Advances in Sheep Welfare
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Advances in Sheep Welfare

A volume in the Advances in Farm Animal Welfare series

Edited by

Drewe M. Ferguson
Caroline Lee
Andrew Fisher
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Animal welfare began to emerge as a scientific discipline in the 1960s, and there is now a large body of published research addressing a range of fundamental and applied topics. However, the field is currently in a stage of transition, with an increasing emphasis on translating the knowledge that has been gained into ‘real-world’ improvements. This is necessitating new and evermore sophisticated research approaches, including collection of more complex data with an increasing focus on solutions, the development and use of new research methodologies and technologies, and integration of information across different disciplines. It also requires enhancing communication and collaboration among diverse stakeholders as well as developing science-based approaches for setting ‘best practice’ standards and on-site welfare assessments to help ensure public confidence.

The five books in this series provide overviews of key scientific approaches to assess and improve the welfare of farm animals and address how that science can be translated into practice. The books are not meant to provide a comprehensive overview, but instead focus on selected ‘hot topics’ and emerging issues for cattle, pigs, poultry and sheep (as well as the overarching issue of linking animal welfare science and practice). Advances and challenges in these areas are presented in each book in the form of an integrated collection of focused review chapters written by top experts in the field. The emphasis is not only on discussing problems, but also on identifying methods for mitigating those problems and knowledge gaps.

Although the topic reviewed in the cattle, pig, poultry and sheep books are tailored to those most important for the particular species, all of the books include overviews of production systems and discussions of the most pressing animal welfare challenges and important advances associated with those systems from the perspectives of normal and abnormal behaviour, animal health and pain management. Emphasis is placed on both management and genetic approaches in improving welfare and emerging scientific tools for investigating questions about the welfare of that species. As relevant, the books also include reviews on human–animal interactions and transport and/or slaughter. Finally, practical tools for in situ (on the farm, during transport or at the slaughter facility) assessment of welfare are presented. The reviews in the overview volume focus on animal welfare in the context of agricultural sustainability, and also address how science can be translated into practice taking into account ethical views, social developments and the emergence of global standards.

The topics covered by these books are highly relevant to stakeholders interested in the current and future developments of farm animal welfare policies, including farmers, food industry, retailers and policy makers as well as researchers and
veterinary practitioners. The editors hope they not only serve to help improve farm animal welfare, but also to encourage discussion about future directions and priorities in the field.

Joy Mench
Series Editor
Introduction

Sheep were one of the first animals to be domesticated by humans, over 10,000 years ago. The domestic sheep breeds form the species *Ovis aries* and are widely farmed for their milk, meat, wool and pelts, particularly in temperate areas of the world. Sheep are also an important, albeit niche, model research animal. Large sheep flocks are a key part of extensive livestock farming in countries such as New Zealand and Australia. Substantial sheep numbers also exist in China, India, the United Kingdom, and in parts of continental Europe, North Africa, South America and the Middle East. Sheep are typically described as vigilant, flock-dwelling ruminants, which may form closer groups for protection. These social behavioural characteristics of sheep probably facilitated the initial management of wild flocks for human purposes, and subsequently, domestication.

In common with other farmed and managed animals, the welfare of sheep has become a core consideration, both for the sheep industries and for the wider public. Farmers, scientists, veterinarians, policy makers and animal advocate all have a role to play in understanding and advancing sheep welfare. Demonstration of improved animal welfare has and will continue to be a primary element of the social licence to farm, particularly in comparatively wealthy societies. In areas where smallholder sheep farming is a critical component of subsistence, improvements to sheep management and welfare have the capacity to benefit both the animals and the people who depend upon them.

Farm animal welfare as an issue that is often mired in controversy, and the basis for this has sometimes been predicated on misconceptions, claim and counter-claim, and unsubstantiated evidence. This book aims to highlight where improvements or advances in sheep welfare have been made and where more effort is required. This will hopefully also serve as a reference to facilitate more informed and balanced thinking and debate regarding the welfare of sheep.

The objective of this book is to provide readers with an interest or stake in sheep with a detailed reference of current knowledge and advancements in sheep welfare. This book describes the biology and natural behaviour of sheep, the range of production systems in which sheep are farmed, and examines the welfare impacts of key production and husbandry practices. It then examines how these welfare risks and impacts can be mitigated or minimized through advancements in animal breeding and/or management strategies. This book includes a focus on recent developments in our understanding of sheep welfare, particularly through the lens of new methodologies to assess welfare, including animal affective states (feelings). The role of the consumer and society in shaping and influencing the welfare debate and animal farming
practices are also explored. The welfare of sheep used in research is also given a
detailed consideration. In the final chapter, we aim to take a forward-looking perspec-
tive and examine how and why sheep industries will need to take a more proactive
approach to achieve the dual aim of improving animal welfare on-farm and meeting
the expectations of consumers and society in general.
Part One

Introduction to Sheep Welfare

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Understanding the natural behaviour of sheep

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The domesticated sheep (*Ovis aries*) has a diversity of genotypes that are adapted to a wide variety of environments ranging from the tropics to the extreme seasonality of the high latitudes and from deserts to high rainfall areas. This diversity of genotypes (with over 2000 breeds) means that the species is highly adaptable to environmental/climate extremes, and to some degree this adaptability is also expressed in variation in the expression of natural behaviours. However, there are a suite of behaviours that have been comprehensively described both for domestic and wild/feral breeds (Grubb and Jewell, 1974; Lynch et al., 1992) that represent the key behaviours of this species.

There are several books on the behaviour and ethology of animals that include sections or chapters on domestic sheep behaviour (Arnold and Dudzinski, 1978; Fraser, 1985; Hafez, 1975; Lynch et al., 1992). These reviews outline the key behaviours in detail and in some cases discuss the underlying biological controls. It is not the intention in this chapter to re-examine these behaviours in detail, but rather to capture an overall impression of the unique behavioural characteristics of the species, a knowledge of which is essential in the consideration of the welfare of individual sheep.

The species has been described as a fearful, gregarious/flocking ruminant and as such organisation and daily expression of behaviours are relatively predictable even though there are a range of adaptations required in different environments. These characteristics are closely aligned with a grazing/ranging species whose natural behaviours are aligned with the need to cover large areas to gather food and whose social organisation facilitates avoidance of predation through formation of large groups. Interestingly, these behaviours are linked with behaviours that facilitate not only movement but also the establishment of close links between mother and precocial offspring.

The main wild *Ovis* species are found in mountainous and high plain regions of the world, and it is thought that domestication of the mouflon (*Ovis musimon*) occurred more than 7000 years ago. If we speculate on why this species was domesticated, there are a number of possibilities, including:

- The diversity of products produced (wool, meat and milk).
- The biological adaptability (capable of adapting to extremes of heat and cold, and to fibrous diets and exhibiting large variation in disease resistance) to move to new environments with nomadic herders.
- Behavioural characteristics that facilitate ease of husbandry and management (highly selective herbivores, gregarious, follower behaviours, precocial young, promiscuous mating patterns with dominant male and a body size and low agility that facilitate ease of husbandry).
It could be considered that the fearful nature of the species would have hindered the domestication process with large flight distances making individual identification and care difficult. However, it is likely that some selection pressure may have been ‘applied’ to retain the animals that could be most easily habituated to human handling.

The behavioural characteristics identified earlier seem to have been largely retained in modern sheep breeds (Lynch et al., 1992). Breed selection has created variation particularly in the levels of gregariousness, which may also be related in some way to fearfulness and thus potentially to the adaptability of the species to more intensive management and confinement. Generally, the behaviours listed before are still the major determinants that shape the interactions between sheep and humans. If these behaviours are understood and considered during handling of sheep, then compromise to well-being is less likely. We will now look more closely at these behaviours and how these characteristics may be challenged in modern production systems where animals may experience greater restrictions on movement, diet and group interactions.

**Highly selective herbivores**

Like most herbivorous animals, feed gathering is the dominant behaviour of sheep in their natural environment and considerable periods of time each day are allocated to the behavioural sequences associated with the identification and gathering of food. Other components of the ethogram of the sheep play a far less dominant role, although social components interact with the food gathering process. The importance of food gathering to the sheep is possibly best illustrated by the fact that when food availability is restricted, or the diet is nutritionally unbalanced, sheep can spend very large proportions of their day in food ‘harvesting’ mode. In a recent study on the motivation of sheep to travel for food, it was shown that they will travel distances of more than 12 km to meet energy requirements (Doughty et al., 2016) and this may take all of 10 h per day (Bown, 1971).

Most herbivores used in farming exhibit a circadian pattern of feeding that includes a major ‘meal’ at, or soon after sunrise. Other meals are then spread throughout the day with the pattern primarily dependent not only on feed availability but also on weather conditions, topography and social factors. Dudzinski and Arnold (1979) reported differences between sheep breeds in grazing patterns exhibited in hot Australian conditions with Cheviot and Suffolk ewes commencing grazing earlier in the morning and evening than the Merino. Such differences in feeding patterns may reflect differences in physiological adaptive responses and highlight the difficulty of defining what is normal in this highly adaptable species. Forbes (1995) has provided a detailed discussion of the patterns of feeding bouts/meals, but the description of Bown (1971) captures the key elements:

*During the early part of the grazing season the sheep left the bed ground before or just after daylight. At daybreak the ewes stood up, collected their lambs and then moved off. The animals left together in a large group, separating into smaller groups as they fed.*
Factors reported to influence foraging behaviour include geographical characteristics such as vegetation type, soils, slope and weather conditions, which influence the distribution of sheep and their habitat choice. Sheep tend to be irregularly distributed over the land area available resulting from the integration of the factors aforementioned. The management of this variability along with sheep protection has, in many cultures, been the responsibility of the shepherd. A book edited by Meuret and Provenza (2014) documents how shepherds can use an understanding of the various factors mentioned before. It is clear from these case studies of sheep management in the French alps that shepherd decision-making is based on an understanding of the geographical and other factors influencing sheep social organisation and movement.

The distribution of grazing animals often correlates well with vegetation type. The vegetation types, which appear to be the most preferred by grazing species and particularly by sheep, are moisture-loving grasslands commonly found in the riparian zone. These plants provide green feed and moisture at times when it is not available elsewhere. Such influences are particularly apparent in arid areas of Australia (Dudzinski et al., 1969; Muller et al., 1976) and in areas with heterogeneous vegetation cover, there are clear preferences for the higher quality feed areas. There is also evidence that animals are more likely to return to these areas in later days, for example sheep grazing plant communities in Morocco (El Aich and Rittenhouse, 1988) visited areas with high resource levels more frequently than other sites, but visited and sampled feed from all areas of a 50-ha paddock.

The distribution of sheep may also be influenced by the location of water and the distances they are willing to travel between preferred food sources and water. These influences can be major determinants of the distribution of animals in drier rangelands, for example sheep forced to walk to water reduced grazing time on the day of walking (El Aich et al., 1991) but compensated by increasing grazing time during the following 24 h. Sheep have been reported to travel for distances of up to 25 km per day in rangeland conditions and much of the distance travelled in such situations may not be directly associated with food gathering but rather movement between preferred ‘patches’ and a source of water. In semi-arid conditions in Australia, Merino sheep are normally found within 3 km of a watering site, although greater distances are covered in cool conditions (James et al., 1999).

Shelter also influences spatial distribution of sheep whether it is shelter protection from heat or cold. The effects are most apparent for newly shorn animals, but sheep do show high levels of motivation to avoid high temperatures. It seems that while sheep are able to physiologically adapt to high heat loads, they are also willing to work hard to achieve conditions in a more thermo-neutral zone. Studies by Taylor et al. (2011) showed that even at relatively low ambient temperatures sheep will seek out shade and that spatial distribution of animals in a large paddock can be largely determined by shade access. It is interesting to contemplate how important the ability to control heat and cold is to the sheep. For instance, Fisher et al. (2008) were able to show that animals were highly motivated to escape from high temperature conditions even at ambient temperatures of around 25°C. Within the period of 4 weeks post shearing, sheep will normally seek shelter from the wind in cold weather (Lynch et al., 1980).
and the results reported by Lynch and Alexander (1977) suggested Merino sheep use the shelter as a night camp site and during the day in inclement weather.

Sheep prefer to camp on hilltops near their grazing areas, and McDaniel and Tiedman (1981) noted that sheep favoured ridges for grazing and camping, but were willing to utilise slopes of up to 40 degree for grazing. In a detailed analysis of the factors influencing distribution they identified slope, soil surface characteristics such as the percentage of bare ground as more important than vegetation variables at least on hilly country. Sheep often establish overnight camp areas that are in upper-slope positions normally facing the early morning sun (Taylor and Hedges, 1984).

Social factors

Social factors are extremely important determinants of many of the behaviours of gregarious species and as such could be predicted to have a large impact on the feeding behaviour of sheep. The impact of associations between members of a flock on animal distribution has been reviewed (Lynch et al., 1992). The formation of bachelor herds and the impact of sexual behaviours are likely to influence spatial distributions, as is the association between ewes and lambs and also the associations between conspecifics. Such associations can also impact group size and the home range areas occupied. This is likely to be reflected in the transfer of feeding/spatial information via traditions of the maternal line where associations are potentially maintained for a number of generations (Lawrence and Wood-Gush, 1988).

The concepts of territory and home range are widely used in behavioural literature to describe the areas routinely defended or frequented by animals and in the case of sheep, where aggression levels tend to be minimal (except for males during the mating season), the concept of defended territory is rarely relevant. However, the concept of a home-range area, the area over which the animals will naturally range, fits well for the species. Home-range areas have been well described for sheep grazing in the Scottish highlands (Lawrence and Wood-Gush, 1988). These workers found that the home-range size of Scottish Blackface ewes varied between 25 and 50 ha depending on season. Similar home-range areas in hill country were observed for groups of South Cheviot ewes (Hunter and Milne, 1963). In contrast, studies of Merino ewes in a semi-arid environment in Australia could find no defined home range for this breed (Lynch et al., 1992), with animals forming sub-groups and ranging over areas measured in square kilometres. In the latter case, the location of water may have been an important determinant of the distances travelled.

Rebanks (2015) in his telling of the story of sheep farmers in the Lake District of England has reflected on some aspects of the home range of sheep.

….. so in theory our sheep could wander right across the Lake District. But they don’t because they are ‘hefted’ – taught their sense of belonging by their mothers as lambs - an unbroken chain of learning that goes back thousands of years.

He provides a definition of the local term ‘heft’—an area of upland pasture to which a sheep/flock has become attached/accustomed. Interestingly, the origins of the
term seem to be Old Norse with the meaning of a tradition—spatial knowledge passed on from generation to generation. It seems sheep have not altered aspects of grazing behaviour over millennia; spatial knowledge of a grazing area can be passed from dam to offspring through generations.

It is very difficult to predict or generalise about the size of ‘home-range’ areas, as this seems to be influenced by a large number of variables. For example studies of both wild sheep and goats show that the formation of male and female groups in the non-breeding season impacts the size of the home range occupied, as do seasonal changes in food quantity and quality (Hunter and Milne, 1963). To a large degree, shepherding practices take account of these changes in the annual cycles of management for grazing animals.

The total feeding time of herbivores is, to a large extent, dependent on availability and characteristics of the feed on offer. Sheep have grazing times that can last between 4 and 14 h, and this is determined by feed availability and also factors such as physiological state (Arnold and Dudzinski, 1978). These authors reported grazing time of ewes in late pregnancy was similar to non-pregnant animals, but that eating rate was higher, reflecting the increased food requirements of pregnancy. The grazing time of lactating ewes on grass/clover pastures has been reported to be 7%–12% greater than nonlactating animals and Penning et al. (1995) reported that when grazing a monoculture of clover, lactating ewes also had slightly longer grazing times. When grazing a mixed rye grass/clover sward, feeding behaviour differences between dry and lactating ewes were minimal, although lactating animals appeared to eat clover at a faster rate (Parsons et al., 1994).

Given the range of ways that sheep can adjust intake levels, it is interesting to speculate if these mechanisms vary in links to motivation and whether, for example provision of high density feeds with limited capacity for foraging time has consequences for aspects of well-being. Again it is clear that the species is highly adaptable and while patterns can be described it is difficult to define what is ‘normal’. As we consider the grazing behaviour of sheep in unconstrained conditions, the question of impact on the animal of reduced opportunity to travel and select preferred foods comes to mind. Clearly, the species is adaptable so, are they able to adapt to energy dense feeds that will inevitably reduce the need for long periods of grazing? Recent studies have begun to examine such questions but in the extreme there is good evidence that high-energy diets can lead to boredom and that lack of fibre can result in the development of stereotypies such as wool biting (Fraser and Broom, 1990; Vasseur et al., 2006).

**Highly selective in food choices**

Sheep have a cleft upper lip, which allows the animals to graze close to the ground and also appears to allow greater selectivity of the plant species on offer. The lips and lower incisor teeth are the principal prehensile structures of this species with the forage bitten through by the lower incisors pressing on the upper dental pad. It is interesting to consider how important the capacity for selection is to the sheep. Certainly, it facilitates the intake of better quality food, but how motivated the animal is to achieve
such a balance is still to be determined. The sheep is classified as a generalist feeder with the ability to adapt their dietary choice according to the environment in which they are located. A good example of this adaptability is the reports of the seaweed-eating sheep on north Ronaldsay Island (Paterson and Coleman, 1982).

Sheep tend to forage and sample the most palatable plant species first and spatial memory of preferential feed and water source locations is good even after one visit in a complex and diverse paddock topography (Dumont et al., 1998; Edwards et al., 1996). Boissy and Dumont (2002) reported that sheep foraging in patchy grasslands showed a preference for larger patches over smaller ones and sheep were willing to expend increased foraging costs to do so. They suggested that this grazing behaviour bias was also influenced by animal social characteristics including social attraction and social tolerance.

We have good evidence that the chemical properties of the plants and the associated sensory characteristics of odour and taste are important determinants of food selected but it seems that sheep do learn to adapt their taste preferences if they are given an opportunity to link tastes with positive ingestive outcomes. It could be argued that generalist feeders are extremely adaptable [e.g. sheep can adapt quickly to unfamiliar, bitter tastes such as quinine treated hay (Jones and Forbes, 1984)], and even if not given food choices will eat to satisfy their appetite.

In the last 2 decades, there has been considerable research focused on understanding the mechanisms that determine food choice in sheep. The role of the senses and feedback mechanisms is relevant not only to aspects of feeding and food choice but also to many other sheep behaviours, including maternal and social behaviours. Likewise, our understanding of learning and memory capacity of this species and implication for welfare has been expanded, as the mechanisms of food choice have been examined (Manteca et al., 2008; Provenza, 1996).

Scott et al. (1996) reported the impact of familiarity with the environment on the ability of sheep to learn about feeds. They suggested that social factors might become more important than previous food experiences/preferences if animals are in a novel environment. However, if most sheep in the group are strangers, then memory of preferred food locations may become a major determinant of foraging location rather than maintenance of social contact. To generalise, the decision about which patch to move to is not only determined by food preferences but also by social and, possibly, environmental conditions.

How important an opportunity to select foods is to the sheep is not clear but it can be argued that this is a mechanism to protect animals in environments, where a diverse range of potential foods need to be ‘screened’ to avoid toxins. The normal behavioural patterns facilitate learning about new food sources while at the same time preventing negative outcomes. With intensification and housing of sheep comes restriction of food sources, but as long as the animals have identified the foods offered as ‘safe’ or ‘rewarding’, then animals will eat to daily requirements. Interestingly, if sheep have a choice of foods they will always sample more than one food but it seems unlikely that thwarted motivation to sample has any impact on well-being.
Followers, fearful and gregarious

Sheep have an innate desire to be with other sheep, although the strength of this attraction varies with breed. Group activities are common in stable social groups such as Merino sheep; however, decision-making may be influenced by relatedness (Ramseyer et al., 2009) and physiological state (Rands et al., 2003). Therefore, group cohesion and coordinated behaviour require individuals to harmonise their behaviour with that of their neighbours (Syme and Syme, 1979) and are probably most apparent in the Australian Merino. These behaviours influence group activities as do leader-follower behaviour.

Follower behaviours

There is clear evidence of follower patterns established in sheep flocks and Merino sheep have been observed to demonstrate leader-following behaviour while walking, running, grazing and bedding down together (Fig. 1.1). There appears to be no dominance rank relationship with leadership (Arnold and Maller, 1974; Lynch et al., 1989; Syme, 1981), and no consistent movement order or leadership during voluntary movement (Nowak et al., 2011; Syme, 1981). Squires and Daws (1975) found that not one sheep was consistently the leader in competitive situations, rather a leader would emerge from a pool of animals that were consistently observed to be leaders at one time or another. Different flock mates might emerge as leaders depending on the situation. Stolba et al. (1990) found that Merino sheep movement was typically initiated by older sheep within the group and passive recruitment of other animals appeared to be unintentional when an individual animal moved to a new grazing patch (Ramseyer
et al., 2009). However, sheep can be trained to initiate behaviours that will influence other members to follow. During trained leader movement trials, Taylor et al. (2011) found that Merino ewes could be trained to successfully initiate movement of flocks, thus influencing pasture and resource utilisation.

Following behaviours are important in determining the movement of sheep flocks; they are now well understood and utilised in facilitating ‘low stress’ handling approaches to sheep management. Interestingly, the movement of sheep is also influenced by pair associations/bonds and nearest neighbour studies indicate that there is a great consistency in nearest neighbours within a flock (Stolba et al., 1990). These pair-links are usually attributable to ‘family’ or previous rearing experiences and while ewes (reports not available for mature rams) seem motivated to retain these associations, it is unclear if the disruption of such nearest neighbour pairs has any impact on affective or cognitive state of the animals.

A more specific form of association/bond that is established between ewe and lamb/s and the development of a close bond within the first 6 h post lambing has been well documented. This bond forms largely as a result of olfactory cues that establish recognition of the lamb by the ewe, although ewes without a sense of smell can compensate using other senses, and auditory cues appear to be vital in the maintenance of the communication bond for the lamb (Sèbe et al., 2010). These links can remain for at least 2.5 years (Hinch et al., 1990), and Arnold (1985) has also reported that olfactory cues are important in-group recognition, for example when mixing groups of different ages.

The capacity to identify other individual animals is clearly important in the social organisation of sheep and knowledge of the sensory mechanisms that allow this recognition can be used in a variety of ways to aid in the husbandry of sheep, particularly the facilitation of good maternal outcomes during lamb rearing. It appears that the sheep, like many other mammalian species, are very adaptable in terms of the senses it uses, if one is not available then another is brought into play. However, in general, visual cues are probably the most dominant influence with olfaction used predominantly for individual recognition. Kendrick (2008) in his review reported growing evidence for highly sophisticated social and emotional recognition skills in sheep linked to shape, sound and olfaction.

**Social dominance**

An understanding of dominance relationships within a group of animals is vital in terms of management and stability of flocks. Dominance can have significant influences on social interactions, frequency of aggression and potential injury in many species, but its importance appears somewhat less in sheep because of the seasonal separation (be it natural or husbandry determined) of ewes and rams. The separation of male and female during most of the year [there are exceptions, e.g. bighorn rams have been reported to stay with the flock all year in desert environments (Lenarz, 1979)] means that there is very little competition for resources except during the mating period when high levels of aggression between rams can cause injury. The high sexual motivation exhibited by rams during this period can result in weight loss over extended periods of
time as the promiscuous mating system results in daily movement over relatively large distances particularly when mating ratios are high. Competition between rams is, to some degree, ‘regulated’ through postural or physical signals such as horn size, which are known to be ‘hard wired’ in sheep (Kendrick and Baldwin, 1987).

In ewes, while dominance structures have been reported they appear to have minimal impact except possibly when animals are crowded together competing for limited resources such as in feedlots or confinement during shipping. Because of the gregarious nature of sheep, crowding of ewes and young sheep is usually not an issue with space allowances of around 2 m² seemingly adequate to avoid chronic stress although resource restrictions may alter competitiveness (Bøe and Andersen, 2010).

**Fearful and gregarious**

Sheep are known to be fearful animals and it appears that this is linked to a predation protection strategy whereby animals are fearful of unknown or predator species. Interestingly, they also exhibit a high level of fearfulness of ‘new’, which has been illustrated in relation to foods and infrastructure such as troughs and raceways. In terms of moving flocks of sheep, fear of a predator (Beausoleil et al., 2005) is commonly used in western societies, where dogs are used to initiate flocking behaviour and then to force animals to move together and follow one another in a certain direction. An alternative still used in many societies is focused on following behaviours where the flock follows the shepherd or trained lead animal; this is arguably a less stressful approach to flock movement. However, the success of the latter approach does rely on considerable ‘gentling’ time between human and sheep (usually from weaning) and smaller flock sizes are common in many extensive grazing systems.

In grazing situations sheep are known to be vigilant, showing alert posture when threatened by the ‘unknown’ (Stolba et al., 1990). Sheep can also use alarm/distress vocalisations, but these are more commonly linked with maternal ewe-lamb separations than with general flock activity. One of the key causes for initiation of distress vocalisations is visual isolation of sheep from other animals and it is well documented that visual isolation is highly stressful with high levels of motivation to retain contact with conspecifics (Barnard et al., 2015; Sibbald and Hooper, 2004). A sheep that is challenged, be it from isolation or exposure to a ‘new and frightening object’, will exhibit fear, which can be largely quelled if the animal can express its gregarious tendencies by flocking together (Fig. 1.2) with other sheep and reducing nearest neighbour distances to around 1 m, although the distance does depend on breed (Arnold, 1985). Interestingly, some breeds may not have gregarious flocking as their default position for a fearful response to a predator as Boyd et al. (1964) reported that Soay sheep responded to a predator by dispersal rather than congregating.

Isolation is not an uncommon outcome of husbandry practices and some forms of housing and as such can be highly stressful to sheep (Averós et al., 2013). Gentling and training (usually food reward based) can reduce this stress and it is well known that sheep can be trained to tolerate confinement with no negative behaviours being exhibited. In a study reported by Taylor et al. (2010) the question of how long memory of training can last was tested and when both visual and auditory cues were combined
correct T maze choices were made by 90% of sheep 130 days after initial training. Whether sheep can generalise training cues to a variety of contexts is not well documented, although farmers in Australia would argue that sheep generalise the sound of a vehicle to the availability of food.

Undemonstrative

It is often difficult to assess if an individual sheep is showing signs of fear or that an animal is suffering in some way. Generally, sheep are relatively undemonstrative in behavioural expressions that would indicate stress and/or pain. A review by Gougoulis et al. (2010), looking at qualitative and quantitative measures related to sheep welfare, noted that there is a need for further research to identify behavioural indicators of distress in sheep, but highlighted that changes in locomotory activity and feeding or social patterns are potential indicators of distress.

However, other researchers have reported that rapid changes in ear position (Reefmann et al., 2009) are usually a good indicator of fear most often followed by flight although, because of the wide variation in ear anatomy of sheep breeds, this will not be a reliable indicator in all contexts. Postural changes such as an arched back are often indicative of pain (Paull et al., 2007) and increases in lying time can also indicate
compromised well-being. Isolation from the flock (e.g. clear separation from the flock during periods of lying, Fig. 1.3) may also indicate that an individual animal is compromised in some way. Phythian et al. (2012) reported that behavioural and physical indicators could be used as a feasible measurement tool for on-farm assessment of sheep welfare. In addition the recent report of repeated qualitative behavioural assessment of sheep flocks in the United Kingdom (Phythian et al., 2016) suggested that there are measures, which can be used as indicators of the welfare of sheep on farm collectively summarised as ‘mood’ (content/relaxed/thriving to distressed/dull/dejected) or ‘responsiveness’ (anxious/agitated/responsive to relaxed/dejected/dull). However, further work is needed to understand how variation in these measures can be influenced by physiological state and thus whether they are reliable indicators of compromise to individual animal’s well-being in all situations. Studies have already illustrated the impact of chronic stress on judgement biases and learning deficits in sheep (Destrez et al., 2013) but such changes are only identifiable with complex testing procedures. It would seem that identification of compromised well-being cannot be done using evidence of deviation from a single, ‘normal’ behaviour alone.

Figure 1.3 Alone? Unlikely unless she is ill!

Conclusions

So, what is the picture of sheep that you have gained from this short chapter? It is a species that is, both physiologically and behaviourally, well capable of adapting to the environment in which it finds itself but it is very hard to ‘read’. The characteristics
described, if taken into account for handling and management practices, make the outcome of interactions with humans less likely to be stressful, and it is interesting to contemplate if this knowledge will help to direct application of new biological knowledge to improve the well-being of sheep into the future.

As our understanding of brain plasticity and sensitive periods in young animals develops, it may well be that the more challenging aspects of sheep behaviour such as fearfulness can be modulated through early life interventions. This has recently been illustrated in layer hens in our lab (Campbell et al., 2017) but to the author’s knowledge has yet to be shown to be possible in sheep. Such outcomes might also be possible through genetic approaches. The recent review of Rodenburg (2014) provides insights into the potential role that genes and their interaction with environment play in behavioural development and fearfulness in particular. Clearly, there is a possibility that at least some of the natural behaviours of sheep can, in the future, be modified in ways that will increase the likelihood of lowered stress levels, improvements in affective state and possibly more consistent positive welfare outcomes for individual animals.

References

Understanding the natural behaviour of sheep


Understanding the natural behaviour of sheep


Overview of sheep production systems

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International perspectives in sheep production: differences in systems and welfare risks

World sheep numbers and production

There are an estimated 1000 million sheep in the world (Morris, 2009). The major sheep farming areas are located within the latitudes 35–55 degree north in Europe and Asia and between 30 and 45 degree south in South America, Australia and New Zealand (Zygoyiannis, 2006). These are the world temperate zone areas reflecting temperate pasture conditions and, as a consequence, account for 60% of the world sheep population. The semi-arid tropics of Africa and Asia between 5 and 35 degree north, including India, the Middle East and the highlands of East Africa, account for 40% of the world sheep population.

Wool and sheep meat are very minor components of the global red meat and textile markets. The total annual world sheep meat production is 14 million tonnes and this constitutes around 3% of global meat production (FAO, 2016). Inter-country trade in sheep meat accounts for 7%–9% of total production with most of the meat being consumed in the country it was produced (FAO, 2016). The bulk of the international trade consists of exports from the Southern Hemisphere (New Zealand has 47% and Australia has 36%) to the European Union, North Asia, the Middle East and North America (Morris, 2009). The current world consumption of sheep meat stands at about 2.5 kg per person annually out of an annual meat consumption of 41.6 kg per person (Morris, 2009). The annual world post-scoured wool production is estimated at 1.2 million tonnes (Cottle, 2010) and comprises just over 1.5% of the textile fibre market (Rowe, 2010). It is estimated that worldwide between 500 and 700 million skins from sheep and lambs are produced annually (Scobie, 2010). Less than 2% of the world milk production is derived from sheep (Balthazar et al., 2017).

There has been a universal decline in sheep numbers throughout the world over the last 10 years especially in Australia and New Zealand. Many of the world’s pastoral systems are in transition, for example in Europe, there has been widespread changes, with abandonment and farming retreat in many areas (Pollock et al., 2013). Australian sheep numbers have plummeted from 150 million head in 1990 to 70 million in 2010 with the main change in land use being an increase in cropping and mixed farming (Rowe, 2010). Key contributing factors to this decline have been on-going and
widespread droughts, high crop prices, low wool prices and increasing on farm costs such as fertiliser, feed, fuels and finance.

Other contributing factors to the decline in sheep numbers is the fact that sheep are inferior converters of feed to meat relative to poultry and pigs (Morris, 2009). However, an important attribute of sheep is that they can live and produce on land unfavourable to other forms of agriculture. Many sheep breeds are adapted for survival on extensive unimproved, semi-natural pastures, in difficult climate conditions. For example, approximately 40% of the ewes in the United Kingdom are maintained in relatively harsh hill and upland environments (Pollott, 2014; Wolf et al., 2014). Sheep are also a very valuable animal in small farm situations, where large ruminants may be out of place due to limited land and other resources and when small quantities of meat are required for local consumption in remote communities.

Sheep production systems

Sheep farmers produce meat, wool/hair, milk and skins for local, national and international markets. The uses of sheep vary in many countries, but in many other countries sheep produce more than one product. Sheep farmed in Iran, Sudan and Turkey are major producers of meat, wool and milk, while sheep farmed in Australia, New Zealand, United Kingdom and Uruguay produce meat and wool (Kilgour et al., 2008). The systems used for farming sheep do, however, vary between and within different countries. In temperate regions, meat is now the major product while in many countries wool production is declining. In Australia, the world’s largest fine wool producer, the importance of meat production is also increasing and the Merino ewe is increasingly regarded as a ‘maternal breed’. The traditional wool production enterprises have adopted new breeding and management practices to produce both meat and wool rather than wool-only (Rowe, 2010). In the more arid regions of Asia, Africa and the Middle East, sheep are increasingly multipurpose in their generation of products and in sustaining the livelihoods of those who farm the sheep.

The management of sheep does vary depending on the product to be harvested from the animals and whether the product is for home consumption or for sale in local or export markets. Sheep’s wool is usually shorn once a year, whereas sheep dedicated to milk production will be milked twice a day. Within the different systems climate, financial and cultural differences affect management factors such as the number of animals supervised by one person and whether the sheep are housed all year round or just for the cold winter months or are always kept outdoors.

Kilgour et al. (2008) has comprehensively described the three major management systems for sheep production that exist in the world, namely extensive production for wool and meat, intensive dairy production and traditional pastoralism. There are, however, new systems being developed that are variations on these such as the emergence of housed lamb production systems in China where female sheep and their progeny spend their entire life indoors and feed is cut and carried to them. Likewise, outdoor feedlot type lamb finishing systems have been developed in countries such
as Australia, México and USA where slaughter lambs are fed high energy diets while confined in a feedlot.

**Welfare risks in different systems**

Many sheep farms have less than 100 ewes within Europe and the USA and in the traditional nomadic systems of Asia, the Middle East and Africa, but in Australia and New Zealand, flock sizes are in thousands (Morris, 2009). Sheep farms with small flocks have a high human to animal ratio and farmers can identify and probably deal with each sheep as an individual. Moreover, each animal is worth more relative to the total flock value compared to one animal in a large flock (Goddard, 2008). Although sometimes the larger flocks have greater resources, and hence superior infrastructure to ensure good handling of sheep and a high level of husbandry and welfare. A diverse range of sheep breeds is managed in the different systems, many of which are adapted to their environments (Kilgour et al., 2008). Generally, the different farming systems have the capacity to provide good welfare outcomes for the animals, provided adequate resources and husbandry (e.g. supplementary feed, labour veterinary care) are given when required. Some specific welfare concerns are mentioned within each of the three systems described; however, most of these are elaborated further in later chapters.

**Traditional, extensive and intensive sheep production systems**

**Traditional systems**

Traditional pastoralism is the main sheep production system of the semi-arid rangelands, where there is unpredictable climate and economic dependence on livestock increases as rainfall decreases. Traditional pastoralism can be categorised by the degree of movement of animals from highly nomadic through transhumance to agropastoral (FAO, 2001). Pastoralists by their nature are flexible and opportunistic, and can swap between systems, as well as have multiple systems in one overall productive enterprise. Nomadic systems are highly flexible systems with seasonal migration of livestock and normally have no home base. Transhumance is the regular movement of flocks among fixed points to exploit the seasonal availability of pastures. In mountainous regions, the movement is usually vertical between established points and the routes are often very ancient. Horizontal transhumance is perhaps more opportunistic with movement between fixed sites developing over a few years and are often disrupted by climatic, political or economic changes (FAO, 2001). Recently, transhumance has been transformed with the introduction of modern transport in many regions of the world and trucks are often used to transfer sheep from lowlands to highland areas for summer grazing in the United Kingdom. Agropastoralism can be described as settled pastoralists who cultivate sufficient areas to feed their families from their own crop production and keep animals but only enough to ensure
they can graze them close to their home base or village. These farmers often own larger flocks that are sent away to nomadic shepherds in rangelands who look after the sheep for the owners.

The main risk to traditional systems is the unpredictability of the climate. This has an impact on the growing season of plants and hence the forage that is available to sheep. The risks are particularly acute mid-winter when sheep are in their poorest condition and least likely to be able to withstand any other challenge, and during the spring lambing season. High losses of newborn lambs can be especially damaging as it limits the supply of new females to enable flock rebuilding, and hence slow recovery from a catastrophic climate event (Kilgour et al., 2008). In traditional systems in arid regions, lack of drinking water for sheep, attack from predators and disease can be a barrier for production and good animal welfare standards.

**Extensive systems**

There are many different types of extensive sheep systems in the world, but a distinguishing feature of these systems is that sheep graze in enclosed fenced systems, where they are usually individually owned. These are the basis of sheep production systems in the United Kingdom, New Zealand, Australia and Uruguay. The systems operating in these four countries will be described in detail to highlight the major differences in systems of production.

**United Kingdom sheep systems**

Sheep farming in the United Kingdom can be divided into hill, upland and lowland systems, all of which are dependent or interact with each other for the supply or sale of sheep (Kilgour et al., 2008; Pollott, 2014; Rodriguez-Ledesma et al., 2011). Stratification is the term used to describe this highly structured sheep industry in the United Kingdom based on the natural resources of the different regions and the sale and movement of sheep between these regions. Farming sheep in the hill farming areas of the United Kingdom relies traditionally on all year round grazing, with sometimes away wintering of the young replacements females on lowland pastures. Most of these farms have large areas of unfenced hill grazing and smaller areas of improved fields or paddocks (Morgan-Davies et al., 2006). There is a wide diversity of breeds and genetic improvement is largely realised through the purchase of breeding males (Simm et al., 1996). Typically, the hill farmed sheep are purebred with the following characteristics: hardy with physical (e.g. wool characteristics), physiological (e.g. cold tolerance) and behavioural adaptations (e.g. grazing behaviour) of low mature body size and produce slaughter lambs with lightweight carcasses and poor conformation classes (i.e. lack of low muscling in the carcass). The breeding ewes tend to remain on hill grazing land throughout the year with little contact between sheep and shepherds. Lambing dates are fixed, typically late April and May with little flexibility due to the time of onset of spring grass growth. Supplementary feed can be given especially the emergency feeding of hay in difficult weather conditions and there has been some increase in concentrate feed fed in recent years (Kilgour et al., 2008). The sale of ewes
after they have produced four or five lamb crops, from hill farms to upland or lowland farms, is a very integral part of the stratification sheep system. Here the ewes may be retained for a further 1–3 years (Kilgour et al., 2008).

Within the stratified breeding system of the United Kingdom, hill breeds make a large genetic contribution to lamb meat production in part, through the direct slaughter of lambs produced by purebred hill ewes, and also through the contribution hill sheep make to the crossbred ewe populations maintained in the uplands and lowlands (Annett et al., 2011; Pollott, 2014; Wolf et al., 2014). This pattern is, however, far from a complete model, and recent changes in the structure of the UK sheep industry have resulted in increased crossbreeding in hilly environments requiring an associated increased level of management to ensure feed resources are adequate to realise the potential for enhanced performance of crossbred ewes with a greater proportion of twin lambs (Wolf et al., 2014). The traditional stratified crossbreeding nature of the UK sheep industry is still identifiable, but the ratio of stratified:non stratified has declined from 71:29% in 2003 to 55:45% in 2012 (Pollott, 2014). A feature now is the emergence of a wide range of ad hoc crossbreds with crossbred ewes outnumbering purebred ewes by 56 and 44% of ewes mated, respectively. In 2003, it was 50:50, although the change was mainly due to a reduction in purebred numbers and maintenance of crossbreds associated with the overall decline in sheep numbers in the United Kingdom (Pollott, 2014). When considering the genetic contribution of the different breeds to lamb output from the industry, terminal sire breeds (e.g. Texel and Suffolk) sired 68% of lambs and contributed to 45% of the genetic makeup of the lamb carcass meat produced in the United Kingdom (Pollott, 2014; Rodriguez-Ledesma et al., 2011).

Upland sheep systems are largely based on improved pastures with a large proportion being sown pasture. Lambs from upland flocks may be born between February and May and quite often the whole flock may be housed from mid/late winter through to shortly after lambing. Ewes may be purebred hill bred ewes purchased from hill farm systems or crossbred ewes also purchased from other farms and managed to produce slaughter lambs with carcass weights of 18–21 kg (Kilgour et al., 2008). Increasingly composite breeds are being used where replacements are bred on the farm and only a proportion of the ewe flock is bred to terminal sire breeds. Lowland systems are similar to upland farms in terms of ewe breeds and crosses with the main difference being the sheep are often confined to areas that are difficult to cultivate or farmed on pasture sown as part of the arable rotation.

