclude that lesions in the central nervous system can explain most lamb deaths within the first 6 days of life and were most likely to be associated with birth injury. However, studies in New Zealand (Lashley et al., 2014; n=65 twin lambs) and Australia (Robertson et al., 2020;

n=64) detected hemorrhage in the central nervous systems of lambs that died of several causes, including those without other evidence of dystocia and in lambs that were euthanized, suggesting that this may be a common pathology in many lambs after birth. Extrapolating from human studies, these types of injuries are associated with severe pain (Moussouttas et al., 2006; Schwedt et al., 2006). In neonatal dairy calves, treatment with NSAIDs increased play behaviour (an indicator of improved welfare: Gladden et al., 2019) and standing ability in calves with a low vigour score at birth (Kovács et al., 2022) compared to calves treated with only saline. A study in beef calves suggested that treatment with NSAID improved ADG compared to saline treatment, although no impact on behaviour was observed (Pearson et al., 2019). Similar studies in lambs do not appear to have been carried out.

4.6.5 Environmental Effects

Lambs are born, often into cold or wet conditions, with low fat cover and have a high surface area to body weight ratio, which exacerbates heat loss (Alexander et al., 1973; Labeur et al., 2017). There is a high energy demand to maintain body temperature, and this must be supplied by efficient metabolism of brown adipose tissue and by showing the appropriate standing and suckling responses to obtain milk. Lambs with low body weight, reduced brown fat reserves, and which are slow to stand and suckle are more vulnerable to unrecoverable heat loss to the environment (Slee & Springbett, 1986). The time course of heat loss, particularly evaporative heat loss, can be shortened when the temperature is low and there is high wind chill or precipitation. Deaths on the day of birth were not strongly affected by a high chill index in an Australian study (Horton et al., 2018), but subsequent deaths were significantly influenced by chilling.

Breed differences in lamb ability to maintain body temperature have been shown (Dwyer & Morgan, 2006; Slee & Springbett, 1986) which are related to greater lamb vigour and speed to stand and suckle (Dwyer & Morgan, 2006) as well as physiological differences between breeds (Dwyer & Morgan, 2006; Plush et al., 2015). Lamb vigour and time to stand were shown not to be affected by weather factors (air temperature and wind speed). However, these did impact on the success of udder-seeking responses of lambs (Slee & Springbett, 1986), suggesting that lambs can struggle to suckle quickly in low temperatures. Differences in birth coat (hairy and long vs. short and woolly) suggest that lambs have better survival with long and hairy birth coats (Allain et al., 2014), with less heat loss and improved growth compared to woolly, short birth coats. Lamb birth coat was highly heritable (h^2=0.60–0.88) in different studies (Slee et al., 1991; Allain et al., 2014), suggesting there is potential to improve lamb resistance to cold weather. In Merino sheep, polymorphisms in the β_3-adrenergic receptors have been found which appear to be associated with improved lamb survival (Forrest et al., 2006) and may allow selection for improved cold tolerance (Forrest et al., 2007). In studies that have carried out long term selection for improved ewe rearing ability, lambs from the high survival line had higher rectal temperatures and better survivability with high chill index (derived from rainfall, wind speed, and ambient temperature) than those from the low survival line (Nel et al., 2021).

4.6.6 Prenatal and Epigenetic Effects

Lamb behaviour may be influenced by its prenatal development in utero, either because the interaction has an effect on birthweight, which has been shown to affect lamb behaviour (Dwyer, 2003), or through epigenetic or “programming” effects. These are permanent changes in the expression of the DNA, due to alterations such as methylation patterns, which lead to altered responses in postnatal life, without a change in the genome (reviewed by Sinclair et al., 2016). Studies in rodents, either through manipulation of maternal care or gestational stress treatments, have provided compelling evidence for permanent and significant alteration in offspring responses as adults (e.g., Darnaudéry & Maccari, 2008; Brunton & Russell, 2010; McGowan & Matthews, 2018). This has been shown to affect various tissues and organs, including muscle development, reproductive development, appetite and disease susceptibility, as well as influencing stress reactivity (Sinclair et al., 2016). Rats which experienced stress during prenatal development have an increased hypothalamic–pituitary–adrenal (HPA) reactivity in adulthood, accompanied by high anxiety and depressive-like behaviours, as well as impairments in other behaviours such as memory in some tasks (McGowan & Matthews, 2018). Note that experimental manipulations in rodents often have a more severe stressor than those commonly applied to sheep (e.g., repeated physical restraint lasting up to an hour on each occasion). Theoretically, however, these impacts could also be seen in other mammalian species, including sheep.

Numerous studies have demonstrated a detrimental impact of maternal undernutrition, particularly in late pregnancy, on offspring birth weight, which then has consequences for lamb survival (Rooke et al., 2017). Low birthweight lambs are slower to stand and suckle after birth (Dwyer, 2003), have more difficulty in maintaining their body temperature (Dwyer & Morgan, 2006), and seem to have a delayed ability to discriminate and follow their mother after birth (Dwyer et al., 2016). Each of these deficits will contribute to an increased risk of mortality. Whether low birthweight has longer term consequences for offspring development, as has been shown in human infants, is rather less clear, perhaps because most studies that have investigated the impacts of prenatal nutrition have not had endpoints that extend even as far as weaning. There is some evidence for increased mortality and disease susceptibility in preweaning lambs undernourished in early to mid pregnancy, even in the absence of an effect on birth weight (Rooke et al., 2010), which may be related to longer term impacts of prenatal undernutrition. Most studies which have a later endpoint do report some postweaning behavioural changes associated with the experience of undernutrition in pregnancy although the direction of change is not consistent. For example, Erhard et al. (2004) suggest an increase in behavioural reactivity following undernutrition, whereas other studies (Corner et al., 2006; Hernandez et al., 2010) report a decrease. Physiologically, there is evidence that basal concentrations of hormones involved in the HPA axis cascade (adrenocorticotrophic hormone or ACTH) in adults are increased following exposure to undernutrition as fetuses (Gardner et al., 2006; Oliver et al., 2012), although other studies (generally with earlier endpoints) do not report these effects.

Only a few studies have considered the impact of exposure to prenatal stress on later development, using a range of different stressors and different outcome measures. As a whole, there is little concrete evidence for a long lasting change in behaviour of lambs exposed to a range of different stressors during gestation, although there is some evidence that basal cortisol release may be increased (reviewed by Rooke et al., 2017). There is, however, some evidence that maternal reactivity may influence the response of offspring (Coulon et al., 2015), with highly reactive ewes having different offspring responses to a stress challenge than low reactive ewes. In general, there is less evidence for a programming effect on the behaviour of lambs than has been seen in rodent studies. This may be because sheep studies have tended to use less severe stressors than rodent studies, with a focus on stressors that are of practical relevance to sheep production, and only with severe stress are offspring responses elicited. It may also be true that ewes are better able to buffer their offspring from the longer term consequences of stress than rat dams, and this lack of an effect is an adaptive response to the unpredictable environment in which sheep evolved. However, with few studies having a relevant endpoint (most studies terminate at preweaning endpoints, some even at fetal stages), variation in stressor type, and severity and variation in outcome measures it is not yet possible to provide firm conclusions.

Exposure to elevated ambient temperatures is increasingly of concern with climate change, and sustained increases in temperature can cause inhibition of fetal growth in sheep (van Wettere et al., 2021). The weight of fetuses and newborn lambs are reduced (by up to a third) when ewes experience high ambient temperatures, particularly when ewes are exposed in mid to late pregnancy. In humans, heat exposure also increases the risk of preterm labour and delivery (Yüzen et al., 2023), although this has not been demonstrated in sheep. Effects on birthweight are accompanied by reduced placental growth, reduced diffusion of blood gases to the fetus, and an increase in neonatal lamb mortality. Although heat stress typically reduces feed intake in ewes, and undernutrition contributes to low lamb birthweight as described above, the negative effects of heat stress on fetal growth are considered to be largely independent of ewe feed intake.

4.7 Fostering and Artificial Rearing

Lambs may be required to be reared by means other than their own mother for a variety of reasons: because their mother has rejected them (as described above), because of high litter sizes in the flock where excess lambs (triplet or higher) cannot be successfully reared by their birth mother, and in dairy systems where lambs are removed from their mothers very early to allow milking. In the first two situations, lambs may be preferentially fostered onto another ewe (or attempts made to reattach them to their own mother in the first instance): often ewes which are only rearing a singleton lamb, or where their own lambs have died. Interestingly, a survey of management practices for triplet lambs between the UK, Ireland, and New Zealand suggested that fostering was much more common in the UK and Ireland and few New Zealand farmers practiced this approach to rearing multiple lambs (Erichsen et al., 2024), suggesting there may be capacity to increase ewe rearing of multiples in some situations. In dairy or intensive systems with high litter sizes, artificial rearing of lambs may be more common.

Due to the selective response of maternal ewes, inducing ewes to accept a lamb that is not their own is not a simple process, and a variety of different methods have been proposed to overcome the biological response to reject an alien lamb. These include restraint for a number of days (e.g., in fostering stocks) to allow the lamb to suckle, applying odorants or jackets to the foster lamb, placing the skin of the ewes dead lamb over the foster animal, rubbing the foster lamb in the birth fluids of the foster ewe (often called “wet fostering”) whilst she is lambing, and artificial stimulation of the cervix and vagina shortly after birth to elicit release of central oxytocin to mimic the birth process (Price et al., 1984; Alexander et al., 1985; 1987; Basiouni & Gonyou, 1988; Kendrick et al., 1991). Fostering is usually most successful when it occurs as close as possible to the parturition of the foster ewe, and when it mimics the natural biology of bonding in the parturient ewe. Thus, wet foster methods, artificial cervical stimulation, and applying the coat of a dead lamb (to which the foster ewe has already formed an olfactory memory) tend to be more successful than other methods. Maternal restraint, although commonly used (Shiels et al., 2021; Whatford et al., 2023), can cause maternal distress and frustration as the ewe is prevented from turning around and can only stand up and lie down. She also cannot interact with the lamb, and as maternal bonds are initially formed by olfaction, this effectively prevents the ewe from learning to recognize her foster lamb. In these situations, the ewe can appear to tolerate the foster lamb but only a weak bond may be formed, and when released from the stocks the ewe may still reject the lamb. Mortality of fostered lambs is significantly higher than dam-reared lambs (Binns et al., 2002; Dwyer, 2008a), which may reflect this poorer quality of maternal bonds, although may also be related to the types of lambs which are candidates for fostering (e.g., lambs of larger litters). A survey of on farm practices to manage orphan lambs in the UK demonstrated a high use of tethering/restraint methods in larger farms and significantly higher lamb mortality (Whatford et al., 2023) compared to smaller farms.

As an alternative to fostering, lambs can be artificially reared, commonly in a group pen with milk replacer provided by bottle, bucket, or automatic drinker. Lambs exhibit a greater stress response when separated from their mothers at an early stage compared to later ages, with a reduced immune responsiveness to antigen challenge and higher mortality than dam-reared lambs (Napolitano et al., 2008). This suggests that considerable care is required to rear these lambs in an environment that does not over challenge a depressed immune system. Similarly to other artificially reared dairy animals, lambs have higher rates of sucking or other oral behaviours directed at their pen mates or other objects in the environment (Stephens & Baldwin, 1971), which may be related to an inability to satisfy their motivation to suckle in the artificial rearing environment. They also show altered behavioural responses when placed into an open field or exposed to a novel object with a lower activity and longer latency to approach and interact with stimuli (Napolitano et al., 2003; 2008; Mialon et al., 2021). Maternally deprived lambs fed milk replacer have also been shown to have delayed brain growth and development (Love et al., 2022), which, although the impacts of maternal care and replacer cannot be disentangled, suggests that artificial rearing has a profound effect on lamb development. In addition, artificially reared lambs are reported to have lower growth rates (Ward et al., 2017; Belanche et al., 2019) and poorer carcass conformation at slaughter than dam reared lambs (Lanza et al., 2006; Ward et al., 2017), although this may be partly or completely ameliorated by providing ad libitum access to milk rather than restricted feeding via bottle or bucket.

Attempts to improve the welfare of artificially reared lambs have focused on improving nutrition, for example by providing ad libitum access to milk (e.g., Danso et al., 2018) or adjusting the composition of milk replacer (e.g., McCoard et al., 2021) and providing early access to solid food to encourage rumen development (Herath et al., 2021). Lambs do show social responses to sampling new food, and without the experience of observing an older animal eating, lambs may be slow to transition to solid food (Freitas-de-Melo et al., 2022). Similar to dam reared lambs, artificially reared lambs which have low vigour, poor suckling behaviour, and a low body weight also have slower growth to weaning than more vigorous lambs (Mialon et al., 2023). Other studies also suggest that lambs can form an emotional attachment to human caregivers (Boivin et al., 2000), and that stroking or gentling can improve lamb welfare by providing an alternative to the emotional comfort provided by the dam (Coulon et al., 2015). However, there is some evidence that a low growth rate to weaning in artificially reared lambs is associated with a high affinity towards humans (Mialon et al., 2023), which may be because these animals require greater human intervention at earlier stages and have formed a rewarding association of food with humans (Tallet et al., 2005). Lambs that are both artificially reared and kept in isolation show the most disturbed behavioural and physiological responses (Napolitano et al., 2008); thus, peer group rearing is advocated to allow the lambs some emotional support through attachment to pen mates.

4.8 Weaning of Lambs

In an unmanaged situation, weaning of the lamb would not take place until at least 6–12 months of age (Geist, 1971), when the ewe resumes cycling and courtship and mating occurs. In this situation, weaning is controlled by the ewe, who will gradually limit lamb access to the udder, and the timing seems to be at least partially dependent on the decline in milk production. Ewes in estrus also appear to be more interested in rams than caring for their lambs (Freitas-de-Melo et al., 2022), suggesting that ewes may also be less attentive to their lambs at this time. However, in common with other farmed species, in commercial practice the lamb is artificially weaned at a much earlier age. Unlike the natural situation, this often involves the abrupt and complete replacement of suckling with solid food or milk replacer if carried out at young ages. Weaning can be early or very early as in the dairy industry (often at 24 hours old, although some systems will allow a 6–8 week suckling period before the lamb is removed), traditional (between 2–3 months of age in more intensive systems), or late (more than 3 months of age in some extensive management systems).

In addition to a source of nutrition, before weaning the ewe is also the most important social contact in the lamb's life, providing comfort and opportunities for social learning (Mepham & Kuhn, 1994; Dwyer & Lawrence, 2000a). Thus, although the lamb may be capable of meeting its nutritional needs from other sources, weaning still represents a considerable stressor and impact on lamb welfare (Freitas-de-Melo et al., 2013; 2015; 2022). Traditionally, lambs are abruptly removed from their mothers, and this is often paired with other stressors including transport, moving to a novel environment, housing, mixing with unfamiliar animals, and exposure to novel feeds, which can exacerbate lamb stress associated with mother removal. Abrupt weaning is known to be associated with increased plasma cortisol concentrations over the first day after separation (Mears & Brown, 1997) and behavioural responses of agitation and high-pitched vocalisations for the first 2 days (Orgeur et al., 1998; Freitas-de-Melo & Ungerfeld, 2016). In older lambs there does not appear to be an impact of weaning on immune function and parasite resistance (Rhind et al., 1998; Shaw et al., 1995); however, early weaning at young ages does have a detrimental impact on lamb immune responsivity (Napolitano et al., 2008). Abrupt weaning can also increase the susceptibility of lambs to disease and decreases weight gain, at least initially (Freitas-de-Melo & Ungerfeld, 2016). Although less studied than lambs, ewes also experience a period of behavioural disturbance following the removal of their lambs (Freitas-de-Melo et al., 2013) and also show physiological indicators of a stress response (Cockram et al., 1993; Pérez-Léon et al., 2006).