With financial pressures on farm labour, the trend over recent times has been towards a higher sheep:stockperson ratio (Goddard et al., 2006). Lower input systems are becoming increasingly attractive to farmers in the United Kingdom, as farm incomes and subsidy payments decline. Overall, the welfare risks are potentially higher in these lower input systems. Nutrition remains an issue with extensive sheep systems especially the hill systems. The nutritional value of hill pastures is low and supplementation levels are also low often because of the low profitability of these sheep farm systems. Nutrition of the pregnant ewe is often sup-optimal and can result in a high level of lamb and ewe mortality although improvements in management strategies can reduce these welfare issues (see Dwyer Chapter 7 and Kenyon Chapter 8).
handling or inspection facilities also dictate if high standards of welfare are practiced on these farms. Often these facilities have not been designed with the welfare of the sheep in mind and this is exaggerated when hill or extensively managed sheep are only having minimal human interaction.

**Uruguayan sheep production systems**

In South America, sheep production is concentrated in the Southern Cone countries (Argentina, Uruguay, Chile and the south of Brazil) where climate is temperate or desert like. These countries have close to 60% of sheep numbers and account for 85% of the wool production in South America. Two defined systems operate, namely small-holder production systems characterised by low input, low productivity and small farms. The other system is commercial where the main objective is wool production, but with an increasing focus on meat production. Depressed worldwide wool prices have led to this change in focus, but it has also resulted in a decline in sheep numbers as farmers move to alternative enterprises with superior economic returns and an increased focus on sheep meat production. Cropping and dairying has also been instrumental in pushing sheep farming to the more marginal land areas (Abella et al., 2010).

Sheep numbers in Uruguay have declined from 25.2 to 13.2 million sheep from 1990 to 2000 and to 8.3 million sheep in 2010 (Montossi et al., 2013a). Sheep production in Uruguay is within a mixed farm system where most farms are running both beef cattle and sheep. These mixed systems are located on the less fertile soils where more profitable farming enterprises are not possible. On fertile soils, cropping predominates although there may be some sheep production. Most flocks are self-replacing with autumn mating and spring lambing being the most common practice to match sheep feed requirements with pasture production. Sheep production is usually low input and sheep usually graze native pastures. The predominant breeds are Corriedale (60%), Merino (20%) and Polwarth (12%), and these breeds can be described as dual purpose, as they generate income from the sale of both wool and meat (Abella et al., 2010). The wool produced is a reflection of these breeds with 70% being in the mid-micron range between 25 and 32 µm and 30% being below 24.5 µm (Abella et al., 2010). The breeding structure of the sheep industry in Uruguay follows the common hierarchical pattern with ‘top’ and ‘multiplier’ ram breeding flocks. Performance recording schemes have been in use since 1969 together with central performance tests and more recently, across flock genetic evaluation through the use of reference sires primarily in the two most numerous breeds, the Corriedale and Merino (Cardelino and Mueller, 2008). With the decline in world wool prices in the mid-micron range, there has been increased industry effort to reduce the fibre diameter of Merino wool, and hence increase returns while maintaining fleece and body weights (Cardelino and Mueller, 2008).

The average percentage of lambs weaned varies between 70% and 85%; however, many farmers have adopted improved management practices and are now achieving 100%. With the increase in meat production, lambs are often finished on improved sown pastures to 17–20 kg carcass weight at between 6 and 11 months of age. Sheep production in Uruguay has been subjected to very strong economic
pressures as a consequence of depressed wool prices, increased costs of production and the competition of alternative enterprises with better economic returns (beef cattle, dairy cattle, cropping and forestry). However, as Montossi et al. (2013a) point out there are opportunities to use more prolific breeds and terminal sires to achieve higher weaning percentages than present and produce heavier lambs at a slaughter age of 6–8 months.

New Zealand sheep industry

Sheep farming in New Zealand in the past has been extensive by nature with sheep being farmed on pasture all round the year, with no housing and mostly with no supplementary feed. New Zealand grasslands where sheep are farmed can be conveniently divided on the basis of topography and elevation into three broad farming groups: high, hill and flat to rolling country. Each varies in the quantity of pasture produced and the number and type of animals carried. High country is characterised by hilly terrain and low pasture production, especially during the cold winter months, and is used predominantly for sheep farming targeting fine wool production. Flat to rolling country usually has good all-year-round pasture production and supports almost all of New Zealand’s dairy cattle in addition to large numbers of sheep and beef cattle. It is estimated that over 70% of lambs are born in hill country farms in New Zealand. There are few specialised sheep or beef cattle farms in New Zealand and most farms run sheep and beef cattle together and increasingly in recent times, sheep and beef cattle farmers may also be contracted to finish dairy heifer replacements for dairy farmers. A farmer having sheep and cattle on the same farm increases management flexibility through the ability to preferentially feed some livestock while maintaining high levels of grazing pressure with other livestock classes. The role of the beef breeding cow has been, and continues to be, important in the sustainability of hill country farms where the contour requires that pasture control—the maintenance of species within the sward, and the prevention of pasture deterioration and weed ingress is primarily a function of livestock pressure and grazing management. This requires that beef cattle graze with sheep and this is seldom to the short-term benefits of the cattle, but often improves the performance of sheep and the pasture (Morris, 2007). The higher herbage allowances required by cattle compared to sheep means that cattle are likely to be wintered separately, but that they are likely to suffer from the low herbage covers operating in early spring on sheep-breeding hill country farms. Electric fencing has revolutionised grazing management because of its greater portability, effectiveness in animal control and lower cost compared with conventional fencing methods. Fencing allows managers to vary the frequency and intensity of defoliation, transfer pasture reserves through time and to impose special purpose grazing regimens. It also allows separate stock classes to be preferentially fed or to control intakes on other classes of stock.

New Zealand is the largest exporter of lamb in the world accounting for around 47% of the world’s trade in lamb (Morris, 2009). New Zealand is the third largest producer of wool in the world, producing 12% of world production on a ‘clean’ basis (Morris, 2013). Most of the wool produced (88%) is described as strong crossbred
wool (greater than 31 µm) and China is the major market with the proportion of wool exports going to China increasing from 27% to 53% over the last 5 years, with 70% of this being classified as strong wool largely used in carpet manufacture. Fine wool (less than 25 µm) accounts for around 10% of New Zealand’s wool production. Thirteen percent of the wool clip originates as slipe wool (that which is removed from pelts after processing of sheep at meat plants) (Morris, 2013). Annual lambing percentages have increased significantly over the last 20 years from 98% in 1987 to over 122% in 2014 and range from 90% (lambs surviving to weaning/100 ewes mated) on high country to 138% on easier or flatter country (Beef+Lamb New Zealand, 2016). Carcass weights have increased from 14 to over 18 kg in 2016. This increased productivity has required a commensurate increase in forage production both in quality and quantity, and utilisation through increased use of fertilisers, fencing and modified management systems. Other gains in production have occurred through widespread adoption of existing technologies such as increasing the number of ewe lambs bred, increasing the weight of lamb weaned per ewe bred each year through increased adoption of management techniques such as pregnancy diagnosis, body condition scoring of ewes and then managing them according to condition, improving pasture production and quality through fertiliser application, fencing and where applicable, sowing new improved pastures (Morris and Kenyon, 2014). Most of the sheep farmed are Romney or their crossbred derivatives and in the last 20 years, there has been an increase in composite breeds incorporating East Friesian, Finn and Texel genes with the existing Romney, Coopworth or Perendale flock to improve fertility and meat production potential. It is estimated that around 25% of the 20 million female breeding sheep are mated to terminal or meat sire breeds such as the Poll Dorset, Suffolk or Texel, or composite terminal sires (Morris, 2013).

The New Zealand sheep industry was genetically isolated from the rest of the world for over 40 years until the release from quarantine of the Finnish Landrace, Texel, Oxford Down and Gotland Pelt breeds in 1990. This release of genetics with improved fecundity led to a rapid improvement in lambing percentage from 100% in 1990 to over 120% in 2015 (Blair, 2011). Furthermore, the improved lambing percentages coupled with concentrated mating patterns lead to large numbers of ewes lambing at the same time. This can be problematic should extreme cold wet weather prevail during lambing. An example is in the Southland region of New Zealand, if a storm hits in late September, there could be 800,000 ewes lambing outdoors with an expectant number of lambs born being 1.2 million. In such an extreme weather event, high lamb mortality could occur resulting in considerable economic losses and large negative animal welfare consequences.

Extensive sheep farming in New Zealand and elsewhere is characterised by the animals maintained outdoors, often without need for supplementary feed and having much behavioural freedom. In this situation, there is the requirement not only to fit the farm to the sheep (e.g. developing shade and shelter and providing suitable forage species) but also to fit the sheep into the farm, assuming sheep adapted to a particular environment will fare better than those that are not (Simm et al., 1996).

Lamb mortality is an issue with mortality rates from birth to weaning ranging from 15% to 25% depending on the farming system and climatic conditions. Although
many factors are not under direct management control (i.e. lamb gender, litter size and year of lambing), examples of how producers make informed management decisions to reduce lamb mortality include choice of sire breed, optimum age at first lambing, optimising nutrition of multiple bearing ewes after pregnancy scanning and choice of lambing paddock for single versus multiple bearing ewes pre-lambing.

In grazing systems, there are some associated health problems, and a range of management techniques is used to alleviate the deleterious effects of some forages fed to sheep, including ryegrass endophyte toxicosis, facial eczema and toxins associated with *Fusarium* fungi (Lambert et al., 2004). Generally, these techniques are not completely effective and more research is required to understand these disorders in intensive sheep grazing systems. Gastrointestinal nematode parasitism is an important factor limiting production of sheep and anthelmintic resistance is a concern for New Zealand sheep producers (Ridler, 2008).

Historically, the sheep meat industry has been supply driven, and dominated by the need of farmers and meat companies to dispose of their respective products (livestock, meat and by-products) as quickly and as profitably as possible, given the constraints of market access and commodity trading. Increasingly, contracts and the development of supply chains with particular processors is becoming normal practice as marketers seek to provide a consistent year round supply of lamb for export.

**Australian sheep systems**

The Australian sheep flock has undergone a significant decline over the last 30 years. Sheep numbers peaked at 180 million in the early 1970s and have declined steadily to 70 million with a breeding base of 40 million ewes. The sheep industry can be divided into two production sectors: one primarily focussed on the production of wool and the other dedicated to the production of lambs for slaughter (Ferguson et al., 2014). However, there are an increasing and significant number of dual-purpose flocks emerging. Wool production is based on the Merino breed and Australia is the largest exporter of wool in the world, with high quality finer micron wool accounting for 44% of export volume. Australia produces nearly 90% of global supply of wool in the super-fine category (Rowe, 2010). The wool production sector also accounts for the majority of the mutton produced in Australia and for the live sheep exported to the Middle East (Ferguson et al., 2014). Australia is the world’s largest live sheep exporter by sea although live export numbers have declined over the last 2 decades but still number around 1.5 million head/year (MLA, 2016).

The lamb production sector is mostly concentrated in south-eastern Australia in the higher rainfall areas (>500 mm/year). This sector comprises both specialist prime lamb and dual-purpose (meat/wool) enterprises (Ferguson et al., 2014). Lambing is concentrated in autumn–early winter and crossbreeding is a feature of the system. Prime lambs are typically second cross produced from crossbred ewes (e.g. Border Leicester × Merino) that have been mated with a terminal sire or meat sheep breed, such as Suffolk and Poll Dorset. In dual-purpose systems, first cross lambs are generated from Merino ewes being bred to a terminal sire. The national Merino lamb-marking rate in 2014 was 94%, while for all other breeds the marking rate averaged
112%. The national average lamb carcass weight has been increasing over the last 15 years and in 2015 it was 22.2 kg.

There are specialist lamb finishing systems where lambs are finished on forage crops or irrigated pasture and there is some opportunistic finishing of lambs in feedlots largely influenced by the price of feed grain (Ferguson et al., 2014). Some abattoirs also operate feedlots to assist with managing the supply of finished lambs for slaughter.

Exports account for around 50% of lamb production with the major markets being the Middle East, China and the USA and Australia is second behind New Zealand in world lamb exports and is the largest mutton exporter. Despite the expansion and importance of lamb exports in recent years, the domestic market remains the mainstay of the Australian lamb industry (MLA, 2016). Lamb consumed in Australia is almost exclusively produced domestically ensuring freshness desired by the Australian consumer, which is considered the most important attribute when purchasing meat.

The main welfare issues specific to Australian sheep production systems are mortality and disease induced by the production environment and/or system, the surgical husbandry practices such as mulesing, long-distance transport and sea transport (Ferguson et al., 2014). Mulesing involves the surgical removal of wool bearing skin around the breach and tail to mitigate against fly strike in Merino sheep. It is a practice relatively exclusive to Australia where Merino ewe lambs kept for breeding are mulesed whilst those destined for slaughter are not mulesed. Efforts to produce nonsurgical alternatives or strategies to minimise the level of pain experienced by mulesed sheep have increased over the last decade. Sheep breeders can now select for fly strike resistant traits, thus reducing the need to mules sheep (Ferguson et al., 2014). Lamb mortality remains a significant welfare concern and economic loss in sheep production systems in Australia. Post weaning death rates in lambs is also a concern as is adult mortality. The size of farms and harsh environment that sheep are farmed in Australia contributes to high adult mortality rates in some seasons and years. Land transport of sheep over long distances is common as lamb ready for slaughter are often moved to the more profitable markets in the eastern states and adult ewes are moved to the two main mutton export abattoirs in central New South Wales and southern Western Australia. Sheep destined for live export are collected onto a pre-departure feedlot and then the typical sea voyage from Australia to the main markets in the Middle East takes around 10–14 days. There has been an increased awareness of welfare concerns and this has led to the introduction of the exporter supply chain assurance system in 2011 (Ferguson et al., 2014).

**Intensive dairy systems**

Milk production from sheep is an important activity in Southern Europe, the Near East and the Middle East. The European Mediterranean countries (France, Greece, Italy, Spain and Turkey) produce 65% of the European sheep milk and raise most of the 40 million milk-producing sheep. These ewes are milked twice a day throughout a 3–6-month lactation period under either an extensive or a semi-intensive system (Kilgour et al., 2008). Dairy ewes produce up to 600 L per lactation period, and although there is a growing market for whole milk, sheep milk is particularly suited to
cheese making and most sheep milk is processed into cheese, yoghurt or ice-cream. Traditionally, husbandry systems involving dairy sheep include a suckling period followed by a milking-only period. In general, lambs either remain with their mothers for 25 days or are taken off at birth and artificially reared. Milk production reaches a peak at 4–7 weeks post parturition and then gradually declines. Peak milk production can be as high as 3.4 L/day (Gootwine and Pollott, 2000).

To overcome seasonal milk production, intensive sheep milking systems are being increasingly adopted in a desire to produce year-round milk supply (Sitzia et al., 2015). This has led to the development of intensive confined systems especially in France and Israel. Housed systems are utilised for summer milk production in pasture fed systems during drought and when the amount and quality of pasture dramatically declines. In Israel, confined systems of milk production have been enhanced by the highly productive Awassi and Assaf dairy sheep breeds (Gootwine and Pollott, 2000). These two breeds can be used in accelerated lambing systems, where ewes might breed more frequently than once a year to produce a year-round supply of milk (Gootwine and Pollott, 2000; Hunter, 2010; Kilgour et al., 2008).

Dairy sheep production exists throughout the world, and it is becoming increasingly popular in the United Kingdom, the USA, Central America, South Africa, Australia and New Zealand. For example in Brazil, importations of the Lacaune breed from France has led to dairy sheep flocks in the Rio Grande do Sul, where the main products are yoghurt and cheese, supplying to a large Italian community in that region (Abella et al., 2010).

Welfare issues identified in dairy sheep include early weaning of lambs, housing and disease issues (Kilgour et al., 2008). The practice of removing lambs from dairy sheep and artificially rearing them can be stressful for both dams and offspring and can lead to reduced lamb growth rates. There is a considerable amount of research being undertaken on artificial rearing of lambs to ensure good welfare and production outcomes (Rassu et al., 2015; Thomas et al., 2014). Close confinement of ewes can be a source of stress in housed dairy sheep. Sheep can be particularly prone to respiratory infections and good ventilation of buildings is paramount (Caroprese, 2010). Confinement ewes in hot climates can also be very susceptible to heat stress. Mastitis is also an issue with dairy ewes, as with dairy cattle, and attention to milking practices and hygiene is required to reduce the risk of infection. As in other intensively managed livestock systems the close animal and stockperson contact inherent in sheep milking systems requires that there be skilled stockpersons involved who bring positive welfare standards to the dairy flock.

Future trends in sheep production

Decline in pastoralism

Throughout Africa, the Near East, the Middle East and South America pastoralists are being driven to ever-more marginal areas through the gradual expansion of arable farming. Pastoralism is likely to disappear in any region where it competes with arable farming. Reduced profitability has also led to traditional upland sheep grazing in
Europe declining, leading to concerns about possible impacts on biodiversity (Pollock et al., 2013). Farming sheep in marginal areas does increase the welfare risks. A common result is seasonal live weight loss in the dry seasons and during winters, during which pasture quality and quantity decreases significantly. In these periods, adult sheep can lose up to 30% of their body weight, with severe consequences to productivity and welfare. Under these conditions, sheep become susceptible to parasitic and other diseases and ultimately have poorer reproductive outcomes. This can severely compromise income and livelihoods of farmers particularly in less developed countries where access to veterinary care, as well as feed supplements is often non-existent or unaffordable. Storage of feed will become important, including many different forage options (shrubs and leguminous trees) and treatment of crop residues, together with the addition of minerals, to improve feeding in some situations. There is no doubt, however, that pastoralists remain a useful resource, as a system of producing meat and milk cheaply on land that is otherwise hard to exploit, and as such they will persist in some form in the future.

**Meat versus wool**

The trend to move away from reliance on wool production to meat production is likely to continue. Lamb meat is considered in most western countries as a luxury meat, and hence most commercial lamb producers in the exporting countries of Australia, New Zealand, United Kingdom and Uruguay are positioning their businesses to produce high quality lamb consistently using traceable and environmentally and welfare-friendly practices.

When production emphasis changes from wool to meat, then it is highly likely that new and imported sheep breeds are often introduced. However, the introduction of new genetics is not always favourable as in most situations, local breeds can be more adapted and resistant to disease and environmental challenges than imported breeds. In countries with developed sheep industries, it is likely that more specialisation will occur in the future. The emergence of specialised breeding and finishing units with increased networking between them and more direct alignment with particular supply chains and processors is also likely to increase (Montossi et al., 2013b; Morris and Kenyon, 2014).

**Increased fertility**

Improvements in production efficiency are essential if many sheep sectors in the world are to remain viable. Increased fertility and hence an improved lambing percentage is one of the main reasons that New Zealand sheep industry has remained viable and increasingly, Australian sheep systems are looking to increase fertility and hence lamb marking percentages. However, studies in high output sheep systems have demonstrated that increasing prolificacy can impact negatively on neonatal mortality rates (Dwyer et al., 2016) and on the longevity of ewes (Hohenboken and Clarke, 1981). Although the latter was not observed by Annett et al. (2011) where prolific crossbred ewes had superior longevity than the hill breeds due to their lower culling rate. Overall, the potential for reduced biological fitness in the more prolific breed types was offset by fewer ewes being culled due to infertility.
An associated impact of increased fertility is often increased neo-natal mortality. New-born lamb mortality rates have proved remarkably stubborn and resistant to attempts to reduce them and published average mortality rates for sheep for the last 40 years across many countries and systems remain almost unchanging at 15% despite considerable amount of research on the causes of, and risks to, lamb mortality (Dwyer et al., 2016). However as these authors point out there is a large variation in lamb mortality and this suggests that improvements can be made. It is clear that some farmers perceive they have a lack of control over lamb mortality and thus may not be motivated to attempt to improve lamb survival or have little knowledge of the extent of the problem on their farms, as records are not kept.

Increasing the frequency of lambing has been proposed as a means to increase efficiency of sheep production, but realisation has often be thwarted by the season- al anoestrus commonly observed in the spring and early summer in most temperate sheep breeds (Goff et al., 2014; Morris and Kenyon, 2014). Accelerated lambing systems without using breeds of sheep that will mate all year-round will require the use of artificial means (hormones or indoor light manipulation) to ensure ewes will breed in the non-breeding spring early summer period. There will be some welfare issues with out-of-season breeding especially if ewes are lambing outdoors in mid-winter (Fisher, 2003).

**Genomic selection**

The use of genomic selection, which has become possible due to high-performance genotyping technology that allows individuals to be typed for thousands of single nucleotide polymorphisms (SNPs), distributed over the whole genome (Shumbusho et al., 2016). The benefits of genomic selection in sheep systems are still being evaluated, but in New Zealand sheep farmers are now less focussed on breeds but more on breed combinations (composites) to achieve their profitability focus. Blair (2011) notes that there are challenges for the breeders of composite rams as many of the flocks are small and they will struggle to maintain genetic diversity. Another issue that might delay the advancement of genomic selection is that many of the numerically small breeds may find it difficult to generate training populations of sufficient size to utilise the new genomic technology (Blair, 2011). The development of accurate genomic predictions requires large numbers of animals within a breed to be phenotyped and this can take some time to achieve especially for meat type traits. Further, for genomic selection to be useful in sheep breeding programmes, the costs of genotyping need to decrease substantially, as presently the economic value of the selection candidate is low compared to costs of genotyping (Shumbusho et al., 2016). These issues are discussed further in Chapter 6.

Probably the most demanded characteristic or trait required of new breeds or sheep in general will be a lower cost (labour and feeding), tied to an easy-care management (increased fitness). Increased productivity will involve both an improvement in offspring survival rate and to breeding ewe hardiness while maintaining good animal welfare outcomes. Using genetics to breed sheep that are well adapted to the various climatic zones of the world may be just as important as breeding for increased production. The benefits of this will be realised through reduced labour requirements,
reduced welfare issues and lower environmental impact. This probably requires choosing local breeds in relation to the main local constraints and achieving a balance between reproductive fitness, growth and meat production abilities.

**Labour will become difficult**

Reduced labour input would be an issue where there is pressure to increase flock sizes and economic efficiency. In the United Kingdom farmers realise the need to have more labour available for dealing with health issues such as ectoparasites (Morgan-Davies et al., 2006). The increase in part-time-farming is also of concern as farmers will have even less time to devote to sheep husbandry or those coming in new to sheep farming lack the necessary skills and training to ensure animal health and welfare (Lawrence and Conington, 2008). Smallholders with low numbers of sheep will be able to stay in business providing their labour input to their own farms or flocks remains below market price, which works well in countries where there are limited opportunities in other sectors. But when employment opportunities in other sectors increase, many small holders opt out of livestock production.

**Labour saving technologies**

Technologies that can substitute traditional husbandry (shepherd time) are likely to be used in future sheep farm systems. Precision livestock farming defined as real-time monitoring technologies aimed at managing flocks on a per animal basis is one such example. Potential applications have been described to include assessing individual animal intake, remote automatic monitoring and early detection of illness or stress and monitoring of animal welfare indicators (Halachmi and Guarino, 2016). The use of electronic identification and rapid throughput of sheep handling systems to record live weights is becoming commonplace in New Zealand and Australia.

The use of radio-frequency identification, which has already begun to revolutionise the management of sheep will allow rapid, efficient and accurate collection and analysis of information on individual animals. Once tagged, animal growth, disease susceptibility, wool production and body condition can be monitored and lifetime information on reproduction and health treatments recorded. Automated drafting facilities configured to enable drafting of multiple mobs on live weight at weaning to facilitate more precise feeding and less variable slaughter weights. Farm management software packages will/are being developed to handle all the data and transcribe it into an easily understood form for sheep managers. Another possible future technology is virtual fencing to allow more flexible movement of animal and enable greater grazing management has been trialled in Australia.

**Large scale sheep milk production systems and intensification to indoor feeding systems**

Intensification of sheep production is taking place with regard to most of the production inputs in some countries. Examples are the housed breeding systems in China and the large-scale sheep dairy systems in New Zealand and Australia. Each of these
systems will result in new issues of providing sufficient forage that meets the nutrient quality requirements of the flock and in providing housing and management that meets the high welfare requirements that consumers will demand in the future. In case of large-scale sheep dairying, the rearing of lambs artificially will require high standards of sheep husbandry to ensure health, welfare and performance of lambs are not compromised. Intensification of sheep production often means an increase in flock size, which will be associated with a decrease in the human:sheep ratio (Stafford and Gregory, 2008). Shepherd and farmers will generally have less time to observe individual animals for problems such as fly strike, cast ewes, or prolapsed vagina, and as individual animals become a smaller proportion of the value of the whole farming enterprise, they are likely to receive less attention. Consequently, animal welfare could be compromised. These negative results may be mitigated if these larger more intensive farms have better resources to improve facilities and employ specialist assistance for shearing, vaccination and supervision at lambing.

Conclusions

Sheep production is undertaken in a multitude of ways throughout the world, providing a variety of products in a wide spectrum of ecological and socio-economic conditions. Sheep tend to be farmed on fragile lands, and many of these are in decline as grasslands become degraded. The need for flexibility is undeniable as the climate variation with seasons on pasture supply will be exaggerated if climate change continues at predicted rates. Sheep systems will need to be designed to cope with these greater fluctuations by building flexibility and possibly having greater numbers of trading (sale) stock to compliment breeding ewes.

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Consumer and societal expectations for sheep products

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The aim of this chapter is to discuss the relevance of public perceptions of animal welfare in the sheep industry for the sustainability of the industry in terms of licence to farm, best on-farm management practices and the public consumption of produce derived from sheep. To do this, it is first necessary to clarify what is meant by public perceptions and how to best measure them. People have a range of views about sheep farming and sheep welfare, but not all are relevant to the consumption of sheep products. For example, people may think of sheep farms in terms of the broad aspects of rural life, or of ewes and lambs in domestic-like settings, but these may neither be the most salient views that they hold with respect to using sheep products, nor may they be anything other than transient thoughts that are experienced while driving in the countryside or while viewing a movie. The focus here is on those public perceptions about sheep welfare that influence use of sheep products or that influence the way in which people act in ways that may have an impact on social licence to farm sheep.

The nature of public perceptions

Public perception refers to the expressed opinions, knowledge and beliefs that are communicated in a multitude of ways—in discussions amongst friends, relatives and colleagues; in writing via letters to newspapers or politicians; in commentary to talk-back radio or in response to surveys or interviews. To understand public perceptions, there are multiple things that can be measured. Values, beliefs, attitudes and norms measure some aspect of perception. As the focus in this chapter is on the aspect of public perceptions that impacts the sheep industry, it is important to consider the way in which these perceptions influence people’s behaviour. Not all aspects of values, attitudes and beliefs directly affect behaviour.

Values are broad preferences concerning appropriate courses of action or outcomes. They are general principles that guide behaviour but lack situational specificity. Rokeach (1973) stated ‘an attitude differs from a value in that an attitude refers to an organisation of several beliefs around a specific object or situation… A value, on the other hand, refers to a single belief of a very specific kind. It concerns a desirable mode of behaviour or end-state … guiding actions, attitudes, judgements … beyond immediate goals to more ultimate goals’ (p. 19). For example, a person expressing a value that we have a duty of care to farm animals does not predict, with any accuracy, whether or not that person will purchase a particular animal product (e.g. wool). To
predict purchasing intentions, it would be necessary to identify the specific beliefs that lead to that purchasing choice.

Attitudes are reflective of a positive or negative evaluation concerning a given behaviour or object and are derived from beliefs (Ajzen, 1991; Eagly and Chaiken, 1993). Generally speaking, a person who believes that ‘meat is healthy’ and that ‘meat tastes good’ would be considered to have a positive attitude towards meat. A person who holds a positive attitude towards meat would most likely be a meat eater. In contrast, a person who believes ‘meat is full of cholesterol’ and ‘meat tastes bad’ holds a negative attitude towards meat and is unlikely to eat meat. Clearly people may hold specific attitudes to the purchase or use of sheep products as well as the consumption of sheep meat, and these attitudes may directly affect consumption and indirectly affect the sustainability of the sheep industry by influencing regulators and retailers. The term ‘societal expectations’ is taken to mean a range of attitudes that people hold towards sheep products and the sheep industry.

This chapter’s priority is to seek to understand attitudes that lead to specific community behaviours and consumer behaviours. Consumer behaviour refers to the purchasing and consumption of sheep products, while community behaviours are those activities that impact the sheep industry and include using media or personal contacts to advocate for or against sheep farming or a specific farming practice.

Attitudes are important because they act as the prime determinants of volitional human behaviours, that is those behaviours that are carried out as a conscious choice (Ajzen, 1991). One of the key theories relevant to the relationship between attitudes and behaviour is the Theory of Planned Behaviour (TPB) (Ajzen, 1991). This theory proposes that people’s behaviour is determined by attitudes to performing the behaviour, their beliefs about others’ (co-worker, spouse, close family or friend, etc.) relevant expectations from them and their beliefs about the extent to which they have control over their ability to actually perform the behaviour (i.e. the extent to which there are no barriers to performing the behaviour). The theory also states that values, knowledge, demographic and similar factors act indirectly by shaping attitudes rather than directly affecting behaviours (Fig. 3.1). The reason for describing this theory is to indicate that attitudes are not to be considered as data in their own right, but as indicators leading to relevant behavioural outcomes and that there are a number of background variables that shape attitudes. As will be seen, despite the widespread use of this theory in other areas (Hemsworth and Coleman, 2011), there are very limited cases where it has been applied in research in public attitudes to sheep animal welfare. Nevertheless, it would be a very useful tool when seeking to understand community attitudes and the specific individual behaviours that they lead to.

Public attitudes and consumption of sheep products

Meat

While many studies do not specifically address welfare attributes in sheep meat purchasing behaviour but focus on sheep meat attributes (Sepúlveda et al., 2010, 2011), nevertheless there is some research to indicate that animal welfare is a relevant
Consumer and societal expectations for sheep products

Gracia (2013) analysed intentions to purchase ‘animal welfare friendly’ meat products using the TPB and found that several beliefs significantly predicted these intentions. The belief that ‘animal friendly products’ are ‘healthier’ and are of better quality were related to stronger intentions to purchase ‘animal welfare friendly’ meat products. Consumers' normative beliefs (beliefs about how important others think they should behave), their perceived ability to control their purchasing behaviour, and competing attributes of food such as taste and freshness, influence food choices (Gracia, 2013). While these beliefs targeted meat products generally, there are some limited data relating specifically to sheep meat purchasing. Burnués et al. (2003) identified a segment of the European population that were characterised by the need to know the origin of the sheep meat they purchased, the production system and its traceability. This group placed high importance on animal welfare. The group comprised 39% of the sample. However, the authors did not relate these preferences to actual sheep meat purchasing behaviour.

Coleman and Toukhsati (2006) surveyed 516 Australian respondents about their perceptions towards farm animal welfare and meat purchases. Of these 516 respondents, 116 respondents were interviewed at point-of-sale. Attitudes, in combination with demographic variables, predicted 13.3% of the variance in self-reported sheep meat purchases but did not significantly predict point of sale sheep meat purchases. The results also indicated that although welfare was moderately important, factors other than concern for animal welfare were more predictive of pork, beef and sheep meat purchases. The fact that animal welfare attitudes play only a moderate role in predicting some consumer behaviours is perhaps not surprising, considering that a host of other factors influence purchasing behaviours. Past research has shown that

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**Figure 3.1 The theory of planned behaviour model.**

when food attributes relevant to meat purchasing are ranked in order of importance, freshness, taste, flavour, safety and price are rated as extremely important, and attributes such as humane treatment and being environment friendly are rated as very important (Curtis et al., 2011). A comparison of consumers’ sheep meat purchasing intentions between Spain, France, the United Kingdom, Switzerland, Argentina and Uruguay indicated that while local production was the most important factor, feeding system was the next most important (Font i Furnols et al., 2011). Regarding the second factor, there was a belief that grass-fed animals produce better meat, probably because of beliefs about naturalness of pasture and extensive production. This aligns with the data from Australia, discussed here, which indicates that people prefer extensive grazing for lambs (Coleman et al., 2014).

Even though animal welfare does not rank high in consumer ratings of important food attributes, the situation is more complex than it appears. Welfare friendly products have been associated with other attributes such as safety (Clark et al., 2016), so it may be that there is a constellation of interlinked beliefs that guide purchasing behaviour. Nevertheless, when making purchasing decisions, animal welfare is not a major driver of purchasing behaviour, with barriers such as price, availability and perceived personal influence being more important (Clark et al., 2016).

Font i Furnols and Guerrero (2014) proposed that the mismatch between concerns about animal welfare and purchasing behaviour can be explained by a cognitive protective mechanism. ‘This behaviour might emerge as a result of a psycho-protective mechanism known as “Directed or Intentional Forgetting” (MacLeod, 1998), which is aimed at de-emphasising unpleasant or threatening memories consciously or unconsciously. Such forgetting may also help to explain the apparent discrepancy between attitudes towards meat and meat products and their consumption’ (Font i Furnols and Guerrero, 2014, p. 363).

Despite these findings, retailers and some producers capitalise on a market that seeks animal welfare friendly products. Retailers in many countries such as Australia, the United States and the United Kingdom, have policies on animal welfare. There are many instances of this, but some examples follow. In the USA, Walmart, in response to a campaign by Mercy for Animals (an animal rights group), developed a policy on humane treatment of farm animals based on the Five Freedoms (Walmart, 2015). Similarly, ALDI Australia subscribed to the Australian Livestock Processing Industry Animal Welfare Certification System. In the United Kingdom, Waitrose claims to ‘champion British produce, support responsible sourcing, treat people fairly and tread lightly on the environment’ (Waitrose, 2016) and, like Walmart, uses the Five Freedoms as the core of its animal welfare standards. These are just a few examples from the large array of retailers that demand their suppliers meet their animal welfare standards.

**Fibre**

There is relatively little research that specifically targets consumer attitude towards sheep welfare affecting the purchase of wool products. In three southern US states, consumers were willing to pay more for US wool over Australian wool (Hustvedt
et al., 2013). However, this research targeted ethnocentricity without reference to environmental or welfare concerns, so it is not known what aspects of the Australian product were less preferred. The practice of mulesing (discussed in more detail later) has attracted considerable adverse publicity. There was considerable media reporting of calls by People for the Ethical Treatment of Animals (PETA) to boycott the purchase of Australian wool and instances where buyers actually boycotted the purchase of Australian wool (e.g., Brennan, 2009). This boycotting was done by wool buyers, not consumers. In fact, a similar pattern is observed with meat products. It is often somewhere in the supply chain that constraints are put on the purchasing of sheep products, not at the consumer level. Despite these boycotts, the Australian national flock numbers were higher in 2016 as compared to those in 2009. Also, in the 2 years from October 2014 to October 2016, wool prices have steadily risen (Australian Wool Innovation, 2016). Nevertheless, Lee (2014) used the TPB approach to investigate the effects of one- and two-sided communications for and against the purchasing of fashion goods based on animal products including wool. He found that attitudes and normative beliefs predicted intention to purchase wool products. Importantly, one-sided messages that described mulesing made respondents’ attitudes more negative, whereas positive messages about the superiority of wool as a fibre did not make attitudes more positive. Respondents exposed to both messages had more negative attitudes than those exposed to irrelevant or positive information, but slightly more positive than those exposed just to negative information. This indicates that for the general community to be properly informed, both positive and negative information needs to be addressed. The sheep industry needs to discuss sheep welfare issues transparently if it wishes to maintain trust and counter the adverse publicity that adverse media campaigns produce.

**Community behaviour**

Increasing concern for the welfare of livestock animals is also reflected in community behaviours in opposition to the livestock industry (Grunert, 2006). Community behaviours take the form of actions in opposition to the livestock animal industry. Community behaviours are distinct from lobbying behaviour, which involves deliberate and repetitive campaigning of politicians and regulatory bodies for change (Coleman and Toukhsati, 2006). According to Coleman and Toukhsati (2006, p. 21) ‘community behaviour is less deliberate and involves taking advantage of situational opportunities to express an attitude through action’. These behaviours include actions such as signing a petition, donating money to an animal welfare organisation, participating in rallies and speaking with acquaintances/friends/family about an issue. With the increasing popularity of social media, community behaviours in opposition to livestock industries may also take the form of posting videos or writing blogs. Coleman and Toukhsati (2006) found the prevalence of these community behaviours to be quite high. They surveyed 1061 Australians at supermarkets and over telephone and found that 56% of respondents reported that they had engaged in at least one activity in opposition to livestock farming. However, the frequency with which community members engaged in online activities in opposition to livestock farming was not investigated.
These behaviours and the public opinions driving them can have a considerable influence on how governments either react to publicised ‘animal welfare events’ or regulate contentious management practices in industry. This is especially the case when concerns are expressed by non-governmental animal welfare or rights organisations. The campaign by PETA in 2004 against the practice of mulesing in the Australian sheep industry is one such example where PETA demanded that the practice of mulesing in Australian sheep flocks be ceased. The industry response to this is discussed later, but the campaign received widespread media coverage and led to some countries banning the import of Australian wool.

More recently, Coleman et al. (2016b) found that information seeking and trust in information, attitudes related to animal welfare and the livestock industries, and membership of an animal welfare group accounted for 43% of the variance in community behaviours that express dissatisfaction with the livestock industries. Of special interest in this study was a finding that about 15% of 479 respondents identified themselves as opinion leaders, that is people who tended to be used as a source of animal welfare-related information by friends and neighbours, tended to be asked about livestock animal welfare and tended to tell people about livestock welfare. These people were characterised by more negative beliefs about livestock animal welfare, a higher self-perceived knowledge of livestock practices, but no better actual knowledge than the remainder of the population. Further, these people tended to engage in more activities in opposition to the livestock industries. It is not known what, if any, role do such people play in forming or reinforcing public opinions about the livestock industries. It would be useful to use a method other than self-report to establish the existence of such a group and its role.

**Impact of public attitudes on the livestock industries**

**Producer practices**

Mulesing is the surgical procedure of removing skin from the tail and breech area of sheep to prevent flystrike. Flystrike, which can lead to death, is a particularly painful and stressful condition where flies lay their eggs in the soiled areas of the fleece and the maggots feed on the fleece and flesh in the area (Colditz et al., 2005; Shutt et al., 1988). Public concerns, however, do not relate to the welfare risks of pain, stress and mortality associated with flystrike, but to the painful and stressful aspects of mulesing to prevent flystrike. Somewhat surprisingly, when asked about the extent to which Australians approved or disapproved of mulesing, about 28% disapproved or strongly disapproved, 22% didn’t know and 32% neither approved nor disapproved (Coleman et al., 2014). However, while difficult to compare between surveys, disapproval had increased since 2000 (3%), (Roy Morgan Research, 2000). By 2006 this percentage grew to 39% (Coleman and Toukhsati, 2006) but reduced to 28% in 2014 (Coleman et al., 2014). In the latter survey, when asked to nominate the correct description of what mulesing entailed from two options presented, only 62% answered correctly. This is not
much above chance. Some ethicists have argued that mulesing should have been phased out in accordance with the original industry target of 2010 (Sneddon and Rollin, 2010) and that this would be necessary for the future survival and success of the industry. They based their argument on the changing social ethics towards animal welfare, the changing demographics and the associated increase in animal welfare activism.

In 2011, a small number of Western Australian wool producers were surveyed about their intentions regarding the practice of mulesing. While they generally held negative attitude towards the practice, half of them indicated that they would continue to mules (Wells et al., 2011). Further, about half of the farmers surveyed believed that consumers don’t care about the issue. This is not too different from the survey results reported previously (Coleman et al., 2014). In fact, mulesing was still reported being practiced in 2016. In Western Australia during 2014–15, of those cases where a declaration was made (48% were not declared), 25% of sheep were not mulesed, and the remainder were mulesed (Lindon, 2015). Nevertheless, there has been some progress on alternatives to mulesing (Agriculture Victoria, 2016) using intradermal technology, insecticides and targeting of the sheep genome and the blowfly genome. While the number of sheep shorn in Australia has declined recently, this is attributed to the very dry recent conditions rather than a loss of market of wool prices (Australian Wool Innovation, 2016). Also, Australian Wool Innovation (a not-for-profit company that invests in R&D and marketing to increase the long-term profitability of Australian woolgrowers) has invested substantially in alternatives to mulesing and pain relief with mulesing (Lindon, 2016). While some may argue that the industry is allowing these campaigns and boycotts to subside over time, there are examples of changes. For example, in 2016, the local anaesthetic Tri-Solfen was used for 73% of mulesed sheep (Lindon, 2016).