Because abrupt weaning has been shown to be associated with a stress response in ewes and lambs, alternative methods, such as fenceline weaning (where ewes and lambs are initially separated by fence such that limited physical contact is still possible), two-stage weaning (where the lamb is initially prevented from suckling for a period before separation, for example through the use of udder covers or nose-flaps), or gradual/progressive weaning (where ewes and lambs are separated for a period over several days or weeks before complete separation), have been suggested (Freitas-de-Melo et al., 2022). Gradual weaning, or temporary separation, also mimics management practices for some dairy animals where lambs are only allowed limited udder access so ewes can be milked. Gradual or progressive weaning does involve greater labour for farmers, and the responses of lambs depend on the age at which this process begins. In very young lambs behavioural, physiological and immunological responses are apparent at separation (Sevi et al., 2003; Napolitano et al., 2008), but cortisol concentrations and body weight are less affected in lambs progressively weaned from 39–45 days compared to lambs abruptly weaned at 45 days (Henrique et al., 2017; Freitas-de-Melo et al., 2023). However, lambs weaned progressively did show a more intense behavioural reaction to social isolation 1 month after final weaning compared to abruptly weaned lambs (Freitas-de-Melo et al., 2023), despite lower cortisol concentrations, suggesting that progressive weaning may induce chronic stress in lambs.

The two-stage weaning process and fenceline weaning have the advantage of allowing the ewe and lamb to maintain visual, olfactory, and auditory contact and separates the psychological component of weaning from the nutritional. Lambs separated by fenceline weaning show more high-pitched vocalisations and less feeding behaviour, but lower cortisol concentration and fecal egg counts compared to abruptly weaned lambs (Orgeur et al., 1998). Lambs that had a closer spatial relationship to their mothers before weaning are reported to approach the fence more often (Galeana et al., 2007), and the behavioural responses have been interpreted as evidence of frustration in these lambs (Freitas-de-Melo et al., 2022). Use of udder covers is reported to reduce behavioural signs of distress at complete separation compared to abrupt weaning (Schichowski et al., 2008; Norouzian, 2015). Use of nose covers in lambs is uncommon, although these are commercially available (Freitas-de-Melo et al., 2022), and no published data exists on their impact on weaning in lambs. In calves, however, there is some evidence that nose flaps seem to reduce distress compared to fenceline weaning, but there appeared to be few advantages over abrupt weaning of either method for growth, and nose flaps were associated with behaviours indicative of frustration (Enríquez et al., 2010).

Alternative methods to reduce the stress of weaning appear to be only partially successful in mitigating the stress of separation, although use of udder covers may be the most effective approach. However, keeping weaned lambs in a familiar environment and not pairing the stress of maternal separation with other stressors can support lambs in transitioning to postweaning life. Interestingly, providing social enrichment at weaning through positive and gentle interactions with humans (stroking and quiet contact) reduced stress responses to future human interactions and improved postweaning growth rates compared to control lambs that did not receive additional human contact (Pascual-Alonso et al., 2015). Providing environmental enrichment, such as feeder ramps and straw, also resulted in higher growth rates, heavier carcases, and improved immune responses in feed lot lambs compared to controls (Aguayo-Ulloa et al., 2014). These data suggest that the stress associated with weaning may be reduced, even if this cannot be completely ameliorated.

4.9 Future Research Needs

- **Although there is a considerable body of evidence surrounding the causes of lamb mortality and contributory factors, there remains a large variation in the implementation of mitigation measures on farm and a wide variability in rates of**

lamb survival. Further research to understand barriers or opportunities to improve uptake of scientific evidence would be valuable.

- **Much of the research on maternal behaviour and lamb survival has come from countries with relatively mild winters, where lambs can be successfully born and reared outdoors. However, in countries where the winter is more severe, indoor lambing may be vital to ensure survival. Further research on methods to optimize environmental management to allow the physiological processes underpinning maternal behaviour to proceed would be useful.**

- **Lambs may be weaned at ages ranging from newborn (in the dairy industry) to more than 3 months of age. Methods for successfully reducing the stress of weaning, particularly in very young lambs, are needed.**

- **Fostering of lambs onto other suitable ewes can be a method to reduce the need to artificially rear orphan or abandoned lambs. However, there are many different methods in use and typically these lambs have poorer growth and survival than lambs reared by their own mothers. Further research to improve fostering practices would help improve lamb welfare and survival.**

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5 Housing and Environment

Conclusions:

1. **The welfare implications of housing sheep, access to enrichment, and impacts of restrictions on movement are infrequently assessed and more research in this area would be valuable.**

2. **Existing research suggests that at high stocking density (< 1 m^2/ewe) there is an increase in lying disturbance, displacements at the feeder, and agonistic encounters and thus this should be avoided.**

3. **Sheep find social isolation extremely stressful, as well as separation from important individuals, and this should be avoided when at all possible.**

4. **Sheep are susceptible to respiratory disease and reduced productivity when air quality is poor, and suitable ventilation should be maintained in sheep housing.**

5. **When grazing, sheep display food preferences and social interactions in utilization of the available forage. Feeding mixed swards, or rotational grazing, can increase sheep exploratory behaviour and interest and may improve overall productivity.**

6. **As with all species, there is an increased availability of sensors and methods to remotely monitor sheep. These have great potential to improve welfare monitoring and management, although most applications are still preliminary, at the research stage and in need of external validation.**

5.1 Key Considerations for Indoor Confinement

Compared to other farmed species, sheep are more commonly kept on pasture for some or all of the production cycle. However, sheep farms can vary markedly, from those where animals are never housed (e.g., in Australia, New Zealand and parts of the UK), to those where animals are continuously housed (dairy sheep in some countries), and some farms where sheep may move between very intensive and very extensive housing diurnally or seasonally. In addition, finishing lambs may be managed in outdoor or indoor feedlots to reach market weights. Movement of animals between housing systems is potentially stressful for sheep, requiring periods of adaptation (Fordham et al., 1991).

Although sheep can benefit from shelter from wind and precipitation (Gregory, 1995) as well as shade from the sun (Schütz et al., 2024), adult sheep are housed primarily for management reasons, including increased comfort for the stockperson. Housing ewes for lambing facilitates the provision of targeted nutrition in late gestation, human intervention during and after parturition, and the care of neonatal lambs. Milking sheep are normally housed during their lactation period to facilitate feeding and milking. Sheep that are moved to a feedlot and offered a high-energy ration to encourage weight gain before slaughter may be housed (Zervas et al., 1999). Housing young lambs in cold conditions can be beneficial for growth. Housing young lambs (16 kg) at an inside temperature of −4°C results in improved growth rates compared with keeping them outside at −14ºC (Xiao et al., 2024). Confinement is also used when there is insufficient land available to keep sheep outside.

5.1.1 Social and Behavioural Deprivation

Sheep are highly gregarious, and a dominant part of their behaviour is the expression of close social relationships. Sheep develop stable social relationships with other members of the flock (Fisher & Matthews, 2001), recognize individual members of their social group (Kendrick et al., 2001), and in free ranging situations will avoid unfamiliar animals (Lawrence & Wood Gush, 1988). Sheep also synchronize their behaviour with that of the flock, which is believed to be an expression of social cohesion and positive welfare (Richmond et al., 2017). Most studies on social behaviour in sheep have, however, been conducted in grazing animals (see below) and only a few studies have considered social behaviour in housed sheep.

A study of ewe–lamb recognition demonstrated impaired social recognition abilities in ewes and lambs when housed permanently indoors compared to outdoor housed animals (Poindron & Schmidt, 1985). These authors suggest that ewes and lambs need to learn recognition at a distance to be able to identify one another other than at close range, and this opportunity is not provided when ewes and lambs are housed. Pen size in housed ewes has also been shown to affect the quality of the ewe–lamb relationship, with ewes housed in small pens (1.5 m^2 per ewe) showing less following, grooming, and suckling behaviour and more suckling refusals than those housed in larger pens (3 m^2 per ewe: Lv et al., 2015). Ewes in small pens also had higher fecal glucocorticoid metabolites than those in larger pens, suggesting that pen size affected HPA axis activity.