Mortality

Lamb mortality, particularly in extensive systems, can be relatively high. In Australia, reported rates for lamb mortality may vary from 20% to 30%, with somewhat lower mortality in New Zealand where the reported rates are between 15% and 18% (Ferguson et al., 2014). In Canada, reported figures in the years 2007–09 were 14% (Ontario Ministry of Agriculture, Food and Rural Affairs, 2012). In all cases, however, mortality is of concern because of its welfare implications and the high economic cost that it represents. Surprisingly, this has not been an issue that attracts public concern, perhaps because there is little awareness in the community. However, a qualitative study of a small sample of Australian sheep farmers (Elliott et al., 2011) found that farmers had positive attitudes to reducing mortality rates. There was no general agreement amongst these farmers on how to best achieve a reduction in mortality and there was a belief that strategies would need to be tailored to individual farms. This suggests that there may be a need for an industry-wide approach to advocate best practice in the monitoring of lambs, especially to increase their survival rate. Without this, there is a risk that public awareness of the issue will increase and it will become another threat to the sheep industry.
Confinement

Matthews (1996) reported that, in New Zealand, general public perceived that extensive production systems provide better animal welfare standards than those provided by more intensive systems. Stocking density, in general, has been shown to be of greater concern for the general public compared to the farmers in Belgium (Vanhonnacker et al., 2008). On a 5-point scale, stocking density was rated by the general community as the most important of 16 housing and climate issues (mean = 4.28), but rated as the 6th most important by farmers (mean = 3.53). However, available space was rated equal the 2nd most important by the general community (mean = 4.16) while farmers rated this issue similarly as the 3rd most important (mean = 3.69). It is noticeable that while the rankings with regard to space were similar for farmers and the general community, the mean for farmers was somewhat lower, possibly indicating that, in absolute terms, farmers attach less importance to space allowance as compared to the general community.

While these data generally focussed on livestock production, a similar issue faces the sheep industry. Coleman et al. (2016a) found that, in Australia, public approval of lamb housing decreased as the degree of confinement increased. Housing in large paddocks was generally approved, while housing in outdoor pens was less approved and housing in indoor pens generally disapproved. Interestingly, respondents from urban areas, regional cities and rural town held similar views. This similarity between respondents is important because it is inconsistent with the often expressed view that the increase in public disapproval of aspects of livestock farming occurs because of increasing urbanisation leading to people becoming more disengaged from farming and farming practices (Jensen, 2006). According to Matthews, ‘An additional complication arises from the comparative lack of knowledge in urban populations about livestock and their ability to cope with natural variations in food supply and environmental conditions. For example, the general public might not readily appreciate that sheep, cattle and deer can survive well outdoors at sub-zero temperatures provided adequate food and shelter is available’ (Matthews, 1996, p. 42).

Transport

In broad-scale sheep farming systems such as those in Australia and New Zealand, lambs and sheep can be transported over long distances (Ferguson et al., 2014). Ferguson states ‘Anecdotally, most lambs destined for slaughter in Australia and New Zealand would not be transported over long durations (<12 h)’, but states later that mature sheep destined for slaughter as mutton in Australia may be subjected to extended transport durations given the location of the two main mutton export abattoirs in central New South Wales and Southern Western Australia. There are clear industry standards that guide transport, for example Meat and Livestock Australia’s (MLA, 2012) ‘Is it fit to load?’, but these guidelines have no regulatory power. Similar frameworks exist in other countries, for example in the European Union, there exists the Welfare of Animals during Transport (DEFRA, 2007). Despite these regulatory frameworks, an Australian study (Coleman et al., 2014) found that 24% of the general
public indicated low trust in workers involved in livestock transport on land and 41% indicated low trust in workers involved in livestock transport by sea. The latter figure may reflect a number of adverse events that might have been reported in the Australian media with regard to live sheep export and strong criticism by the Australian animal rights group, (Animals Australia, 2013) at the time of the survey.

**Farmer attitudes**

In Ireland, a comparison of the rated importance of a range of problems in Irish agriculture between farmers and the general public showed that animal welfare was ranked second of the six issues by farmers and fourth by the general public (Howley et al., 2014). Good on-farm practice can assist in controlling existing diseases, and on-farm biosecurity can avoid the introduction or reintroduction and spread of the diseases not present within a property and/or region. Toma et al. (2013) found that, in British sheep and beef farmers, attitudes towards animal welfare was one of the key drivers of a range of biosecurity behaviours. While a range of factors were considered, only the rated importance of biosecurity practices had consistently higher loading in structural models for England, Wales and Scotland that described the factors that predicted biosecurity behaviours.

As indicated earlier, when studying attitudes towards lamb finishing systems in Australia, Coleman et al. (2016a) found that farmers expressed lower levels of concern as compared to the general public on many welfare risks for the sheep on-farm. Doughty et al. (2016) asked the general public, sheep producers, sheep industry-related scientists and service providers to provide their thoughts on the importance of a range of sheep welfare issues and possible key indicators. All respondents thought sheep welfare was adequate but improvement was desired. Issues perceived to cause the most risk to sheep included flystrike (infestation of the sheep with blowfly maggots), nutrition, environmental extremes and predation, while key indicators were related to nutrition, food availability, mortality/management, pain and fear and illness/injuries. Beliefs about the extent to which husbandry practice was seen to compromise sheep welfare were highest for the general public (mean = 3.83 on a 4-point scale) and lowest for producers (mean = 2.73).

**Licence to farm**

Animal welfare issues, together with issues relating to climate change, water scarcity, environmental degradation and declining biodiversity, threaten farmers’ social licence to farm. Social licence to farm is defined by Martin and Shepheard as ‘…the latitude that society allows to its citizens to exploit resources for their private purposes’ (Martin and Shepheard, 2011, p. 4). Social licence is granted when industries behave in a manner that is consistent, not just with their legal obligations but also with community expectations (Arnot, 2009; Gunningham et al., 2004; Williams et al., 2007). Failure to fulfil the obligations inherent to social licence can lead to increased litigation, increased regulations and increasing consumer demands (Arnot, 2009). According to Martin and Shepheard (2011), working with the community, understanding their opinions towards important issues like animal welfare and the environment and
in a manner indicative of cooperation rather than working against them in a defensive manner, is the most successful means to addressing threats to social licence. In this light, exploring public opinions towards the livestock animal industry is an important first step towards engaging with the community. 

Matthews (1996) argued that non-sustainable practices are ‘those in which the welfare status of animals is poor and the level of acceptance by the public is low’ (p. 44). It can be argued, however, that either, rather than both, of these conditions will impact the sustainability of livestock farming. Poor welfare status can impact the productivity of livestock as well the public’s attitude towards a particular practice. However, even if the practice is characterised by low mortality and morbidity, good general health and good productivity, public may still perceive the practice unfavourable.

Influence on regulators and legislators

Earlier examples were given of cases where public concerns about animal welfare expressed by PETA led to Australian sheep industry responses in the management of mulesing. However, this way of bringing about changes to industry practices or codes of practice runs the risk of lacking coordination and may lead to changes that are not based on good science, even if the original welfare concern is highly justified. Timoshanko (2015) has argued that a ‘market-based’ approach to animal welfare regulation does not work. The market-based approach is based on the premise that an individual can reflect his or her concerns and values about the treatment of animals through his or her purchasing behaviour. Timoshanko states that the market-based approach to regulation is actually a form of social control or influence, rather than an industry- or government-prescribed set of rules. It assumes that ‘consumers are able to control suppliers by using their purchasing power (through increased demand for more humanely produced products) to influence the production systems of suppliers of farm animal products’ (p. 518). As we know, healthiness, price and so on, drive consumption, leading Timoshanko to conclude that ‘the market, political and social considerations either override an individual’s animal welfare values due to necessity, or, faced with the complex task of evaluating the ethics of each brand or product, the consumer prioritises harmonious relationships with significant others over better welfare for farm animals’ (p. 518). Thus, while public concerns may raise certain possible welfare issues, regulation and legislation need to be based on good science while clearly taking into account the industry’s capacity to implement changes in practice.

Industry responses

Troy and Kerry (2010) have said ‘In general, there is a need for greater innovation and knowledge utilisation to enhance consumer perception (both expected and experienced) by the meat industry. The authors believe there has been much research carried out at various institutes and universities which has not transferred or been adopted by the industry. A number of reasons for this are evident. Firstly, the meat industry, although global, is quite fragmented with limited research capability. Secondly, the research and development investment by the industry is relatively small compared with
other sectors. Thirdly, most meat research is carried out by public entities often with little intellectual “buy-in” from the industry. This creates a disconnect between the research outputs and their utilisation by the industry’ (p. 223).

In fact, in Australia, the sheep meat industry has considerable research capability through MLA; and this body funds welfare research, including social research, and welfare is one of its research priorities. The wool industry also funds research through the Australian Wool Innovation but the emphasis is on health and welfare, not on welfare-related social science issues.

Generally speaking, in those countries where sheep welfare research is carried out, the emphasis is on sheep health and disease, and social research, other than market research, does not appear in their priorities. This may reflect the relative recency of licence to farm as a social issue and the absence of a clear strategy for the livestock industries to engage in dialogue with the community on welfare issues.

In addition to commissioning relevant research, sheep industries need to communicate better with the community. Grandin (2014) has argued that the livestock industries need to be more transparent in communicating with the public (Coleman, 2010). She cites several examples where industry sources have made videos of practices available to the public or where public tours of farms have been set up. Bad practices are those where the livestock industries seek to suppress their practices. Grandin says that industries need to ask ‘Can I explain this to my guests from the city?’ (p. 467).

Some scientists have already argued the need to integrate public opinions and concerns in decision making about legislation, the development of welfare assurance schemes and product differentiation (Boogaard et al., 2008; Sørensen and Fraser, 2010). The popularity of free-range systems fits with this idea, as it capitalises on the public importance attached to natural living. A better understanding of public perceptions of animal welfare should also assist in reducing the discord between citizens and other stakeholders in the supply chain and close the gap between public perceptions and scientific facts (Vanhonacker and Verbeke, 2014, p. 157).

In all, an industry response to societal expressions of concern about sheep welfare should include seeking to understand relevant public attitudes and beliefs, as well as the knowledge base that underpins them. The way in which sheep farming can respond to public perceptions needs to be a combination of practice change, where a current practice has a traditional base that can no longer be justified and a public refutation where the community concerns may not be justified when subjected to rigorous evaluation or where viable alternatives have not been developed. Mulesing is a case where public concern has led to these responses leading to a greater use of analgesics and considerable research into alternatives.

Conclusions

Given the threats to social licence, there is a need to understand community expectations if sheep industries are to be sustainable both with regard to farming practices and access to markets. Public opinions change over time; livestock animal welfare issues
thought to be particularly salient at one point in time can be superseded by another animal welfare issue at another point in time. Responses by government in the form of changes to regulations, industry responses and media exposure are the likely factors underlying these changes in opinion. It is therefore important to not only measure current concerns of the community but also to monitor changes in opinion over time. Knowledge of public perceptions towards the livestock industry and livestock animal welfare can be used to inform the industry of possible changes in practice throughout the supply chain and provide a basis for educating the public where this is desirable. This knowledge will also allow industry and government to align their policies with consumer and community perceptions and to assist in developing research policy on animal welfare topics/risks and this, in turn, should lead to improved sheep welfare.

References


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Further reading

Consumer and societal expectations for sheep products


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Part Two

New Advances in Sheep Welfare Assessment

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Sheep cognition and its implications for welfare

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Cognition refers to mental action of acquiring and processing of information, and the cognitive capacity of an individual organism is tightly tied to its evolution. Humans and animals have evolved certain skills that help us acquire the resources needed to survive, thrive and reproduce. Cognitive processing is energetically demanding, thus, unless there is an evolutionary benefit, complex cognition is hypothesized to be detrimental to survival (a first example of this in nature: Evans et al., 2017). With this in mind, we can view animal cognition in a different light. Both the existence and absence of a cognitive skill are a reflection of the evolution of a species. Sheep receive a lot of poor press for being stupid or dim. They may well be the ultimate prey species: their primary defence strategy is to group together or take flight, and that is about them. As a result, they are very alert, and can be easily fearful and distressed, all of which influence their cognition and behavioural reactions. They are also stoic by nature and so it is not easy to see if they are experiencing negative or positive affective states. They are however, exceptionally flexible and adaptable. They can be found in the wild in Asia, Europe and North America, and domestically across all continents (Dwyer, 2009a). Sheep are used in medical research, and are farmed in large numbers, both, intensively and extensively and for milk, wool and meat. In order to succeed in such diverse situations, they require a significant degree of cognitive flexibility.

Our understanding of the cognitive capacities of sheep has grown substantially in recent decades. This development is the result of a changing perspective on how we evaluate animal intelligence, the broad use of sheep globally and the accompanying need to understand their welfare. As we advance the ways we evaluate animal intelligence, we are moving away from the traditional comparative approach where we measure an animal’s abilities against our own. Different species have evolved certain skills for a reason, and comparing them to humans, with our vastly different anatomy, is restrictive. Rather than looking at cognitive abilities as a comparison between us and them, or species against species, we now consider the presence and absence of cognitive skills as evolved abilities that allow different ecological niches to be occupied by different species.

Understanding and measuring the cognition of animals can give us insight into their welfare and help us to care for them more effectively (Broom, 2010). The relationship between cognition and emotion is bi-directional; cognition can influence the formation of affective states (Desiré et al., 2002), and affective states can alter the processing of information (Paul et al., 2005). As a result of this relationship, a better understanding of cognition can help us to understand how behaviours arise and what affective state they represent.
Cognitive capacities of sheep

Insight into the cognitive capacities of sheep reveals that they have excellent spatial and visual cognitive abilities, a strong social network that is geared around survival and facilitates learning, and a reasonable degree of executive control functioning. These findings show that they have a series of advanced cognitive abilities to a level that has not been attributed to them in the past.

Spatial navigation

Sheep employ spatial cognition to increase foraging efficiency in broad and small-scale foraging situations (Hewitson et al., 2005). Extensive research conducted to measure these ecological cognitive traits has revealed that sheep can recall the location of food sources in heterogeneous environments through developing comprehensive spatial maps (Dumont and Hill, 2001; Dumont and Petit, 1998; Edwards et al., 1996). This ability to map their environment goes hand in hand with strong visual senses, but sheep also have good senses for hearing and olfaction. Chapter by Kendrick (2008) on sheep cognition in The Welfare of Sheep (Dwyer, 2008) gives an excellent review of the sensory abilities of sheep and how they utilise them.

These spatial abilities have been investigated in a variety of studies (Hosoi et al., 1995; Hunter et al., 2015; Johnson et al., 2012; Kendrick et al., 2001; Rushen, 1986) through the use of both Y mazes and more complex spatial mazes. While many of these studies highlight the strong spatial abilities of sheep, some controlled experiments have not been able to replicate the spatial skills sheep demonstrate in natural settings. For example, Morris et al. (2010) demonstrated that sheep could discriminate between two visual cues in a Y maze; however, they failed to detect a directional audio cue (Morris et al., 2010), whereas it has been shown that ewes can orientate and approach their lambs solely based on vocalisations (Searby and Jouventin, 2003), which suggests that they can discriminate and spatially identify a noise. This specific contrast between results from an experimental context and a biologically relevant behaviour suggests that greater consideration is required in the design of experiments focusing on spatial recognition.

Sheep are commonly observed to have lateralisation biases in Y mazes (Anderson and Murray, 2013; Johnson et al. 2012; Morris et al., 2010). Lateralisation is a preference to perform behaviours by one side of the body, or to process information differentially in the brain, and information processing by the right brain hemisphere is associated with reactivity to novel stimuli and distraction (Rogers, 2010). Lateral behaviour can skew results as individual sheep may exhibit a preference to take the left or right arm of a Y maze, regardless of consequence. At the population level, sheep do not display a predominance of one side (e.g. right) in their lateral preference across breeds, but they do display their own individual biases. Studying these relationships in sheep may give some useful insights into individual differences in cognitive performance. Practically, this tendency to form biases needs to be considered in experimental designs. Pseudo-random sequences are commonly used to reduce the chances of lateralised responses. The implementation of correction trials to prevent the formation
of lateralised biases, at least in situations where operant conditioning is being applied (McBride et al., 2016), may also be valuable.

A more complex spatial maze developed by Lee et al. (2006) uses the evolutionary motivations of sheep to test their spatial cognitive abilities (Fig. 4.1). Utilizing the natural flocking behaviour as the motivation to transit the maze, most naive sheep are able to traverse in less than 5 min. The maze assesses several aspects of cognition with the total time to complete the maze and errors made on the first test providing an indication of cognitive abilities, and the rate of improvement over three consecutive days measuring spatial learning. Importantly, the maze requires no pre-training and the majority of sheep can complete the task, and for animals that cannot complete the task, information on errors and progress made can still be assessed. After three to four exposures in the maze, sheep reach a plateau in performance, which is in line with ecology-based foraging tasks by Dumont and Petit (1998). Sheep also retained or improved performance in the maze 6 weeks later, allowing their long-term memory to be tested. The maze has now been used to assess the impact of scopolamine (a memory inhibiting drug) and tunicamycin (Lee et al., 2006), GnRH manipulation (Hough et al., 2017; Wojniusz et al., 2013), prenatal stress (Coulon et al., 2011) and acute stress (Doyle et al., 2014) on the cognitive performance of sheep. Stress and scopolamine both impaired the spatial cognition of sheep, but in different ways. The GnRH studies showed varied effects, despite the administration of the GnRH blocker being at a similar time of maturation (around puberty). This suggests that spatial cognition can be affected by a variety of factors, but that these influences are somewhat variable or inconsistent.
Social cognition and learning

For social species, an ability to recognise individuals is described as the cornerstone to complex society (De Waal and Tyack, 2009). Sheep do have the ability to recognise individuals in their social group (Kendrick et al., 2001), and can use facial cues to discriminate between different species, breeds and between sexes of the same breed (Kendrick et al., 1995). In this study by Kendrick et al. (2001), sheep showed clear recognition of individuals that had previously been in their social group, as well as the faces of current members. Kendrick’s research indicated that sheep may utilize the same neural encoding strategy to remember and respond emotionally to individuals in their absence as humans do. Social affiliations in sheep are generally subtle and difficult to distinguish, particularly in ewes and sub-adults, as agonistic interactions and overt hierarchies are difficult to ascertain (Fisher and Matthews, 2001). Sheep break into smaller social groups for grazing within a larger home range (Boissy and Dumont, 2002), but the structure of these smaller groups are not always consistent. In grazing groups, sheep do display preferences for certain types of individuals but do not consistently form stable sub-groups (Doyle et al., 2016). It may well be because of these broad, flexible social structures that sheep have evolved the capacity to differentiate between a number of individuals, and have a capacity to remember past members.

Flocking is the key defence strategy for sheep. While this is the primary driver for close proximity of the mob, these complex social bonds and differentiation between individuals facilitate social learning. The strongest social learning is that which facilitated through the ewe-lamb bond. Learning from example via maternal behaviour is the most effective way to reduce neophobia in young sheep. Exposing lambs to novel feed before weaning so they are able to learn from their mothers facilitates acceptance of new food (Savage et al., 2008). This is not restricted to the close maternal bond; however, sheep can also learn through social observation when in close proximity to a demonstrating animal (McLean, 2001; Thorhallsdottir et al., 1990). Both of these examples display social cognitive learning, and may be linked to the ability for individual recognition.

Executive decision-making

Some recent developments in the understanding of sheep cognition have arisen through human medical research. Sheep are a popular animal model in neurological research for conditions such as Huntington’s disease (McBride et al., 2016), and cognitive tests are needed to assess symptoms for the model. From this research, new understanding of the cognitive capacities of sheep, particularly their executive functioning, has been gained.

Executive control functioning describes cognitive processes that require an individual to adjust their behaviour in response to a change in a task (Banich, 2009). It reflects the individual’s cognitive flexibility, set shifting (redirecting attention between tasks), and attentional control. Essentially, executive control means that an animal can learn associations between stimuli, actions and outcomes, and then adapt their behaviour to environmental changes. Morton and Avanzo (2011) describe this need for executive control as being fundamental to survival. They tested the capacity for executive functioning of sheep in a series of step-wise experiments. The sheep had to discriminate according to colour and shape, and were shown to be able to perform reversal learning and
Sheep cognition and its implications for welfare

Attentional set shifting. The results also indicated that sheep learnt each discrimination task faster as compared to the last. Sheep took longer to learn the reversal tasks at each step, as compared to initial discrimination, but this improved with repeated exposures. Once the sheep had been exposed to the concept of the task and of reversal learning they were faster to adjust their behaviour the next time they experienced it. The effect of experience on reversal learning has also been demonstrated in other studies in sheep (Hunter et al., 2015), and reflects an adaptable learning and a capacity to generalise.

A more simplistic executive control task was used by McBride et al. (2016). In this study, sheep rapidly learnt a visual discrimination task, and could demonstrate reversal learning. Learning times were faster than those reported by Morton and Avanzo (2011), and may be a reflection of the task being more simplistic. One other notable feature of McBride’s study was the step-wise process to habituate and train the sheep to the full task. A slow habituation and training process can be a particularly useful strategy when training sheep to a cognitive task in isolation from conspecifics. This may be another major contributing factor to the success of McBride’s test. Another test using this step-wise habituation measured the ability of sheep to inhibit an already started response (Knolle et al., 2017) and demonstrated that sheep can shift their responses when new information is received. These tests focus on ethologically salient behaviours, which are key to unlocking the cognitive abilities of sheep. Together they demonstrate that sheep have reasonable executive control functioning, indicating that sheep have the capacity for flexible behaviour following information processing.

Inferential reasoning

Inferential reasoning is a complex cognitive skill, as it requires an individual to make an association between a visible and an imagined event (Premack, 1995). The individual must reach the correct conclusion, and exclude incorrect options, with only indirect information available. A comparative study by Nawroth et al. (2014) tested the capacity for inferential reasoning of both sheep and goats. Using a test that is broadly applied across taxa, they investigated whether sheep and goats could infer the location of a food reward, from direct and indirect information. Animals learn that there is a food reward located under one of two cups, and they have to select the correct one. In the direct trials, the experimenter lifts the cup covering the food and covers it again. In indirect trials, the experimenter lifts the empty cup. Evidence of inference demonstrated if the animal selects the food reward in the indirect trials (above the frequency of chance). The animal must apply the information (no food under this cup) to infer that the food must be under the other cup.

Goats outperformed sheep in all test situations, as all sheep were unable to use indirect information to obtain the reward. This result is thought to reflect species-specific differences in feeding ecology. As sheep are non-selective grazers, the consequences of making a wrong choice, or in biological terms, selecting a less nutritionally valuable food patch, is not as significant to them as it is for goats. As a result, the need to use indirect information to infer where food would likely be less important for sheep than goats.

The test result suggests a win-stay foraging strategy, when sheep are pre-disposed to return to forage in places that were previously successful. This foraging strategy
has been proposed by Hosoi et al. (1995); however, other studies have demonstrated that sheep display flexible foraging strategies based on the quality of the environment (Hewitson et al., 2005). Win-stay strategies and spatial memory are dominant when resources are plentiful, but win-shift strategies have also been recorded (Hewitson et al., 2005; Johnson et al., 2012).

**Sense of self**

The capacity for spontaneous self-recognition using a mirror is a significant cognitive ability, as it is associated with the capacity to experience self-identity. McBride et al. (2015) showed that sheep demonstrated two of the three steps in typical mirror engagement: exploration and contingency behaviour, but no self-directed behaviour. Similar results were also found in pigs (Broom et al., 2009). Self-directed behaviour in the mirror is not common, with only a handful of species demonstrating that level of investigation (Reiss and Marino, 2001), and has not been demonstrated in any livestock species.

Pigs, however, demonstrated a capacity for assessment awareness by using a mirror to solve a task (Broom et al., 2009) that sheep failed to perform (McBride et al., 2015). Sheep did not use mirror information to solve a task, although the task set in both studies differed and arguably, the task for sheep was more complicated than for pigs as it required pre-training. As demonstrated in other studies, including those where lateral biases are learnt, this shifting of behaviour away from a previously learnt task does not come easily to sheep, although they are capable of it (Morton and Avanzo, 2011). Mirror use and recognition are not concrete evidence of consciousness. However, there is a hypothesised link between the concept of self-awareness and consciousness. Therefore, further research is required but in the study of consciousness or awareness of one’s self, it should be done in ways that ensure species-specific nuances (Wemelsfelder, 1997).

**Stress and cognitive processing**

The section earlier highlights some of the key cognitive abilities sheep possess based on our current understanding, but the role of stress and fear on the cognitive processing of sheep is an important consideration when assessing task performance and abilities. Impeded performance in problem solving, learning or memory formation, and recall can all result from stress (Mendl, 1999). This is because in times of stress, animals may default to a more automatic method of processing information, rather than using cognitive control. As a result, their behaviour becomes more rigid and inflexible, preventing them from solving a problem effectively (Toates, 2006). A stressor can be attention demanding; diverting focus away from the task and resulting in cognitive overload. This attentional shifting can result in poorer task performance (Shettleworth, 2001). When it comes to evaluating the effects of stress, the cause of this reduced performance is hard to pin point, but the effects are clear.

Being a prey species, sheep are notoriously fearful of isolation, novel situations or unfamiliar stimuli (Dwyer, 2009b). Because many of the situations we test sheep in involve a component of novelty and/or isolation, they are likely to experience fear
and stress that can influence the cognitive performance. Step-wise habituation, as described by McBride et al. (2016), and in the judgement bias section later, are examples of ways to mitigate the impact of isolation/novelty stress in test situations. Starting the habituation process with sheep in a group, using positive reinforcement, and then progressing to isolation is the most effective strategy. Underlying factors of individual sheep can also contribute to task success. Research by Qiu (2015) highlighted that calm temperament sheep have better reversal learning than reactive sheep, which could be one reason for individual differences in trial learning.

There is a significant body of literature reporting the effects that maternal stressors and management on the cognition and learning of offspring (just some examples include Erhard et al., 2004; Coulon et al., 2015; Hernandez et al., 2009), although effects are not always consistent or persistent. Coulon et al. (2015) demonstrated that prenatal stress can influence cognitive problem solving in the complex spatial maze described earlier. Prenatally stressed lambs had poorer initial problem solving and poorer learning over the 3 days of the task, and lambs continued to perform worse in the recall test 2 weeks later. The persistence of these differences was not tested on a longer time scale, but even if they are only present in the short term, the result provides important information on how management can influence cognitive performance during development.

Traditional methods to move sheep to a new location usually involve negative reinforcement by fear-inducing stimuli. The most commonly used reinforcers are people, noises and dogs. These stimuli are very effective if they are applied in a controlled manner where the sheep have significant space, are in a group, and the stimulus is being applied at a steady rate. However, if the reinforcers are not used in a controlled fashion, the level of stress can escalate. Practically, this can be seen by sheep failing to move through yards effectively or panicking and running into objects when isolated. All of these behaviours contribute to the misconception that sheep are difficult and frustrating to manage, or are ‘dumb’ animals. These sorts of behaviours arise, at least in part, as a result of excessive stress inhibiting cognitive processing and subsequent problem solving. In a scientific example of these commonly observed stress-induced behaviours, problem solving in sheep was impaired when sheep were exposed to a dog and novel (white) noise when tested in a spatial maze as demonstrated by a slower overall completion time and more frequent errors (Doyle et al., 2014).

Stressful interactions where cognition is impaired may compromise the welfare of sheep in the short term, and also increase the risk of injury to the animals when they are panic. In the longer term, experiences of repeated negative handling and repeated exposure to fear-inducing stimuli can be remembered by sheep and may influence future behaviour making them more reactive and harder to move and handle. This has been demonstrated experimentally such as avoidance of an arm of a Y-maze associated with aversive stimuli (Rushen, 1986) and reluctance to move through a raceway associated with unpleasant situations (Hargreaves and Hutson, 1990).

The influence that stressors can have on sheep cognition and subsequent behaviour are important to understand. Stress can impair cognitive processing of sheep at the time, and sheep will learn from negative situations and this can make them difficult to manage in the future. Moreover, management at critical time points, even prenatally, can influence consequent cognitive flexibility. Simple changes to practices may have
significant benefits to both the welfare of sheep, and how they behave towards stockpeople. The role of stress is also critical to consider for future controlled cognitive studies, and gradual step-wise habituation processes will increase the likelihood of successfully training of the sheep and identifying their cognitive abilities.

Learning and expectations

The appraisal theory framework, developed from human cognitive psychology, proposes that specific emotions are formed through the evaluation of stimuli or situations and that this step-wise evaluation can be broken down into specific categories (Desiré et al., 2002). The outcomes of these evaluations then lead to the formation of a short-term emotion. Appraisal of the novelty, intrinsic pleasantness, relevance to the individual, implications for the individual’s own needs and expectations, coping potential, and how the situation affects personal and social standards are the core components of this framework. Each evaluative step involves cognitive components, and can give us insight into both the information processing of sheep and the affective states they can experience. The body of work done in this area is particularly useful to helps us understand how the expectations sheep form, and deviations from this, can influence their welfare.

Behavioural and cardiac changes indicate that sheep have emotional responses to the predictability of a situation, which demonstrates that they have the ability to anticipate future outcomes, and that being able to do so reduces the stressfulness of that outcome. For example, Rushen (1986) showed that sheep have the ability to predict outcomes and avoid aversive situations. In order to do this, the animal must have the ability to recall memories and apply the recollection to both the current situation and likely future events. In situations that cannot be avoided, sheep displays more muted behavioural and physiological responses to negative events if they are preceded with a warning signal (Greiveldinger et al., 2007). Furthermore, when lambs are able to control the occurrence of a sudden event, they are less likely to avoid (or may even prefer) the test context and are less stressed by the stimulus (Greiveldinger et al., 2009). Thus having the capacity to exert control can reduce the negative perception of an ordinarily aversive event.

Further confirmation of the ability of sheep to anticipate future outcomes is shown by the capacity of lambs to evaluate a reward according to previous experience. This means that lambs are able to form expectations, and when the anticipated reward is below expectation it can be met with frustration. In contrast, when the reward exceeds expectation it is associated with hyperactivity (Greiveldinger et al., 2011). Recent work has further demonstrated that sheep have the capacity to anticipate positive outcomes (Anderson et al., 2015). These results suggest that the lead up and the subsequent positive situation are associated with positive emotional states, characterised by an increase in behavioural transitions and locomotor activity.

The ability of sheep to anticipate an outcome is anecdotally apparent when we see sheep bleat and run towards a feed truck entering the paddock. Appraisal theory studies have provided a valuable framework to help us to understand the processes behind these capacities. By considering the building blocks of appraisal of a situation we can begin to pull apart complex behavioural responses, and start to understand the emotional states that arise from them. In practical terms, understanding how sheep evaluate
specific components of a situation can help to predict how they respond to challenges in the production system. Higher levels of social distress and reactivity to novelty were both predictive of stress during slaughter (Deiss et al., 2009). These consistent responses between the laboratory and the abattoir suggest a sheep’s responses to social isolation and novelty are generalised across different situations.

Sheep are characteristically ‘stoic’ in nature (Roger, 2008). They have evolved to hide signs of pain, illness, or weaknesses that would make them susceptible to predation. As a consequence, signs displayed by distressed sheep may be subtle to the eye of the human observer. This makes it hard to clearly detect affective states, both positive and negative, in sheep. As outlined by Boissy and Erhard (2014) and Veissier et al. (2009), understanding the ways sheep evaluate events, and the emotional states that follow, could be harnessed to provide opportunities for positive experience, and so enhance welfare. These controlled experiments allow us to measure those subtle behaviours and so objectively support the existence of a range of emotions in sheep. These results demonstrate that sheep have the capacity to evaluate different situations based on common characteristics of the situations, and that these evaluations lead to the generation of affective states. The ability to respond to both negative and positive situations indicates that differently valenced events will generate different affective states in sheep, and importantly, that they have the capacity to experience positive emotions.

**Cognitive biases**

Human studies have consistently shown that how an individual feels to influence their cognitive processes, including attention, memory and judgement (Paul et al., 2005). The judgement of ambiguous information is particularly insightful as it can provide information about the valence (the positivity or negativity) and arousal of an affective state. If individuals are in a positive affective state, they are more likely to have a more optimistic judgement, or greater expectation of a positive outcome. In contrast, individuals in a negative affective state typically display a more pessimistic judgement and show greater expectation of a negative outcome. Attention biases are commonly characterised by an increased tendency to direct attention towards threatening stimuli when in more anxious affective states, and they also possess the ability to discriminate between the affect based on valence and arousal. The measurement of affective states using cognitive biases in sheep is still in its infancy, but interesting and unique insights have been developed from current work.

**Judgement bias**

Interest in the cognitive processing of animals as a tool to assess welfare growth significantly with the first judgement bias study in rats in 2004 (Harding et al., 2004). Following the first study in sheep (Doyle et al., 2010), sheep have been one of the most studied species. Despite it being a relatively new topic, there have been several recent reviews on judgement biases (seven reviews in 7 years). This is largely to do with both the novelty and complexity of the topic, and the benefits and limitations for the design and analysis of judgement bias studies have been reviewed most recently.
by Baciadonna and McElligott (2015) and Roelofs et al. (2016). Thirteen studies conducted to date on judgement bias of sheep have demonstrated that this methodology can give insight into positive and negative affective states. Judgement bias research in sheep can be grouped into three different types of studies: long-term treatments, short-term treatments, and neurobiological investigations.

**Long-term treatments**

Long-term unpredictable housing and frequent negative husbandry have been demonstrated to generate pessimistic biases in sheep (Destrez et al., 2013; Doyle et al., 2011b). Of these studies, Destrez et al. (2013) imposed these treatments for longer (9 weeks vs. 3 weeks) and saw a more pronounced treatment effect than Doyle et al. (2011b), suggesting that duration increases the negative affect experienced by sheep. While duration has an impact, it was the presence of husbandry practices that contributed substantially to this negative affective state. By comparison, research by both Vögeli et al. (2014) and Guldimann et al. (2015) managed sheep in conditions of ongoing mild unpredictability without negative husbandry interventions. While longer in duration (~5 months), significant differences in judgement biases were not found. This indicates that the presence of repeated negative handling and husbandry, not simply an unpredictable environment, contributes significantly to the formation of negative affective states in sheep.

Two other studies using this unpredictable housing and negative husbandry challenge provide additional insights into the impacts of ongoing negative affective states in sheep. Coulon et al. (2015) identified judgement bias differences in the offspring of ewes subjected to the negative housing and husbandry treatment, confirming that the treatment was a significant stressor to the ewes, and importantly provides new insights on the impacts of stress on the affective state of offspring. Destrez et al. (2014) delivered 4 weeks of short, positive interventions to sheep while they were exposed to the same housing/husbandry challenge. These positive interventions, which included brushing, positive human interactions and anticipation of food, counterbalanced the negative effect, leading to more optimistic judgements compared to sheep that had experienced the housing and husbandry challenge only. This suggests that the effect of negative management can be offset by the provision of positive experiences.

These studies suggest that the long-term affective state of sheep can be influenced by routine practices, and this can compromise welfare. It is important to note, however, that some of the conditions used in the experiments are not situations that sheep would commonly experience in production. The provision of food and water at unpredictable times would occur frequently on farm, but as discussed, they seem to have limited impact on the affective state of sheep. The negative husbandry practices were all common, but the frequency with which they are delivered, particularly in Destrez’s studies, are not common on farm. Further investigation of the impact of production practices that sheep would normally experience on farm would be valuable if we want to understand affective states in a more relevant production setting. Frequent negative interventions would be more common in intensive conditions, particularly in laboratory environments, so these results may be particularly pertinent to the affective states of sheep in these conditions.
**Short-term treatments**

Contrary to expectations, both a 6 h restraint and isolation treatment (Doyle et al., 2010) and shearing (Sanger et al., 2011) induced more optimistic judgement biases in sheep. This suggests that despite both of these short-term negative treatments generating a physiological response indicative of acute stress, they positively altered the affective state of the sheep. It may be that these results are a scenario of positive contrast, where the removal of a stress leads to a feeling of ‘relief’, or a motivation to offset a negative with reward (a potential food reward in the case of the Doyle and Sanger studies). It could also reflect a heightened state of arousal, the other component of affect that led to a greater engagement with the task. Regardless of the cause of the positive judgement, both studies indicate that, once removed, sheep either recover from acute stressful situations quickly, or their affective states were not affected in the first place. A third study in sheep has also identified optimistic biases in response to a challenge. Using social companionship as a positive reinforcer, rather than food, in the judgement bias test, Verbeek et al. (2014a) showed that despite weight loss, nutritional restriction in sheep led to a more optimistic judgement bias. While the type of treatment applied was different to the acute physical treatments of Doyle et al. (2010) and Sanger et al. (2011), this same optimistic judgement in the face of a short-term negative situation was evident.

Cognitive judgement biases are commonly used to measure mood disorders, and so it is reasonable that this method does not detect short-term changes in affective state (Paul et al., 2005). This is supported by a variety of studies (Hernandez et al., 2015) and reviewed by Roelofs et al. (2016). However, social isolation of short durations (5 min and 60 min) generated the hypothesised pessimistic judgement biases in chicks (Salmeto et al., 2011). Sheep display clear behavioural indicators of fear, anxiety and pain, making their capacity to experience these affective states evident. They actively avoid negative handling situations, and find isolation distressing. It’s unlikely that the two treatments used by Doyle et al. (2010) and Sanger et al. (2011) did not impact their affective states. At least superficially, this optimism after experiencing stress may be unique to sheep. Investigating this concept in other grazing animals, and measuring the effect of other short stressors on sheep would help to understand this phenomenon further. In the meantime, it suggests that sheep recover, affectively at least, from negative situations once they cease. Furthermore, providing opportunity for positive reinforcement following a negative situation may be valuable from a management perspective (Boissy and Lee, 2014), with the opportunity to obtain a reward being a possible cause of the optimistic judgement following stress.. This result complements the findings of Destrez et al. (2014), where positive opportunities during a long-term negative situation had a positive impact on affective state. It seems that positive situations and experiences are valuable and can offset negative affective states, to a degree at least, in sheep.

**Neurobiological investigations**

Significant developments in the understanding of judgement bias as a welfare tool have been developed from research in sheep. A variety of work out of the group led by Caroline Lee in CSIRO, Armidale, Australia and another study from Alain Boissy’s
group at INRA, Clermont-Ferrand, France, have used pharmacological treatments to demonstrate that: (1) reduced brain serotonin was associated with negative judgement biases in sheep (Doyle et al., 2011a), (2) that pharmacologically-induced states of calmness with Diazepam administration result in more optimistic judgement biases (Destrez et al., 2012), and (3) that the opioid agonist, Morphine, can play a important role in positive affective states in sheep (Verbeek et al., 2014b). These studies indicate that neuroendocrine pathways that are well-understood to elicit negative and positive affective states in people and other animals also do so in sheep. This provides important insight into the level of complexity of the affective state of sheep. Reduced brain serotonin, investigating physical situations that influence these pathways can give insight into the best ways to manage sheep and provide them with opportunities to experience positives and reduce chronic negatives. Another important pattern is that these pharmacological studies have resulted in findings consistent with predictions, whereas short, and to a lesser extent long term, stress treatments have not.

Existing issues and future directions

While judgement bias tests in other species include a variety of techniques, including active choice task and natural behaviour tasks, all judgment bias work in sheep has focused on the go/no-go paradigm. Adapted from Burman et al. (2008), this test was selected due to the ease of training sheep to perform the task. As a result of their strong spatial senses, sheep learn the spatial test readily, but even then, it takes weeks to train experimental animals and a significant portion of the sheep still fail to reach the learning criteria. An underpinning factor for these issues is the fact that sheep are isolated in the test context. Having them in isolation for the test may create a problem of adaptation in the first place, or makes them hyper-reactive to small stressors in the testing system. A slow, step-wise habituation process significantly facilitates learning. Modifying the task to enable the sheep to have company with conspecifics would overcome the issues associated with isolation and provide opportunities for a natural behaviour task to enable more rapid training of sheep.

Attention bias

Another type of cognitive bias that is less well-studied in animals is attention bias. Specifically, this is when humans and animals display increased attention towards threats when they are in an increased state of anxiety. Attention bias offers advantages over judgement bias as it does not require previous training, does not exclude animals, is rapid and more practical to apply. An attention bias test has been developed and pharmacologically validated as a measure of anxiety in sheep (Lee et al., 2016). This test measured the response of the sheep to a threat of a dog and demonstrated that sheep showed increased attention towards the dog when they were in a pharmacologically induced anxious state compared to a calm state (Fig. 4.2). In a further study, Monk et al. (2015) reported that the test could be refined by eliminating the need for prior training and reducing the duration to 45 s which makes it more practical to apply in an on-farm situation. While it has been confirmed that the attention bias test in sheep can indicate increased and decreased states of short-term negative affect (anxiety), further studies to determine if attention bias testing can identify long-term affective states such
as depression and positive states are needed. Research applying tests of attention bias to assess the impact of housing and husbandry practices would also be of value.

**Implications for welfare**

Sheep have comprehensive spatial and social cognition, along with the ability to demonstrate executive decision-making. These cognitive abilities reflect the natural environments they have evolved in and give sheep the capacity to adapt to the diverse environments in which they are kept. Their ability to evaluate different stimuli shows they have a capacity to experience affective states, and these affective states can influence their cognitive processing.