Social isolation or single housing can be a very potent stressor for sheep, resulting in behavioural, physiological, immunological, and neurobiological alterations. For example, socially isolated sheep make frequent high-pitched vocalisations, show agitated pacing and escape attempts (Barnard et al., 2015), and may not eat or drink, at least initially. This is accompanied by elevated heart rate, increased cortisol release, dysregulated release of dopamine and prolactin (Guesdon et al., 2015), and suppression of carbohydrate larval surface (CarLA) IgA concentration measured in saliva (Sutherland et al., 2019). CarLA IgA is elevated in sheep challenged with gastrointestinal nematodes, which may indicate impaired immune responses to parasites in socially isolated sheep. Separation of animals from a preferred social partner, particularly ewes and their lambs, also results in marked behavioural agitation and high frequency of vocalisations, behaviours which are strongly correlated with each other (Barnard et al., 2015). In a study of individually housed sheep, sheep spent 62% of the time idle, and 71% of the sheep displayed abnormal behaviours (pacing, chewing, or nosing pen fixtures) for more than 10% of the day (Lauber et al., 2012). When presented with a sudden stimulus, isolated sheep demonstrate much greater fear reactions than sheep kept in groups of 5 or 10 animals (González et al., 2013), suggesting the social group helps to buffer fear responses in sheep.

Although group size and social relationships are important parts of the sheep environment, the social group can also act as a source of stress and welfare compromise, particularly when resources are limited. A study of group size in housed sheep found less synchrony in resting and feeding behaviours in larger group sizes (36 ewes) compared to smaller (9 ewes), although also less queuing for the feeder (Jørgensen et al., 2009). No difference in aggressive interactions was observed, which led these authors to speculate that stocking density is more important than group size in aggressive interactions. Studies of the impact of space allowance with consistent group size suggest that the amount of social space available to sheep is more important in terms of stress and agonistic social interactions than the numbers of individuals in the group (Averós et al., 2014a; 2014b; 2015).

In addition to reducing the social space available to sheep, housing also often involves mixing animals, sometimes on several occasions if animals are moved into different groups for management purposes and the disruption of preferred social partners. A study which compared the effects of restricted space and social mixing compared to greater space and a consistent social group demonstrated that increased ewe aggression occurred with mixing and that younger ewes were more affected by housing than older, more experienced ewes (Yusof et al., 2023).

Many expressions of dominance in sheep are not necessarily associated with overtly aggressive behaviours. Sheep maintain social hierarchy through subtle behaviours associated with head movement and eye contact. Dominant sheep may displace subordinates from the feed troughs (Neave et al., 2018) and from preferred lying positions by resting their chins on the backs of subordinate sheep or by pawing (Done-Currie et al., 1984). There are a number of consequences for the subordinate sheep. When feeder space is limited, the number of displacements or disturbances from the trough increases (Arnold & Maller, 1974) and a progressively greater proportion of sheep cease to compete for food, becoming non-feeders. These subordinate animals are usually the very young or older sheep (McBride et al., 1967).

5.1.2 Feeding Behaviour

Feeding behaviour of sheep is influenced by individual factors, such as early life exposure to different food types, timing and frequency of food delivery in confined systems, feeding place structures or access, and space allowance (Neave et al., 2018). Feeding behaviour in housed sheep is often highly synchronized, with the group preferring to feed simultaneously. This can mean that sheep may compete for access if feeder space is limited, or some animals may need to feed at less preferred times, when they may not eat their full ration, or in more frequent but smaller meals if they are frequently displaced (Yusof et al., 2023). This can also affect feed efficiency, as more efficient sheep in terms of food utilization were observed to have fewer, larger meals than less efficient animals (Muir et al., 2018).

Sheep display food neophobia—that is, a reluctance to eat unfamiliar foods (Provenza & Balph, 1987)—like many ruminants, and this can be exacerbated with a novel environment. Lambs introduced to a feedlot may develop inappetence due to this phenomenon, and a study in Australia suggested that up to 20% of lambs may refuse to eat (termed “shy feeders”) and lose weight in the first week on arrival in a feedlot (Rice et al., 2016). Shy feeders were also more likely to visit the feed trough when no other lambs were present, compared to lambs which were eating well. Lambs that are food neophobic were also seen to be more fearful in a novel environment (Villalba et al., 2009), although Rice et al. (2016) did not see any temperament differences between those that did and did not eat on arrival at the feedlot. When novel foods were paired with a novel aroma (oregano oil) at weaning, lambs preferentially selected foods with oregano oil up to 11 months later (Simitzis et al., 2008), showing persistence of familiarity with the aroma.

Wool-biting, an abnormal behaviour which is seen almost exclusively in housed sheep (Parés et al., 2023) fed on high levels of concentrate feed or deprived of access to forage, involves pulling, biting, and chewing of wool from other animals. This is believed to be a stereotypic response, not related to aggressive behaviour, and has been associated with inadequate access to fibre (Vasseur et al., 2006), with provision of barley straw reducing the incidence of the behaviour and wool damage.

5.1.3 Effects on Health

The level of environmental contamination with pathogens is likely to be greater in housed sheep compared with those kept extensively. Keeping sheep in a large air space can be beneficial. Sevi et al. (2001) showed that lactating ewes (56 kg) kept in groups of 12 in naturally ventilated pens (22 m^3/h/animal) on straw bedding with 4 m^3 of air space/animal were exposed to higher relative humidity and greater concentrations of airborne bacteria and had greater milk somatic cell counts than those provided with 7 m^3 air space/animal.

Sheep show an aversion to 31 mg/m^3 ammonia (Phillips et al., 2012a). Exposure to ammonia concentrations of 11–34 mg/m^3 for 12 days reduced feed intake and increased sneezing compared with control sheep (Phillips et al., 2012b). Exposure to an ammonia concentration of 21 mg/m^3 for 7–8 days reduced feed intake, eating, and rumination behaviour and increased respiration rate compared with control lambs (Zhang et al., 2018).

Increasing the ventilation rate from 23 m^3/h/animal to 47 m^3/h/animal can reduce the concentration of ammonia (Sevi et al., 2003b). The aerial concentration of dust in sheep housing that uses straw bedding can be reduced by regular renewal of the straw (Sevi et al., 2003a).

Cross-species analogy and circumstantial evidence suggest that exposure of sheep hooves to moisture when housed on damp bedding is a risk factor for infectious foot-related lameness (Angell et al., 2015; Gelasakis et al., 2019). A study in Norway (Stubsjøen et al., 2022), where sheep are housed over the winter, most commonly in insulated buildings on metal floors, observed callus on the carpal joints in 27.5% of sheep, as well as dirty abdomens (18.8%), overgrown claws (18.1%), and wool loss (16%). This study reported a reduced likelihood of callus when the ewes were provided with deep litter bedding, and more positive mood when sheep were given access to outside.

When sheep are housed in naturally ventilated barns, the internal temperature can exceed the outside temperature, thereby increasing the risk of heat stress during hot conditions (Papanastasiou et al., 2011). Ewes housed for lambing require shearing to prevent heat stress and excessive moisture in their fleece. However, shearing can cause stress (Hargreaves & Hutson, 1990a) that can be greater than that of other types of handling procedures (Hargreaves & Hutson, 1990b). Therefore, when ewes with a full fleece are housed, the risk of heat distress has to be balanced against the stress involved in shearing.

5.1.4 Opportunities for Exercise

Sheep on pasture can walk between 0.2 and 5.5 km in a day (Zanon et al., 2022). However, older studies in semi-arid pasture suggest that sheep may walk between 8 and 14 km a day between water sources and grazing (Squires, 1976). Exercise increases the metabolizable energy requirements of sheep (Pethick et al., 1991). Whether housed sheep experience detrimental welfare as a consequence of restricted exercise is not clear. A study of two farms with indoor and outdoor management respectively, where activity was monitored by accelerometers, suggested that housed pregnant ewes lay for 13.1 hours/day whereas outdoor managed pregnant ewes lay for 11.7 hours/day (Williams et al., 2021). Indoor animals lay for a median bout duration of 29.5 minutes and had 26.8 bouts of lying per day; outdoor ewes lay for a median duration of 35.9 minutes per bout and had 19 lying bouts per day. In this study, housing management was confounded with farm so these could not be directly compared but suggest there is not a large difference in standing and lying in sheep housed indoor or outdoors. The authors suggest that ewe age and litter weight were more important determinants of lying response.

5.1.5 Restricted Feeding Space

Restricted feeding space can increase competition at a feed trough and reduce feed intake. Groups of 100 wethers (castrated males), mean weight 45 kg (range 25–75 kg), had reduced growth when offered feed at a trough that provided 0.02 m/animal compared with those that provided 0.05–0.15 m/animal. When water was provided in a trough that provided 0.06 m/animal, growth was reduced compared with a trough that provided 0.15 m/animal (Dundon and Mayer, 2015). Groups of 40 wethers (about 28 kg) had reduced growth, lower feed intake, and spent less time feeding with fewer feeding bouts when offered feed at a trough that provided 0.04 m/animal compared with those that were provided with 0.1 m/animal (Jongman et al., 2017).

In a study by da Silveira et al. (2018), where group size was confounded with available trough length, a group of 3 ewes (35 kg) provided with 0.33 m of trough length/animal was able to feed simultaneously 54% of the time. Groups of four and five ewes had 0.25 and 0.20 m of trough length/animal, respectively. Compared with 0.33 m of trough length/animal, those with a shorter trough length/animal had reduced dry matter intake/animal, and those at 0.20 m of trough length/animal had reduced weight gain and were only able to feed simultaneously 30% of the time.

5.1.6 Floor Space

Floor space requirements have been considered in relation to the physical space required to accommodate an animal’s body dimensions, to undertake normal behaviour, and to interact with other animals (Petherick, 2007). Overcrowding occurs when animals are crowded to the point that feeding, resting, and other basic maintenance behaviours are restricted. There is increased competition to obtain access to resources such as feeders, drinkers, and lying areas, and there can be an increased risk of aggression, injury, and stress.

Restricted floor space can reduce lying and increase disturbance when sheep are lying down. Pregnant ewes (80–85 kg) kept at 0.5 m^2/animal spent less time lying down, more time walking, had a greater number of displacements from a lying posture, and were rarely observed to be lying simultaneously compared with those kept at either 0.75 or 1 m^2/animal (Bøe et al., 2006).

Pregnant ewes (89 kg) kept at 0.75 m^2/animal spent less time lying down, had a greater number of displacements from a lying posture, spent less time lying simultaneously, and had more aggressive interactions when active than those kept at either 1.5 or 2.25 m^2/animal (Vik et al., 2017).

In a study by Averós et al. (2014a; 2014b), pregnant ewes provided with 1 m^2/animal moved a shorter total distance during the observation period, spent less time moving, and had an increased rate of disturbances (frequency of scans where location had moved) than those kept at either 2 or 3 m^2/animal. However, they spent longer eating and had a greater frequency of feeding bouts and social interactions than those kept at the higher space allowances.

Non-pregnant ewes (55 kg and 72 kg) kept at 4 m^2/animal moved a greater distance and were observed to walk more than those kept at 2 m^2/animal. Those kept at 2 m^2/animal lay down more and moved location more frequently than the ewes kept at 4 m^2/animal (Orihuela et al., 2016).

Lactating ewes kept at 1 m^2/animal had a reduced humoral immune response, lower milk production, and a higher milk somatic cell count than those kept at 3 m^2/animal (Caroprese et al., 2009).

Lactating ewes (51 kg) kept in groups of 12 in naturally ventilated (30 m^3/h/animal) straw-bedded pens that provided 1, 1.5, or 2 m^2/animal were exposed to greater air concentrations of microorganisms at the low space allowance (1 m^2/animal), and these ewes had a lower milk yield (Sevi et al., 1999).

Lambs (28 kg) kept at 0.48 m^2/animal had greater growth than those kept at 0.32 m^2/animal (Gonyou et al., 1985). Lambs (7 kg) kept at 0.34 m^2/animal showed reduced eating behaviour and walking compared with those kept at either 0.48 m^2/animal or 0.63 m^2/animal. Those kept at 0.63 m^2/animal showed greater dry matter intake, more rumination, and more time spent lying down than those kept at 0.48 m^2/animal (Norouzian, 2017).

Based on studies in sheep and cattle, Petherick and Phillips (2009) concluded that an appropriate floor space allowance for housed sheep could be estimated by using the following allometric equation: floor area in $m^2 = 0.033 \times \text{liveweight}^{0.66}$ (in kg).

5.1.7 Enrichment

Typically, when sheep are housed indoors, they are held in pens with provision of food and water and, sometimes but not always, bedding but little else, suggesting these are relatively barren environments. The literature on environmental enrichment in sheep is sparse, although there is evidence that sheep are positively influenced by the opportunity to show choice (for example, studies have demonstrated that sheep have improved mood when offered the chance to go outside when housed: Stubsjøen et al., 2022) and will make use of brushes, deep bedding, and environmental complexity when this is available. Environmentally enriched adult ewes (provided with more space, straw bales, mirrors, and puzzle feeder toys) also demonstrated more optimistic behaviour in a “go/go” cognitive bias task and were less fearful when tested with a novel object compared to ewes kept in pens that were only straw-bedded (Stephenson & Haskell, 2022). Although not specifically a study of environmental enrichment, sheep kept in a predictable, stimulus-rich environment with calm human–animal interactions were less reactive to negative stimuli than sheep kept in barren and unpredictable environments with harsh human–animal interactions (Reefmann et al., 2012), although these animals were also less interested in positive stimuli. Lambs reared with their mothers in an enriched environment (hanging coloured boards, a human-like model) did not show any difference in fearfulness to lambs reared in a barren environment (Vandenheede & Bouissou, 1998) either at weaning or at 8 months of age. However, their mothers did show a significant and long-lasting reduction in fearfulness following environmental enrichment (Vandenheede & Bouissou, 1998). These studies demonstrate some improvements in mood and fearfulness in sheep when housed with additional enrichment items, although some of the things introduced into the pen may be less ethologically important or relevant to sheep and may require further development to provide suitable outcomes (Taylor et al., 2023).

When offered a choice between lying on metal slats, solid wooden floors, rubber mats, or straw, unshorn sheep did not exhibit a strong preference for any flooring type (Faerevik et al., 2005). However, when shorn, sheep preferred to lie on straw-bedded surfaces over all other types of flooring, and on wooden floors or rubber mats compared to metal floors. Shorn ewes also lay down less than they had before shearing unless they were offered access to straw-bedded floors (Faerevik et al., 2005).

A series of studies of lambs kept in feedlots in Spain demonstrated that provision of straw bedding and foraging substrate, play ramps, and feeder ramps resulted in less aggression, fewer stereotypic behaviours, and higher indicators of immunity compared to lambs reared in a barren environment (Teixeira et al., 2014; Aguayo-Ulloa et al., 2014). Further, lambs in the environmentally enriched feedlot had a higher average daily gain, heavier carcasses, and improved indicators of meat quality (Aguayo-Ulloa et al., 2014).

5.2 Key Considerations in Extensive Systems

There are many descriptions of what defines an extensive system. In general, these are based on the number of animals per labour unit, the stocking rate, and sometimes the degree of confinement or restriction on the animal's movement. Outdoor management of sheep can involve large, unfenced pastures where stocking rates can be extremely low (e.g., < 1 animal per hectare), often with poor quality grazing, through to fenced paddocks of re-seeded and improved grazing, which can support many more animals per hectare. Sheep may be set stocked onto the pasture, drift managed, or may graze the pasture rotationally, with the aim of achieving greater production per unit area of land. Management practices and welfare impacts are often determined by the facilities available on the land and what can be achieved.