Importantly, negative affective states can significantly impact cognitive processing when sheep are stressed, but they can recover readily once the stress is removed, or habituated to. The impact of negative affective states on sheep may also be modulated by short positive situations. This seems to be the case for both long-term stressors, and short-term stressors. This concept should be cautiously investigated further, as prolonged negative situations or environments or acute and persistent treatments (like surgical husbandry procedures) have not been tested.

We know less about management or environmental practices that generate positive affective states; however, we do know that situations that are predictable and relatively frequent can have a positive impact on affect. Their abilities and capacity to experience affective states suggest that cognitive enrichment would be a useful tool for the management of sheep. While this is not necessary for extensively managed sheep, these tools would be extremely valuable to sheep in medical research settings or intensive production systems.
References


Advances in Sheep Welfare


New physiological measures of the biological cost of responding to challenges

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Introduction

The way that an animal responds to an applied challenge is pivotal to the physiological assessment of welfare. In response to various events during life, animals adjust morphologically, physiologically and behaviourally. In sheep, the most spectacular example is the reproductive cycle during which the reproductive organs, as well as several other systems, adapt to the requirements associated with producing and raising an offspring. Under ideal circumstances, ewes will not be negatively affected by the demands of the predictable life events that are part of the reproductive cycle. However, when challenged with unpredictable life events, either from external environmental influences such as nutrition or internal environmental influences such as poor health, the ewe may experience negative effects. To assess the welfare of animals, it is essential to know when the predictable or unpredictable challenges that occur in life become threatening enough to disrupt, prevent or abolish the capacity of the animal to adjust to the events. The capacity of an animal, or any of its physiological functions, to adjust to challenging events or stimuli can be illustrated by the classical strain response to a physical challenge used in mechanical engineering (Fig. 5.1). This graph is not intuitive to biologists because, in terms of cause and effect, the axes are transposed; however, it illustrates well the different phases and problems that animals (or functions) face when an imposed stress increases and the strain developed in response to the stress increases (Fig. 5.1).

The strain of the response as described before is the summation of different costs, including the processing of information and the regulatory responses that are activated to maintain homeostasis in the impacted functions (Fig. 5.2). It is important to reiterate that life events or challenges can originate from both the internal environment (increase in body temperature during activity, decrease in blood pressure, etc.) and the external environment (handling, high ambient temperature, social and olfactory signals, etc.). The genetics of the animal, its previous experience and its capacity to perceive a challenge define whether a given challenge is predictable or unpredictable. For example, in sheep breeds naturally found in a marked photoperiodic environment, reproduction is controlled predominantly by day length, while sheep breeds from a Mediterranean climate will not respond to changes in day...
Figure 5.1 Different relationships between stress and strain as defined in mechanical engineering. The different curves represent different individuals, but could also represent different relationships within an individual at different times or/and exposed to different environmental circumstances. For the average curve black (dark blue in the web version), from the origin to point ‘a’ (the point called the yield strength or elastic limit), the system is plastic and there is no deformation when the stress is removed. When the strain is greater than point ‘b’ (the point called the tensile strength), the system can recover from the stress, but it is submitted to some degree of deformation because the strain has exceeded the elastic limit. Point ‘c’ denotes the fracture or breakpoint, and denotes when the system fails and recovery is not possible (as when glass breaks). The position of these three points varies for each other curve. Arrow 1 illustrates the principle of ‘use it or lose it’ meaning that, with no or little stimulation, a biological function is not being used and will possibly be lost. Arrow 2 illustrates the notion of ‘wear and tear’, and the variability in strain in response to an allostatic overload. The top bar aligns the chain of events as described in Moberg (2000) with the concept of stress and strain in mechanical engineering. Each of the different levels of strain in the response to stress coincides with a part of the stress–strain curve. (b) Variation in the shape of the stress–strain curve according to different values of the three parameters of strength, ductility and toughness. In biology, the x and y axes would be reversed because, by convention, the dependent variable (the response that varies as a function of the stimulus or independent variable) is always presented on the y-axis, while the independent variable would be presented on the x-axis.

The brain processes incoming information according to the emotional status of the animal, and aligns the challenge or event along a continuum anchored between positive to negative valence. The personality of the animal, and its emotional status, will also affect this valuation. Following this processing of information, the response generally is mediated by the brain using three different biological pathways; the autonomic nervous system (ANS), the hypothalamo-pituitary-adrenal (HPA) axis and feed forward systems that control specific functions such as the reproductive axis. In response to the array of signals sent by the brain, each biological pathway will modify

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**Figure 5.2 Schematic representation of the processing and response to life events by animals.** The initiation of a response by the brain depends on (1) the characteristics of the event that can be perceived as environmental information or challenge (stress) and (2) the perception of the events according to the emotional status and the influence of moderating factors such as life history (memory or physiological status) and genes. The response either includes ‘general syndrome’ type that includes the activation of the hypothalamo-pituitary axis and the sympatho-adrenal axis in response to an applied stress, or specific feed-forward systems such as the reproductive axis. These feed-forward systems include the ANS and the HPA in the control of the response of the biological functions. Each physiological response triggers the production of mediators and non-signalling compounds that can affect other physiological systems. The mediators also exert negative feedback on the brain at both the level of perception and also of signal production. Depending on the amount of strain, additional energy will be required that can come from the catabolism of energy reserves or an increased intake of energy. The possibility to match the energy requirements during the response to exposure to a stressor will depend on the capacity of the organism to find adequate sources of energy in its environment. If the energy available is restricted, then the organism will experience a greater strain. **ANS,** Autonomic nervous system; **HPA,** hypothalamo-pituitary-adrenal.
specific gene expression and adjust biological function, producing mediators that will exert feedback on the brain at both level of the process, by acting on the ‘emotional brain’, and at the level of the elaboration of the responses.

The aforementioned description of the strain response to varying degrees of challenge and of the pathways involved in the response can be used to indicate when the welfare of an animal is compromised. But they do not help to identify what would be the best physiological indicators to decide when the function or the organism is no longer able to adjust or adapt. Classical mediators of the response have been used to indicate the progression from coping to being unable to cope. The outcomes might be more relevant than the mediators to assess welfare, as pointed out by Moberg (2000, p. 8) ‘It is the change in biological function that is important to welfare, not the mechanism that induces the change’. Experimentally, it is useful to consider the outcomes that can be identified when the animal is already experiencing a large amount of strain: the pathological state in Moberg’s chain of events, although, by then, the welfare of the animal is certainly compromised. The other approach is to measure mediators, and once the limits of the regulatory systems that can maintain homeostasis are known, then deviations from these limits can be considered as indicators of decreased welfare. That approach seems logical, but, unfortunately, mediators outside of the normal range do not necessarily indicate a decrease in welfare, as these can occur during preparation for predictable future demands, events such as reproduction or migration.

In the two paragraphs aforementioned, the overview of the central and peripheral physiological mechanisms that describe the cascade of steps that occur in responses to ‘life events’ illustrates the importance of emotional processing of the challenge and the role of mediators. Therefore, indicators of the emotional state are paramount to the assessment of animal welfare. However, indicators of the integrated response are more relevant than the measurement of single mediators. Moberg (2000, p. 7) suggested that ‘…the changes in biological function during stress result in a shift of biological resources away from biological activities occurring before the stressor’. So, indicators of energy flow within the organism could be the best measure of the overall cost of the response or strain (Fig. 5.2).

The capacity to support strain is dependent on the energy demand of the response and the energy available to mount the response. All the organs and functions in the body require energy and nutrients. Even though energy is required to build complex molecules out of primary molecules such as amino acids or carbohydrates, the energy alone is not sufficient, but it is the limiting factor (Kafri et al., 2016). The strain of the response will be driven by the capacity of the systems or functions to mobilise energy and use it to mount the appropriate response. As organisms have a limited amount of energy available at any time, the consumption of energy by different biological functions will reflect the strain. The organism can increase it’s energy intake and either catabolise the excess into reserves or anabolise the reserves if there is energy shortage. A measure of the amount of reserves, and importantly a measure of the partitioning of energy between biological functions, could be one of the best, or possibly the best, indicator of welfare.

To summarise, welfare could be assessed by measuring indicators of the emotional processing of the life event(s), the central outputs, including the HPA, the ANS and
specific feed forward pathways that are activated by the central processing. The brain-derived signals control biological functions, which also produce mediators that orchestrate the integrated response between functions, feedback to the central controls and often manage energy. However, some guidelines or decision-making is needed to gauge when the responses to life events have a negative impact on the welfare of the animals, a state that was once defined as an animal being in distress (Moberg, 2000).

Numerous theories have been proposed to understand the biological response to stress from the early concept of homeostasis, the ‘general adaptation syndrome’, to the most recent theories such as allostasis. The first theories such as ‘fight or flight’ (Cannon, 1914), general syndrome of adaptation (Selye, 1936) and the most recent concepts of stress such as the psychoneuroendocrine hypothesis (Hennessy and Levine, 1979), the adaptive biological responses (Levine and Ursin, 1991) and the threatened homeostasis (Chrousos and Gold, 1992) have been reviewed elsewhere (Blache et al., 2011). Here we will focus on the allostasis theory that offers an interesting framework to help define both positive and negative welfare states. Allostasis has been described as stability through change; a cryptic definition that sometimes has hindered the adoption of the theory. Allostasis theory says that each system or organism can sustain an allostatic load (strain) and cope with it using systems of feed forward and feedback as described earlier. The allostatic load can be positive or negative. If the load is negative, the particular functions are not used much or even not used at all; a state named ‘lose it or use it’ by some authors (up to point ‘a’ in Fig. 5.1). The allostatic load can be positive (up to point ‘b’) and can increase further. Beyond point ‘b’ the function experiences an allostatic overload, meaning that the response is no longer adequate to compensate for the stimulus, and the function is not able to generate a reversible adjustment. Some authors refer to this state as ‘wear and tear’ (Korte et al., 2007; Swaab and Swaab, 1991).

Some features of the allostatic theory make the concept very relevant to the assessment of animal welfare. The allostatic load includes the load on the brain, emotions and even the strain from past challenges and future predicted challenges. All of these inputs, as well as phenotypic programming of the animal, can change the position of the breaking points (a, b and c in Fig. 5.1). Changes in the position of these points will result in an animal being either better at adjusting to the challenge, or weaker and breaking down sooner when faced with the same challenge. Energy is central to the concept of allostasis (McEwen and Wingfield, 2010). Allostasis theory is very integrative and not constrained to the normality of the response, and can account for both predictable and unpredictable life events. Allostasis and the allostatic model have been proposed as a useful concept to help assess animal welfare (Korte et al., 2007). In the last few years, allostasis has become popular in the health sciences and has proven itself a solid theory to help understand and predict the outcomes of exposure to stressors in relation to the life history of the subject, including early life experience (Olson et al., 2015), a very interesting feature in terms of animal welfare.

Some of the limitations of allostasis include (1) the relevance and difficulty of measuring energy balance to assess allostatic load, (2) the assumption that an increase in glucocorticoids is associated with an increase in energy expenditure, (3) the assumption that a response to a challenge will increase energy consumption and
(4) the reliance on glucocorticoid effects (Romero et al., 2009). Given these limitations, some new concepts have been proposed that are equally relevant to the assessment of animal welfare. One attempt to combine homeostasis and allostasis has led to a more heuristic model, known as the reactive scope model, that aims ‘to retain the benefits of the concepts of homeostasis and allostasis while at the same time removing some of the weaknesses identified in the current formulation of allostasis’ (Romero et al., 2009). The model has been tested to predict the survival of iguanas (Romero, 2012), suggesting that this model could have value in the assessment of animal welfare. The adaptive role of the stress response in changing developmental pathways has been conceptualised in the adaptive calibration model, which includes long-term adaptive changes, or calibration of systems such as the autonomic, neuroendocrine, metabolic or immune systems, to match new environmental conditions (Ellis and Del Giudice, 2014). Similarly, the concept of stress resilience has emerged from studies that have demonstrated the flexibility of the brain, both structurally and functionally, due to gene expression and epigenetic factors (McEwen et al., 2015; Oken et al., 2015).

Regardless of the degree of complexity of the concepts used to measure strain, a quantitative and scientific assessment of the response to stress and, therefore animal welfare, requires the use of physiological measurements. In the next sections, we will discuss two classical pathways that are involved in the response to challenge, the HPA and the ANS. From the discussion before, rather than listing mediators that are, or could be, used to assess the welfare of sheep, it is more useful to focus on novel indicators that are likely to have relevance in the future assessment of animal welfare. Ideally, the indicators should:

1. be integrative and assess the output (rather than mediators),
2. reflect the emotional component of sheep welfare,
3. reflect the cost of the response to the challenge and
4. have the potential to be used in the field or on-farm.

Using these criteria in the next sections, we discuss ‘classical’ physiological indicators that have been extensively used to assess the welfare of sheep (section, ‘The Classical Responses to Challenge and the Associated Indicators of Welfare’) and then some new and proposed future indicators (section, “New Physiological Indicators”). While specific to sheep, some examples are taken from others species to demonstrate the value that such measures could have in sheep.

The classical responses to challenge and the associated indicators of welfare

The hypothalamo-pituitary-adrenal axis

Glucocorticoid (GC) secretion, in sheep that is cortisol, is the most commonly used physiological measure of an animal’s response to stress and therefore is seen as pivotal in the assessment of sheep welfare (Hemsworth et al., 2015; Ralph and Tilbrook, 2016).
Briefly, the activation of the HPA can be identified by the production of GCs by the adrenals (for structure of the HPA, see review by Turner et al., 2012).

In sheep, changes in the production of cortisol and its metabolites can be measured in different biological media such as blood, saliva (Yates et al., 2010), wool or hair (Stubbsjøen et al., 2015a), urine and faeces (Berman et al., 1980), each media having advantages and limitations. Stress associated with the method of collection (venepuncture) or the handling associated with sampling (restraint, fearfulness of human) potentially confounds the results. Training the sheep to blood collection and/or using sheep with jugular cannulae reduces the stress (Rietema et al., 2015). Cortisol response to acute challenges will be detected in blood samples, while chronic challenges can be measured in urine, faeces and fibre.

In sheep, the HPA-axis is part of the physiological response to a perceived stressor, or related to the level of feed and water intake, temperature or activity of the immune system. The HPA response, which spans both acute and chronic responses to stress (Moberg and Mench, 2000), is dependent on many factors, for example, the type of stressor, the duration of exposure, the genetic background of the animal and the difference between expected and actual outcomes of a physiological response, as discussed in the previous section.

Compromised welfare status has been proposed to start when the levels of GC exceed the ‘non-beneficial stress of activation’ (e.g. an increase of 40% in the concentration of plasma GCs from the baseline; Barnett and Hemsworth, 1990). Such thresholds have been questioned because the HPA-axis activity (1) does not always increase in response to apparent negative life events, (2) increases to apparently pleasurable stimuli such as mating, (3) does not necessarily have a negative effect on the biology of the individual (Sapolsky et al., 2000) and (4) is influenced by factors unrelated to stress such as age, gender and physiological status (Turner et al., 2012), and displays an ultradian and circadian rhythm (Fulkerson and Tang, 1979; Rietema et al., 2015) with rapid increases in concentration and a slow return to baseline levels (pulse lasting about 90 min) (Rietema et al., 2015). Regardless of the relevance, it is preferable to use statistical validations to quantify physiological changes from baseline or in response to treatment such as when changes are scaled against the standard deviation of the reference period (Blache and Martin, 1999).

The measure of GC can also reflect emotional stress, as shown in lambs (Moberg et al., 1980). Increases in plasma cortisol concentrations in sheep have been recorded in response to unpleasant treatment (Hild et al., 2011), housing conditions (Caroprese, 2008), cognitive bias (Doyle et al., 2011b), isolation (Tilbrook et al., 2008), injury, heat stress (Caroprese et al., 2014), cold stress (Berman et al., 1980), food deprivation (Parrott et al., 1996) with gender affecting some of these responses (for review, see Turner et al., 2012). The response of the HPA to a given stimulus varies between individual sheep and can be affected by emotional reactivity (Hawken et al., 2012, 2013).

The interpretation of the HPA response thus needs to be considered in a broader context of time and consequences (Mormède et al., 2007). Moberg proposed that activation of the HPA-axis that leads to a pre-pathological state is indicative of a decrease in animal welfare (Moberg and Mench, 2000). While difficult to interpret, glucocorticoid data provide a reflection of the integrated brain response to exposure to life
events. Unfortunately, the valence and the amplitude of the response are not always correlated to a decrease in welfare, as discussed before.

**The sympatho-adrenal system**

Activation of the sympatho-adrenal system in response to challenges can be assessed via the measurement of plasma catecholamines (adrenaline and noradrenaline, also called epinephrine and norepinephrine) \(\text{(Lowe et al., 2005)}\). An indirect measure can be obtained via measurement of heart rate and its variability, which vary directly with the plasma level of catecholamines (section, ‘New Physiological Indicators’). The catecholamines are released within 1–2 s after the perception of a threatening stimulus, and are metabolised rapidly \(\text{(McCarty, 1983)}\). Therefore, the timing of their measurement dictates their relevance to welfare. Variations in adrenaline and/or noradrenaline have been measured in sheep after restraint \(\text{(Niezgoda et al., 1993)}\), chronic pain due to lameness \(\text{(Ley et al., 1992)}\), road transport \(\text{(Parrott et al., 1998)}\), exposure to cold \(\text{(Thompson et al., 1978)}\) or heat \(\text{(Sasaki et al., 1973)}\), isolation \(\text{(Tilbrook et al., 2008)}\) and audio-visual stimuli \(\text{(Turner et al., 2002)}\). The concentration of catecholamines in biological fluids provides an index of the level of activation of the ANS. The changes are short term and reflect the integrative role of the brain in the initiation of pathways responsible for the keeping the *milieu interieur* within the homeostatic range. Therefore, the measurement of the activity of the ANS is non-specific and provides limited information on the level of strain experienced by sheep.

**New physiological indicators**

In this section, we will discuss new indicators and avenues to develop future indicators that reflect the key criteria stated before. For each indicator, the methodology, the known applications and the limitations are discussed.

*Thermal-based markers*

*Body temperature*

Body temperature is a good indicator of stress and health. Core body temperature in homeotherms is very well regulated and its maintenance is essential for the optimal functioning of biochemical reactions at the cellular level. In sheep, the average temperature ranges between 38.3 and 39.9°C and is affected by breed \(\text{(Blaxter, 1967)}\). Therefore, any deviations from this range potentially provide a very good indicator of exposure to challenges. Sheep core temperature responds to a range of specific challenges, including thermal \(\text{(Cruz Júnior et al., 2015)}\), psychological \(\text{(Pedernera-Romano et al., 2010, 2011; Sanger et al., 2011)}\) and nutritional \(\text{(Maloney et al., 2007, 2013)}\). In addition to possible changes in the mean daily core temperature, the ultradian and circadian rhythms around a set point rhythm \(\text{(Fig. 5.3)}\) can be affected by challenges. While the rhythm can be impacted by environmental influences \(\text{(Lowe et al., 2001)}\),
the underlying daily rhythm of core temperature is not driven by external cues such as ambient temperature, as the daily rhythm is sustained in sheep that are kept indoors and exposed to constant temperature and hygrometry (Maloney et al., 2007, 2013).

Body temperature can be measured using a hand-held thermometer, thermal probes or loggers inserted in the ears, rectum, vaginal or abdominal cavity or on the skin surface or the ear-pinna. Values of body temperature obtained from within the body are more reliable than skin or ear-pinna temperature because the latter are more sensitive to external parameters that do not necessarily change the internal temperature such as wind speed and radiation (Lowe et al., 2001). A single measure of body temperature
provides limited information that is difficult to interpret, as body temperature exhibits a diurnal variation. Changes in mean body temperature can be used to assess cold stress (Ellis et al., 1985; Nixon-Smith, 1968) or heat stress in sheep (Marai et al., 2007). The mean body temperature should be considered with:

1. the behavioural components of thermoregulatory responses such as panting or search for shade, orientation towards solar radiation or wind speed and direction;
2. in woolly sheep such as the Merino, the length (as well as the density) of wool carried by the animal because of the insulation capacity of wool;
3. the nycthemeral profile of body temperature, since this pattern can present an amplitude of 0.1–0.8°C (Maloney et al., 2007, 2013), so the timing of measurement and the number of time points might influence the daily mean value.

Rather than an isolated single core temperature value, the analysis of the daily pattern could provide an integrative measure of the impact of some stressors (Fig. 5.3). Recent studies have shown that the amplitude of the daily sinusoidal rhythm of core temperature is affected by nutrition (Maloney et al., 2013).

**Infrared thermography (IRT)**

The techniques described before provide a reading of the body-core temperature and are either immediate (hand thermometer), lagged (loggers) or impractical (hand thermometer and loggers). Infrared thermography (IRT) potentially provides an answer to some of these limitations. IRT is a non-destructive and non-invasive imaging technique that measures the radiation emitted in the infrared spectrum during heat loss by radiation using an infrared camera or a laser infrared thermometer (Incropera, 2007). IRT offers instantaneous readings of temperature of different parts of the body, including the eyes, udder, ears, axillae and flanks (Fig. 5.4). IRT generates a false-colour image of the surface temperature in which ranges of temperature are colour coded (Fig. 5.4). The accuracy of IRT has increased with improvements in both image capture and image processing (for review, see McManus et al., 2016). IRT can be used almost anywhere as long as one is aware of the environmental factors that can interfere with the surface temperature such as wind drafts, sunlight or the presence of hair and dirt on the animals (McManus et al., 2016). Since the first use of IRT to assess the health of horses in the early 1980s (Purohit and McCoy, 1980), IRT has received much interest as an assessment tool of animal welfare (Stewart et al., 2005).

The temperature of the inner canthus of the eye can be used as an index of the core temperature, to assess the response to stress in farm animals, including sheep. Eye IRT is highly correlated to vaginal temperature ($r = 0.93$) and rectal temperature ($r = 0.82$), in non-febrile and febrile hair sheep (George et al., 2014). In sheep infected with the bluetongue virus, eye IRT discriminated between febrile and non-febrile sheep with a sensitivity of 85% and specificity of 97% (Pérez de Diego et al., 2013). However, eye IRT is not very sensitive when it is used to detect pain in sheep (Stubsjoen et al., 2009). While very promising, IRT of the eye is very sensitive to environmental factors such as humidity, wind speed and radiation exposure, as well as presence of tears in humans (Tan et al., 2009).
In sheep, IRT can help to detect mastitis by measuring udder temperature (Castro-Costa et al., 2014; Martins et al., 2013), foot lesions by assessing inter-digital space temperature (Talukder et al., 2015), testicular heat tolerance (Cruz Júnior et al., 2015) or testicular cooling capacity (Capraro et al., 2008) from the heat radiation from the surface of the scrotum, the impact of shearing on capacity to thermoregulate (Al-Ramamneh et al., 2011) or the heat tolerance of different breeds of lambs (McManus et al., 2015). IRT could be used as a diagnostic tool for udder infection allowing early detection of infection, as suggested by data obtained in cattle 1 h after the injection of bacterial cell wall extracts (Scott et al., 2000).

**Stress-induced hyperthermia**

The core temperature can increase by a few tenths of a degree within minutes following the exposure to an emotional stimulus, a phenomenon termed stress-induced hyperthermia (SIH) (Kleitman and Jackson, 1950; Renbourn, 1960). Sheep exhibit SIH during shearing (Sanger et al., 2011), and during an open field test (Pedernera-Romano et al., 2011). The repeatability of the SIH over multiple exposures to the open field is affected by breed (Pedernera-Romano et al., 2011). The increase in core temperature starts soon after the events (4–14 min; Sanger et al., 2011) similar to the fever response observed after immune challenge, but lasts a shorter time (Bouwknecht et al., 2007). SIH could be a good indicator of exposure to emotional stimuli in sheep, but the valence of...
the emotion is not necessarily negative, as sheep offered food also present a brief increase in core temperature, which does not seem to be associated with a negative experience (Maloney et al., 2013 and see Fig. 5.3). In fact, in sheep, genetic selection for behavioural reactivity affects the shape of the post-prandial increase in both core and retroperitoneal fat temperatures in response to meal anticipation and fasting (Henry et al., 2010).

**Physiological indicators of brain activity**

As aforementioned, measuring and understanding the activity of the brain is essential to understand the perception, the integration and the allostatic load following exposure to stressors. Alongside classical measures and techniques that target neurochemical signals from either within the brain or in the periphery, a new array of physiological measures is becoming available to investigate the emotional responses of sheep (Boissy et al., 2007). In this section, we will discuss indicators of welfare based on specific mediators such as brain chemical signals. Then we will discuss non-invasive techniques that are either currently used, or are developing at a great speed, to measure: (1) the integrative role of the brain by the measurement of heart rate as a proxy for the activation of the autonomic nervous system and (2) the processing role of the brain by assessing the activity of regions, or of the whole brain, using measures of electrical activity (electroencephalography), hemodynamic response (functional near infrared spectroscopy), blood oxygen levels (functional magnetic resonance imaging) or metabolic activity (positron emission tomography). Importantly, these techniques have excellent potential and relevance in the investigation of the affective component of sheep welfare (Buller, 2014; Yeates and Main, 2008). However, some of these imaging techniques are not yet practical such as positron emission tomography, or are only available in a research laboratory environment. Rapid technical developments could bring them to the field in the future.

**Neurochemical signals**

Interrogating brain processes directly by measuring changes in neurochemical signals would be a powerful way to assess welfare. In sheep, the concentration of some neurotransmitters has been measured in samples of the cerebrospinal fluid (CSF) collected either from the lateral ventricle or in the third ventricle of the brain (Fabre-Nys et al., 1991) or in neuronal tissue using micro-dialysis (Fabre-Nys et al., 1994). An issue is that the measurement of substances in the CSF is not as routine as that of plasma sampling (Vaessen et al., 2015). In sheep, opioidergic and GABAergic [gamma amino-4-butyric acid (GABA)] pathways are activated in the somatosensory cortex during nociception and their activation is dependent on the group social structure (Cook et al., 1996). Psychological stress, such as exposure to predator, increases GABA in the amygdala (Cook, 2004). In addition, the sight and ingestion of food increases GABA in the zona incerta of sheep (Kendrick et al., 1991), suggesting that GABA is involved in some cognitive and hedonistic aspect of food intake in sheep.

Within the brain, dopaminergic pathways are activated during the acute and chronic responses to stressors (Tielbeek et al., 2016; Vaessen et al., 2015) and they might also
be involved in the regulatory impact of emotion on the response to stressors (Qiu et al., 2016). Endorphins have been linked to nociception in sheep and other species (Broom and Johnson, 1993). An interesting neurotransmitter is serotonin because it is involved in a myriad of functions, and when activated, it is a reflection of positive welfare such as appetite, mood, temperature, sleep cycles, sexual behaviour and nociception (Mohammad-Zadeh et al., 2008). In sheep, serotonin has been associated with the HPA response to restraint (Frey and Moberg, 1980), appetite and positive mood status (Doyle et al., 2011a). The release of oxytocin, amino acids and monoamines has been measured during parturition and suckling (Kendrick et al., 1988, 1992). These studies have suggested that oxytocin, glutamate and GABA are involved in mood adaptation in the periparturient ewe, a physiological state associated with decreased anxiety (Lonstein et al., 2014). Brain oxytocin also responds to heat exposure (Kendrick et al., 1989). In fact, in other species, it has been proposed that oxytocin could have a role in stress resilience (Walker et al., 2017). These results suggest that oxytocin and serotonin are the most promising candidates as more heuristic indicators of welfare. However, while neurotransmitters are responsive to stressors, their pathways are quite complex and not well understood in sheep, making the interpretation and the relevance of the measures to welfare difficult at present.

Heart rate and heart rate variability

The activity of the cardiac branches of both the sympathetic and the parasympathetic nervous systems affect heart rate (von Borell et al., 2007), and variation in the balance between sympathetic and the parasympathetic input has been used to assess the welfare of sheep. Rather than heart rate (HR), heart rate variability (HRV) parameters are alternative indicators of the balance between the activities of the two branches of the autonomic nervous system. HRV increases with parasympathetic stimulation and decreases as sympathetic input increases (Crawford et al., 1999). In some circumstances, such as predator avoidance in a prey species including sheep, changes in behaviour will be coincident with changes in autonomic function, and therefore with changes in HRV. But in many other situations, when the behavioural response develops over time such as shade seeking on a hot day, the HR and HRV will illustrate the early response of the animal to exposure to stressors since changes in cardiac function are apparent before any alteration of behaviour (von Borell et al., 2007). HRV seems to be a better indicator of animal welfare than HR because HRV seems to be more sensitive. Some situations induce a change in HRV but not in average HR (von Borell et al., 2007).

In sheep, heart rate has been measured using electrodes glued or held using a belt on the skin surface, connected to either a transmitter sending data to a remote monitoring unit located in the vicinity of the animals (e.g. LifeScope, Nihon Kodhen, Japan; Désiré et al., 2006), or to a logger as used in humans (Modular Digital Holter Recorder, Lifecard CF, DelMar Reynolds GmbH, Switzerland; Reefmann et al., 2009b) and horses (Polar heart rate monitor RS800, Polar Electro Oy, Helsinki, Finland; Stubøsjen et al., 2009). HRV can be measured by calculating different parameters, including the variability in the time interval between consecutive heart beats [inter-beat interval (IBI), i.e. the interval between subsequent R waves of the QRS complex on a
standard electrocardiogram], the standard deviation of all inter-beat intervals (SDNN) and the root mean square of successive R–R intervals (RMSSD). Lately, HRV has been analysed using fractal analysis (detrended fluctuation analysis) to extract information from the heart rate recording that is not illustrated by IBI, SDNN or RMSSD (Stubsjøen et al., 2010).

In sheep, HR has been shown to be a reliable indicator of cold stress (Berman et al., 1980), heat stress (McManus et al., 2015), road transport stress (Wickham et al., 2012) and fear responses such as isolation or exposure to a sudden or unpredictable stimuli (Désiré et al., 2004, 2006). HRV varies when sheep experience pain (Stubsjøen et al., 2010), sea transport motion (Santurtun et al., 2014), chronic stress in response to an infection (Stubsjøen et al., 2015b), chronic stress in response to psychological stressors (Destrez et al., 2013), emotional reactions to human contact and isolation (Tallet et al., 2006) and positive and negative emotions (Reefmann et al., 2009a; Coulon et al., 2015). Depending on the nature of the stressor and on the animal history and genetics, HRV can either increase or decrease, possibly as a function of the animal’s interpretation of a stressor (von Borell et al., 2007) and the animal’s capacity to exert control over the situation (Greiveldinger et al., 2009).

While HR and HRV can give us a great insight into the processing and response to stressors that is occurring in the brain, caution is paramount because HR is affected by a large number of factors, some not necessarily related to welfare such as exercise (Lowe et al., 2005) and feeding and digestion (Animut et al., 2006). In addition, it is essential to obtain baseline values, when the animal is stationary and not exposed to any challenge, and to take into account circadian variation, season, age and metabolic state of the animal (von Borell et al., 2007).

**Electroencephalography**

Electroencephalography (EEG) is the measurement over time of cortical electric activity using electrodes located at specific locations either on the surface of the skull or around the brain within the cranial cavity. In sheep, while EEGs were recorded in the 1960’s (Baldwin and Bell, 1963), there are no standardised methods to implant or locate the electrodes around the brain. Some authors have described the use of surface electrodes that are only connected to the bones skull after insertion under the skin (Cwynar et al., 2014). The electrical activity of the brain is amplified and a typical electroencephalogram will comprise of eight traces that illustrate the variations in potential between the different electrodes over time. The interpretation of these traces is not simple but, as the locations of the electrodes are constant, the expected traces should be constant. Changes in the EEG traces reflect changes in brain activity and therefore, the EEG is a very useful technique to assess the impact of psychological and physiological challenges on brain function.

EEGs have been used mainly in confined environments because of the necessity to capture the information from the electrodes that are wired into amplifiers and recording devices. With the development of telemetry (Létourneau and Praud, 2003), wireless technology and miniaturisation of devices for data storage, it is becoming possible to record EEG on free-moving sheep (Perentos et al., 2017). Furthermore,
less invasive methods for the implantation of electrodes are being developed. A very promising method is the use of ‘stent-electrodes’ implanted in venous networks distributed on the surface of the cortex (Oxley et al., 2016). The stent-electrodes can be located with precision within the now well-described ovine cerebral venous system (Hoffmann et al., 2014) and can remain in place for 190 days in the brain of a free-moving sheep (Oxley et al., 2016). Right now, this technology is used for research only but it could become widely available, as the use of stents has expanded in human cardiac therapy. In addition, new algorithms, such as ‘fuzzy logic systems for spike detection’ (Abbasi et al., 2014), are being developed to extract more reliable data out of the complex pattern of the electroencephalograms.

EEG could also be used to assess the effect of fatigue and sleep deprivation in sheep, as has been done in cattle (Ternman et al., 2012). Furthermore, EEG has been used to assess pain in animals (Murrell and Johnson, 2006). In sheep, changes in EEG traces have been related to behavioural activity and noxious stimulation either induced by electric shock (Ong et al., 1997) or by castration, tail docking or mulesing (Jongman et al., 2000). These EEG responses to noxious stimuli may reflect cognitive pain, as described in humans. Therefore, the EEG could be used to study the emotional reactions of sheep, but this application has been limited by technical restrictions such as confinement, or EEG artifacts due, for example to rumination (Cwynar et al., 2014). Recently, EEG has been used for the early detection of disease by analysis of the sleep EEG (Perentos et al., 2016) or the EEG traces linked to rumination (Nicol et al., 2016).

Since neurons require oxygen to function, EEG is sensitive to reduction in blood flow (Baldwin and Bell, 1963) and hypoxia and therefore, provides a good indication of the level of oxygenation to the brain. EEG is also a good indicator of consciousness and unconsciousness (Verhoeven et al., 2015); consciousness is defined as the presence of recordable neuronal activity of the cortex. The EEG has been used extensively to define the onset of consciousness in the unborn lamb (Mellor and Diesch, 2006) or the cause of distress to unborn lambs (Wang et al., 2014). EEG activity has been used to (1) study the loss of consciousness at slaughter (Blackmore and Newhook, 1982; Newhook and Blackmore, 1982), (2) develop the best methods of electric stunning (Lambooy, 1982) and (3) investigate the efficiency of stunning practices in meat animals, including sheep (Sánchez-Barrera et al., 2014). EEG data have helped to develop an ethical position (Nakyinsige et al., 2013) and accelerated the acceptance of stunning in sheep by consumers of halal and kosher products (Velarde et al., 2014).

**Functional magnetic resonance imaging (fMRI) and positron emission tomography (PET)**

Functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) may provide valuable information on the involvement of brain areas in the response to challenges. fMRI is a non-invasive technique that measures the blood-oxygenation-level-dependent (BOLD) endogenous contrast, providing spatiotemporal patterns of regional brain activation in response to external stimulation. fMRI does not require the use of radiolabelled chemicals (Lee et al., 2015). By contrast,
PET imaging is based on the injection of specifically labelled molecules such as water, dopamine, serotonin or opioids to measure the activation of specific pathways (Leknes and Tracey, 2008). The production of labelled molecules for PET scanning requires the proximity of a cyclotron facility, limiting the use of PET to specific research facilities. Importantly, fMRI and PET can measure different aspects of the affective response. fMRI may help to understand the cognitive component of the emotional response because it can measure rapid changes in response to a challenge and also target cortical structures (Burgdorf and Panksepp, 2006). PET can measure long term changes in activity in sub-neocortical brain regions, which are thought to be an elaboration of affect and possibly of the emotional status (Burgdorf and Panksepp, 2006).

fMRI and PET are both routinely used in humans during clinical investigations and research. The techniques require controlled conditions (Hudson, 2005), which can be adapted for use in animals, although the animals must be restrained in a large and expensive scanner (Olsen Alstruo and Winterdahl, 2009). The technical requirements and limitations on the use of imaging techniques in large animals, including sheep, have been discussed in Olsen Alstruo and Winterdahl (2009). The basic tools that will assist in the use of fMRI and PET in adult sheep are being developed. Detailed three-dimensional atlases of the sheep brain (Ella et al., 2017; Nitzsche et al., 2015) are essential to identify the structures activated and detected by fMRI.

There is great potential for the use of fMRI alone or in combination with PET to study the functional neuroanatomy of emotion (see studies in human; Phan et al., 2002). The use of fMRI to visualise central pathways that are activated in response to noxious stimuli has increased our knowledge of the physiological differences and similarities between humans and other animals in sensations such as pain and pleasure (Leknes and Tracey, 2008). However, there are drawbacks to the use of fMRI to study emotions, including: (1) the imaging of large animals requires the animal to be anaesthetised and therefore, unconscious, and (2) that the expression of emotions are often time dependent (Burgdorf and Panksepp, 2006). Because of these limitations, fMRI and PET have been used only in neonatal sheep (i.e. small). However, the study of brain activity in anesthetised sheep following visual and tactile stimulations has shown that fMRI can be used to study brain processing (Lee et al., 2015).

Functional near infrared spectroscopy (fNIRS or fNIRS)

Functional near-infrared spectroscopy (fNIRS) is a neuroimaging technology that can be used for the mapping of functioning of the cortex. fNIRS is a non-invasive optical technique that measures the absorption of NIR light (spectral window 650–1000 nm) by pigmented compounds (chromophores) in the brain. Near-infrared spectroscopy has a very high time resolution (ms) and good spatial resolution (cm) (Wolf et al., 2002). The newest fNIRS technology measures the cortical haemodynamic ratio of the concentration of oxygenated and deoxygenated hemoglobin (Ferrari and Quaresima, 2012), providing an indication of oxygen use and by logical extension, of neuronal activation. The main advantage of fNIRS is that the subject does not need to be restrained (as it does with fMRI and PET) or
New physiological measures of the biological cost of responding to challenges

injected with exogenous tracer (as in PET). In humans, the reproducibility of the location and quantity of signals is excellent at a group level (96%) but is mediocre within an individual (as low as 36%; Plichta et al., 2006) possibly because of motion artefacts and physiological and psychological changes between sessions (Plichta et al., 2006). There are many commercially available fNIRS technologies and special equipment has been developed for sheep. The fNIRS technology has been miniaturised, and can be powered by lithium batteries providing for 180 min of data collection. This enables fNIRS to be used in freely behaving animals (Muehlemann et al., 2008).

Probably, because the fNIRS method is easy to use and does not require anaesthesia or restraint, the technology has been developed and validated for the study of emotion and mood in sheep (Gygax et al., 2013; Schroeter et al., 2004). fNIRS has revealed differences in neuronal activation, interpreted as subtle differences in emotion, in response to housing conditions and grooming (Muehlemann et al., 2011). However, the results of fNIRS are not very discriminative between stimuli valence when sheep are exposed to stimuli that are presumably of negative, intermediate or positive valences, although a stimulus with presumably negative valence (prickling) induced the strongest decrease in concentrations of deoxyhaemoglobin (Vögeli et al., 2014). Supporting these findings, frontal cortical deactivation was induced when a visual emotional stimulus was delivered, especially if the stimulus was negative (Guldinmann et al., 2015). On the other hand, the level of predictability in the previous housing conditions can modulate the frontal activation to a negative stimulus (Vögeli et al., 2015). Aside from the study of emotional reactivity in sheep, fNIRS has been used to investigate the impact of hypoxemia in preterm lambs (Van Os et al., 2005), and on neuronal function and the capacity of near-term lambs to respond to somatosensory stimulation (Nakamura et al., 2016). Theoretically, fNIRS should allow the investigation of the impact of any feedforward and feedback mechanisms on brain activity (Gygax and Vögeli, 2016).

Metabolic indicators

As the strain of any response to an imposed challenge is ultimately energetically costly, mediators and outcomes related to the regulation of metabolism are potentially very good markers of animal welfare. There is a similarity between the concept of stress and the regulation of energy resources in that, past, current and future events are integrated in both concepts. At any given time, the energy available to support the strain of a response is dependent on the amount of energy available from three compartments; first, the energy (in the form of volatile fatty acids) from the digestion and absorption of nutrients from the gastrointestinal tract; second, the capacity of the organism to increase energy availability by increasing the intake of nutrients and third, the amount of energy available from glycogen stores (muscle and liver) and through catabolism of fat. The capacity to sustain any amount of strain by any physiological system, including the brain, will be limited by the ability of the individual to manage the partitioning and replenishment of these three compartments. In addition, the energy available to support a
strain response will be dependent on the energy used to satisfy any other strain in addition to the basic functions associated with maintenance.

In sheep, the regulation of intake and metabolism in ruminants involves a large number of hormonal signals that are produced by different organs and tissues, including the gastrointestinal tract, fat, and the brain and neuronal pathways that link the brain to the peripheral organs (for review, see Roche et al., 2008). Amongst the myriad of mediators secreted by all the organs playing a role in metabolism, two hormones, insulin and leptin, are quite integrative making them good candidates for a heuristic measurement of energy availability. In sheep, both hormones are sensitive to the level of intake, as well as the mass of fat, and the rate of energy expenditure. Both act at the brain level to control intake, and their receptors are present in most tissues, suggesting a role in coordinating the function of those systems such as reproduction (Blache et al., 2006). However, it is not known when the plasma concentrations of insulin or leptin are indicative of good or poor welfare. Knowledge of the level of catabolism or anabolism, as measured by the concentrations of non-esterified fatty acids and volatile fatty acids in plasma, would assist this decision.

**Indicators from the immune system**

The immune system is a very good indicator of the welfare of an animal because: (1) it responds to exposure to stressors, (2) its activation in response to the presence of foreign organisms or molecules is energetically costly (Colditz, 2008a) and (3) its response is affected by the emotional status. In sheep, a major welfare issue is the gastrointestinal parasite load that is associated with a high-energy cost (Colditz, 2008b). As described before, fever and an increase in heart rate provide an indication that the immune system has been activated, and therefore is demanding more energy (Marais et al., 2011). The markers of the level of activation of the immune system can be divided into two categories, the mediators of the immune response and the indirect mediators that are affected by the activation of the immune response. The mediators of the immune response are natural killer cell activity, peripheral white blood cells, salivary immunoglobulin-A concentrations, as well as interleukin (IL)-2 and IL-3 and decreases in IL-6 and tumour necrosis factor (Colditz, 2008b). IL-6 and tumour necrosis factor both have a role in inducing the fever response that can be detected by the thermal techniques described before. It has to be noted that, as is the case in humans, the response of most of the factors listed earlier to immune challenge can be affected by emotional state (Colditz, 2008b). It is then possible to consider that the mediators of immune system activation could represent some integrated measure of welfare.

**Biomechanical markers**

The maintenance of postural balance is energetically costly and, therefore, a measure of balance and the efficiency of locomotion could be considered as indicators of sheep welfare. The technology for biomechanical measurements was developed originally for use in sport science and motor-developmental studies in humans, and has only recently been used in animals. The study of horse biomechanics has been intense because the
optimisation of the biomechanical cost of movement improves the performance of race horses (Buchner et al., 2000; Clayton and Nauwelaerts, 2014). But techniques for other species have been developed, including studies of locomotion and the detection of motor problems in dogs (Gillette and Angle, 2008). Assessing the biomechanics of balance and of movement can be achieved using several techniques that measure acceleration in two or three dimensions. The most relevant technology to welfare is the use of three-dimensional accelerometers that produce data that can be translated into directional forces, directional workload or total workload and therefore energy use (Gillette and Angle, 2008). These accelerometers can be attached to an animal’s limbs and measure the gait. The same type of accelerometers can be inserted between two solid (non-deformable) plates to measure the ground reaction forces generated by a body standing on or moving across it (Fig. 5.5).

**Figure 5.5 Schematic representation of a force plate system comprising of two non-deformable plates (in blue and orange) with triaxial actometers or accelerometers (black cylinder) located between the two plates at the four corners of the plate.** The accelerometers record acceleration along the three-dimensional axis. Specific algorithms can visualise the pattern of ground reaction forces produced by a 2-month-old lamb during a walk through the force plate system (left bottom panel) or when standing on the force plate system in a stressful situation (isolation, right bottom panel). The raw data from the walk (left bottom panel) were converted into vertical force \( z \): top black trace (blue in the web version) and fore-aft force \( x \): bottom grey trace (red in the web version). The raw data obtained while the lamb was standing (left bottom panel) were converted into vertical force \( z \): top black trace (blue in the web version) and fore-aft \( x \): bottom grey trace (red in the web version) and medio-lateral force \( y \): middle grey trace (green in the web version). The forces exerted and the work produced by the limbs can be calculated for each axis, as well as their variation over time. The weight distribution between the fore and back limbs, and the displacement of the centre of gravity can also be calculated.
Special algorithms can calculate the displacement of the centre of gravity during a walk or stationary period providing a measure of the balance and the total force required for maintaining balance. The data collected from force plates can also be used to determine the partitioning of weight between the forelimbs and hindlimbs, as well as the force and the work produced in each of the three dimensions (Fig. 5.5).

Biomechanics is a rather new and somewhat under-developed method to assess welfare but has a very promising future. In dairy cattle and sows, it has been shown that force measurement can be used to predict lameness (Conte et al., 2014; Dunthorn et al., 2015; Grégoire et al., 2013; Pluym et al., 2013). Force plate technology could be used to detect slight changes in posture or muscular effort induced by external or internal injury. Data obtained recently also suggest that, in sheep, emotional reactivity could influence the work output produced by lambs when they are isolated. Standing lambs born with a high emotional reactivity (Beausoleil et al., 2008) do more mechanical work than lambs born with a low emotional reactivity, when they are kept in isolation (22.78 ± 6.80 J/kg vs. 6.83 ± 1.71 J/kg; $P < 0.05$, $N = 12$ in each group; D. Blache, unpublished data). Measuring the variation in ground force reaction and the associated changes in weight distribution between the fore and back limbs, and between the right and left limbs, may represent a very useful indicator of pain as suggested in work done in pigs (Conte et al., 2015; Pairis-Garcia et al., 2015). These subtle biomechanical measures might detect posture pain associated with painful husbandry practices given that sheep, as prey animals, normally attempt to conceal behavioural expressions of pain (Molony and Kent, 1997). The use of this technology could also help to measure fatigue in sheep and vigour in lambs, for which there is presently no standardised quantitative measure.

**Interpreting physiological indicators**

The new indicators of welfare, even if they are still experimental, offer the potential to provide a more integrated approach to welfare and, importantly, to include assessments of affective state, to better reflect the energy cost of the response. However, like any welfare indicator, having a methodology to interpret physiological indicators is essential to conclude if animals have compromised welfare (and by how much) or that they are experiencing a positive welfare state.

First and foremost, indicators need to be validated. Methods used to collect and analyse indicators need to be validated against known challenging situations. The intensity of the situation should be varied to validate the sensitivity of the indicators. These validations would also help to understand the relevance of the indicators to welfare. As previously discussed, even classical indicators such as glucocorticoid concentrations in biological fluids are not always relevant to welfare in sheep (Ralph and Tilbrook, 2016). Moreover, the changes in indicators should be interpreted against values obtained in a relaxed or neutral situation, when the animal is experiencing minimal strain. A large number of classical physiological indicators have been developed and used extensively to assess the welfare of sheep that are exposed to different production
environments or stressors. The nature of the challenge in these different environments is quite variable (Kilgour et al., 2008) and the consequences on the physiology of the animals are equally variable between environments and between individuals. This complexity is not surprising since sheep have been domesticated for a long time and the perception of challenges can be affected by genetic traits, as well as memory or experience (Fig. 5.2).

We have stressed that the time of the collection of physiological data can lead to misinterpretation (see the discussion of the use of fMRI technology vs. PET scan in the study of affective states). Similarly, IRT data are impacted by the thermal environment and emotional status, as suggested by the stress-induced hyperthermia response. The best data would be that collected live and in real-time. In sheep, kept in extensive conditions, telemetry is becoming a very important tool in the collection of physiological measures (Samson et al., 2011) and is even experimentally possible in newborn lambs (Létourneau and Praud, 2003).

The interpretation of physiological data can be difficult because there are several facets to the response to stressors and a lack of universal agreement on when strain increases to the level of welfare concern. As discussed throughout this chapter, any physiological data to assess strain should be interpreted in concert with other physiological and/or behavioural parameters, while at the same time taking into account the genetic, environmental and temporal contexts. In sheep, the rather good understanding of the relationship between the external and internal environments, the physiological responses and the emotional state of an animal should be capitalised to develop integrated approaches to the assessment of welfare. This is not to say that we have to measure everything and then try to make sense of it, but rather to use this knowledge to build up a composite index of welfare. Theoretical frameworks such as allostatics can help to build an index of welfare. Biomarkers of allostatic load have been proposed (Juster et al., 2010) and used to calculate an allostatic load index associated with ‘burnout’ symptoms in humans (Juster et al., 2011). Similar approaches could be used to assess the welfare of sheep.

Indicators and indexes of welfare are still post-hoc and might serve to change the way we treat, interact with and keep animals. However, there is no such thing as a perfect production system, and the level of human control of the environment can, especially with free-range systems and extensive sheep production systems, have both positive and negative impact on sheep welfare (Blache et al., 2016; Villalba et al., 2016). In addition, there is a strong argument that welfare should be measured at the level of the individual, rather than at the group or farm level (Mellor, 2016). The development of predictive tools will need strong algorithms that can integrate, simplify and project the future course of not only physiological but also behavioural data. Such algorithms, that address large data sets and analyse global networks of information, have been developed and are still being developed and will provide excellent tools to assess multiple data sets over time periods in an objective way so that the flexibility of the system can be assessed. Quite importantly, these algorithms, as complex as they will be, will perform better if they are seeded with more reliable and sophisticated data, therefore the pursuit of integrative or even isolated indicators is still necessary.
Conclusions

In this chapter, we have stressed that brain processing is based on complex neuronal circuitry that involves the processing of the information from life events, and also from the emotional state of the animal, including the input from memories (impact, positive or negative, of the past), the programming of the animal (preparation for future needs) and the current feedback from biological functions (present physiological status). Having integrated this information, the brain generates outputs that are either specific or general. All these responses require energy; some require very little (emotion building), while some responses require more energy such as the response to thermal challenge. We have described some integrative indicators, ranging from temperature patterns that could reflect energy balance to brain imaging that could provide insights into the processing of information. At present, for sheep, while we have accumulated a decent amount of knowledge in ‘stress’ physiology and emotional states, we still do not have universal tools to help us decide if the welfare of a sheep is right or compromised in any production environment. As explained in the last section, for each indicator, we need to quantify the baseline and to understand the relationship between the indicators and the timeframe of their interconnectivity. Finally and most importantly, we need indicators that are predictive rather than descriptive of the ‘post impact’ or adaptive response to life events.

References


Advances in Sheep Welfare

## Part Three

### Current and Future Solutions to Sheep Welfare Challenges

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Genetic solutions

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Introduction

Based on current trends, increased consumers’ perception of animal welfare in agricultural production will impact livestock systems, including meat sheep and wool production systems. Sheep breeding programmes target the most profitable type of animal for future production circumstances in three ways: increasing production to increase returns, improving health to decrease cost and considering future production and product requirements such as welfare-related traits, to retain the social licence to operate. To integrate novel traits in existing breeding programmes, methodologies are required to determine the economic value of these traits, which can be challenging, especially if the trait does not have a direct value that can be derived from the current market.

Breeding strategies are essential components of any integrated approach to future sheep production, as breeding programmes provide long-term and potentially low input solutions. An attractive aspect of selective breeding for improved welfare and disease control is that the genetic gain is cumulative and permanent over successive generations. Selective breeding in this context can also reduce reliance on management interventions requiring chemicals and drugs, and their associated potential residue issues.

Methods of different levels of complexity are used to integrate welfare-related traits in sheep breeding programs, ranging from mass selection over selection on traditional breeding values to genomic approaches. Genomic applications can be particularly useful for difficult to measure traits, which welfare-related traits often are.

The objective of this chapter is to provide a general overview of breeding strategies in relation to welfare traits in sheep, to outline the challenges of incorporating welfare-related traits in breeding programmes and to illustrate examples where welfare issues in sheep have been successfully addressed through breeding strategies.
Welfare-related breeding objectives and novel trait concepts in livestock breeding programmes

In the context of genetic improvement, breeding objectives define the direction of breeding programmes and combine the main profit drivers to maximise profitability (Goddard, 1998). A number of tools aid sheep breeders to make decisions on the genetic merit of selection candidates to meet their breeding objective. Breeding values provide a description of the genetic merit of an animal for a single trait. They can be estimated on the basis of phenotype and pedigree information as estimated breeding values or instead of pedigree, with genomic information as genomic estimated breeding values. Generally, if a combination of pedigree and genomic information is used, breeding values are referred to as genomic-enhanced breeding values. Throughout the chapter ‘genomic breeding values’ will be used to describe any breeding value, which incorporates genomic information. For selection of multiple traits, estimated or genomic breeding values are weighted by their economic value and combined in a selection index, which yields the genetic ranking of selected candidates for a multi-trait breeding objective. It has been shown that strong selection for production traits will potentially lead to unfavourable correlated responses in other functional and health traits (Rauw et al., 1998). It is important to balance the weight given to production traits with other traits related to health and welfare. The integration of novel traits such as those related to welfare, into existing breeding objectives is challenging. How are they measured? What are the genetic and phenotypic relationships with traditional production and health traits? How is the economic value determined? These challenges for integrating welfare-related traits into breeding programmes are discussed.

Animal resilience and breeding for better animal welfare

The concept of breeding animals to be more resilient generally refers to their ability to reproduce, grow and produce (meat, wool and milk) in the context of likely, or ‘normal’ farming practice. From a farm animal welfare point of view, having animals that are genetically well adapted to their production environment reduces the likelihood of negative health and welfare problems. Generally, the emphasis has been on adapting the farming environment to better suit the needs of the animals, for example by modifying housing and management practices. However, breeding animals that are better suited to the farm environment can also help to improve animal welfare such as breeding for resistance to disease or useful behavioural traits. Questions as to whether we should be breeding animals to ‘cope’ with less than optimal farming environments or if the ‘easy care farm animal’ concept promotes less rigorous animal monitoring and individual attention are part of a separate ethical debate, and one, which is outside the scope of this chapter. Suffice it to say, even a ‘natural’ environment provides challenges for animal health and welfare, selection of animals better suited to environments makes sense.

Animal resilience can mean being resistant to, and being able to overcome disease challenges, adequately recovering following periods of limited nutrition or
additional demands such as during lactation and/or following adverse and extreme weather events. The terms ‘robust’, ‘resistant’ and ‘resilient’ are often used interchangeably in the literature, but they do in fact have different meanings (Colditz and Hine, 2016), particularly in an animal-breeding context.

In animal breeding, a ‘robust’ animal is one that overcomes genotype by environment (GxE) interactions and is able to deliver good or high levels of production across a range of different environments for a range of different traits such as growth, reproduction efficiency or disease resistance.

Furthermore, the farm environments can also be classified and the selection of animals can be ‘tailored’ to better suit these, as defined by the ‘reaction norm’ theory as illustrated for pigs (Knap and Su, 2008), dairy cattle (Kolmodin et al., 2002) and more recently, for Texel sheep in the United Kingdom (McLaren et al., 2015). The regression of sire breeding values on a continuous measure of ‘environment’ (e.g. topography, level of average animal performance, temperature and so on) in which records from their offspring exist, allows reaction norms to be predicted for individual sires. In this way, the phenotype expressed by a certain genotype over a number of different environments is quantified, which can be particularly useful when environments are described along a continuous scale or gradient (de Jong and Bijma, 2002). This approach can both tailor animals to better match specific environments or else be used to identify sires whose estimated breeding values are high, regardless of the different farm environments, thereby resulting in a ‘robust’ sire.

A resistant animal (to disease), generally, refers to the ability of an animal to reduce its pathogen burden, as in the example of internal parasite infection in sheep (Bisset and Morris, 1996). More recently, this concept has been extended through the application of genetic modification via the gene editing procedure, to create animals that are unaffected by specific pathogens, for example porcine reproductive and respiratory syndrome (PRRS): resistant pigs (Whitworth et al., 2015). The method has the potential to revolutionise livestock industries to reduce the impact of diseases, which are caused by major genes. Although the technology is still in its infancy, gene-editing animals for resistance to diseases of major economic importance is a win-win opportunity for livestock and their keepers internationally, with societal acceptance being one of the main non-technical hurdles to overcome to achieve industry application.

The ability to withstand disease is often accompanied by a trade-off in productivity, highlighted by Turner et al. (2015) and quantified by the genetic correlations amongst indicators of disease and production. In general, these two groups of traits are largely antagonistic at a genetic level, for example the positive genetic correlation between milk yield and somatic cell count (an indicator of mastitis) in dairy cattle (Pryce et al., 1998), sheep (Conington et al., 2008a; Rupp et al., 2003) and goats (Rupp et al., 2011). This means higher yielding animals tend to be more prone to mastitis. Similarly, the genetic correlations amongst footrot and ewe performance (for litter size reared and lamb mortality as a trait of the ewe) in Scottish Blackface sheep shows that ewes with higher levels of footrot tend to rear fewer, and lose more lambs from birth to weaning at 4 months (McLaren et al., 2008). This problematic relationship is often not apparent at a phenotypic level, because the incidence of footrot is often reduced through good animal health management, ‘masking’ the genetic propensity for the
disease. However, unless aspects of animal robustness such as disease resistance are included together with selection for higher productivity, the ability of farmers to manage the manifestation of disease becomes problematic, as more productive animals become increasingly unable to withstand disease. When breeding for productivity is accompanied by breeding for disease resistance within the same selection regime (selection index), then breeding for resilient animals to disease is possible.

There are clear economic benefits associated with breeding for resilience to disease (Albers et al., 1987). In this context, Hermesch (2014) advocates that it may be better to focus on reducing the effects of infection rather than reducing the infection level itself. However, genetic selection ordinarily relies on having the infection present at the time of selection—and the implementation of breeding strategies that include elements of disease resistance can be challenging for this very reason. Breeding for animal resilience to disease is also problematic because very often it is expensive to identify the causative organism as this entails the use of veterinary laboratory analyses. To overcome this constraint, proxy measures such as somatic cell counts, milk flow symmetry, California milk test (CMT), and aspects of udder and teat conformation are currently being researched for inclusion into meat sheep and dairy goat breeding programmes in the United Kingdom, so that more resistant genotypes to mastitis can be identified. Similarly, to avoid costly laboratory analyses for the identification of footrot in sheep, a severity scale and other hoof lesion scoring protocols (Conington et al., 2008b,c) have been adopted in the United Kingdom, so that both mastitis and footrot-resistant genotypes can be integrated into a new genomic breeding programme for Texel sheep. The approach is outlined later in this chapter.

Having the capacity to resist disease at the same time as maintaining productivity are only two elements of animal resilience. If, in addition to these effects, the animal has to be culled sooner than normal, and is unable to maintain body condition score and available body reserves, or fails to reproduce, then ignoring these key aspects of animal resilience will lead to unsustainable livestock systems.

**Temperament as a selection criterion for improved welfare outcomes**

Temperament has been defined as a combination of behavioural and emotional responses to objective tests that measure escape or avoidance behaviour in response to a fear stimulus (Box, 1999). Temperament reflects variation in activity, reactivity and emotional and sociable behaviour (Buss et al., 1987) and is a characteristic that is consistent over time and expressed early in life (Box, 1999), which would indicate a strong genetic component. Whilst it is known that environmental influences, maternal imprinting and conditioning are non-genetic effects that can modulate temperament, evidence from Merino temperament selection lines demonstrates that temperament is mainly determined by genetic effects (Bickell et al., 2009).

Temperament in sheep is characterised in general by the expression of fearfulness, as manifested by high flight distance and a strong flocking instinct, evolved as effective behaviours to minimise the impact of potential predators (King et al., 2012). Sheep are also averse to novel objects and situations (Romeyer and Bouissou, 1992).
As a result of these innate characteristics, isolation and handling during common husbandry procedures such as shearing and yarding can cause sheep high levels of stress and phenotypic variation exists in the response to these challenges (Romeyer and Bouissou, 1992). Elevated stress levels can have impact on the welfare of sheep, ranging from injury through erratic behaviour and anxiety. Sustained exposure may result in higher incidence of disease as a result of lowered immune response and negative impacts on growth (Rauw, 2012). Improved yarding and handling procedures have been shown to be effective at reducing stress in sheep (Hemsworth and Coleman, 2011). As a complementary strategy, genetic improvement in temperament could provide a long-term strategy to reduce stress in sheep.

The usefulness of temperament as a trait in a breeding programme depends on heritability, correlations with other traits and the cost and ease of measurement. A range of objective tests have been developed to characterise and measure the expression of temperament as behavioural phenotypes in response to, for example novel objects, isolation and restraint (Dodd et al., 2012) or flight time after release from a weigh crate (Burrow et al., 1988). Stress manifests itself physiologically in an organism through elevated cortisol, amongst other indicators. It has been demonstrated that temperament affects the resulting cortisol levels under stress (Blache and Bickell, 2010; Dimitrov et al., 2012). Behavioural tests offer a non-invasive methodology to phenotype aspects of temperament. One advantage of temperament as a trait is that a single time point record with an arena test or an isolation box test is sufficient to provide an accurate estimate of the phenotypic variance, as judged by the repeatabilities reported for temperament of $r^2 = 0.55 - 0.77$ (Falconer and Mackay, 1996; Murphy et al., 1994). However, behavioural tests have the disadvantage that they can be quite time intensive and are therefore costly and the majority require special equipment, facilities or trained operators.

Temperament, as assessed through behavioural tests, is moderately heritable ($h^2 = 0.10-0.48$) indicating that genetic improvement for temperament is possible (Boissy et al., 2005; Brown et al., 2015a; Gavojdian et al., 2015; Murphy et al., 1994; Plush et al., 2011).

The correlations between temperament and production traits influence the scope for concurrent genetic change in each of the traits. If correlations are favourable and high, genetic gains can be maximised. Temperament traits have been explored as indirect selection criteria to improve maternal behaviour and consequently reproduction traits. Genetic correlations ($r_g$) between temperament traits measured on the ewe and lamb mortality or litter size ranged from low in Merino and Dorper sheep (Gavojdian et al., 2015; Murphy et al., 1994) to moderate ($r_g = 0.39 \pm 0.18$) in Merino sheep (Plush et al., 2011). Plush et al. (2011) concluded that direct selection on maternal behaviour would provide faster genetic gain in litter size compared to selection on temperament. The majority of genetic correlations with production traits, including growth, reproduction and wools traits, were zero or moderately favourable (Brown et al., 2015a; Gavojdian et al., 2015; Plush et al., 2011), which would indicate that production and temperament could be either genetically improved concurrently or in the case of no correlation, could be improved independently.

Currently, commercial breeding programmes do not include temperament traits as selection criteria to improve welfare directly or indirectly. The majority of methods to
phenotype temperament are not straightforward, which might indicate that genomic selection approaches may be more appropriate. Overall, selection for temperament is a feasible strategy to improve welfare in sheep, but direct measures of the actual behaviours such as maternal behaviour, might provide more efficient means for selection programmes.

**Lamb mortality: an existing trait revisited**

Lamb mortality, most of which occurs within the first few days of life, is the largest cause of production losses particularly within extensive sheep production systems (Lane, 2015). World-wide, pre-weaning mortality typically ranges between 10% and 30%, including intensive systems [see reviews by Dwyer (2007) and Hinch and Brien (2014)]. The most common causes of lamb mortality are dystocia, the mismothering-starvation complex, along with exposure and predation, which are generally influenced by ewe age, nutrition and maternal behaviours (Dwyer, 2007), birth type, genotype and environment and management (Hinch and Brien, 2014). Birth type, or more specifically, litter size, is a large contributor to lamb mortality observed in flocks with significant levels of multiple births. On average, lambs from twin or multiple births are more than twice as likely to die pre-weaning as singletons in low input systems (Hinch and Brien, 2014). The relative risk of mortality also increases for lambs born to yearling dams, for multiples born to less ‘maternal’ breeds and in adverse environments (Amer et al., 1999; Bunter and Brown, 2013; Bunter et al., 2015; Conington et al., 2012; Hinch and Brien, 2014). Therefore, earlier age at first lambing, breeding goals or management practices which increase litter size could be expected to result in increased lamb losses unless ewe and lamb management is adapted and lamb mortality is actively selected against. Despite the availability of better management practices, improvements in lamb survival have generally been negligible to date (Lane, 2015).

Genetic improvement of lamb survival would be enormously beneficial for lamb welfare and production outcomes, particularly in low input production systems (Dwyer, 2007). In cattle (Bunter and Johnston, 2014), sheep (Brien et al., 2014; Hatcher et al., 2010; Vanderick et al., 2015) and pigs (Bunter, 2009), there is evidence of at least some genetic variation contributing to offspring mortality outcomes, particularly when evaluated early in life. However, heritability estimates for mortality traits are generally very low ($h^2 < 0.05$), and mortality of offspring are currently influenced by both genetic and non-genetic characteristics of the dam, such as a ewe’s mothering experience (parity), behaviour and lactation performance. Estimates of the maternal genetic effect ($m^2$) for mortality, which determines a ewe’s ability to provide a nurturing environment, are therefore frequently of greater magnitude than direct heritabilities for offspring mortality ($m^2 < 0.10$ and $m^2 > h^2$). Consequently, the most complex genetic evaluation systems evaluate both direct (offspring genes) and maternal (dam genes) genetic influences on mortality/survival outcomes, which require detailed pedigree information. Accurate and complete data on individual mortality outcomes, combined with full pedigree information, result in relatively accurate estimated breeding values for progeny survival, which have subsequently been demonstrated to be
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effective in decreasing mortality in intensive pig production systems (Knap, 2014). This suggests that despite low heritability, scope exists to improve survival outcomes genetically, concurrent to any improvements which may be generated through better nutrition and management, with appropriate data and genetic analysis.

Mortality traits have historically not been directly tackled in national breeding programmes for extensive livestock species, including sheep, due to the difficulty of recording accurate data in the field and also due to a lower priority for implementation, underpinned by the expectation of low accuracies for estimated breeding values. Mortality is a difficult trait to obtain accurate breeding values on selection candidates because it is generally analysed as a binary trait (i.e. alive or dead), is very lowly heritable and is expressed only once by an individual. Therefore, living, young selection candidates can only have low accuracy breeding values. In field data, there are also limitations to accurate evaluation due to incomplete pedigree, often for the informative (dead) offspring (Bunter and Johnston, 2014) and missing mortality phenotypes for unobserved lambs. Accompanying data on other attributes, which could also be used to improve accuracy of estimated breeding values for mortality such as litter size or birth weight, can also be lacking. While sires with many offspring recorded can have more accurate breeding values for mortality, this is only the case if sires of all lambs are known and if observations for mortality remain unbiased (i.e. all progeny of all sires are recorded). In addition, contemporaries are assumed to be essentially compared under a common ‘challenge’ to their survival, whereas specific (unrecorded) events might alter this challenge for subsets of lambs within contemporary groups (e.g. extreme weather events) or over time, thereby reducing accuracy of sire comparisons for mortality. Lack of pedigree is particularly limiting for traits such as mortality because all selected candidates and their parents have the same phenotype for mortality, so differentiation in genetic merit amongst individuals available for breeding comes predominantly from the extended family information. Genetic evaluation systems for sheep, which include mortality as a trait are currently limited to Sheep Improvement Limited (SIL, NZ), the Centre for Genetic Improvement of Livestock (CGIL, Canada) (Schaeffer and Szkotnicki, 2015; Vanderick et al., 2015) and are under development in the United Kingdom (Conington et al., 2012).

An alternative approach to genetic evaluation for the mortality trait itself is to use data for other specific traits, which can be recorded on individual lambs, or their dams, which are genetically correlated with lamb mortality outcomes. Ideally, these traits are also more highly heritable and easily measurable than mortality itself. For example specific lamb traits associated with mortality can include lambing ease, individual birth weights and vigour score (Brien et al., 2014), which are relatively easily recorded on lambs in the field soon after birth. Other traits such as rectal temperature, measures of cold tolerance and various physiological parameters, are more invasive, less practical in the field or require additional specialised laboratory services. To be useful for genetic evaluation purposes, lamb traits need to be recorded on all lambs with full pedigree, which is frequently not the case in large breeding flocks. In addition, lamb traits must typically be evaluated with models that concurrently account for maternal effects, which require maternal pedigree. Genetic tests for allelic variants (e.g. the ADRB3 locus, Forrest et al., 2006) associated with cold tolerance and lamb mortality
can potentially replace difficult to measure, cold tolerance phenotypes, but should be evaluated within different populations.

Considerably, more opportunity exists to record and evaluate maternal traits affecting lamb mortality, because they are expressed more than once by ewes, and can be recorded even when offspring are not pedigreed. Potentially useful maternal traits, which are correlated with lamb or litter survival, include maternal behaviour score (Brown et al., 2015a; Hatcher et al., 2010), the maternal component of lambing ease (Brown, 2007) and possibly teat or udder characteristics, as identified for beef cattle (Bunter and Johnston, 2014). Genetic variation for lamb mortality is only partially exploited for selection when composite or derivative traits such as the number of lambs born or weaned or total litter weight weaned are the traits included in genetic evaluation systems. This is because these traits also include genetic variation due to other traits of ewes and lambs such as fertility or weaning weight. In Australia, the impact of lamb mortality for maternal performance is currently assessed via the ewe trait ‘number of lambs weaned’ (Brown et al., 2007), although a data pipeline is under development to enable genetic evaluation for the contributing component traits (fertility, litter size and lamb survival) in the longer term. Largely due to scarcity of both phenotypes and genotypes in existing populations, genomic breeding values for lamb mortality traits are as yet to be developed in Australia, or elsewhere.

Breeding for breechstrike resistance in Merino sheep

Flystrike is a major disease and welfare risk for the Australian sheep and wool industries. It is caused by the infestation of wrinkled and/or soiled areas on the sheep’s body by the sheep blowfly, Lucilia cuprina, causing infection, ill health and death if left untreated. Blowfly strike has traditionally been effectively mitigated by the painful procedure of mulesing, which entails removal of skin with hand-shears from the perineal region of sheep.

Resistance to blowfly strike in Australian Merinos highlights the challenge for using welfare-related traits in a breeding programme if the trait that needs to be improved cannot be measured. To assess flystrike resistance animals firstly need to get infected or struck. The experimental protocol to achieve this involves no chemical prevention combined with labour intensive monitoring and recording procedures, which for economic and ethical reasons are both undesirable in a farming situation. Because of the limitation to record flystrike directly in a commercial environment, genetic improvement in flystrike resistance is achieved via indirect selection criteria, which might include wrinkle and wool cover around the breech region, and genetic predisposition to dags (faecal soiling around the breech).

In a response to pressure from the international animal welfare lobby on the Australian wool industry to cease the practice of mulesing for breech flystrike control, research into the quantitative genetics of breech strike resistance has been conducted (Greeff et al., 2013; Smith et al., 2009). The project evaluated a suite of traits for their potential as indirect indicators of breech flystrike resistance, and determined the industry best-practice guidelines for incorporation of these traits into Merino breeding programmes (Greeff et al., 2013; Smith et al., 2009).
It has been determined that breech flystrike is moderately heritable ($h^2 = 0.21–0.57$, Greeff et al., 2013; Scholtz et al., 2010; Smith et al., 2009). Possibly, more importantly, the key indicator traits for breech flystrike are more highly heritable than breech flystrike itself, which bodes well for indirect selection. While there were some favourable associations between breech strike indicators and production traits such as body weight with both breech wrinkle and breech cover, there were also some unfavourable correlations between some of the breech traits and key production traits. Specifically, breech wrinkle is unfavourably correlated with both clean fleece weight and fibre diameter: two of the key profit drivers for wool production enterprises (Brown et al., 2010). These unfavourable relationships only pose a problem if the antagonistic correlations are large and not managed through appropriate recording strategies and weighting in a selection index. Nevertheless, it is the estimation of the genetic parameters (heritabilities, phenotypic and genetic correlations) that facilitates the development of balanced breeding programmes enabling genetic gain in all of the traits of interest.

Valuation of welfare-related traits

To develop a value proposition for sheep breeders to consider novel traits in breeding programmes and to integrate these in a selection index, it is necessary to determine the economic value of these traits. The methodology for establishing economic weights for production traits such as growth is well developed and can be derived using profit equations (Brascamp et al., 1985; Goddard, 1998). This method is based on prices and costs in the market, and is consumer driven. For welfare-related traits this approach is inadequate, because consumer attitude to welfare is not directly reflected in the costs of production or returns from the sale of animals or their products. Therefore, economic values are not readily available from the current market. This renders the classical methodology inadequate for the valuation of traits with social and ethical values. Hence, the challenge is to value such intangibles as animal welfare in monetary terms. The objective of this section is to consider characteristics and valuation of sheep welfare traits in breeding goals by outlining approaches that have been used for other species.

In economic terms, animal welfare as a characteristic of livestock production can be considered as public good as defined by Randall (1987) (McInerney, 2004; Nielsen et al., 2011), and is a characteristic of animal products, which is not or only partly traded and valued in the market today and usually cannot be valued in the future. Hence, market prices that fully reflect the economic value that people place on animal welfare are not available.

In order to put a market value on such traits, Randall (1987) suggested enforcing approaches such as labelling and marketing lamb products that have been produced with better welfare standards to capture the higher market price that people are willing to pay.

Several studies have reported that consumers are willing to pay for higher animal welfare (Bennett and Thompson, 2011; Bennett et al., 2011; Grimsrud et al., 2013). Organic lamb and Freedom Food meat are examples of such eco-labelled animal products. Animal welfare, as well as environmental and social benefits, is principal elements for certifying organic products. ‘Freedom Food’ is another international label with stricter animal welfare production criteria than the standard criteria of animal
farming. The market values of the characteristics of such eco-labelled products, given the present sociological and political situation, can then be obtained by market studies. Therefore, we can elicit consumers’ willingness to pay for improvement in animal welfare through market experiments. These market (use) values can be regarded as a minimum economic value of the welfare or environmental characteristics of the product or service. Possible non-market (non-use) values will add to these market values. The implementation of a welfare-breeding programme for outdoor pig production was studied (Gourdine et al., 2010) and demonstrated that emphasis on welfare traits reduced genetic progress in production traits and consequentially, market gains were 34% lower. It was concluded that only a higher price from labelling as ‘animal friendly’ or additional non-market value of welfare traits would incur increased profit for the livestock producer.

Although consumers are willing to pay for improvements in animal welfare through redirecting their product purchases, Kjørstad (2005) found that in Sweden, the Netherlands, United Kingdom and Norway most people believe the primary responsibility for welfare standards in livestock production sits with the government and secondly, with the producers and the retailers. This finding indicates that consumers may subscribe to a duty-based set of ethical norms and it follows logically that laws, rules and regulations should govern the industry. This may have further implications to address the relevant traits in breeding programmes and livestock production. Furthermore, consumers have little knowledge about animal production and breeding (Ellingsen et al., 2015; Grimsrud et al., 2013; Ouédraogo, 2003). Hence, they are seldom able to value differences in animal welfare in different production systems and animal breeding programmes. This may be one of the explanations of the discrepancy between attitudes and concerns between animal welfare, on the one hand and buying practices, on the other.

This demonstrates that market prices of labelled and animal friendly products do not reflect the total economic value people place on animal welfare. The question is whether the public or consumers are willing to cover the costs of stricter regulations on animal welfare. A shift in the political situation can, however, make tax financed or subsidised breeding programmes emphasising animal welfare profitable. Grimsrud et al. (2013) reported a significant willingness to pay extra tax among Norwegian citizens for supporting breeding programmes to improve welfare of farmed salmon. This may make a basis for a non-market value of animal welfare and hence justify a higher total weight in the breeding goal without a change in market price of the product.

To estimate the total value people place on animal welfare, we need both market studies and other approaches surveying people’s attitudes and willingness to support breeding initiatives for improved animal welfare. For a breeding objective with several traits affecting animal welfare, we also need to specify the possible non-market value for each trait. Olesen et al. (2000) suggested weighing each trait by both non-market and market economic value in order to arrive at a breeding objective for sustainable animal production. Several methods can be considered for deriving non-market values of traits in animal breeding objectives.

Methods may be based on individual preferences (stated and revealed preference methods), opportunity costs principle (restoration costs), decision makers and
politicians revealed preferences (implicit pricing) or experts’ preferences, in addition to methods based on desired gains or restricted selection indices (Nielsen et al., 2005, 2006; Olesen et al., 1999). Contingent valuation has become a popular method for valuing non-market goods such as environmental goods. It can measure all parts of the total economic value, including future and/or hypothetical changes. The method is based on surveys of people’s willingness to pay for a certain improvement of a service or willingness to accept compensation for a certain reduction in a service. In stated choice experiments, respondents are asked to choose between different products with different characteristics and prices, or to rank several products according to their preferences. Lately, a new type of experimental markets using posted prices has been used for eliciting willingness to pay for private, as well as public goods.

Nielsen et al. (2005, 2006) presented two other approaches for deriving non-market values for functional traits in dairy cattle (e.g. mastitis and still birth) using deterministic simulation and selection index theory. The first method applied restricted indices or desired gain approach. In the second method, the non-market values were based on how much loss in selection response in milk yield could be accepted to improve functional traits in dairy cattle. The authors concluded that the two methods could be used to derive non-market values for functional traits in dairy cattle.

Nielsen et al. (2011) summarised the following approach for defining the value of animal welfare traits for inclusion in the breeding objective:

1. Use profit equations to derive market values.
2. Define traits in the breeding objective related to animal welfare.
3. Use stated preference techniques to obtain non-current values or future market values from, for example labelled products, and for obtaining economic value for specific welfare traits with non-market value. Real choice experiments can be applied for products that may be marketed, whereas stated choice experiments and contingent valuation studies may be applied to economic value.
4. Sessions with focus groups should be held to obtain knowledge about consumer and/or citizen knowledge about animal welfare and breeding, and proper questions for the surveys and possible experiments should then be formulated.
5. Market, non-market and total selection response should be predicted for the traits in the breeding goal.
6. Methods based on selection index theory should be applied to determine trade-offs in production traits versus traits related to animal welfare.
7. Finally, the results should be discussed with stakeholders (e.g. farmers, NGOs and animal welfare authorities) in animal breeding and food production. The option of adjustments of the applied breeding goal after stakeholder consultations should be applicable.

Breeding strategies to improve welfare in sheep

Breeding strategies optimise the use of available technologies for the purpose of selection and mating. The focus, in the context of this chapter, is on strategies for selection. Selection can be based on phenotypic information only (mass selection), on genetic merit through estimated or genomic breeding values or on a specific genetic marker
profile, mostly based on single-nucleotide polymorphisms (SNP) or a variant of a gene itself that is linked to a desirable trait expression or which represents an actual gene (marker or gene assisted selection). In most cases, different tools are combined to form the most comprehensive selection strategy. In the following, breeding strategies are described and illustrated with examples where selective breeding has contributed to the advancement of sheep welfare.

**Mass selection**

Although it may seem counter intuitive, mass selection is a form of individual selection, referring to the selection of animals entirely on their own phenotype for a specific characteristic. As phenotypic selection incorporates selection on desirable genotypes, the overall effect of mass selection is, like selection on genetic gain, incremental in the population with each successive generation. However, the rate of progress is often slower because the genetic and environmental effects cannot be separated and therefore selection is less accurate.

Mass selection can be conducted on a single trait of interest, or concurrently on a suite of traits, and can be performed alongside index selection if the appropriate information exists. For example in a stud breeding system, the breeder might be able to use index selection for production traits, and apply mass selection for those traits without estimated breeding values. In the case of welfare traits, these might include resistance to a specific disease or parasite, or a set of conformation characteristics that impact on longevity and ability to thrive in a given environment. This procedure can work equally for quantitative traits that approximate a normal distribution in the population, or for binomial or ‘all-or-nothing’ type traits such as conformation characteristics.

Mass selection is an appropriate and an effective method for traits with at least moderate heritability for use in sheep flocks where there may be hundreds, or even thousands of animals in the population. This method is commonly applied under two circumstances. Firstly, mass selection can be applied in commercial flocks where a producer aims to change the incidence of a particular characteristic yet the information required for selection on genetic merit is not available due to a lack of the necessary data to estimate breeding values.

The second circumstance under which mass selection might be applied is where it may be desirable to exclude animals that exhibit a particular characteristic, yet there is insufficient information on the genetic parameters for that trait, for example phenotypic and genetic variances, correlations and heritability estimates, which are essential to form a selection index. This situation is equally applicable in both stud and commercial flocks. Conformation characteristics that can affect longevity and ability to thrive fall into this category. These include under- or overshot jaw affecting the ability to feed, leg and feet structure, affecting the ability to walk long distances, back and shoulder conformation, which can predispose to fleece rot and body flystrike, and face cover where animals with a high degree of wool growth on their face can become ‘wool-blind’ which affects their ability to survive in an extensive environment. Mass selection alongside selection on breeding values for production traits is often
necessary in a stud situation, but less than ideal because, genetic gains for production traits are most likely somewhat compromised.