Sheep kept in extensive systems mainly depend on grass and forage crops for nutrition and may access water from natural water courses as well as through the provision of troughs. There can be seasonal differences in the availability of feed and water, and access to adequate feed and water can at times be a problem. Some sheep can benefit from supplementary feeding, including minerals, in addition to pasture at specific times of the year. Although sheep are traditionally considered to be grazing animals, they can also browse and may supplement their grass diet with herbs, leaves, tree branches, fruits, shrubs, and other plants if these are available. Sheep have been shown to be more selective grazers than some other species, such as cattle, with a limited impact of sward composition on intake preferences (Cuchillo-Hilario et al., 2017). There is strong evidence for diet preferences in sheep (which can be considered what the animal "wants" to eat); thus, meeting the animal's preferences is likely to improve welfare (Rutter, 2010). There is evidence that sheep will prefer to go outside if offered the choice, but whether sheep prefer to graze a mixed sward or a monoculture, or, indeed, if there are welfare implications of not being able to graze, has not been studied.

5.2.1 Grazing Cycle

Sheep in extensive systems normally have almost continual access to grazing, but feed availability varies in quantity and quality according to the season. When grass growth is limited during the winter or dry seasons, supplementary feeding can be required.

There is a seasonal cycle of grass growth that depends on the temperature and rainfall/irrigation. This affects the quantity and quality of the pasture at different times of the year. The liveweight and body condition of sheep vary in response to the quantity and quality of the pasture that is available. Group size, stocking density, period of grazing, field size, fertilizer use, and irrigation practices can affect the availability of grass.

The quality of forages deteriorates during a growing season and as a result of adverse weather conditions (such as low/high temperature and drought). The nutritional value is highest when there is active leaf growth. At this time, the crude protein and soluble carbohydrate content are high, and the structural components (hemicellulose, cellulose, and lignin) are low. As the season progresses and the plants mature, the proportion of leaf, stem, and dead material changes and the structural components of the plant increase, and the protein and soluble carbohydrates as a proportion of the dry weight of the plant decrease (Waghorn & Clark, 2004).

During the grass growing season, sheep can gain body condition and store surplus energy reserves that they then utilize when the available feed is poor and limited in quantity during winter conditions or during a dry period. To meet the extra nutrient demands of the last stages of pregnancy and lactation, these events can be planned to occur when feed is readily available.

Compensatory growth can occur following a period of restricted feeding. In some circumstances, following a period of undernutrition, sheep show an increased rate of body weight gain and an increased efficiency of energy utilization (Hornick et al., 2000). This compensatory growth following a period of feed restriction is used in extensive sheep production systems as a means of reducing feed costs.

5.2.2 Feed Quality and Access

Many pastures typically focus on a limited number of grass species with the aim of improving productivity and avoiding selective behaviour of sheep. For example, grazing may be based on perennial ryegrass and clover mix, which can have high nutritional value at some times of the year. When presented with a clover/ryegrass sward, sheep have a partial preference for clover, consuming 70% clover and 30% ryegrass (Rutter, 2010). However, at other times the nutrient content of these grasses can be poor, as described in the section on the grazing cycle (section 5.2.2), and there has been increasing interest in alternative forage species and mixed swards

(Cranston et al., 2015). For example, mixes of chicory, plantain, and red and white clover have been used to provide nutritive value at some times of the year, which can lead to improved lamb growth rates compared to ryegrass and clover swards (Somasiri et al., 2015). The increased growth rates may be related to higher consumption as chicory is palatable and more rapidly consumed by sheep than ryegrass (Niderkorn et al., 2019). A study of diet selection in ewe lambs suggested seasonal changes in preference for and selection of plant species when grazing a mixed sward: in early spring lambs preferred plantain and chicory over red and white clover, switching to an increase in red clover as these species became more abundant and nutritive quality of the sward decreased (Cave et al., 2015). Bioactive plant species, such as chicory and plantain, also have some natural anthelminthic properties through condensed tannins, which can reduce worm burdens and reduce the need for chemical drenches (Peña-Espinoza et al., 2018).

For growing lambs, growth rates (average daily gain) were similar for lambs grazing cereal crops alone (wheat) and when the cereal crop was mixed with other forage species that included vetch and legumes, although not when the forage contained brassicas (Clayton et al., 2025). A more diverse sward may allow sheep to express diet selection preferences relating to food palatability and quality whilst still maintaining good growth.

Sheep grazing behaviour is an important component of efficient pasture utilization and management, which can also interact with social behaviour. The grazing process involves searching and foraging behaviours to optimize nutrient intake, influenced by pre and post ingestive indicators of palatability. If searching costs are low, in that preferred forage species are abundant, sheep may consume a greater proportion of preferred forages (Chapman et al., 2007) and sward heights can facilitate optimal bite-mass (Mezzalira et al., 2014). Traditional rotational stocking of sheep focuses on target sward heights and pasture rest periods, without considering the animals' behaviour, whereas "rotatinuous " stocking strategies also consider sheep behaviour and aim for a greater daily intake of a high-quality diet (Savian et al., 2020). This strategy has a narrower range of sward heights, aiming to keep forage at a height that encourages the greatest bite rates in the sheep (Carvalho, 2013).

Social cohesion and flocking behaviour can impact the utilization of grazing. Dumont and Boissy (2000) showed that sheep will move to preferred grazing sites, either alone or in a group, if the preferred grazing patch is close to the social group but will not move to a more isolated area if alone. Similarly, Sibbald et al. (2008) showed that foraging on preferred patches was influenced by the preference to stay at a specific social distance from other sheep. Furthermore, sheep are more likely to graze with familiar animals and further from the social group than with unfamiliar sheep (Boissy & Dumont, 2002). More recently, social network analysis suggests that interactions occur between the social behaviour of the sheep and the types of foods on which they are foraging, with greater network cohesion when grazing grasses and forbs and a less organised network when browsing on shrubs and trees (Yiakoulaki et al., 2019).

A recent innovation in sheep farming has been to combine the use of solar panels with targeted grazing by sheep. A study of sheep grazing behaviour suggested that sheep grazing 1-day or 4-day rotations under the solar panels spent more time expressing grazing behaviour (as measured by a sensor) than sheep grazing native rangelands, and that sheep spent less time grazing on the intensive 1-day rotations compared to the 4-day rotations (Kampherbeek et al., 2023). The authors speculate that the solar panels may have provided protection for the sheep from heat, wind, or rain and so facilitated more time grazing.

5.2.3 Stocking Rates

Stocking rates and pasture rotation can be adjusted to balance the forage consumed and trampled with the growth of forage. Stocking rates, usually defined as the relationship between number of animals and the total area of land utilized over time, is an important component of farm profitability (Young et al., 2022). This is often considered from an economic perspective, taking into account quantity and quality of feed at different times of the year, seasonal variation, and livestock productivity goals among other factors. However, the sheep are also impacted by stocking rate, which may impact their ability to consume sufficient amounts of preferred forage. At high stocking rates, animals might have to compete for access to forage, especially higher-quality forages. With rotational or strip grazing, animals are kept at a much higher stocking rate than if they are set stocked but can move on to new forage on a 1-day (intensive) or 3–5-day (traditional rotational) cycle to allow fresh forage to be consumed with each sheep movement. The quality and quantity of the pasture may be depleted by overgrazing caused by overstocking. Overgrazing can occur when grazing exceeds the recovery capacity of the plants.

5.2.4 Malnutrition

Malnutrition is a deficit, imbalance, or excess of nutrients that affects normal physiological function, health, and productivity (Hogan & Phillips, 2008). Deficiencies occur when there is an inadequate feed supply or when the sheep cannot obtain sufficient nutrients from low-quality feed. A nutritional assessment to evaluate potential welfare issues should include an evaluation of the animal, the feed offered and consumed, the environment, and methods of feeding in relation to how the sheep are managed (Swecker & Thatcher,1988).

Sheep obtain their mineral intake from forages, concentrate feeds, and mineral supplements. The mineral content of plants varies between plant species, stage of vegetation, soil composition, and climate. Susceptibility to mineral deficiencies varies with location (Reid & Horvath, 1980). The vitamin and mineral content of grass and other plants is variable, and some pasture might be deficient in nutritional requirements. If, when foraging outside, animals have access to a range of plants, a supplemental concentrate diet, and mineral blocks, this can potentially provide beneficial nutritional supplements, such as essential vitamins and minerals.

Dietary mineral imbalances, such as iodine, cobalt, manganese, or selenium (reviewed by Rooke et al., 2008) can occur because of the type of soil used for grazing land (Suttle, 1991). Deficiencies in minerals and vitamins can cause significant effects on physiological functions that can result in weakness and non-specific signs of ill health and negative feelings. Many vitamins and minerals are involved in cellular energy metabolism. Minerals are required for numerous body functions, including biochemical reactions, cofactors for enzyme reactions, and protein composition. These can be important in pregnant ewes as they affect the development of the fetal lamb with health and welfare consequences. For example, cobalt deficiencies impair lambs' behavioural development and growth, copper deficiency causes swayback in lambs, and selenium deficiency causes nutritional myopathy. Providing trace elements and minerals in feed, in boluses, or via injection to ewes that are deficient in trace elements can have positive impacts on the welfare of their lambs. However, there is little evidence that supplementation in ewes that are adequate for trace elements will have additional benefit, and some of these elements can be toxic if given at high doses.

5.2.4.1 Undernutrition

When animals are kept on pasture, the forage quality and availability are sometimes limited, and the animals are not able to consume sufficient nutrients from the pasture. Undernutrition occurs when the intake of nutrients is insufficient to meet the animals' requirements for optimal physiological function. Inadequate dietary energy intake to meet energy needs can arise due to lack of feed, low digestibility of feed, or increased metabolic demand (Webster, 2009). Other factors that can contribute to undernutrition are those that reduce feed intake, including poor forage quality, restricted access to drinking water, and heat stress. Undernutrition is accompanied by mobilization of body fat reserves to meet energy requirements, which can lead to catabolism of other bodily tissues such as muscle tissue if an inability to meet requirements continues. This is most commonly seen as a decrease in backfat depth as assessed by body condition scoring. This has been shown to be accompanied by an increased motivation to access feed: for example, sheep in low body condition will walk further to obtain food rewards than sheep in better condition (Verbeek et al., 2012a). This behavioural response was accompanied by lower muscling indicators, a lower plasma glucose, leptin, insulin, cortisol, and higher free fatty acid concentrations compared to ewes with higher body condition score. These authors suggest that leptin and glucose concentrations may be useful biomarkers for hunger in sheep (Verbeek et al., 2012a).

When animals are kept entirely on pasture/range, there is a risk that at certain times of the year the animals might not receive adequate protein, energy, vitamins, and minerals. They may also have to range further and spend more time foraging to respond to poor pasture. Some sheep lose body condition at times of the year when pasture quantity and quality are reduced (especially when energy demands are high, e.g., during lactation) and then regain their condition when grass growth is improved. For sheep, the period of lowest pasture quality and quantity typically coincides with pregnancy. For example, pregnant ewes kept over-winter on poor grazing lose body condition, and there is an increased risk of ewe and lamb mortality (Cunningham & Russel, 1979; Morgan-Davies et al., 2008). Inadequate pregnancy nutrition has several specific impacts, such as reducing placental development, reducing fetal growth, reducing mammary development, hence quantity and quality of colostrum, as well as impacting on the expression of maternal behaviour and lamb development (Dwyer, 2003; Dwyer et al., 2003).

Weather events such as drought, flooding, or heavy snow can remove or cover herbage, thereby preventing grazing (Kenyon & Cranston, 2017). Undernutrition can also occur when the available diet and amount of feed changes (e.g., during a season), if the need for supplemental feeding is either not recognized, cannot be delivered for practical reasons, or is avoided due to financial constraints. In situations where there are increased energy demands due to factors such as lactation, pregnancy, and heat loss to the environment, the animal might not always be able to meet these by increased feed intake.

The implications of a period of feed restriction are greater if the animal is pregnant, lactating, and has a low level of body reserves. Pregnant ewes kept extensively and exposed to cold conditions without adequate supplementary feeding have to utilize their fat and protein reserves. If sheep are exposed to cold and have ad libitum access to feed, they increase their feed intake to increase their metabolic rate. However, ewes in low body condition are already compromised if exposed to cold temperatures and have a reduced ability to respond and adapt to cold challenge (Verbeek et al., 2012b). When the intake of protein and energy is limited over a prolonged period, an animal will redistribute these limited resources so that the requirements for maintenance receive the greatest priority. In adult animals, a loss of body weight and condition and, in young animals, poor growth can be signs of undernutrition.

Ovine pregnancy toxemia can occur during late pregnancy when the nutrient intake does not provide sufficient energy to meet the requirements of multiple fetuses. This can occur for several reasons, including a period of reduced feed intake and/or low-quality feed, reduced ruminal capacity due to excessive intra-abdominal fat, or by the size of the uterus. This leads to the mobilization of body fat reserves, and ketone bodies are formed faster than they can be metabolized. Metabolic acidosis, hypoglycemia, and uremia can also develop. Poor body condition can reduce the body's energy reserves and increase the risk of this disease. Clinical signs can include anorexia, reduced responsiveness, nervous signs, weakness, recumbency, and death (Mongini & Van Saun, 2023).

When supplementary feed is offered in addition to grazing, additional labour is required to ensure that it is distributed to all of the animals. At some times of the year, for example, after heavy snow, there can be a delay in providing supplementary feed. Supplementary feed can be provided in blocks, licks, snackers, hay feeders, and by delivering feed into troughs.

5.2.4.2 Starvation

The term "starvation" tends to be used to describe a situation that is normally inadvertent, when an animal does not have access to essential nutrients for longer than 1 day (or less, in the case of neonatal lambs), and this leads to loss of body condition.

There are many situations in which starvation can occur. These include:

- Lack of plant growth due to season or adverse weather
- Adverse weather and natural disasters
- Neglect
- Lack of nutritional knowledge by the owner
- Inadequate financial resources to purchase feed
- Deterioration in ground conditions that limits the ability of animals to walk to gain access to feed
- Health conditions that reduce appetite, the ability to ingest feed or walk to gain access to feed
- Lack of or restricted access to drinking water.

Sheep have several types of responses to severe limitations on feed availability. These include:

- Increasing foraging and, where possible, moving location to environments where feed is not limiting
- Storing fat in their tissues during periods when feed is readily available so that it can be used during periods when feed availability is reduced
- Adjusting metabolism to redistribute energy use, e.g., by reducing energy use for growth and reproduction
- Reducing total energy expenditure, e.g., by reducing activity and lowering basal metabolic rate
- Differentially mobilizing stored body energy reserves, and
- Adjusting physiological set-points to allow disruptions in homeostasis, e.g., allowing body temperature to decline
(McCue, 2012).

The ability of an animal to respond to a period of starvation is related to their ability to store energy when feed is available and to utilize available energy effectively so that it maintains essential functions when feed is limited (Wang et al., 2006). The ability of sheep to respond to starvation (i.e., duration of survival) improves when (a) body mass and fat levels are high at the beginning of the fasting period, (b) if water is available, (c) there are no increased energy demands for pregnancy, lactation, and thermal homeostasis, and (d) they are healthy at the start of the feed restriction.

5.2.5 Toxic Plants

Some plants are toxic or poisonous to sheep in that they contain or produce substances that can cause sickness, death, or other forms of ill health. Some are palatable, but even if they are unpalatable they can become abundant, and if the preferred plant species have been grazed, they pose an increased risk. During periods when grass growth is restricted (e.g., due to drought), sheep are more likely to eat toxic plants that they would normally avoid. Among the most common causes of plant poisoning in livestock is consumption of plants containing pyrrolizidine alkaloids, which can cause wasting and death (Molin et al., 2021). These plants are not generally palatable to sheep but may be consumed if other sources of forage are scarce, or if they contaminate hay or preserved forage. Sheep are typically quite resistant to this form of poisoning as the rumen can detoxify these components, but poisoning can still occur if present in high quantities (Molin et al., 2021).

Toxicosis can be acute, sometimes resulting in mortality, which is often easily recognized. However, subclinical chronic toxicity may impact welfare and production but be less readily detected. Sheep do learn to avoid toxic plants through behavioural means when grazing with their mothers (Provenza et al., 2003) or through the post-ingestive consequences of consuming toxic plants (Catanese et al., 2016). Ruminants can also learn the medicinal benefits of some plants (such as those with antiparasitic properties) even though these plants may contain toxins (Distel & Villalba, 2018). When given the opportunity to select and avoid toxic plants, these long-lasting behavioural mechanisms can limit exposure of animals to toxicosis. Thus, animals are most at risk when other food stuffs are limited and their dietary choices are constrained.