Selection against fleece rot is an example of the application of mass selection and demonstrates the shortcomings of this method. Fleece rot is an important disease trait in its own right, and a predisposing factor to fly strike in some Australian Merino populations and environments (Norris et al., 2008). Each year in the process of selecting replacement young ewes for a breeding flock, those that exhibit fleece rot would simply be excluded. However, expression across years is highly environment dependent due to varying local climatic conditions, which affects the amount of variation that can be observed in fleece rot within a population and selection choices are inadvertently affected.

Mass selection, based on phenotype only, is not as effective as selection on genetic merit because of inconsistent phenotypic expression and the inability to distinguish between the environmental and genetic component of the trait expression. However, in relation to welfare traits, mass selection is often the only possible approach and some selective pressure will certainly affect traits favourably in the long term.

**Selection on estimated breeding values**

Selection on genetic merit using estimated breeding values is more accurate, particularly for lowly heritable or sex-limited traits, and enables faster genetic gain than mass selection using phenotypes. The estimated breeding value encompasses not just the phenotypic information of the individual, but also information from relatives. Adjustments can be made for other factors that contribute to phenotypic expression such as birth-rearing type (single or twin), age of the dam, sex and any management group effects. This also enables accurate selection based on estimated breeding values across generations.

In some cases of selective breeding, the breeding objective is not achieved by selection directly on the trait of interest, but rather, an indirect selection criterion, as outlined earlier in the example of breeding for flystrike resistance. Candidate traits for indirect selection are those breeding objective traits that are difficult to measure, sex-limited or not consistently expressed in the population at all times. There are several important requirements of indirect selection criteria. Firstly, the indirect trait must be heritable and genetically correlated with the breeding objective trait. Secondly, the indirect selection criterion must exhibit reasonable phenotypic variation in the population to enable separation of the superior and lesser animals. Finally, it is helpful if the selection criterion can be quickly, easily and cheaply measured or assessed on a large number of animals.

There are many examples from around the world demonstrating genetic variation and the potential for selective breeding for disease resistance to a wide range of endoparasites, ectoparasites and bacteria (Gray et al., 1995). However, there are few examples in sheep of across-flock estimated breeding values for disease resistance to specific diseases and formal inclusion in breeding objectives and multi-trait selection indices. Breeding for disease resistance has been pursued most vigorously for those diseases that are a consistent and persistent problem, and that have eluded vaccine development.
Genomic approaches to improve welfare traits in sheep

Genomic selection

Genomic selection, as proposed by (Meuwissen et al., 2001), incorporates genetic markers such as SNP (a single change in the genetic sequence of animals, SNP), into breeding programmes. The backbone of a successful genomic selection strategy is a reference population, which consists of animals measured for the phenotypic trait of interest and genotype for thousands of SNP. This reference population is then used to estimate effects at all SNP [using various methods (de los Campos et al., 2013)] and for all traits measured. The estimated SNP effects can then be used to predict the genomic breeding values for (young) animals that have not been measured for the phenotypic trait.

A key measure of the usefulness of genomic prediction is the accuracy with which the genetic merit or phenotype can be predicted using markers. High prediction accuracy is achieved easier in traits of high heritability, when reference populations are larger, and when populations are less genetically diverse (Daetwyler et al., 2008; Goddard, 2009). It is also important that selection candidates are genetically connected or related to the reference population (Habier et al., 2007, 2010).

While principally all traits can benefit from the use of genomic breeding values, those which are difficult or expensive to measure (e.g. disease and behavioural traits), expressed later in life or are sex-limited (e.g. ewe reproduction), or are of low heritability (e.g. survival) may be especially attractive candidates for genomic selection (van der Werf, 2009; van der Werf et al., 2010). The combination of genomic selection with reproductive technologies such as juvenile in vitro embryo transfer, offers additional opportunities for genetic gain (Granleese et al., 2015).

Welfare traits with moderate heritability that are already routinely measured in research and industry flocks, for example breech wrinkle, have been predicted with moderate accuracy of 0.4 in Merino sheep (Daetwyler et al., 2010), allowing breeders to select less wrinkled sheep using genomic breeding values that will have reduced incidence of flystrike. Traits that are routinely measured and are of moderate heritability will achieve good genomic predictions with moderate sized reference populations (<10,000 animals). Traits with low heritability such as parasite resistance (Brown et al., 2015b; Kemper et al., 2010), foot rot (Nieuwhof et al., 2008), mastitis infections (Duchemin et al., 2012; Riggio et al., 2010) and ewe reproduction (Safari et al., 2005), will continue to be challenging in the genomic era, because very large reference populations (thousands of animals) are needed to achieve genomic breeding values that are predictive of genetic merit. Building large reference populations for genomic selection requires genotyping of potentially several thousand sheep for thousands of SNP, which makes genotyping costs a crucial component in the success or failure of such strategies. However, genotyping costs continue to decline due to new advances in sequencing technologies (Elshire et al., 2011). Furthermore, low-density genotypes of approximately 12,000 SNP are cost effective. Low-density genotypes can be amended with the ‘missing’ SNP genotypes to obtain comprehensive high-density genotypes (e.g. 50,000 SNP) through computational methods that allow the inference of the unobserved genotypes, also called imputation (Bolormaa
et al., 2015). Lower genotyping cost will spur greater application of genomic selection in breeder flocks, which, in turn, will increase the size of reference populations for genomic selection.

Difficult or expensive to measure traits with moderate to high heritabilities such as temperament and feed conversion efficiency, are especially good candidates because moderate reference sizes will be able to achieve useful predictions of genetic merit. In these traits, the best models to build reference populations are likely to combine data from several research or co-operator flocks (Gonzalez-Recio et al., 2014; Pryce et al., 2014). This would allow for genomic breeding values to be predicted for industry, provided that these research flocks are well connected to industry flocks. However, even in a reference population scenario the capture of lowly heritable or expensive to measure traits remains still too costly to obtain sufficient animal numbers for adequate prediction accuracy and are unlikely to be good candidates. Currently in the United Kingdom and France, new research is centred on the identification of, and selection for more resistant Texel sheep and dairy goats to mastitis, incorporating the use of genomic selection for these traits into new breeding programmes. Nevertheless, it may be possible to improve these traits by finding correlated traits that are more heritable. For example in dairy cattle, mid-infrared spectra of milk are correlated with subclinical ketosis (Vanlierde et al., 2015). Similar novel traits could be discovered in sheep to aid genetic improvement of sheep health and welfare traits. In summary, there are exciting opportunities for the genetic improvement of sheep using genomic selection, but it is important to evaluate its merits on a trait-by-trait basis.

**Marker/gene assisted selection**

Molecular markers have enabled the discovery of quantitative trait loci (QTL), mutation-causing variation in phenotypes. If the actual causal mutation can be identified, gene assisted selection (GAS) can be implemented to choose selection candidates based on the favourable variant or if there is no knowledge on the location of the QTL, on non-functional genetic markers that are linked to the QTL, called marker assisted selection (MAS) (Andersson, 2001; Dekkers and Hospital, 2002). Despite a lot of promise, few QTL have been detected that could successfully be implemented in sheep breeding programmes, due to complicated inheritance pathways or undesirable effect sizes (Dekkers, 2004). Direct selection on the causative gene through GAS is favourable to selection on linked markers in a MAS approach. However, GAS has only been used as independent culling tools for welfare related traits such as health and disease traits (Baylis and Goldmann, 2004; Cockett et al., 1999; Zhao et al., 2011).

The most widespread focus on GAS has been the European effort to eliminate susceptible genotypes for scrapie in sheep (European Union, 2003). Scrapie is a neurodegenerative disease. Affected animals display in co-ordination, trembling and social modification amongst other symptoms resulting in eventual death with an annual mortality rate of 3%–5%. Scrapie is believed to be a prion disease and infected animals
carry it for life. It is transmitted through contact and can be passed on to other animal species and humans, which has raised the urgency of eradication of the disease (The Center for Food Security and Public Health, 2007). Genetic differences in the levels of susceptibility to scrapie in sheep are based on variants at three sites of the PrP gene, producing five different alleles of the PrP gene (Baylis and Goldmann, 2004). Based on a gene test, animals with the favourable genotype can be selected and the frequency of resistant genotypes increased in sheep populations. To date, substantial progress has been made but the goal of eradication has not yet been fully achieved (European Food Safety Authority, 2014; Melchior et al., 2010).

Chondrodysplasia is also a genetic disorder that has been able to be addressed through selection based on a genetic test. Chondrodysplasia in sheep affects cartilage development and is characterised by skeletal deformation of the front legs and dwarfism in lambs. The disorder has been prevalent in British meat sheep breeds such as Hampshire, Texel and Suffolk sheep (Beever et al., 2006; Cockett et al., 1999; Zhao et al., 2011). In Suffolk sheep, the disorder, also called ‘spider lamb syndrome’ due to the spider-like legs, has been mapped to chromosome 6 (Cockett et al., 1999) and has been identified to be a single-base change in the fibroblast growth receptor 3 gene (Beever et al., 2006). These findings have led to the development of a genetic test that enables the identification of animals with the unfavourable mutation. Despite the similarity in symptoms, chondrodysplasia in Texel has been mapped to a different gene on chromosome 4 (Zhao et al., 2011), which makes the genetic test for chondrodysplasia in Suffolk and Hampshire ineffective for the Texel breed. This characteristic highlights the need to validate the underlying mutations of gene tests for GAS across breeds.

An example of MAS is the test for polledness or hornlessness in the Australian Merino sheep. The genetic test provides an opportunity to address the welfare issues associated with horns in Merino sheep, in particular, in rams. The partial removal of horns in mature rams can be required if their shape or size causes rams to get caught up in commercial raceways. Removal might also be required if horns grow close to the jaw, which can prevent the jaw from moving freely, restricting food intake. It can also cause issues with crutching around the face, which increases the risk of fly strike around the horns. Removal of horns in mature animals is stressful, painful and carries risks of infection, injury and even death if not done correctly. The gene for polledness has been mapped for a range of breeds to ovine chromosome 10 (Dominik et al., 2011; Montgomery et al., 1996; Pickering et al., 2009). The Australian Sheep-CRC has developed a test based on SNP linked to the polled locus that enables selection strategies for genetically hornless Merino sheep (van der Werf, 2012). Barriers to adoption might include cost. Therefore, it is important to provide effective selection strategies so that information from the test is used successfully by industry (van der Werf, 2012).

MAS has also been an approach to address footrot. Footrot is a serious disease, which impacts directly on animal welfare and survival, as well as on productivity and costs of production worldwide (Greer, 2005; Nieuwhof and Bishop, 2005; Sackett et al., 2006). Control strategies include management (movement restrictions and veterinary treatment), immunisation (Raadsma and Dhungyel, 2013) and also selection
for resistance to footrot. Breed and flock differences (Emert et al., 1984) and within flock variation in susceptibility to footrot have both been reported (see review by Raadsma and Dhungyel, 2013). Moreover, the footrot phenotype assessed using appropriate lesion scoring under informative natural or artificial challenges with virulent strains of Dichelobacter nodosus (D. nodosus) is generally considered to be a low to moderately heritable trait (0.15–0.25), depending on the challenge conditions, breed and scoring systems used (Raadsma and Dhungyel, 2013).

Selection to improve resistance in traditional structured breeding programmes can offer a long-term solution for reducing footrot incidence, in populations and environments where this is possible. Skerman and Moorhouse (1987) reported a substantial reduction in disease incidence following selection on response to artificial challenge in a New Zealand Corriedale population, demonstrating utility of recording for selection under a consistent challenge. However, in contrast to circumstances in New Zealand, footrot is a notifiable disease in Australia, which restricts both livestock movements and sales (Glynn, 2003). Therefore, ram breeding studs typically retain a footrot-free status and have limited capacity to select against footrot from challenge scenarios in an industry-wide setting. Legislative that restricts animal movement makes it difficult to obtain phenotypes directly on selection candidates and are a strong motivator to develop genomically assisted selection strategies for footrot. The same restrictions also limit sale of breeding stock directly from populations deliberately challenged with footrot. However, genomically enhanced breeding values could become available if reference populations are challenged with footrot and genomic predictions developed. Genomic tools are also desirable in the context of a typically variable natural challenge with D. nodosus, which can limit utility of industry data for traditional genetic evaluation systems based solely on pedigree and phenotypic data.

A specific genomic test developed in New Zealand for Merino and other sheep breeds (Escayg et al., 1997; Hickford et al., 2004) based on the DQA2 gene marker in the major histocompatibility complex (MHC) of genes is currently used to identify sires whose progeny will be more resistant to footrot. Selection of more resistant rams based on this test has generally seen a reduction in footrot incidence in participating New Zealand flocks and this test remains well supported (Greer, 2005). However, the test does not have the same level of association with footrot across all populations (Conington et al., 2008c; Ferguson, personal communication, 2016) suggesting alternative genomic tests are required. Genomic reference populations have subsequently been created for Texel sheep (Mucha et al., 2015) and New Zealand Merino sheep (Ferguson et al., 2013). With appropriate validation strategies and well-defined phenotypes (Ioannidis et al., 2009), genomic information can be potentially used to identify additional causal variants associated with footrot through genome-wide association studies. With appropriate reference populations, genomic information can also be used to generate genomic breeding values for non-phenotyped industry sires from both breeding and commercial flocks, using prediction equations, or through genomic relationships (Hayes and Goddard, 2010). Strategies based on pooled progeny DNA and sire genotyping, as illustrated by Bell et al. (2014), could also be of value to estimate sire performance for difficult to measure, commercially important traits such as footrot, but requires further investigation.
Conclusions

Genetic approaches have been successfully applied to improve sheep welfare. The majority of the success stories have been based on gene or gene marker tests, but unless the underlying mutation can be eliminated from the population, such tests can become ineffective because of the constant recombination of the genome. If acceptable to the public, gene editing could replace very effectively the tests that operate at the level of the actual mutation. The main challenge for genetic solutions of complex welfare traits such as behaviour, resistance to disease or lamb mortality, is the currently limited capability to measure accurately the relevant phenotypes. Novel phenomic technologies will address this limitation and open opportunities to improve welfare related traits through selective breeding using a combination of classical and genomic approaches.

References


Reproductive management
(including impacts of prenatal stress on offspring development)

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Introduction

A successful pregnancy and the production of viable offspring, accompanied by the onset of lactation, are crucial to the economic performance of sheep farms, whether the main production purpose is meat, milk or wool. Thus management of reproduction, from conception, through pregnancy, birth and lactation, is an important part of sheep farming. Welfare interacts with this in two main ways: first, reproductive output can serve as a barometer for the underlying welfare state of the flock as poor reproductive efficiency accompanies poor welfare, and second, actions taken to manage pregnant and lactating ewes can impact on welfare. These twin interactions of sheep welfare with efficient reproduction will be the focus of this chapter.

In evolutionary terms, ewes invest heavily in their offspring. Only one or two lambs are produced each year (three or four with very prolific breeds), and they are relatively expensive for the mother to raise until weaning. For example, the litter can weigh more than 10% of the mother’s own body weight at birth (in comparison to only 3%–4% in human pregnancies), and ewes may achieve the equivalent of her own body weight in lamb growth by weaning. Due to this high cost, the ‘decision’ to breed or not each year (since in temperate regions ewes will only breed once a year), will depend on maternal condition and whether the environmental conditions are likely to lead to a successful outcome. Physiologically, the ewe is responsive to these conditions with ovulation rate, and thus the potential number of lambs ewes will raise per year, is sensitive to pre-conception nutrition. Psychological stress can also cause at least a temporary cessation in ovulation and reproductive behaviours. Under conditions of poor welfare, where nutrition may be variable or low, or environmental stress may be high, it might be better for the ewe to delay breeding until conditions improve. Thus poor welfare can lead to a lower-pregnancy rate, or perhaps higher stillbirth or neonatal mortality, than might be expected with good welfare.

Modern sheep breeds have been selected for increased litter size and increased productivity traits in the offspring such as larger birth weight and faster growth. The production system may also require ewes to be housed for parts of their reproductive cycle, especially around lambing, and this can be a cause of social stress or poor welfare. Handling, transport, shearing, relocation, exposure to novelty and social mixing are all relatively common events in the management of sheep pregnancy and these can
impact negatively upon the mother, and may also have an impact on her developing foetus. In this chapter, the evidence for welfare costs of these events in pregnancy will be considered, and whether management can be improved to reduce or eliminate the negative consequences of pregnancy management.

Mortality is an unambiguous indicator of poor welfare, and is also an important cost to production. The risks for mortality are higher in the newborn animal than at any other time in its life, and parturition also carries significant risks for the mother. This chapter will also discuss the issues and potential solutions to mitigate high rates of lamb and ewe mortality.

Conception

For the majority of sheep production, systems are based on grazing and rely on natural mating. Ewes may be first synchronised in oestrus by the use of progesterone-containing vaginal sponges, or by the presence of males (the ‘ram effect’; Hawken and Martin, 2012), to ensure a short or compact lambing period. A compact lambing allows specialist care for obstetrical problems, or difficulties in neonatal adjustment, to be provided more readily or economically. In temperate regions, mating takes place in the autumn when ewes will generally be in the best condition following summer grazing, and lambs will be then born in the spring time when forage availability is high to meet the energetic demands of lactation. These systems make use of the natural cycles and behaviour of sheep and are unlikely to impose a significant welfare cost to the animals, although in wild sheep, competition between males for access and female mate choice is also a part of natural reproductive behaviour. In multi-sire mating systems, it is likely that these behaviours also occurs in domestic sheep since some rams will mate with many more ewes than would be expected by chance alone, and there is no relationship between mating success and pre-mating assessment of breeding ‘soundness’ (Alexander et al., 2012). Differences in ram success, therefore, are probably related to behavioural interactions between rams, and between rams and ewes.

Mating behaviour and welfare

Mating and sexual activity in sheep are controlled by the oestrous cycles of the ewe. Males are sexually active throughout the breeding season, and for some breeds throughout the year, thus it is the oestrus behaviour of the ewe that controls mating and conception. For both sexes, sexual behaviour and fertility is under the control of the hypothalamic–pituitary–gonadal axis. The hypothalamus, in the brain, releases a hormone (gonadotrophin-releasing hormone), which regulates the release of luteinising hormone and follicle stimulating hormone from the pituitary gland, which in turn regulates the production of the sex steroids (testosterone in males, oestrogen and progesterone in females). During the breeding season, the ewe exhibits regular (every 17 days) cycles of oestrus accompanied by behavioural changes described as
attractiveness (her ability to attract the attention of the male), proceptivity (seeking and being attentive to rams) and receptivity (acceptance of mating; Beach, 1976). Sexually mature rams will detect, court and mate ewes in oestrus, using specific behavioural patterns in response to ewe receptivity, with the intensity of these behaviours related to the concentrations of circulating testosterone.

The hormonal cascades that govern the mating behaviours of ewes and rams are sensitive to external influences. Photoperiod, nutrition, stress, social signals and climatic variables will all interact with the hormonal control of sexual behaviour (Blache et al., 2003; Dobson et al., 2012). In ewes, common farm management practices, such as transportation, shearing, social isolation, rough handling by dogs, handling by strangers, as well as experimental manipulations such as injection with endotoxins (to mimic infectious disease) or cortisol (to simulate psychological stress) can all interfere with the signalling between gonadotrophin-releasing hormone and luteinising hormone (Dobson et al., 2012) and hence with the release of a mature oocyte. Ewes under stress also show an inhibition of oestrus behaviour, which may reduce the ability of rams to detect and court stressed females. The practical outcome of this is a delay or reduction in fertility and lamb production. Rather less is known about the effect of external factors on ram reproductive responses. High temperatures are known to have a detrimental impact on sperm structure and motility, and are also likely to affect interactions between ewes and rams as both sexes seek shade during high temperatures. Undernutrition is reported to reduce circulating testosterone and sexual behaviour in rams (Kumar et al., 2015). In addition, stress associated with mixing unfamiliar animals together also causes a reduction in testosterone accompanied by increases in plasma cortisol (Lacuesta and Ungerfeld, 2012). Health issues such as lameness, in either sex, will also reduce the ability and willingness of sheep to seek out sexual partners and mate. Thus poor fertility can act as a marker for poor welfare, since stress, from many causes, will impair the physiological and behavioural mechanisms underlying conception in both males and females.

**Artificial manipulation of conception and fertility**

Although natural mating is generally the norm in sheep production, forms of assisted reproduction [artificial insemination (AI), embryo transfer etc.] are used, albeit at a lower rate than with cattle and pigs. Anatomically the cervix of the ewe is relatively long and convoluted, meaning that trans-vaginal insemination has very limited success. Attempts to soften the cervix pharmacologically to improve conception rates have tended to be associated with tissue damage and are not routinely carried out. As better conception is obtained by the laparoscopic route, generally following sedation, inversion and local anaesthesia, this tends to be the most common AI method in sheep. In some countries, this may only be carried out by a veterinary surgeon, which may also limit the level of use of this technique. The welfare implications of these procedures have not been formally assessed. However, all surgical procedures carry some risk of pain and infection, and sheep are known to find inversion highly unpleasant (Rushen, 1996), thus the welfare costs to sheep of this method will be significantly greater than natural mating.
Better success with AI has been achieved using fresh semen, which can be obtained by training a ram to serve an oestrus ewe standing in stocks, and diverting the penis into an artificial vagina attached to a collection tube, or by use of electroejaculation. Electroejaculation has been shown to cause increased heart and respiratory rates, increased vocalisations and increased plasma cortisol, and reduced testosterone in rams (Damian and Ungerfeld, 2011).

Embryo transfer may be used by sheep breeders to bring new genetic lines or breeds where importation of live animals is prohibited, or as part of accelerated breeding programmes. As with AI these procedures require the laparoscopic collection and transfer of embryos between donor and recipient ewes, and thus carry similar welfare costs as AI. In addition, in vitro-derived embryos may be subjected to developmental anomalies, leading to large offspring syndrome where excessive growth in the foetus occurs. This may lead to difficulties in parturition (see section ‘Birth and Dystocia’ later) and offspring mortality.

Accelerated lambing systems, where the ewe produces more than one litter per year, are sometimes practiced in tropical regions or using breeds of sheep which do not display pronounced seasonal anoestrus. The advantage of these systems is an increase in reproductive efficiency, but systems often require sensitive nutritional management and manipulation of ewe fertility and lamb removal to cause the ewe to come into oestrus. Generally, this can only be achieved under fairly intensive management which may not be pasture-based (see section ‘Housing’ later). These systems have also been reported to be associated with high lamb mortality (Goff et al., 2014).

**Pregnancy management**

In pastoral systems, ewes will spend most or all of their pregnancy at pasture. However, increasing intensification or use of highly selected genotypes means that greater attention is given to ewe nutrition, and animals may be housed and shorn during pregnancy. The welfare impacts of these management actions will be considered here.

**Nutritional management**

Nutritional management of sheep is covered in Chapter 8; this section will focus only on the welfare implications of nutritional management of ewes in pregnancy. The main welfare consequences relate to when mothers are fed too little or too much in pregnancy and when nutritional imbalances occur. Undernutrition, either chronic or acute, is one of the most common risks during ovine pregnancies. In early pregnancy, the additional nutritional demands over maintenance are negligible, however, once the placenta is established and foetal growth accelerates towards the end of pregnancy then the requirements for good nutrition rise significantly. Lactation is also an energetically expensive period when the ewe needs to meet the high metabolic demands of milk production.
Undernutrition will result in the ewe needing to mobilise her own body reserves (fat and then protein with severe undernutrition) to meet the requirements of sustaining pregnancy. In late gestation, thin ewes are at the risk of metabolic disease (ketosis/pregnancy toxaemia or ‘twin lamb disease’), when they mobilise their own body reserves at such a high rate that high levels of ketones are produced from the liver. This is thought to be associated with pain, as the ewe is being poisoned, and is often fatal, even with prompt treatment, because of the tissue damage and appetite suppression caused by excessive ketones. Ewe undernutrition, particularly in the last third of pregnancy, is also associated with increased perinatal lamb mortality, due to reduced lamb birth weight, reduced expression of maternal behaviour (Dwyer et al., 2003) and impacts on the quantity and quality of colostrum and milk.

Over-nutrition, or ewe fatness, can also have negative consequences for reproduction and ewe welfare. As with underfeeding, over feeding can also cause metabolic problems in late pregnancy, and may result in high birth weight lambs, which is a predisposing factor to dystocia (see section ‘Birth and Dystocia’). In young adolescent ewes, where the mother is still growing herself, over-nutrition can, paradoxically, cause very low birth weight lambs. Metabolic rules prioritise maternal growth in a nutrient rich environment in young sheep at the expense of partitioning nutrients to the developing placenta. Placental growth is severely restricted and this prevents normal foetal growth in late gestation (Wallace et al., 1999). From a welfare perspective, however, both very heavy and very light lambs are at an increased risk of mortality, thus over-nutrition of the ewe, regardless of her age, is likely to lead to increased lamb mortality.

Malnutrition, where the diet is deficient in specific micronutrients (trace elements and vitamins) has an impact on pregnancy or lamb outcomes, particularly deficiencies in cobalt, copper, iodine, iron, manganese, selenium and zinc (Rooke et al., 2008). Cobalt deficiency is associated with low appetite in ewes (probably leading to low milk production), poor neonatal vigour and health in lambs, and high lamb mortality. Iodine deficiency is related to poorer survival, possibly due to an impaired ability to maintain body temperature. Low selenium is associated with myopathy (or muscular disorders) and has also been related to lamb weakness and poor weight gain. Vitamin E supplementation may increase lamb survival, via increased birth weight, vigour and immune status at birth. However, some of these trace elements (e.g. copper) are toxic at high doses, and although correcting deficiencies have beneficial impacts on ewe and lamb welfare, levels in excess of requirements do not seem to bring additional benefits (Rooke et al., 2008).

Poly-unsaturated fatty acids are important in development as they are required at high levels in developing neural tissues. Although they do not appear to be present in high amounts in natural sheep diets, there is evidence that feeding artificial diets containing high levels of long chain n-3 fatty acids, such as docosahexaenoic acid found in fish oils, boosts lamb vigour (e.g. increases the speed with which lambs stand and suck after delivery), and may improve thermoregulatory abilities through its effects on brown fat production (Rooke et al., 2008), although it may also have negative impacts on milk production.
Housing

In comparison to other livestock species remarkably little is known about the welfare implications of different forms of housing management for pregnant ewes. Some information on bedding preferences, and ventilation requirements can be extrapolated from studies on finishing lambs or lactating dairy ewes, and recent studies have investigated the space requirements of pregnant ewes. Pregnant ewes housed at 1 m² per ewe showed an increase in restlessness and social behaviours, particularly negative social behaviours, perhaps as a consequence of displacements from feeders and preferred lying areas, compared to ewes with 2 or 3 m² per ewe (Averos et al., 2014). Space restriction is also associated with less lying behaviour, more displacements and reduced lying synchrony in pregnant sheep (Bøe et al., 2005), and reduced milk yield and increased somatic cell count in dairy sheep (Caroprese et al., 2009). Studies of lactating ewes, with lambs at foot, suggest that ewes show physiological indicators of stress when housed at high stocking density (Lv et al., 2015).

Unshorn pregnant ewes do not appear to exhibit a marked preference for different flooring types (in studies comparing wood, straw, rubber mats and expanded metal floors; Faerevik et al., 2005), although shorn ewes preferred softer flooring with better thermal insulating properties. In finishing lambs, however, lack of bedding was associated with an increase in stereotypy and physiological indicators of stress (increased cortisol). Parturient ewes display birth-site selection and display ‘pawing’ behaviours at the onset of labour which may be related to preparing a suitable birth environment. Whether parturient ewes have specific requirements or preferences for bedding has not been investigated. Newborn lambs are more susceptible to hypothermia than ewes and will require a more protective environment, such as the insulated flooring provided by straw, to help them regulate their body temperature more readily. Thus softer floors, with better insulating properties, such as those provided by straw, are preferable particularly during the perinatal period or if ewes have been shorn.

Sheep are sensitive to poor or inadequate ventilation, particularly if housed in hotter temperatures, with low ventilation rates associated with increased plasma cortisol, and reduced milk yield and feed efficiency. This is related not only with the effects of heat stress, but also the amount of ammonia, micro-organisms and dust particles to which the sheep will be exposed. In general, a good level of ventilation is required by sheep in all conditions. In hotter temperatures, if ewes are still housed, then particular care is needed to ensure ewes do not suffer from heat stress, which will also impact on their lambs due to the reduced milk production, or productivity of dairy sheep.

Feeding of housed ewes may also be a source of competition and social stress between ewes. The arrival of a relatively small volume of highly palatable food (concentrate feed) once or twice a day can cause aggression, displacements and fighting at the feed troughs. Subordinate animals may not compete effectively for food and may become undernourished even if food is available. The disruption and arousal associated with food arrival, particularly if this is not very predictable, may be a source of chronic stress in housed ewes. Use of a total mixed ration (as is common for cattle) where food is present all day may help to reduce the fighting seen at food arrival.
Overt aggression at social mixing is not commonly seen with sheep. However, social mixing (when sheep are re-grouped) can occur unintentionally in the management of pregnant ewes and is a source of social stress. Sheep have excellent recognition abilities for other sheep and form social bonds with pen mates that can be disrupted by regrouping. There is also some evidence that presence of unfamiliar animals can be stressful, at least initially. This may lead to aggression and bullying (butting and chasing behaviour) or more subtle displacements from preferred feeding and resting spaces.

**Shearing in pregnancy**

Shearing pregnant ewes, particularly in early to mid gestation, has been shown to increase lamb birth weight (e.g. review by Sinclair et al., 2016), and this is now practiced in some systems. The increase in birth weight seems to be related to the thermal responses of the ewe and as a secondary impact of increased feeding by the ewe rather than as a direct effect of wool removal. Shearing is, however, also known to induce considerable stress reactivity in sheep, and shearing is not recommended in colder climates unless the sheep can be housed or protected from the elements particularly immediately after shearing.

**Stress during pregnancy**

Common management practices for pregnant ewes can cause stress, as outlined in the previous section. Other stressors, such as exposure to dogs, unsympathetic handling or transportation, are also known to be stressful and may be frequently experienced by pregnant ewes. The effects of stress on sheep have been well-described, thus this section will focus on what is known about the specific effects of stress on pregnant and maternal ewes, and the impact on the developing foetus.

**Impact on the mother**

Undernutrition of pregnant ewes is associated with impaired udder development and reduced milk and colostrum production. 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 at the birth site and are quicker to return to feeding after birth. 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.

In rodent species psychological stress in pregnancy reduces or abolishes the expression of maternal care, with less maternal grooming accompanying heightened anxiety responses. In extreme cases, if stress occurs close to parturition, maternal cannibalism of her pups can occur. 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 for lactating ewes also reduced maternal grooming behaviour and suckling durations. Thus overall, in most situations, stress in pregnancy, at the levels experienced in these studies, tends to have only a small negative impact on the onset of expression of maternal care.

**Impact on the offspring**

Studies in rodent models, either through manipulation of maternal care or gestational stress treatments (although often with a more severe stressor than those commonly applied to sheep e.g. daily physical restraint lasting up to an hour on each occasion) have provided compelling evidence for permanent and significant alteration in offspring responses as adults. 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 reactivity in adulthood, accompanied by high anxiety and depressive-like behaviours, as well as impairments in other behaviours such as memory in some tasks. This is associated with permanent alterations in the expression patterns of DNA due to methylation of regions controlling expression of specific genes known as promoter regions. These changes are termed ‘epigenetic regulation’, and thus events occurring early in development can have a life-long impact on the offspring. Theoretically, similar mechanisms would be expected to occur in other mammalian species, and can also have permanent impacts on responses (stress, behavioural responses, health and survival) that would impact on welfare. The evidence supporting this in sheep is rather patchy and inconclusive but will be outlined briefly here.

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. Low-birth weight lambs are slower to stand and suckle after birth, have more difficulty in maintaining their body temperature 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-birth weight 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 pre-weaning lambs undernourished in early to mid-pregnancy, even in the absence of an effect on birth weight.
Reproductive management (including impacts of prenatal stress on offspring development) (Rooke et al., 2010), which may be related to longer-term impacts of prenatal undernutrition. Most studies which have a later endpoint report some post-weaning behavioural changes associated with the experience of undernutrition in pregnancy although the direction of change is not consistent. For example, Erhard et al. (2004) suggests an increase in behavioural reactivity following undernutrition, whereas other studies (Corner et al., 2006; Hernandez et al., 2010) report a decrease. Physiologically there is a evidence that basal concentrations of hormones involved in the hypothalamic–pituitary–adrenal axis cascade (adrenocorticotrophic hormone) in adults are increased following exposure to undernutrition as foetuses (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. However, there is 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. Ewes may be better able to buffer their offspring from the longer-term consequences of stress than rat dams perhaps as an adaptive response to the unpredictable environment in which sheep evolved. In addition, sheep are born at a later stage of development as compared to rats, which may influence the impact of epigenetic programming. However, with few studies having a relevant endpoint (most studies terminate at pre-weaning endpoints, some even at foetal stages), variation in stressor type and severity and variation in outcome measures, it is not yet possible to provide firm conclusions.

Lambing and lactation

The lambing period is generally the most labour-intense and demanding part of the sheep farming cycle. Ewes and lambs are most vulnerable to illness, mortality and other welfare issues, and the success of this period can influence the productivity of the farm for the subsequent year. Lambing normally occurs over a short period of time which, in temperate regions, coincides with the onset of growth of spring grass. From a biological perspective, individual lamb survival is maximised by the ‘dilution effect’ where there are many vulnerable newborn lambs present at the same time, and thus the likelihood that any one lamb will be caught by a predator is reduced. The appearance in the flock of many young and highly mobile lambs at the same time dictates the organisation of lambing and the biology of the onset of maternal behaviour. These processes, and the welfare implications, will be discussed here.
Preparing for birth

Immediately before giving birth the highly gregarious ewe will start to become less interested in the flock. In wild sheep species, ewes will choose to isolate themselves in remote and inaccessible parts of their home range where they give birth alone. Birth sites for these ewes are sheltered and help to protect their newborn lambs from predators and adverse climatic conditions. Isolation seeking may also reduce the opportunities for interference by other ewes during the onset of maternal behaviour and ewe–lamb bonding.

In domestic sheep birth sites are also important for lamb survival, the longer the ewe spends at the birth site, the better chance of offspring survival. However, ewes do not seem to preferentially select sheltered sites, unless they themselves require shelter (e.g. after shearing), preferring to lamb in elevated areas or along fence-lines. In other species, nest building is a highly motivated behaviour of pre-parturient mothers, and can result in physiological stress and behavioural abnormalities if thwarted. Whether ewes show a similar drive to select an optimal birth site is unknown. The selection of an inappropriate birth site, or an inability of the ewe to show birth site seeking responses, may result in early abandonment with consequences for lamb survival, but could also cause stress to the parturient ewe.

There is some evidence for isolation seeking in domestic sheep, which may vary in strength with different sheep breeds and where they are kept (Dwyer and Lawrence, 2005). In housed sheep, lambing in close proximity to other ewes may be both stressful and likely to lead to increased interference from other parturient ewes. Studies that provided housed sheep with opportunities to lamb in more protected cubicles found that parturient ewes show a marked preference to lamb in cubicles rather than the open pen (Gonyou and Stookey, 1983). Furthermore, there were fewer incidences of ewe–lamb separation or mis-mothering (where lambs are cared by ewes which are not their biological mothers) when cubicles were present, suggesting that some degree of isolation or protection is important for the welfare of ewes and lambs at birth.

Birth and dystocia

Ordinarily, the lamb is presented front-feet first, with the nose lying along the forelegs. This presentation ensures that the lamb is able to take its first breaths as the umbilical cord becomes compressed in the pelvis of the ewe and eventually detaches from the placenta. Birth, from the point where the amniotic fluid-filled sac first becomes visible at the vulva to the complete expulsion of the lamb, takes up to an hour in most cases, although some breeds will give birth more quickly than others (Dwyer and Lawrence, 2005). Dystocia, or birth difficulty, can occur when the lamb is too large and becomes stuck in the birth canal, or where the presentation of the lamb makes expelling it very difficult (e.g. lambs have one or both forelimbs retracted, are presented backwards or more than one lamb is present in the birth canal simultaneously). Difficult or prolonged deliveries can cause physical trauma and pain to the ewe, and hypoxia and injury, including cerebral haemorrhage and broken bones, to the lamb. Lambs born following a difficult birth are slower to stand and suck, have impaired
locomotor behaviour and a poorer ability to maintain body temperature. In addition, ewes are slower to stand and lick their lambs after a prolonged labour, due to exhaustion and perhaps the pain and stress associated with the delivery.

**Expression of maternal behaviour**

Prior to birth ewes are indifferent to, or actively avoid, newborn lambs and the smell of amniotic fluids. This repulsion is reversed immediately before birth, when ewes become attracted to lambs and the spilt amniotic fluids of other parturient ewes. As the lamb is delivered, ewes transfer this attachment to the newborn, stimulating active licking or grooming behaviour (Fig. 7.1). This can occur at high intensity for the first hour or so after birth, and then declines such that by 4–6 h after birth, ewes rarely lick their lambs. This behaviour serves a number of 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 temperatures of wet newborn lambs to plummet. Ewes may also remove membranes and fluids from the mouth and nose of the lamb to stimulate breathing. The smell of the lamb, and the licking and grooming behaviour expressed

![Figure 7.1](image)

**Figure 7.1** The development of the ewe–lamb bonding, and lamb neonatal behavioural progress from (A) onset of maternal grooming, (B) lamb begins to push up on chest, (C) standing and (D) udder-seeking.

*Source:* Photos by Ann McLaren, SRUC.
by the ewe, is also vital in the development of maternal ‘selectivity’ where the ewe learns to recognise the smell of her own lambs. This maternal learning occurs within a very short period, perhaps less than an hour, after birth, and thereafter the ewe will restrict her maternal care only to her own offspring. Separation between the ewe and lamb, or contact with other newborn lambs, either accidental or due to management actions, during this crucial period can result in maternal rejection of her own lamb, as the ewe is prevented from forming an olfactory memory for her own offspring.

In addition to licking and grooming, the ewe emits frequent low-pitched bleats or ‘rumbles’ towards the lamb, which may provide reassurance, and strengthens the developing relationship between ewe and lamb. She also facilitates the udder-seeking and sucking responses of her lamb as it finds its way to the udder. Disturbances to the normal onset of maternal behaviour may be seen 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. These responses may result in lambs dying from starvation and hypothermia, as the selectivity response of ewes will prevent other ewes from caring for a rejected lamb, or require management actions to deal with the un-mothered lamb.

The timely and precise expression of maternal behaviour is under hormonal control, which regulates the onset of maternal behaviours. Changes in the relative concentrations of circulating oestrogen and progesterone in late gestation act as ‘primers’ for a maternal state. The central (brain) release of a hormone, oxytocin, during the birth process, and sensory cues from the lamb, results in the expression of maternal behaviour once the lamb is delivered. However, these internal signals can be disrupted or disturbed by a number of internal and external (management) factors which may influence the development of the relationship of the ewe with her lamb and affect the welfare of the ewe and lamb. These impacts will be briefly outlined here.

Mothers giving birth for the first time are known to be less efficient and more likely to show behavioural disturbances as compared to more experienced mothers. In sheep, this is characterised by a slower onset of maternal licking and grooming, a high frequency of moving away as the lamb attempts to suck, leading to prolonged intervals between birth and first ingestion of colostrum, and a propensity to show maternal aggression and rejection. These responses are partly responsible for the 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 more susceptible to any environmental disturbance. 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. Currently, with selection for increased growth rates, an increasing number of systems are starting to breed ewe lambs, such that animals are lambing for the first time at 1 year of age. As described earlier, this may have particular consequences for nutritional management, but the impact of this on the expression of maternal behaviour has not been thoroughly investigated.
As a prey species, ewes are very responsive to stress and disturbance at lambing time, particularly when they have been unable to choose a safe and secure location in which to give birth. Disturbances occurring during labour can cause a temporary cessation of uterine contractions. In a natural situation, this may allow the ewe to flee from danger and find a safer location in which to deliver her vulnerable newborn. In a managed situation, however, this may prolong labour, increasing the risks that newborn lambs will be born damaged from lack of oxygen. In addition, unnecessary movement of the ewe from the birth site, through stress or management activity, may prevent the proper transfer of maternal interest from amniotic fluids to the lamb and lead to an increase in lamb rejection. Maintenance of a quiet and calm lambing environment, free from excessive interventions, will reduce the impact of stress on the progress of birth and expression of maternal care.

Expression of neonatal behaviour

Newborn lambs are precocious, since they are active and mobile at birth, and able to regulate their own body temperature. Lambs are, therefore, not passive in the immediate post birth period but express coordinated standing, locomotor and udder seeking behaviour soon after birth (Fig. 7.1). This requires that the lamb is able 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. As lambs are born with finite body reserves, which can be rapidly depleted particularly in cold weather, they need to accomplish these behaviours as soon as possible after birth.