5.2.6 Drinking Water Supply

The availability of drinking water can be a problem in extensive systems. The sheep might have access to natural water sources such as streams, lakes, and springs. Otherwise, water has to be provided from tanks, wells, pipelines, and other water systems. The sheep may have to walk a considerable distance to a source of drinking water. Although it is sometimes assumed that sheep can obtain all the hydration they need from consuming plants, this is not supported by evidence that sheep will drink every day if drinking water is provided, even at pasture. Merino sheep on dry pasture in the summer consumed 1.37 litres of water per day, with maximum intakes on hottest days (McGregor, 1986). Daily water intake was reduced in cold weather and on green pasture. A study in South Africa suggested that housed sheep drink between 2.2 (Black Persian desert adapted sheep) and 5.4 (Mutton Merino) litres of water per day (Schoeman & Visser, 1995), with Merino ewe lambs consuming 3.05 litres per kilogram feed consumed. Similarly, in Brazil, 3-month-old lambs consumed a mean of 3.15 litres of water per day (de Freitas et al., 2021). Thus, sheep at pasture are able to substitute for some of their water intake through consumption of green forage, but this does not entirely replace drinking from open water sources.

In semi-arid and arid rangelands, the frequency of drinking can reduce when the pasture quality declines due to drought. This is often at a time when the sheep require increased drinking water due to higher temperatures. The need to graze further from water points increases the distance the sheep have to walk each day, reducing the frequency of drinking. When the frequency of drinking is reduced, this can also reduce feed intake and body weight. The water requirements of animals in an extensive system can also be influenced by the water and salt content of the forage and physiological state, as lactating ewes have a higher requirement for water than sheep in other states.

During winter, the water supply is at risk of freezing. The water supply needs to be checked regularly, the frequency depending on the water capacity, weather, and the requirements of the sheep. In some locations, the sheep are not provided with drinking water over winter but are left to rely on fresh snow as a source of water (see Cockram et al., 2012, for a discussion on the welfare implications of snow as a water source for sheep).

5.2.7 Drought and Other Natural Disasters

Concern for heat stress and the consequences of prolonged periods without rainfall are increasing as a consequence of climate change. Although heat stress can be an issue for housed sheep as well as those managed at pasture, lack of available water is particularly relevant for extensively managed animals, especially as the water content of forage will also decline, increasing the need for sheep to drink. A drought is a prolonged shortage of water. It occurs regularly in arid and semiarid areas as a normal seasonal event. Drought can also occur when precipitation is below normal, and the severity is increased when it is combined with high temperatures. In hot conditions, evapotranspiration (drying because of the sun) can decrease the soil moisture faster than it is replaced by rain. During drought and other hot or dry periods, water sources may dry up.

During a drought, the reduction in the water content of the soil restricts the normal growth of grass that livestock require to graze. During this time, the pasture produces less dry matter, and the feed value of the plants is reduced. Supplementary feed may need to be provided to reduce mortality due to starvation and dehydration.

Multiyear droughts have a severe impact on the availability of forage and the cost of supplementary feed. They can also lead to damage due to grazing, reduced plant cover, and soil erosion. Perennial grass plants need sufficient leaf area after grazing to recover and regrow when conditions improve. Potential mitigation measures are limited but could include increased water supply and storage, infrastructure for irrigation and drinking water, more use of drought and grazing-tolerant plants, use of breeds adapted to arid regions, increased reserves of grazing land, preserved forage, and a reduction in the number of sheep (NSW Government, 2023).

Other events that put the welfare of animals at risk by reducing the quantity and quality of feed available include floods, prolonged cold or hot weather, and bushfires.

5.3 Monitoring and Early Warning Systems

In very extensive farms, monitoring or even seeing sheep on a regular basis can be very challenging, although close observation or contact with sheep can also be difficult even in fenced pastures if the sheep are unfamiliar with human contact and express fear and flight responses. A consequence of low levels of monitoring can be that health and welfare conditions are not observed, not diagnosed, or not treated in a timely manner. A Delphi study of welfare issues with farmed animals identified lack of timely treatment in sheep as one of the most important welfare concerns (Rioja-Lang et al., 2020). However, even in housed systems, being able to detect early signs of disease or poor welfare before overt clinical presentation can be valuable in reducing disease spread and avoiding suffering. Changes in behaviour or weight may be initially subtle and not easily observed by producers until there has been a marked change. Opportunities to make use of developments in sensor technology, image analysis, and AI/machine-learning for welfare management are therefore starting to receive more attention as they potentially have the capacity to detect patterns of responses or smaller changes in state or activity (Fogarty et al., 2023; Morgan-Davies et al., 2024). These undoubtedly have some advantages in terms of providing continuous assessments rather than a snapshot observation, can provide information at times when a human observer may not be present, and may appear less open to subjective interpretation than human observation and scoring. However, developments of this technology for use in sheep are still at an early stage and few technological methods of assessing welfare have been subjected to external validation, even in more studied species (approximately 7% in a review of methods developed in pigs: Gómez et al., 2021; and 14% in dairy cows: Stygar et al., 2021). Sheep are too biologically complex and variable for stockpeople to be entirely replaced by technology. There is a risk that stockpeople may place too much reliance on sensors and give insufficient consideration to issues that sensors cannot detect (Cornou, 2009; Tuyttens et al., 2022).

Intensively managed/housed sheep: Several potential methods for assessing sheep welfare have been suggested for housed sheep, which are largely off-animal sensors (non-wearable); that is, sensors or cameras that are fixed and rely on the sheep passing nearby to assess changes in behaviour or state, such as weight (Caja et al., 2020). Walk-over weighers, where the animal may be weighed several times as it passes over the weight plate to access feed or water (González-García et al., 2018; 2021), have the potential to allow sensitive assessment of changes in weight gain or loss to be recorded, which may act as an indicator of disease. Individual animal measures taken in the milking parlour of dairy sheep can assess behavioural changes, such as order of voluntary entrance into the parlour (Wasilewski, 1999) and individual variation in milk yield. A sensor-fusion system to track individual sheep behaviour and position in a sheep barn has also been developed (Ren et al., 2020) as a research tool.

Although not directly measuring welfare of individuals, sensors have also been utilized to provide warnings about changes in air quality (García-Ramos et al., 2018), temperature, and humidity (Ciliberti et al., 2025), which can impact the risk of respiratory disease and heat stress in housed sheep.

Extensively managed sheep: In extensively managed sheep, wearable sensors have more commonly been investigated for welfare monitoring, although walk-over weigh plates have successfully been implemented in outdoor systems. Sensors have been used for a variety of purposes but have focused on assessing animal movements, behaviour, and proximity (to one another or to various features or resources) via accelerometry (Ikurior et al., 2021), Global Navigation Satellite System (GNSS) (Keshavarzi et al., 2021), and proximity beacons (Walker et al., 2024; Broster et al., 2010), as well as methods to restrain animals within a prescribed location (virtual fencing: Marini et al., 2018). In addition, indwelling boluses have been used which can measure heat stress, ruminal acidosis, and reproductive function (Lewis Baida et al., 2021).

Weather stations to characterize the environmental conditions sheep may face have been used for years. However, more recent approaches to provide data at the microclimate level can help with assessing aspects of the availability of pasture and local variation in temperature such as that in shade and shelter, and can be paired with other technology (e.g., accelerometers, proximity sensors, GNSS) to understand how these influence environmental use by sheep (Masters et al., 2023). This information may help to improve sheep welfare in the future by more closely matching environmental conditions to sheep requirements at specific times of the year.

Although there are considerable opportunities for future development in this area, it is noteworthy that very few sensors are yet commercially available for sheep for welfare applications and few have been externally validated. There is potential for growth and development in this area in the future which may lead to improved sheep monitoring.

5.4 References

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