Lambs have brown fat reserves located around the major organs and the periscapular 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. This can provide the lamb with sufficient heat to maintain body temperature immediately after birth, but requires 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. Suckling also provides the lamb with passive transfer of antibodies through colostrum. Sheep placenta do not allow the passage of macromolecules, such as immunoglobulins, thus the newborn lamb is immunologically naive. Newborn lambs therefore must acquire immunological protection from their mothers by ingesting immunoglobulins in colostrum. For a short period after birth the gut is permeable to the passage of immunoglobulins (but also other large molecules such as bacteria), and rapid sucking allows the immunoglobulins to pass into the lamb. Colostrum also contains growth factors that encourage the gut to close and thus limit the passage of pathogens, such as Escherichia coli, which can cause disease in newborn lambs. Finally, sucking also plays a key role in ewe–lamb bonding, helping the lamb to learn how to recognise its mother (Nowak et al., 2007). Therefore, lambs that are slow to stand and suck are vulnerable to the development of hypothermia and starvation.
at risk of infectious disease, and may be susceptible to predation if they are poorly bonded to their mothers.

The behavioural development of the lamb is known to be affected by several factors, including breed, litter size, sex, birth weight and ease of delivery, which will affect how quickly the lamb first sucks after birth. Light weight lambs, those born in larger litters and lambs that have experienced a difficult birth process all take longer to stand and reach the udder than heavier lambs from smaller litters which have a quicker birth (Dwyer, 2003). Male lambs, of some breeds, are also slower to progress to sucking compared to females. As sucking colostrum is associated with improved survival, any factor that slows ewe–lamb bonding and early sucking will increase the risk of lamb mortality.

**Development of the maternal bond and weaning**

Following the short period immediately after birth, when the ewe spends time actively licking the lamb and developing a recognition memory for the lamb, maternal licking of the offspring declines rapidly. This period, and contact with the young, is important for the development and maintenance of maternal responsiveness to lambs. Studies of the time course of maternal bonding suggest that ewe–lamb separation of 4 h at birth will result in only 50% of ewes showing maternal care, and this decreases to only 10% with 24 h of separation (Poindron et al., 2007). However, ewes which have had 24 h of contact with their lamb still show maternal responsiveness when separated from their lambs for 24 h. Clearly, conditions which allow continuous mother–offspring contact over the first 24 h of life are important for ensuring maternal care of the lamb.

In the initial few weeks after birth ewes are extremely attentive towards their lambs, maintaining a close physical contact with frequent sucking bouts. The frequency of these interactions, and the closeness of spatial contact is known to be affected by ewe breed, and more recently has been also shown to be influenced by management conditions. Ewes managed at high stocking density during early lactation showed an increase in physiological stress responses, and a decrease in grooming and following behaviour, accompanied by an increase in udder refusals and reduced sucking durations (Lv et al., 2015). At 4 weeks of age there is a dynamic shift in the ewe–lamb relationship, with an increased responsibility for the lamb to approach and suckle as the ewe ceases actively approaching the lamb very frequently. However, the ewe controls the frequency of these interactions, using postural and vocal cues to manage the behaviour of her lamb (Pickup and Dwyer, 2011). These cues are part of the species-specific communication that occurs between sheep within the flock, with the ‘head up’ posture acting as a signal to other sheep that a potential threat has been detected. Ewes therefore teach their lambs to be attentive to these signals, which can be important for their future survival.

The ewe–lamb relationship then enters a stable phase, where spatial proximity is maintained and the lamb learns about the environment and food choices through observation and close contact. In an unmanaged situation, weaning of the lamb would not take place until about 6 months of age, when the ewe comes into oestrus. In
Reproductive management (including impacts of prenatal stress on offspring development) this situation weaning is controlled by the ewe, who will gradually limit access to the udder, and the timing seems to be at least partially dependent on the decline in milk production. However, in common with other farmed species, the lamb is artificially weaned, typically at 3 months of age, although in dairy systems this may be much earlier. 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. Thus, although the lamb may be capable of meeting its nutritional needs from other sources, weaning still represents a considerable stressor and impacts on lamb welfare. 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 the stress associated with separation. Abrupt weaning is known to be associated with increased plasma cortisol concentrations over the first day after separation (Mears and Brown, 1997), and behavioural responses of agitation and high-pitched vocalisations for the first 2 days (Orgeur et al., 1998). 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). Although less studied than lambs, ewes also experience a period of behavioural disturbance following the removal of their lambs, and also show physiological indicators of a stress response.

As 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 allowing limited physical contact), two-stage weaning (where the lamb is initially prevented from sucking for a period before separation) or gradual weaning (where ewes and lambs are separated for a period over several days or weeks before complete separation) have been suggested. 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. The two-stage weaning process is reported to reduce behavioural signs of distress at complete separation (Norouzian, 2015), however, other practices do not provide very convincing evidence that ewe or lamb separation distress is mitigated by these methods.

Fostering and artificial rearing

Lambs may need to be reared by means other than their own mother for a variety of reasons: because their mother has rejected them (as described earlier), 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 re-attach them to their own mother in the first instance), when she is only rearing a singleton lamb, or where her own lambs have died. In dairy, or intensive systems with high litter sizes, artificial rearing of lambs may be more common. The welfare issues associated with these two practices will be considered here.
Due to the selective response of maternal ewes, inducing a ewe to accept a lamb that is not her own is not a simple process and a variety of different methods have been proposed to overcome her 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 suck, 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. 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, can cause maternal distress and frustration as the ewe is prevented from turning around and can only stand up and lie down. She cannot interact with the lamb, and as maternal bonds are initially formed by olfaction, this effectively prevents the ewe from learning to recognise 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 (Dwyer, 2008), which may reflect this poorer quality of maternal bonds, although it may also be related to the types of lambs which are candidates for fostering (e.g. lambs of larger litters).

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 at 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. Similar 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, which may be related to an inability to satisfy their motivation to suck 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 the object. In addition, artificially reared lambs are reported to have lower-growth rates, 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, although without the experience of observing an older animal eating different foods, lambs may be slow to transition to solid food. Other studies also suggest that lambs can form an emotional attachment to human caregivers, and that stroking or gentling can improve lamb welfare by providing an alternative to the emotional comfort provided by the dam. Lambs that are both artificially reared and kept in isolation show the most disturbed behavioural and physiological
responses, thus peer group rearing is advocated to allow the lambs some emotional support through attachment to pen mates.

**Lamb survival**

For mammals, the most vulnerable period of an animal’s life is the day of birth, with nearly 50% of pre-weaning mortality in sheep occurring within the first 3 days of life (Nowak et al., 2000). At birth the foetus transitions from a warm and protective environment where it is provided with continuous nutrition and oxygen via the umbilical cord, to a relatively hostile extra-uterine environment. This is associated with rapid adjustment of many physiological processes to enable breathing, to develop motor functions, maintain body temperature and seek a food source (usually the maternal udder followed by sucking). The transition itself can also be a mortality risk when the birth process is prolonged or difficult, with physical injury and hypoxia increasing with the duration that the animal is in the birth canal. Although maternal behaviour can facilitate these transitions, failure to accomplish this successfully is a significant cause of offspring mortality. In addition to the individual biological challenges faced by the newborn lamb, it may be exposed to a number of external or environmental challenges (e.g. threats from predators, extremes of temperature, risks of rejection or injury from interactions with its own mother, aggression from other animals), that threaten its survival. Given these many challenges experienced within a few moments of birth it is perhaps not surprising that mortality of newborn lambs is a significant challenge for producers, and for sheep welfare.

Lamb mortality is generally quoted at 15% across the sheep producing world, although between farm variation can be much higher (Dwyer et al., 2016). Lambs die due to multiple reasons, but the main causal factors are injury or trauma during the birth process, failure to establish a good maternal bond, infectious disease and a number of other minor causes such as congenital malformation, accident and predation. It has been suggested that prior to and during birth, foetuses are not conscious and therefore may not have the capacity to experience poor welfare (Mellor and Diesch, 2006), thus the welfare costs associated with stillbirth may, for the lamb, be negligible. However, once breathing and conscious experience has been established, the lamb may experience poor welfare associated with the damage it may have experienced during delivery, or due to breathlessness, hunger, hypothermia, sickness, pain or fear (Dwyer, 2008; Mellor and Stafford, 2004), before it dies.

The risk factors for lamb mortality have been well-described and are related to birth weight, litter size and maternal parity or experience. Low-birth weight is associated with slow behavioural development, a high surface area to body weight ratio leading to rapid heat loss from conduction and limited body reserves. These lambs are, therefore particularly vulnerable, as they will be slow to replenish their energy reserves through sucking, and this can be compounded by birth into a cold, wet or windy environment. Conversely, heavy lambs are more susceptible to birth difficulty, which can also reduce the speed of standing and sucking and impair thermoregulation. Thus an optimal birth weight, falling between these two extremes, is most compatible
with survival. Lambs from larger litter sizes are also more likely to die in the early postpartum period, by a mechanism which is not entirely accounted for by their lower-birth weight. It may be that prenatal undernutrition or crowding in the uterine horns have altered their developmental trajectory such that they are less mature at birth and hence slower to show behavioural progress at birth and have more difficulty regulating body temperature as neonates. As described earlier, first parity mothers are less efficient, less likely to stand to allow their lambs to suck and tend to give birth to lambs of lower-birth weight. The combined effect of these different responses is increased time taken by lambs to suck and reduced offspring survival. Management factors relating to pregnancy nutrition, maternal health, breeding objectives, hygiene management, stress and intervention practices can all contribute to the level of lamb mortality as has been discussed in more detail in the earlier sections. Biologically, however, a key requirement for neonatal survival is for the lamb to ingest colostrum quickly after birth. Lambs that stand and suck quickly, within an hour of delivery, have better survival than lambs that are slow to perform these behaviours (Dwyer and Lawrence, 2005). Improving lamb survival, and lamb welfare, can be achieved by improving the environment to ensure good lamb vigour, although there is also interest in genetic selection for lamb survival. In general, the heritability of lamb survival has been found to be very low (Brien et al., 2014), perhaps because of the multi-factorial nature of lamb mortality. However, measures that target specific behaviours, such as speed of sucking or birth difficulty (Matheson et al., 2012), have higher heritability, and suggest that improving survival by genetic selection should be possible.

Conclusions and future directions

Efficient reproduction is a crucial component of sheep production. Ewes and their lambs are most vulnerable to stress, predation and poor hygiene practices around parturition and during early neonatal development. Although some aspects of management that are designed to improve productivity may not be optimal for sheep welfare (e.g. housing at high stocking density, shearing, mother-young separation), for the most part, welfare improvements for ewes and lambs go hand-in-hand with improved productivity. For example, in a study of UK hill farms, productivity (in terms of lambs weaned per ewe mated) and sheep welfare status were found to be positively correlated (Stott et al., 2012). Maternal stress, undernutrition and ill-health all contribute to reduced ovulation, conception and lambing rates, as well as reduced ewe and lamb survival and poor welfare, whereas improvements in nutrition, low stress handling and lambing environments and good maternal health lead to better survival. However, despite this, lamb mortality is still a significant constraint to both good welfare and productivity. It is a complex issue that probably requires consideration of individual farm characteristics to determine the best strategy to improve survival. In addition, heritability of survival or fitness traits is low so, although variability is high and genetic progress can be made, there will always be a need for good management practices to achieve good rates of survival.
Although a good deal is known about the behavioural relationships of ewes and lambs, the biology of reproduction and the onset of maternal behaviour, there are still many areas where knowledge is rather scarce. Perhaps the most obvious knowledge gap is an understanding of the impact of prenatal events on longer-term welfare of ewes and lambs. Only a few studies have considered these impacts, using a range of different stressors and outcome measures, and the current picture is fragmented and inconclusive. Biologically, it would seem logical that sheep, as with other mammals, are affected by the programming effects of prenatal and early life events. However, whether these are commonly experienced in normal farming practice, or are only induced by extremes, is not known.

New developments in management and breeding offer some potential improvement in animal welfare, but may also bring costs, and in many areas, need further research. For example, improved genetic selection practices, involving genomic selection, may make difficult-to-record traits (such as ewe and lamb behaviour) more accessible to be incorporated into breeding programmes. New technological developments, such as the use of electronic identification in ear tags or boluses, coupled with electronic monitoring, measurements and surveillance (e.g. walk-over weigh plates, shedding gates, GPS tracking), can improve management practices enormously, allowing better record keeping, targeted management interventions and the potential to remotely monitor ewe parturitions and ewe–lamb relationships. These technologies have yet to be fully exploited in sheep production, but could lead to much closer management of flocks with sufficient data to identify and target reproductive issues.

In terms of management, faster growing lines of sheep, and improvements in nutrition mean that it is possible to breed young ewes to lamb at 1 year of age. There is some evidence that this is accompanied by an increase in lamb mortality, perhaps because of lighter-birth weights, but the reasons for increased mortality is not yet well described, and strategies to improve survival in these lambs may be developed. Selection for improved productivity has, as with many farmed species, also been related to increasing litter size. The survival of lambs from larger litters is poorer compared to twins or singles, but knowing whether management can be improved to promote better survival in this cohort would be useful. Artificial rearing of lambs is, as described earlier, known to be a particular welfare challenge. Thus improved methods for achieving good growth and survival, coupled with a more complete understanding of what maternal deprivation means for longer-term lamb development and welfare, is also needed.

References


Introduction

The ‘Five Freedoms’ are the backbone of welfare recommendations in many countries and one of these includes freedom from hunger (Dwyer, 2009). As a ruminant, sheep have evolved to utilise relatively poor quality feed and are often farmed in marginal environments, subject to seasonal variation and/or in farming systems with little supplementation. Under these environments and farming systems, sheep can be subjected to both short and long periods of undernutrition. Their ability to cope with this is very much dependent on the duration and level of deprivation and the animals’ body reserves.

The common cause of underfeeding is lack of available forage; however, other factors may reduce voluntary intake, including low quality forage, water starvation, the depressive effect of high temperatures or prolonged searching for food. Furthermore, extreme climatic events such as drought, flooding or heavy snow can remove or cover herbage thereby preventing grazing. This can lead to short- or long-term feed and/or water deprivation.

Short-term feed and water deprivation, such as through pre-shearing management and transportation (see later sections for further information), can result in a loss of body weight (Burnham et al., 2009; Wilson et al., 2015) which occurs quickly in the first 24 h, the majority of which is body water (Cole, 1995). If dehydration is the major cause of weight loss, its effects can be relatively quickly reversed with access to water. However, young lambs that have only recently been weaned are more susceptible to dehydration (Jacob et al., 2006) and may be less adapted to drinking from a trough which can affect their recovery. When feed becomes available again, intakes to pre-fasting levels can take some time to reoccur. It is possible that short-term feed and water deprivation could affect meat quality (Ferguson et al., 2014); however, such affects can be reversed by adequate feeding over a few days.

When the level of feeding and water intake does not meet maintenance requirements over a period of time, two effects are observed. Firstly, there is the catabolism of body reserves resulting in weight loss and a loss of body condition, and secondly, there is a decrease in energy and protein output resulting in a reduction in animal performance. In regions where droughts or snowfall are common occurrences or when there are extended periods of feed shortages, alternative feed sources should be available.

Food deprivation increases motivation to feed and suggests sheep display an altered state, but whether this is experienced as ‘hunger’ is unclear (Dwyer, 2009). Furthermore, it is actually difficult to accurately determine when health and welfare
effects begin to occur from feed and water deprivation. Factors that affect this include level and duration of deprivation, physiological state (i.e. pregnant and lactating), age and weight and level of body reserves. In addition, sheep with mouth problems (broken, crooked or worn down teeth) or leg and feet problems may be unable to masticate and locate their food, respectively, and therefore can suffer from undernutrition (Dwyer, 2009). It is difficult to develop welfare indicators of appropriate nutrition; options could include production data such as lamb survival or second-level indicators such as body condition score (BCS) (Caroprese et al., 2016), although these have their limitations. Potential metabolic markers include non-esterified fatty acids and 3-hydroxybutyrate as indicators of body reserves utilised to meet a nutritional shortfall; however, an animal with low body reserves may not display a significant increase in these. In addition, in many environments in which sheep are farmed, it may be impracticable to examine metabolic markers. Live weight could be monitored as a welfare indicator however; rumen fill, physiological state and fleece wetness all impede the accuracy of this technique. It is reasonable to assume that an animal losing both live weight and body condition, while making attempts to find suitable levels of feeding, is not in good welfare (Dwyer, 2009).

Energy is the most common limiting nutrient for livestock production; therefore, nutritional requirements of sheep are most often expressed in metabolisable energy (ME) requirements, although in some environments and systems metabolisable protein (MP) is more appropriate. The nutritional requirements of a sheep are affected by a large number of factors, including live weight, age, sex of the individual, grazing environment, topographical environment, climate, feed quality and physiological state. It is beyond the scope of this chapter to provide details on specific ME and MP requirements, although this information is readily available in a number of sources (Corbett and Ball, 2002; Dryden, 2008; Freer et al., 2007; Nicol and Brookes, 2007). This chapter, instead, focuses on the impacts of undernutrition and only where appropriate briefly outlines appropriate feeding levels.

Body condition score

Body condition scoring of sheep as a technique was first developed in the 1960s (Jefferies, 1961). In comparison with live weight, measurement of BCS circumvents the potential confounding issues of skeletal size, breed, physiological state, gut fill and length and wetness of the fleece (reviewed by Kenyon et al., 2014). The BCS of a sheep is assessed by palpation of the lumbar region, specifically on and around the backbone (spinous and transverse processes) in the loin area immediately behind the last rib and above the kidneys to examine the degree of sharpness or roundness. It is a means of subjectively assessing the degree of fatness or condition of a live animal (Russel, 1984) and is based on a 0–5 scale including half units (1 = very thin, 5 = obese; Fig. 8.1). BCS is correlated with the degree of body fat and GR depth (soft tissue depth 100 mm from the midline over the 12th rib) and fat score, although the relationships are not strong, presumably due to the differences in site of measurement.
### Figure 8.1 Description of the body condition scoring technique and illustration of vertebra and ribs and approximate muscle and fat distribution.

**Source:** From Kenyon, P.R., Maloney, S.K., Blache, D., 2014. Review of sheep body condition in relation to production characteristics. N. Z. J. Agric. Sci. 57, 38–64.
Advances in Sheep Welfare

There are also established relationships between BCS and live weight which differ between breeds. BCS is, in general, positively related to most production traits, including onset of breeding in seasonal breeds, ovulation rate, sperm motility, sexual behaviour, conception rate, ova loss and embryo mortality, pregnancy rate, numbers of lambs born and weaned, lamb survival and growth to weaning and ewe survival (Kenyon et al., 2014). For many of these traits, a curvilinear response is observed with significant gain in performance being achieved by increasing the BCS of otherwise low BCS animals (below 2.0), with little to no gains being achieved above a BCS of 3.0–3.5. Therefore, there is likely an optimum range of BCS for an ewe over a calendar year, although this will vary based on the number of lambs carried and reared (Fig. 8.2). There is also potential for an interaction between BCS and nutrition, with increased levels of nutrition having a large effect on the performance of otherwise low BCS animals with a lesser to no effect in animals of high BCS.

BCS is a potential indicator of animal welfare (Morgan-Davies et al., 2008; Phythian et al., 2011). However, the use of BCS to simply define animal welfare has limitations (Keeling et al., 2011), for example as outlined earlier for many traits the relationship with BCS is not linear and therefore simply stating a higher BCS indicates greater welfare may not be correct. Furthermore, a very high BCS (obese) animal is not a desirable outcome. Caldeira et al. (2007) proposed that metabolic imbalance can occur with a BCS below 2 or above 4, which may be suggestive of reduced health outcomes. Furthermore, ewe survival has been shown to increase up to BCS 2.5, but above this level no further gain is apparent (Annette et al., 2011; Morgan-Davies et al., 2008). Although at extreme BCS, animals can have problems expressing normal

Figure 8.2 Stylised ideal body condition score (BCS) profile for singleton and twin bearing/rearing ewes. Singleton bearing ewes are more able to cope with a larger loss of BCS in late pregnancy than twin bearing ewes without significant impacts on performance. Within pregnancy rank ewes may be able to cope with an additional 0.5 drop in BCS above those indicated, if feeding levels are adequate, before a decline in performance might be observed.
Nutritional management

behaviour, for example obese rams might not be able to mount a female, or will injure her when mounting (Mori, 1959). These studies identify that animal welfare issues can occur at both low and high BCS and that data are not easily interpreted and like any other animal welfare indicator, BCS should not be taken in isolation (Kenyon et al., 2014). Breed, nutrition level, physiological state, season and age are all sources of variation for BCS that should be taken into consideration if BCS is used to assess animal welfare.

Nutritional management pre and during transportation and prior to slaughter

In developing countries, sheep may have to walk great distances to slaughter plants or to rail or road transportation prior to a slaughter plant, and in many of these countries there is currently a lack of nutritional guidelines for transportation. In developed nations, sheep are routinely transported from farm to farm or to abattoirs due to the extensive nature of sheep farming. The distance of a given farm from an abattoir plant varies, but lambs are rarely transported for longer than 12 h either in Australia or in New Zealand (Ferguson et al., 2014). However, longer transport durations are sometimes required when transporting ewes to specialist abattoirs, selling sheep to far away locations (due to local drought conditions) or for overseas export. In the European Union (EU), slaughter processors are streamlining and closing many smaller abattoir plants, consequently sheep are being transported increasing distances prior to being slaughtered. Furthermore, many EU countries import sheep for finishing (fattening) or slaughtering from other countries within the EU or from outside the EU. These sheep may be transported across large distances. Furthermore, some countries export live animals for slaughter (i.e. from Australia to the Middle East) and in these circumstances sheep can be transported via boat over prolonged periods (see later section).

In some countries, a feed and water curfew period is either recommended or required prior to land transportation of sheep. Transporting ‘full’ sheep can increase the likelihood of effluent spills and can lead to injury as a result of slipping. However, the total curfew and transportation period should not exceed maximum transport duration regulations. During land transportation, access to food and water is routinely denied. In the EU transportation periods greater than 8 h have to be carried out on special vehicles, which provide litter, drinking water and forced ventilation (Hartung and Springorum, 2009). In Australia, sheep are given access to water at abattoirs, while in New Zealand provision of water is optional (due to shorter transportation periods). Generally, there are regulations surrounding the maximum period of water deprivation for sheep in each country based on age and physiological state (maximum ranging from 8 to 48 h) (Ferguson et al., 2014; Hartung and Springorum, 2009). Healthy adult sheep show reduced live weight and increased hemoconcentration with increasing transport durations between 12 and 48 h; however, they can tolerate transport durations and associated feed and water withdrawal for up to 48 h without undue compromise on
their welfare (Fisher et al., 2010). The mobilisation of body reserves helps sheep to adjust to periods of feed deprivation (Fisher et al., 2015). Therefore, animals in better body condition are more able to tolerate longer transportation periods. Once sheep are unloaded from their transport they will generally eat before they will drink. Therefore, where transportation periods are long enough that rest stops are required, the stopped period must be long enough to allow sheep to eat and then to drink.

Sheep can be moved long distances over the ocean for either live slaughter at destination or for export as breeding animals. Australia is the biggest transporter of animals by sea in the world, with 1.48 million sheep exported in 2015 (Meat & Livestock Australia, 2016). The main destination for live sheep export is the Middle East, with the majority of animals being destined for slaughter. Mortality rates of sheep during live export are approximately 1%, and animal welfare standards within individual countries generally state that an inquiry will be carried out when mortality rates are greater than 2% (Australian Government Department of Agriculture, 2011). The two major causes of death during shipping are Salmonella and inanition (failure to adapt and eat a new diet during shipping) (Richards et al., 1989). Hodge et al. (1991) suggested sheep travelling from Australia to the Middle East are likely to lose 2–3 kg; however, a small proportion may lose over 20% of their initial live weight. Prior to shipping, sheep should be transported close to the port and kept under feedlot conditions to allow time to adapt to the novel pelleted grain-based diet (Ferguson et al., 2014). Sheep should be monitored during this time and those which fail to adapt to the novel feed should not be shipped. This should help to minimise the number of deaths during shipping as a result of inanition. During shipping sheep should be offered the same diet, at a level sufficient to support maintenance energy requirements at a minimum. Palatable water must be delivered in a reliable manner, and meet minimum daily requirements. Ships should also have forced ventilation systems to improve air flow and reduce the risk of heat stress.

**Pregnancy management**

The nutritional requirement of the pregnant ewe increases exponentially in the last 6 weeks of pregnancy and is well documented (Freer et al., 2007; Fthenakis et al., 2012; Nicol and Brookes, 2007; Robinson et al., 2002; Table 8.1). Undernutrition of ewes during late pregnancy, a sudden change in diet, or a short-term starvation, resulting in depletion of maternal body reserves, can have a number of negative consequences. These include pregnancy toxaeemia, hypocalcaemia, ewe death, extended birth processes, birth difficulties, lighter lamb birth weights, lambs with lower energy reserves, impaired thermoregulation in lambs, lambs with less vigour, reduction in underweight and mammary gland development, reduced colostrum production, delayed milk letdown, delayed and reduced peak milk production, reduced total milk yield, increased lamb death rates insufficient maternal energy and mineral reserves to meet demands of early lactation and impaired maternal instinct (Fthenakis et al., 2012; Kenyon and Webby, 2007; Robinson et al., 2002; Rooke et al., 2015; West et al., 2009).
Combined, these factors increase the risk of peri-natal lamb losses and result in lower than expected weaning weights of lambs. These effects tend to be exacerbated in multiple-born lambs. Furthermore, ewes that lose body reserves may have difficulty regaining this condition prior to rebreeding which might affect future reproductive performance. Extreme levels of undernutrition can result in ewe death and therefore foetal death. Recently it has also been shown that there can be longer term impacts, the so-called foetal programming, on the offspring from sub-optimal nutrition of the ewe in pregnancy which can impact future productive performance (Bell and Greenwood, 2016; Kenyon et al., 2014).

Ewe lambing percentages are increasing worldwide due to improvements in breeding and more appropriate feeding. Neonatal lamb mortality is a significant welfare concern, with birth weight being the single greatest contributor to mortality (Dwyer, 2009). Birth weight has a U-shaped relationship with lamb death, whereby light birth weight lambs (those that are born as multiples) are more likely to die due to starvation and exposure (in outdoor systems) (Fisher and Mellor, 2002; Scales et al., 1986) and heavier birth weight lambs (particularly those born as singles) are more likely to die due to dystocia (Smith, 1977). Targeted feeding during ewe pregnancy can be used as a tool to manipulate lamb birth weight (i.e. offer single-bearing ewes maintenance only diets and multiple bearing ewes above maintenance diets).

### Table 8.1 The metabolisable energy requirements for ewes during pregnancy and lactation in addition to maintenance requirements

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<tr>
<th>Pregnancy (MJ ME/ewe/day)</th>
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<td>3</td>
<td>1.5</td>
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<td>5</td>
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<td>6</td>
<td>3.0</td>
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<tr>
<th>Lactation (MJ ME/ewe plus lamb(s)/day)</th>
<th>Weeks after lambing</th>
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Maintenance energy requirements for 40, 50, 60, and 70 kg ewes of 7.0, 8.0, 10.0, and 11.0 MJ ME/ewe/day must be added to pregnancy and lactation energy requirements. Increase pregnancy and lactation energy requirements proportionally for extra lambs (i.e. double for twins). Based on a diet of 11.0 MJ ME/kg DM. Adapted from Nicol, A.M., Brookes, I.M., 2007. The metabolisable energy requirements of grazing livestock. In: Rattray, P.V., Brookes, I.M., Nicol, A.M. (Eds.), Pasture and Supplements for Grazing Animals (Occasional Publication No. 14). New Zealand Society of Animal Production, Hamilton, New Zealand, pp. 151–172.
In late pregnancy the nutritional demand of the ewe increases significantly due to rapid foetal growth (Fig. 8.3). Under grazing conditions, especially if late pregnancy coincides with either a cold winter or a summer dry period, it is possible that many ewes do not consume enough herbage to meet their theoretical nutritional requirements in late pregnancy. A ewe in good body condition is better able to buffer against the effects of poor nutrition (Kenyon et al., 2014), as is a single lamb-bearing ewe in comparison to a multiple lamb-bearing ewe. Through the use of ultrasound pregnancy scanning in mid-pregnancy (Fig. 8.4) farmers can identify ewes of varying pregnancy status and manage their nutrition accordingly to maximise productive performance and minimise potential negative welfare impacts. Using this combined knowledge, farmers can use a targeted feeding approach in both pregnancy and lactation, to ensure those animals that need it the most receive an adequate level of nutrition when feeding levels do not allow for optimal feeding for all ewes. Optimal grazing conditions in late pregnancy differ between environments based on the herbage type, sward structure and units of measure. For example, optimal grazing conditions in late pregnancy in New Zealand and in the United Kingdom for twin bearing ewes occur when pasture covers do not drop below, 1200 kg DM/ha or a 4-cm sward height (Morris and Kenyon, 2004; Phillips et al., 2014) or 8 cm with a Plantain, Chicory and clover mix (Cranston et al., 2015), while, in Australia, a Food On Offer (FOO) minimum of 1500 kg DM is stated as optimal for pasture in late pregnancy (Oldham et al., 2011). Therefore, it is inappropriate to develop a uniform feeding guideline.
Figure 8.4 The productive and welfare benefits of ultrasound pregnancy scanning.
for farmers across various environments and herbage types. Interestingly, there is no evidence of improved lamb welfare from feeding ewes above their theoretical need in pregnancy (Rooke et al., 2015), indicating it is inefficient to do so.

In some farming systems/environments it may be possible to supplement ewes or feed ewes solely with conserved herbages, concentrates, by-products or grains. The management of these is outside the scope of this chapter; however, using these comes with risks as new feeds need to be introduced slowly, and in advance of when needed, as the ewe’s rumen needs to adapt to prevent adverse health complications such as pregnancy toxaemia and lactic acidosis. One potential advantage of feeding solely a concentrate supplement to ewes in late pregnancy is that allowance and therefore potentially intake levels can be accurately monitored (Fthenakis et al., 2012) to ensure they meet their theoretical need.

Management during lactation

The nutritional requirements of the ewe and her offspring in the lactation period are well established (Freer et al., 2007; Nicol and Brookes, 2007; Robinson et al., 2002; Table 8.1) but outside the scope of this chapter. It is important to recognise that in many texts the requirements for lactation are additional to maintenance requirements. Poor nutrition of the ewe in lactation has a number of welfare implications, including increased peri- and post-natal lamb losses, reduced lamb live weight gain, increased ewe mortality and reduced ewe live weight and body condition at weaning which can impact on future performance.

Lambs do not begin to consume significant amounts of feed (other than milk) until 4–6 weeks of age. Therefore, ewe milk supply and lamb milk intake is the dominant factor in lamb growth and survival in the period immediately post birth. When lamb milk intake is restricted due to poor ewe nutrition or when multiple-born lambs are competing for their share (Moffat et al., 2002; Peterson et al., 2006), lambs try to compensate by increasing their grazing time. However, they cannot fully compensate for reduced milk intake, and this change of behaviour suggests the lambs are under a level of nutritional stress.

There is an interaction between nutrition in pregnancy and in lactation on ewe and lamb performance. For example, the data suggest that ewes of good body condition can be offered only slightly above maintenance feeding levels to at least day 136 of pregnancy with few impacts for their offspring, if well fed in late pregnancy and in lactation (Morris and Kenyon, 2014). However, poor nutrition in lactation extenuates the impact of poor nutrition in pregnancy. Ideally at lambing, ewes should have a minimum BCS of 3.0 (Kenyon et al., 2014). Using this knowledge, farmers should use targeted feeding in lactation to ensure those ewes in poor body condition and those rearing multiples have access to more feed than those in better condition or only rearing singletons if feed availability is restricted not allowing all ewes and lambs to be fed optimally.

An important aspect that is often ignored is the importance of timing lambing to coincide with not only suitable weather but also feed availability. There is often a
Nutritional management

temptation for farmers to lamb early to ensure lambs are older, and hopefully heavier, at a given sale date. However, in many studies this has been shown not to be the case (McEwan et al., 1983) due to late pregnancy/lactation not matching herbage supply which can also have impacts not only on lamb growth but the welfare of the dam and her lambs. If early lambing is to be utilised, extra feed resources need to be available (McCall et al., 1986).

Nutritional management post-weaning

In some extensive systems, often found in developing counties or in traditional farming scenarios, ewes and lambs remain together as one flock all year round. Lambs in these situations are weaned naturally as the ewe dries off (stops lactating, generally 4–6 months after lambing). In systems where farmers have limited ability to manage the ewe and her older lamb separately they can actually become competitors for herbage, which can limit the ability for the ewe to regain body condition prior to rebreeding and can impede the growth of the lamb. Conversely, in more intensive pasture-based or indoor systems, lambs are physically weaned from their dams. Following weaning the priority stock class in a sheep production system is often the lamb, with the goal being to maximise average daily live weight gain to get as many lambs as possible up to slaughter weights as quickly as possible and to get replacement breeding animals to suitable live weight targets to maximise lifetime productivity. In extensive pastoral systems lambs should be offered a high quality herbage, while in intensive systems lambs can be transferred to feedlot facilities for finishing. Regardless of the type of finishing system, lambs require a high allowance of a diet with a minimum crude protein concentration of 15%–18% and an ME content of 10–11 MJ ME/kg DM to achieve high live weight gains (>300 g/day) (Hodgson and Brookes, 2002). A 25 kg lamb requires 8, 10.5–11.5, 13–15 MJ ME/day to gain 100, 200 and 300 g/day, respectively (Table 8.2).

<table>
<thead>
<tr>
<th>Live weight (kg)</th>
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<tbody>
<tr>
<td>25</td>
</tr>
<tr>
<td>Ewes/wethers</td>
</tr>
<tr>
<td>MJ ME/day maintenance</td>
</tr>
<tr>
<td>MJ ME per 100 g live weight gain</td>
</tr>
<tr>
<td>Rams/cryptorchids</td>
</tr>
<tr>
<td>MJ ME/day maintenance</td>
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<td>MJ ME per 100 g live weight gain</td>
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Table 8.2 The metabolisable energy requirements for the maintenance and live weight gain of young sheep

Based on a diet of 11.0 MJ ME/kg DM.

In pastoral systems farmers should target green leafy pasture heights between 5 and 8 cm. Offering pasture with a sward height less than 5 cm will limit feed intake, while swards greater than 8 cm have significantly more dead material and less green leaf and therefore lamb performance is reduced (Webby, 1990; Webby and Pengelly, 1986). Forage crops such as chicory, plantain, red clover, alfalfa and leafy turnips can also be used to obtain high lamb live weight gain (Campbell et al., 2011; Cranston et al., 2015; Fraser et al., 2004; Marley et al., 2005; Moorhead et al., 2002; Somasiri et al., 2016).

Under post-weaning conditions where feed on offer can be limited and of poor quality due to summer dry conditions, such as in Australia, high death rates can occur. Not only are feeding levels important, but a minimum live weight at weaning of 20 kg is recommended to minimise lamb deaths post-weaning (Thompson et al., 2011).

In feedlots, lambs are often fed a grain-based concentrate (70%–90% of the diet) and require roughage (hay or straw or silage) to make up the remaining 10%–30% of the diet from a nutritional, mortality and enrichment perspective (Aguayo-Ulloa et al., 2014; Davis, 2003; Flint and Murray, 2001). The lambs must be slowly adjusted to the new diet to minimise the risk of acidosis. A small proportion of lambs (up to 20%) will not adjust to the feedlot environment and/or diet (commonly referred to as ‘shy feeders’) and will display reduced productivity and increased rates of mortality (Savage et al., 2008). Feeding behaviour should be monitored and those which feed for 30 min or less over a 24-h period or lose weight over the first week (shy feeders) should be removed from the feedlot (Rice et al., 2016). A clean unrestricted water supply is required to ensure lambs drink and therefore maintain their feed intake (Davis, 2003).

**Early weaning management**

Early weaning can be a feature of sheep milking systems and in highly fecund flocks where one or more lambs may be removed from the dam and as an option to reduce overall feed demand. There is also growing interest in the use of relatively early weaning (6–8 weeks of age) when ewes and lambs begin to compete for herbage and milk production starts to decline.

Lambs are traditionally weaned at a minimum of 10 weeks in meat production systems. Early weaning can be stressful for the ewes and the lamb with enforced ewe–lamb separation resulting in elevated cortisol secretion in both the ewe and lamb(s) (Pérez-León et al., 2006; Rhind et al., 1998) and a behavioural response including an increased frequency of vocalisations, time pacing and standing and a reduction in the time lying down and ruminating (Damián et al., 2013; Freitas-de-Melo et al., 2013; Orgeur et al., 1998). Furthermore, it is known that weaning lambs less than 6 weeks of age (∼14 kg) can have a negative effect on both lamb survival and live weight gain, due to insufficient rumen development (Hodge, 1966; Wardrop and Coombe, 1961). Therefore, a minimum live weight of 12 kg is recommended prior to weaning (Geenty, 1980). Furthermore, early weaning can increase lamb susceptibility to both disease and parasitism (Napolitano et al., 2008).

To minimise the impact of early weaning on the lamb, it needs to have access to unrestricted levels of a high quality feed. Lambs weaned between 6 and 10 weeks of age
Nutritional management

onto a high quality forage (e.g. alfalfa, chicory, plantain, clover, mixed pasture) or supplemented with grain/meal can display similar growth rates to unweaned lambs of the same age (Corner-Thomas et al., unpublished; Geenty, 1980; Smeaton et al., 1983). In grass/clover-based swards, lamb live weight gain is positively correlated with both pasture allowance and the proportion of clover in the sward, with lighter lambs being most responsive to increased clover content (McEwan et al., 1988).

Nutrition, wool and shearing

There is a well-established positive relationship between the level of sheep nutrition and the wool fibre traits of micron (diameter), length and strength (Hynd and Masters, 2002; Kenyon and Webby, 2007). It is often missed that published maintenance requirements for sheep include the requirements for ‘normal’ wool growth and development (Corbett and Ball, 2002; Nicol and Brookes, 2007) and therefore feeding at above maintenance levels to increase body growth will result in greater fibre production. In contrast, very poorly fed animals produce wool that can be termed ‘hunger fine’ which tends to be shorter, fine for its type and is of weak tensile strength.

The value on a per kg basis for wool generally increases as the fibre diameter declines below 30 µm before, a sharp increase in price at 18 µm. Therefore, in breeds such as the merino, in which fleeces are commonly in the range of 16–23 µm (Cottle, 2010), some farmers choose to manage these animals intensively with the aim of ensuring the fleece is as fine as possible (often terms ultra-fine wool) without fibre breakage occurring (Graunt et al., 2010). To undertake this, farmers control daily intake with a balanced diet fed at a maintenance level only and managed intensely to ensure a consistent very fine fibre. It is important to provide constant monitoring of live weight and BCS to ensure an adequate level of feeding, otherwise negative health and welfare impacts can occur. Farmers might be tempted to offer slightly below maintenance levels of feeding to reduce the micron of the fleece further; however, this risks the health and welfare status of the animal and can result in a weak fibre. In Australia to ensure minimum standards of welfare practices, a voluntary Code of Practice for the Welfare of Sheep Housed for Wool Production exists (Graunt et al., 2010).

The fleece has a number of advantages for the sheep from an evolutionary perspective and these include warmth in cold conditions especially when it is wet and windy, it can help the sheep keep cool in very hot conditions, protects the skin against sun damage and reduces food requirements in cool conditions. Humans have selected sheep for increased wool production and the cessation of natural shedding in many breeds to allow for the harvest of wool. However, this has resulted in some disadvantages, especially if the fleece gets too long. These can include ewes being insensitive to cold conditions when lambing which can increase lamb deaths (Dwyer, 2008), limiting the ability of sheep to lose heat in hot conditions and when being moved and manipulated, thereby reducing appetite in hot conditions which can reduce performance, increased risk of casting (being recumbent on their back), limiting vision, accumulation of dung, mud and vegetable matter making the sheep more susceptible to fly strike (maggot infestation) and the elimination of external parasites being more difficult. In fact in
most environments, there is little advantage to the sheep from a thermoregulatory perspective from having a fleece greater than 30 mm (Gregory, 1995). At that length the fleece prevents excessive loss of body heat except in extreme combinations of cold, wet and windy conditions.

In sheep the dissipation of excess body heat occurs via evaporation of water from the respiratory tract via panting and through sweating on the skin surface (Marai et al., 2007). However, sweating in a sheep with a deep wool cover is much less effective. In hot conditions or during movement in heavily woollen sheep, the rate of heat loss is accelerated by increased shallow panting or avoided by reduced feeding activity which can have negative impacts for body weight and average daily gain. Shorn animals are better able to maintain normal behaviour and body temperature (Dikman et al., 2011) and do not display depressed production levels compared with unshorn sheep under hot conditions. Therefore, regardless of environmental conditions non-shedding breeds of sheep need to be shorn at least once yearly.

From a wool quality perspective, in terms of fibre strength, colour and plant matter contamination, the best time to shear a ewe is pre-lambing which in many environments can coincide with winter. Shearing ewes in cold conditions can be risky and if not well managed death can occur (Dabiri et al., 1995; Gregory, 1995). Even at twice maintenance feeding levels a recently shorn sheep can be exposed to its lower critical temperature (4°C) in calm, dry conditions (Gregory, 1995). In many animals, one mechanism used to limit heat loss in a cold environment is to restrict blood flow in the blood vessels of the skin and immediately below the skin. In the newly shorn sheep this mechanism does not seem fully functional and therefore the sheep resistance to cold conditions is below normal for the first few days post shearing. Dabiri et al. (1995) reported that shorn ewes took at least 5 days to return to normal rectal temperature post shearing in the winter. Wind and wetness further increase the risk of cold stress and death (Gregory, 1995). There are a number of management steps that can be put in place to limit the potential for death from cold exposure post shearing; these include avoid shearing when cold, wet and windy conditions are forecast; the use of blades or cover (winter) combs rather than the standard comb which leave a greater stubble depth post shearing (Dabiri et al., 1995); ensuring the period sheep are kept off feed is limited, providing a sheltered area with unrestricted access to feed and return sheep to a woolshed if environmental conditions turn poor. There are potential production benefits besides improved wool quality from shearing ewes in winter. In many environments this coincides with mid-pregnancy. Shearing in mid- to late-pregnancy can be associated with greater lamb birth weight, growth and survival (De Barbieri et al., 2014; Kenyon et al., 2003). However, for these effects to occur ewes need to be well fed and in adequate body condition (Kenyon et al., 2003).

Pre-shearing, the nutrition and access to water of a sheep needs to be limited to reduce the chance of faecal contamination on the wool (often referred to as pen stain). However, exact guidelines are not easily obtained (Anon, 2010). The aim should be to ensure there is enough time off feed to empty the intestine without having a negative impact on the health and productivity of the animal. One group at particular risk is pregnant ewes which are susceptible to pregnancy toxemia if kept off feed for a prolonged period. Although a non-pregnant animal might display little ill effects of being
off feed for 24 h pre-shearing, the time off feed for late pregnant ewes should be limited to less than 12 h. To help facilitate this it is advised that farmers shear pregnant ewes in batches rather than large mobs, so that individual ewes are off feed for shorter periods.

**Intensive farming systems**

Housed or intensive farming systems are clearly different from the environment in which sheep have evolved. An intensive system reduces the ability of sheep to perform normal grazing and foraging behaviour. Although the animal welfare implications of a lack of diet selection and grazing preference have not been well studied (Rutter, 2010), Manteca et al. (2008) suggested that removing the animal’s ability to select its own diet by offering total mixed rations (TMRs) or monocultures compromises their welfare. Under many intensive systems sheep are not given the opportunity to display dietary preference and instead have to select based on what is available. Furthermore, in many intensive systems, utilising TMRs, a constant diet is provided and therefore selection is not possible. In contrast, under unrestricted grazing conditions ruminants will show clear preferences for certain herbage over others and this preference can change based on season and time of day (Cave et al., 2015; Pain et al., 2015; Rutter, 2006). Therefore, it is possible that an animal faced with a TMR may face a level of frustration whenever it feeds, which could impact on its welfare (Rutter, 2010). In support of this, Aguayo-Ulloa et al. (2013) reported that lambs finished on a traditional feedlot ration of barley grain and alfalfa hay had a more natural behaviour repertoire with lower stress levels than those finished on a concentrate-based diet only.

In some pastoral grazing systems, concentrates and or grains can be used to supplement the diet when herbage availability is not adequate to meet nutritional needs. Although it is recognised that at low levels of supplementation there is little to no substitution with pasture, as concentrate levels rise substitution levels increase at a rate of up to 0.5 kg of herbage dry matter per 1 kg of concentrate dry matter (Phillips et al., 2014). Under this scenario the economics of supplementation should be questioned. Care is also advised when offering concentrate/grain supplements to avoid these being a large part of the diet, especially if they contain a lot of starch or if the animals have not been slowly introduced to it, as rumen acidosis and death can occur. Furthermore, ensuring there is adequate space at the trough to enable all animals to obtain their share of the supplement is important.

**Mineral trace(elements) requirements**

Sheep suffering from mineral deficiencies can display a range of symptoms, including impaired animal growth and reproductive performance, poor skeletal growth, poor health and if severe, death can result (Cottle, 2010). The minimum requirements for a range of minerals (macro- and micro-nutrients) which are essential for sheep are well defined as is the management of these minerals in the diet (Grace et al., 2010; West et al., 2009), and a detailed consideration is outside the scope of this chapter. It is probable in many
farming systems there is scope to expand the usage of mineral supplementation through more accurate and frequent testing of appropriate blood/serum or tissue samples (Grace et al., 2010; West et al., 2009) to improve the health, welfare and performance of individual animals. Conversely, there are likely incidents of farmers supplementing animals with minerals when they are not needed, through lack of knowledge of the mineral status of their animals. It is also important that these samples are collected at the appropriate time, which can vary depending on the mineral (Grace et al., 2010).

Many types of herbages used for sheep grazing have mineral levels that are satisfactory from a mineral balance viewpoint. However, when deficiencies do occur in herbages these tend to be associated with low availability of the mineral on a particular soil type and not the herbage type/species offered. Therefore, if appropriate mineral fertilisers are applied to the soil, mineral deficiencies in the herbage which the animals consume can be addressed. Alternatively, there are many short-term treatment options for mineral balance, including oral dosing, subcutaneous injection and insertion of an intra-ruminal bolus. In contrast, when grain and grain-product-based concentrate diets are fed, considerably more care must be taken with mineral levels. In grazing systems the most common trace elements not supplied sufficiently through herbage alone are selenium and iodine (West et al., 2009), while in feedlot systems sodium and calcium are often limiting and therefore added to the ration in the form of salt and limestone (Davis, 2003).

Dietary toxins

Dietary toxins can not only reduce animal performance, but they can adversely affect the health and welfare of the animal and in extreme cases cause death. The common defence against toxic substances is avoidance behaviour which is partly innate while some is learned. Nutritional disorders may arise from alteration to the normal metabolism within the rumen, mycotoxins of fungal origin on or within the plant, or plant-derived secondary components (Nicol, 2007). In addition, problems occur when feed sources which are normally safe suddenly become toxic, such as through fungal infection (i.e. facial eczema) or in nitrate poisoning, or when a new feed source is suddenly introduced into the system. The latter is especially an issue when this new feed source comprises a significant amount of the diet, without its potential impacts being tested first or without it being slowly introduced allowing for adjustment to the new diet. The potential impacts of a given toxin depends on the amount consumed, its form, rate at which it is absorbed and rate of detoxification. Under some environmental conditions the concentrations of potential toxins can be low and therefore have no effect; however, under a different set of environmental conditions, concentrations can rapidly rise. Therefore, farmers need to be aware of environmental conditions and the impact these can have on potential toxins. There are a large range of potential toxins which vary depending on the environment and the farming system. It is outside the scope of this chapter to review toxins in detail and several good reviews are available on the topic (D’Mello, 2000; James et al., 1992; Nicol, 2007; Waghorn et al., 2002; West et al., 2009).
Plants have developed secondary compounds often to protect themselves from predation and damage and these can have negative effects for sheep, but not always. For example, phytoestrogens present in red clover help to protect it from fungal and insect infestation. This compound has little impact on a growing lamb but in a mature ewe, ingesting significant amounts of some varieties prior to and during breeding period can have negative impacts on reproductive performance. Therefore, knowledge of the potential impacts, which classes of sheep are most susceptible and when, allows the farmers to manage this potential problem. It is also important to note that significant progress has been made by plant breeders over recent years to reduce the concentrations of potential toxins. Farmers can also use grazing management to reduce potential exposure. For example, endophyte concentrations in ryegrass, which can cause staggers, heat stress and death, are greatest in the reproductive material of the plant. Therefore, sheep exposure can be limited by ensuring ryegrass does not enter its reproductive stages of growth (i.e. set seed).

**Future considerations**

In the future a greater proportion of consumers, especially in developed countries, are likely to base their purchasing decisions on their perception of how ‘welfare friendly’ a given farming system is. Nutritional level and animal body condition, which is driven by nutrition, are likely to be high on these consumers’ minds. Therefore, those production systems which are dependent on the sale of products to consumers who can afford to be discerning, based on welfare considerations, will need to ensure their animals are fed adequately. In addition, in developed countries, increasingly large processing and selling companies are increasingly implementing quality assurance programmes that their farmer suppliers must meet to encourage consumers to buy their products. These are often associated with nutrition and BCS minima and welfare codes of practice. Furthermore, in many countries legislation is either being put in place, or is being strengthened, to ensure animals receive a minimum level of nutrition and are not below a given level of body condition. These are all likely to be associated with increased compliance costs and will require farmers to be more vigilant with the nutrition of their flocks.

Flock productivity has increased significantly in many countries. However, a potential negative effect of this is that the traditional nutritional sources may no longer meet demand. Therefore, in those countries where cultivation and sub-division or supplementation is possible, there is likely to be increased use of specific herbages, mixes of herbages, grains or grain-based concentrates to meet increased nutritional demands in high performing flocks. However, many of these non-traditional herbages types require specific management and can be associated with increased costs, which may not easily fit into a production system. Therefore, further work will be required to cost effectively integrate these nutritional sources into production systems.

In highly fecund flocks there is likely to be an increase in the use of targeted feeding based on the need of the individual. Currently, there are many instances of inefficient feed use by feeding to the ‘flock average’. There will be increased use of tools, such as electronic identification and ultrasound pregnancy scanning, to identify both
foetal number and foetal age, and body condition scoring to determine which animals have the greatest nutritional need and when exactly that need is. Using a targeted feeding approach based on individual needs may not actually increase overall flock feed demand. This works by reducing the feed allowance to those animals that do not provide a productive response from additional nutrition while increasing the feed allowance of those that will respond. However, targeted feeding requires sub-division of grazing areas and may require the use of high quality feed types, both of which may not be feasible in all sheep production systems.

There has been increased interest in the use of maternal nutrition to developmentally programme offspring, often referred to as foetal programming in mammals. In sheep there is growing evidence of the effects of pregnancy nutrition on the offspring (reviewed by Bell and Greenwood, 2016; Kenyon and Blair, 2014; Meyer and Caton, 2016; Symonds et al., 2016). Therefore, it is possible that in the future, maternal nutritional regimens will be developed to result in the desired outcome being expressed in the offspring. However, further research is still required to identify the exact timing of these interventions, the level and types of nutrition to be utilised and whether the effects observed in the offspring are large enough to warrant the additional nutritional costs involved. Currently, it is clear that under nutrition of the ewe in pregnancy can have negative long-term impacts to the offspring (Kenyon and Blair, 2014). However, it is less clear whether there are long-term advantages or disadvantages of offering ewes feed above-theoretical nutritional requirements during pregnancy.

Conclusions

In developed countries and in those that are export-focused there is going to be increased focus on appropriate levels of nutrition from an animal welfare perspective. However, it should not be forgotten that in all farming environments, if livestock are to perform to their genetic potential they need to be well-fed. Therefore, utilising nutritional regimens and recommendations that meet the nutritional guidelines, for a given environment and genotype, allows for high levels of productive performance, so that animal welfare concerns from a nutritional perspective should not occur. There is going to be a shift in focus towards assessment of individual animal nutritional needs rather than ‘flock’ or ‘group’ needs. Furthermore, the nutritional needs will likely consider not only feed allowance, composition and quality, but also the supplementation of macro- and micro-nutrients. In addition, there is likely to be an increased awareness of body condition scoring as a means of identifying optimal needs for a given individual.

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Predation control

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Introduction

All domestic animals are susceptible to predation, but sheep are especially vulnerable for two main reasons. First, like other domesticated animals, they generally show weaker anti-predator responses than their wild ancestors (Price, 2002). Anti-predator behaviours exhibited by wild sheep are motivated by fear and stress at the detection of a predator and include vigilance, appropriate flight distance, flight to cover, flocking, synchronisation of behaviour, maternal aggression towards predators and posturing and vocalising at the sight of a predator (Dwyer, 2004). In addition, wild sheep avoid using areas where the risk of encountering predators is high (Dwyer, 2009; Mckinney et al., 2003). Reduced expression of these behaviours in domesticated sheep is probably due to elevated thresholds for eliciting stress responses and fearful behaviours as a result of functional alterations in the adrenal glands and reduced reactivity in both the hypothalamic-pituitary-adrenal axis and the sympathetic-adrenomedullary system (Dwyer, 2004; Hemmer, 1990; Künzl and Sachser, 1999). These changes are probably a result of artificial selection for docility and wool, milk or meat production rather than behavioural traits that contribute to defence against wild predators. They could also reflect adaptation to life in enclosures where opportunities to perform anti-predator behaviours are limited and predators are not encountered (Price, 1984, 1999). Even though the thresholds for anti-predator behaviour are elevated in domestic sheep, these behaviours are still exhibited, although this appears to occur at varying levels for different breeds of sheep (Dwyer and Lawrence, 1999; Hansen et al., 2001; Warren et al., 2001). This suggests that some breeds are less capable of dealing with predators than others, and might therefore pay a higher price when grazed in areas where there is a risk of predation (Dwyer, 2009).

Second, due to their intermediate body size sheep are susceptible to a wide range of predator species. Large predators such as wolves and big cats have declined or been eradicated in many parts of the world, mostly because of attempts by livestock producers to protect their animals (Ripple et al., 2014; Treves and Karanth, 2003). However, many smaller predators capable of attacking sheep remain abundant, and feral dogs are a significant threat in many areas. In addition, due to legislative protection, populations of large carnivores are now increasing again in many parts of the world (Chapron et al., 2014).

For these reasons, we can expect the impacts of predation on sheep to be significant in the future, as they have been in the past. In this chapter we provide an overview of
the impacts of wild predators on the welfare of sheep, the measures that are available to protect sheep from predators and the impacts that these measures themselves might have on sheep welfare.

**The impact of predation on sheep welfare**

Predation can have both direct and indirect effects on the welfare of sheep. Direct effects include acute stress and fear induced by attacks and the injury or death that might follow. Indirect effects occur when sheep are chronically affected by stress due to recurrent attacks or harassment by predators.

A quick death resulting from a predatory attack is, arguably, not ‘inhumane’, but attacks by predators often do not cause instant death of the prey. Different predator species have characteristic hunting and killing styles, some being more efficient than others (Curio, 2012; Main, 2001). For example, large felids typically execute a killing bite to the throat, but canids are more likely to maul their victims (Vaughan et al., 2013), causing prolonged distress, fear and pain. Within predator species, killing efficiency also varies between individuals. For example, juveniles are often not very efficient killers due to lack of experience (Gese et al., 1996). Some predators are prone to attacking sheep without completing a kill, instead moving on to pursue and attack other members of the flock (Fleming and Korn, 1989; Woodroffe et al., 2005). This behaviour can leave many injured sheep to either die later from their injuries or be euthanised when found by the owner. Survivors not only experience acute stress and pain of the initial attack, but also have to go through a period of recovery. During recovery, the sheep are likely to be restricted in their movements, segregated from the flock, confined to a small area and handled regularly. All these factors induce stress, and prolonged exposure can lead to chronic stress (Dwyer and Bornett, 2004; Hargreaves and Hutson, 1990; Niezgoda et al., 1987).

For animals not directly attacked, the fear and distress provoked by the approach of predators is likely to cause acute stress of a temporary nature. Temporary bouts of acute stress may in fact be beneficial in promoting the expression of anti-predator behaviours that increase the likelihood of surviving current and subsequent encounters with predators. The loss of a lamb or other familiar individuals can also induce stress in sheep (Napolitano et al., 2008; Newberryl and Swanson, 2001; Newberry and Swanson, 2008) as the bond between an ewe and her lamb is strong (Arnold and Pahl, 1974; Arnold et al., 1979) and sheep are social animals that recognise their group members and form relationships with other individuals (Boissy and Dumont, 2002; Lawrence and Wood-Gush, 1988; Ligout and Porter, 2003). Therefore, in addition to the acute stress from the attacks themselves, regular loss of flock members killed by predators probably also represents stressful events (Newberryl and Swanson, 2001). Repeated exposure to acutely stressful events can create a state of chronic stress (Clinchy et al., 2013; Dwyer and Bornett, 2004). Chronic stress can have long-lasting impacts on welfare as it can affect the immune response, suppress reproduction, reduce production outputs or cause changes in behaviour (Dwyer and Bornett, 2004). The effects of recurrent incursions by predators in causing chronic stress and reducing
performance of flocks may be significant, but they are often unrecognised as many of
these effects are not clearly associated with particular incidents of predation. This is
an area of sheep welfare that would benefit from more research.

**Protecting sheep from predators**

There are many different options for protecting sheep from predators, but they can be
divided broadly into lethal control, which involves killing of wild predators, and non-
lethal control, which uses various methods to reduce the exposure or susceptibility of
sheep to predation.

**Lethal approaches**

Lethal control of predators is often undertaken by using poisons or traps or by hunt-
ing. Lethal control programs can be classified into four types (Treves and Naughton-
Treves, 2005). First, eradication campaigns that aim to remove all predators from a
defined area by any means possible. Such campaigns have been successful in the past,
especially for large-bodied predators with low population densities and low popula-
tion growth rates (Ripple et al., 2014; Woodroffe, 2000). Second, culling programs
that aim to reduce population densities of predators in the vicinity of livestock on the
assumption that fewer predators means fewer attacks (Wagner and Conover, 1999).
Third, recreational or commercial hunting that may be permitted or encouraged to re-
duce the general abundance of predators that threaten livestock (Linnell et al., 2001).
Fourth, killing or removal of individual predators known or suspected to be guilty of
preying on livestock; this highly targeted approach may be used to ameliorate damage
from threatened or endangered wildlife (Treves and Naughton-Treves, 2005).

With correct application and sufficient effort, all types of lethal control of predators
can reduce livestock losses, at least temporarily (Treves and Naughton-Treves, 2005).
However, the long-term effectiveness of culling programmes, regulated hunting or
selective removal of problem individuals has never been properly evaluated in studies
with a rigorous experimental design, and it is therefore unclear (Treves and Naughton-
Treves, 2005). On the other hand, all forms of lethal control of predators have well-
documented drawbacks and pitfalls. Reduction in livestock loss due to lethal con-
trol is typically short lived as predator numbers recover rapidly through immigration
(Allen and Gonzalez, 1998; Brainerd et al., 2008; Robinson et al., 2008; Saunders
et al., 2002). In some cases when predators are abundant, lethal control has no effect
on rates of attack on livestock, as predator numbers cannot be reduced sufficiently.
Ironically, lethal control can actually lead to an increase in livestock predation instead
of a decrease (Allen, 2000; Peebles et al., 2013; Treves et al., 2010; Wielgus and Pee-
bles, 2014). This increase is probably a result of the fact that young male animals are
over-represented among the animals that immigrate, following removal of resident
predators (Allen, 2000; Peebles et al., 2013). Such animals might be more likely to
attack livestock—especially vulnerable animals like sheep—due to a combination of
aggression and lack of experience in hunting of wild prey. In social species of predators that hunt cooperatively, these effects can be exacerbated by the social disruption and associate changes in space-use that result from lethal control (Allen, 2000; Peebles et al., 2013; Wielgus and Peebles, 2014). In all the circumstances described previously, it is the case that even though attacks on sheep might be reduced in the short term by lethal control of predators, sheep continue to be exposed to predation and are subjected to both acute and chronic stress caused by predator incursions.

There are other objections to lethal control, some of these depend on the method used to kill animals. Traps and poisons cause suffering in the target animals and may also affect non-target species or individuals that are not responsible for attacks on livestock (Davidson and Armstrong, 2002; Glen and Dickman, 2003; Treves and Naughton-Treves, 2005). Use of poisons may also place working and pet dogs at risk. Lethal control of top-order predators disrupts the ecological services provided by these predators in regulating ecosystem functioning and sustaining biodiversity (Ripple et al., 2014; Ritchie and Johnson, 2009; Terborgh et al., 2001), and in many cases is in conflict with societal goals of conserving native carnivores. Disruption of ecosystem services can also be counterproductive to livestock production if a smaller predator takes the place of the top-order species at a higher density, leading to an increase in livestock losses (Gompper, 2002; Pearson and Caroline, 1981; Prugh et al., 2009). For example, the extirpation of wolves across much of North America resulted in increased abundance of coyotes Canis latrans (Newsome and Ripple, 2015), which became important predators of sheep.

For all these reasons, killing wild predators is increasingly limited by legislation that aims to conserve these animals or mandates their humane treatment (Treves and Karanth, 2003). Accordingly, non-lethal methods for predator control are often encouraged, and in some cases may be the only options available to livestock producers (Landry et al., 2005; Marker et al., 2005b).

Non-lethal control

There are many non-lethal livestock protection methods that are derived from a wide range of management practices in different parts of the world. This section provides a short overview of the effectiveness and feasibility of these methods.

Shepherding. In shepherding, a shepherd is continually present with the sheep and tends, herds, feeds and guards the flock. Many pastoral cultures have a long tradition of shepherding. This tradition persists in many parts of the world, both in traditional societies, for example Africa or Asia and in more western cultures such as in the USA or Western Europe. Shepherded flocks are often small but can number a thousand sheep or more. Shepherding is an effective strategy for reducing predation (Jackson et al., 1996; Ogada et al., 2003; Wang and Macdonald, 2006; Woodroffe et al., 2007). Shepherds prevent their animals from wandering, restrict access to areas with high predation risk, encourage flocking behaviour and directly repel predators and thieves (Atickem et al., 2010; Coppinger and Coppinger, 2001; Rigg, 2001).

Night confinement. Similar to shepherding, many pastoral cultures have a long tradition of night confinement, and it is still widely practised in many parts of the world.
Most predation on sheep happens at night, so losses can be reduced by keeping sheep in night enclosures where they are more easily protected (Jackson et al., 1996; Ogada et al., 2003; Woodroffe et al., 2007). However, if predators break into a night enclosure, they get easy access to large numbers of trapped sheep (Patterson et al., 2004). Therefore night confinement is often combined with guarding by people or dogs (or both). The use of night confinement as a predator control methods is probably only practical for a small to medium number of sheep due to the labour intensive nature of the method (Fig. 9.1).

**Management of sheep distribution.** Predation risk is often highest in certain habitats such as forest or woodland and can be reduced if sheep are kept away—by fencing, shepherding or other means—from such habitats (Bradley et al., 2005; Ciucci and Boitani, 1998; Michalski et al., 2006; Robel et al., 1981).

**Management of lambing.** Lambs are more vulnerable than mature sheep. Attacks on lambs can be reduced if ewes are kept under close supervision, for example in a paddock close to the homestead or in sheds during birthing (Moberly et al., 2003; Robel et al., 1981; Saunders et al., 1995). Sometimes, the timing of lambing can be controlled to reduce risk. For example, coyotes are more likely to kill livestock during pup rearing (Till and Knowlton, 1983), so sheep should not be lambing at that time.

**Carcass disposal.** Sheep carcasses can attract predators (Fritts, 1982; Lehner, 1976) while also providing a food resource that boosts predator numbers (Yom-Tov Shoshana, 1995). Also, scavenging on carcasses could teach predators to feed on livestock (Lehner et al., 1976). Removal of carcasses whenever possible is, therefore, likely to reduce the risk of predation.

**Fencing.** It can be used to exclude predators from areas grazed by sheep and also to prevent sheep from using risky areas. Two types of fences can exclude predators: wire
mesh and electric fences. There are specific mesh-fence designs for exclusion of a range of species that prey on sheep, including coyotes, bears, foxes, dingoes and other dogs (Decalesta and Cropsey, 1978; Fleming et al., 2001; Kang and Huaidon, 2011; Moseby and Read, 2006). Electric fences have been shown to reduce or eliminate predation by coyotes on lambs (Dorrance and Bourne, 1980; Gates et al., 1978; Linhart et al., 1982) and exclude dingoes from flocks of sheep (Bird et al., 1997; Long and Robley, 2004). They are used for the exclusion of many other carnivores from livestock areas. Erecting and maintaining predator-proof fencing can involve a substantial financial and time investment. Proper maintenance is essential to success, as any breach of the fence renders it less effective or useless (Fleming et al., 2001; Linhart et al., 1982; Nass and Theade, 1988) (Fig. 9.2).

Livestock guardian animals. A variety of domesticated animals can be used to guard sheep, of which dogs, donkeys, mules, llamas and alpacas are the most popular. Livestock guardian dogs (LGDs) originate from Europe and Asia, where they have been used for centuries to protect stock from predators and thieves. Their use is now increasing in many parts of the world (Marker et al., 2005a; Van Bommel and Johnson, 2012). LGDs are raised with sheep (or other livestock) from an early age and they become bonded to them (Coppinger and Coppinger, 2001, 2007). As adults they accompany their livestock and display strong affiliative and protective behaviour towards

Figure 9.2 A wire mesh fence surrounding a sheep and cattle grazing property in Queensland, Australia, designed to exclude dingoes and other dogs.
them. They provide protection in three main ways: by directly confronting predators that approach ‘their’ livestock and driving them off (Lorenz and Coppinger, 1986; Mcgrew and Blakesley, 1982), by disrupting the prey-seeking and hunting behaviour of predators (Coppinger et al., 1988; Coppinger and Schneider, 1995) and by establishing territories that wild predators avoid and from which they are actively excluded by the LGDs (Mcgrew and Blakesley, 1982; Van Bommel and Johnson, 2015), a form of protection that is probably most effective against other canids.

There is good experimental and comparative evidence that LGDs can be effective in protecting many types of livestock, including sheep, from a range of predator species, including canids, felids, mustelids and ursids (older studies reviewed in Rigg, 2001; see also Gehring et al., 2010b; Hansen et al., 2002; Marker et al., 2005a; Otstavel et al., 2009; Rigg et al., 2011; Van Bommel and Johnson, 2012). They are equally effective on small farms guarding a few animals, as they are on extensive rangeland properties, guarding thousands of animals (Van Bommel and Johnson, 2012). In addition to protecting livestock from predators, LGDs can provide benefits to livestock production by deterring wild herbivores from livestock paddocks (Gehring et al., 2010b; Vercauteren et al., 2008), although this can be undesirable if a threatened or endangered species is involved (Gingold et al., 2009). There can be disadvantages to using LGDs (Gehring et al., 2010a), mainly related to the time and effort required to properly raise and manage them, and to the occasional expression of undesirable behaviours such as roaming (Gehring et al., 2011; Green and Woodruff, 1990; Lorenz and Coppinger, 1986) (Figs 9.3 and 9.4).

Figure 9.3 A Maremma sheepdog on a hobby farm in Victoria, Australia, living with a small flock of sheep to protect them from predators.
Use of donkeys or mules to protect sheep is relatively new but is increasing (Jenkins, 2003; Landry, 1999; Walton and Feild, 1989). Donkeys and mules are sociable animals that readily attach themselves to flocks. They are capable of attacking or intimidating predators that approach too closely, and this behaviour indirectly protects the sheep accompanying them (Bourne, 1994; Braithwait, 1996; Green, 1989). They have low maintenance requirements, and are long lived and quite inexpensive. Little research has been done on the effectiveness of donkeys or mules in protecting sheep, but anecdotal evidence indicates that they can be effective (Jenkins, 2003; Marker-Kraus and Fund, 1996; Walton and Feild, 1989). However, not all individual donkeys or mules make good guardians. In addition, they are probably effective only in small areas (<240 ha), with small numbers of stock (max. 200 individuals), and can only work alone or in pairs, as in larger numbers they prefer to associate with their own species rather than other livestock (Bourne, 1994; Green, 1989; Walton and Feild, 1989).

Llamas and alpacas work in ways similar to donkeys and mules, with the same advantages and limitations, although they are more expensive to purchase initially. Like donkeys and mules, their popularity is increasing (Mahoney and Charry, 2005; Meadows and Knowlton, 2000; Tyrell and Hunt, 2008). Evaluations show that they can reduce or eliminate predation (Franklin and Powell, 1994; Mahoney and Charry, 2005; Meadows and Knowlton, 2000). Little is known about optimal flock or paddock size for these guardian animals, but llamas have successfully guarded up to 1000 sheep in a variety of pasture situations (Markham et al., 1993). They are probably effective

against smaller sized predators only, as they are themselves vulnerable to larger predators (Linnell et al., 1996; Mahoney and Charry, 2005).

Running sheep with cattle can also provide some protection for sheep. Due to their larger size and more hostile behaviour towards predators, cattle are more capable than sheep in intimidating some predators (Anderson, 1998). Therefore, sheep that remain close to cattle and seek refuge with them, when threatened, receive some protection. Cattle and sheep do not ordinarily choose to graze together (Anderson et al., 1985). For this to happen, lambs need to be raised in close association with cattle (Anderson, 1998; Anderson et al., 1996; Fredrickson et al., 2001). This initial bonding need only be accomplished when a mixed-species system has been established first, as subsequent generations of lambs acquire loyalty to cattle from their mothers (Hulet et al., 1992). Cattle have been found to protect lambs from predation by coyotes (Hulet et al., 1987, 1989), but little is known about their effectiveness against other predators.

Other non-lethal measures. The approaches summarised previously have been used more or less successfully, depending on context. We now summarise a diverse set of alternative approaches that have limited application or appear to be less effective despite major efforts to develop and test some of them.

Many repellent substances and devices have been used in attempts to keep predators away from sheep or disrupt their hunting behaviour (Bomford and O’Brien, 1990; Koehler et al., 1990). Visual and acoustic repellents—sirens, flashing lights, fireworks and flare guns—have been variously deployed against wolves, bears, coyotes, mountain lions, foxes and bobcats (Fritts, 1982; Fritts et al., 1992; Linnell et al., 1996). Initially, wild predators often find unusual stimuli alarming and avoid them when they are concentrated in small areas. However, most predators have flexible behaviour and habituate quickly to stimuli that are not actually threatening. For example, predation by coyotes can be reduced by using visual or acoustic stimuli but these retain their effectiveness for only 3 months or less (Linhart, 1984; Linhart et al., 1992; Pfeifer and Goos, 1982). Biologically significant sounds such as distress or alarm calls or ultrasonic noisemakers can also be used as acoustic repellents but there is little evidence on their effectiveness (Bomford and O’Brien, 1990; Edgar et al., 2007; Koehler et al., 1990).

Chemical repellents are typically substances that cause irritation to the mouth of a predator or produce repellent odour. They can be applied directly to sheep or to fence lines or fence posts (Shivik, 2004). Again, trials with such repellents sometimes demonstrate short-term effects in small areas, but large-scale or long-term application is ineffective or impractical (Burns and Mason, 1996; Lehner, 1987; Landa et al., 1998). Mechanical protection collars that do not contain a chemical repellent but physically protect a sheep’s neck from predator bites are also used in several European countries; however, their effectiveness has not been evaluated (Linnell et al., 1996). Chemical repellents could also be based on biologically significant odours such as scent marks left by territorial predators to mark territorial boundaries. A trial in which scent marks of coyotes were artificially created in hopes of repelling coyotes failed as it attracted them instead (Shivik et al., 2011).

Fladry, that is, flags or ribbons hung along a line to demarcate a boundary, can deter some predators from crossing that boundary. This is evidently quite effective against wolves (Davidson-Nelson and Gehring, 2010; Musiani and Visalberghi, 2001; Musiani
but less so for other predator species (Mettler and Shivik, 2007; Shivik et al., 2003). Fladry probably deters wolves when it is unfamiliar and elicits a neophobic response. Eventually, even wolves become habituated to it and its effectiveness in preventing access is lost. Electrifying the wire on which the flags are suspended (creating ‘turbo fladry’) increases effectiveness but adds to cost (Lance et al., 2010).

Conditioned taste aversion develops when an animal learns to associate the taste of a particular food with illness and therefore avoids that food (Garcia et al., 1974). There have been attempts to condition predators to avoid preying on sheep by feeding them sheep meat laced with illness-inducing chemicals. Aversion can be developed in this way in captive trials (Gustavson et al., 1983), but this is not effective in preventing the predators from killing sheep (Burns and Connolly, 1980; Hansen et al., 1997). Most field trials of the method suffer from poor experimental design, especially lack of controls (Griffiths et al., 1978; Sterner and Shumake, 1978). One well-designed study found no effect of conditioned taste aversion on predation rates (Bourne and Dorrance, 1982). Killing of prey is probably elicited by specific prey behaviours, and this may be independent of conditioned taste aversion (Sterner, 1995).

The impact of predator control methods on sheep welfare

While the impact of predation on sheep welfare is clear, the welfare impacts of the different predator control methods themselves are often not considered. These impacts can be twofold. First, they consist of the effectiveness of the control method in preventing attacks as discussed in the previous section. Second, there are the direct effects of the methods on sheep. These are explored later.

Some practices that reduce exposure of sheep to predators can themselves have negative impacts on sheep welfare. Regular confinement can increase stress levels (Dwyer and Bornett, 2004; Manteca and Smith, 1994; Sevi et al., 2009). This is especially the case when there is animal over-crowding or when animals are provided with insufficient food, water or ventilation (Caroprese et al., 2009; Manteca and Smith, 1994; Sevi et al., 2009). Ewes prefer to lamb in isolation (Gonyou and Stookey, 1985) and select distinct habitat features for birth sites (Alexander et al., 1990). These behavioural needs cannot be met in confinement and this can increase stress levels during lambing (Dwyer, 2009). Repellents used to deter predators could have similarly alarming effects on the sheep they are intended to protect. Loud noises and bright, flashing lights elicit fear and stress responses in sheep (Grandin, 1989; Brouček, 2014). The hearing range of sheep also extends well into the ultrasonic domain (42 kHz) (Kendrick, 2008), so sheep might experience stress or fear in response to ultrasonic noisemakers (Algers, 1984; Morgan and Tromborg, 2007). Repellents mainly operate at night, leading to a disturbed sleep pattern, which reduces welfare in the sheep (Brouček, 2014). The variable schedules that are often used on these devices to prevent habituation of predators will also delay habituation in sheep, increasing the length of time during which the welfare of the sheep is negatively impacted. In addition, if a movement sensor is used to trigger the repellent when the predator approaches, it could trigger an even higher stress response in sheep once the predator habituates to the stimuli, as in that case the
repellent will signal an impending predatory attack. Chemical repellents with a strong odour may be unpleasant to sheep as well as to predators. Chemical repellents may also be unsafe when applied to sheep, causing injuries or irritation to skin (Botkin, 1977; Lehner et al., 1976).

Other protection measures can have direct benefits for welfare. Removal of carcases is not only good management of predation, but can also help prevent diseases. Managing sheep distribution can also benefit sheep welfare. Wild sheep avoid habitats such as dense forests where evading predators is difficult and preferably occupy suitable terrain to escape from predators (Dwyer, 2009; Mckinney et al., 2003). This anti-predator strategy is probably also present in domestic sheep (Dwyer, 2009). Therefore exclusion of sheep from high-risk areas such as forests should help meet the sheep’s behavioural needs and reduce stress. However, areas where sheep are grazed should ideally not only exclude high-risk features, but also contain suitable escape terrain; Merino sheep displayed more alarm behaviours in flat, open paddocks than in a more complex terrain (Stolba et al., 1990). Fences are often used to restrict livestock movements and when properly designed, they can be an effective predator control method in addition to being a stock management tool. However, if fences fall into disrepair, they can increase the risk of injury to sheep.

Livestock guardian animals can affect sheep welfare both positively and negatively. The initial introduction of a new livestock guardian animal can be a frightening experience for sheep, although this effect should be short lived (Franklin and Powell, 1994; Green and Woodruff, 1990; Van Bommel, 2010). Guardian animals can sometimes harm or harass the sheep. Most LGDs go through a boisterous juvenile phase in which they can display rough play behaviour towards livestock, potentially harming them in the process (Green and Woodruff, 1990; Van Bommel, 2010; Lorenz and Coppinger, 1986). Some donkeys can become aggressive at lambing time and injure lambs (Bourne, 1994; Walton and Feild, 1989); llamas can also be aggressive towards ewes or lambs (Franklin and Powell, 1994; Meadows and Knowlton, 2000). However, proper training and management of guardian animals can prevent or eliminate these problem behaviours (Green and Woodruff, 1990; Meadows and Knowlton, 2000; Walton and Feild, 1989).

Once a guardian animal is established in a flock, sheep come to rely on it for security. When threatened, they will often run towards their guardian and stand behind it as the guardian faces the threat (Coppinger and Coppinger, 2007; Hulet et al., 1987; Walton and Feild, 1989). Sheep that are guarded by a LGD also travel further than sheep not guarded, indicating they spend less time being vigilant and more time grazing and moving (Webber, 2012). Further, sheep without a guardian dog appear to stay near areas that are proven safe from predation or that allow them to stay in closer proximity to other sheep (Sibbald et al., 2008). These observations suggest that the presence of a guardian dog reduces stress in sheep and may, therefore, have many benefits for health and performance. Many sheep farmers who use guardian dogs report that their animals remain calmer and are, therefore, easier to manage (Van Bommel, 2010). Although these effects of guardian dogs on welfare and performance of sheep have not been rigorously studied, they could be a fruitful area for research. Other guardian animals, including shepherds, could have similar effects.


Conclusions

The direct and indirect effects of predation on sheep can severely affect sheep welfare and performance. There are many options for protecting sheep against predation, but the suitability of different methods is greatly influenced by the scale of the production system. Some methods such as night confinement or lambing in sheds are suitable for small to medium-sized flocks but would be too labour intensive for use with large numbers of sheep. Therefore, for individual farmers, the choice of a method is typically based on cost, in money and time, and legality, which depend on the scale of the enterprise and the geographical area where it is located. In addition, the perception of likely effectiveness also plays a large part in choosing a method. However, impacts on welfare of the sheep should also be considered.

Among non-lethal predator control methods, sheep management practices, fencing and livestock guardian animals can provide long-term and effective protection from predation. Repellents and deterrents are either ineffective or temporarily effective. Lethal control of predators typically produces short-term relief at best, and continuous or large-scale effort is required to hold predation at acceptable levels.

Many of the effective non-lethal predator control methods have an impact on sheep welfare themselves. For some of these methods, the impact is negative and in the interest of the welfare of the sheep, the negative impacts of the methods should either be minimised or another more appropriate method should be selected. However, in many cases management techniques such as night confinement or lambing under close supervision are the most feasible or only methods available for livestock owners to prevent predation on their sheep. In any case, the welfare impact of these management techniques is preferable to the impacts of predation, and the negative impacts of these methods should be minimised. Other methods can provide a benefit to livestock. Probably, the most substantial welfare benefits are provided by livestock guardian animals whose presence appears to greatly reduce stress levels in sheep. The same can probably be achieved with the presence of a sheepherder. The total impact of a predator control method on sheep welfare is a combination of its effectiveness in preventing predation and the direct impact of the method itself. Considering both these aspects, it would seem that the method that does most to enhance sheep welfare is the use of livestock guardian animals, and perhaps sheepherders.

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Managing disease risks

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General introduction

There are many descriptions of the different elements that define animal welfare, some of which are ambiguous and potentially allow for selective interpretation, depending on the circumstances to which they are applied. The World Organisation for Animal Health (OIE) has a mandate to ensure good standards of animal welfare, defined as being the state of the animal in coping with the conditions in which it lives. Animals are considered to be in a good state of welfare only if there is scientific evidence to show that they are ‘healthy, comfortable, well nourished, safe, able to express innate behaviour, and not suffering from unpleasant states such as pain, fear, and distress’. This broadly aligns with the UK Farm Animal Welfare Committee’s five freedoms: from hunger and thirst; from discomfort; from pain, injury or disease; to express normal behaviour; and from fear and distress (Farm Animal Welfare Council. Five Freedoms. http://fawc.org.uk/freedoms.htm). Each of these indices of good animal welfare states is relevant to the concept of planned animal health management, including the principles of disease risk management. Conversely, animals that are not in a good state of welfare are invariably unhealthy and susceptible to infectious disease. Although there is more to ensuring good animal welfare than just animal health management, and vice versa, the two topics are inextricably linked and the management of disease risks is an integral part of good welfare management. The principles of sheep welfare discussed in this chapter are equally applicable to all commercially farmed small ruminants.

The five freedoms, in turn, are discussed as follows: (1) failure to provide freedom from hunger and thirst can result in nutritional deficiencies and stress. These are important risk factors in causing metabolic diseases such as pregnancy toxaemia and hypocalcaemia, and infectious disease outbreaks such as salmonellosis or systemic pasteurellosis. Conversely, avoidance of hunger and thirst is necessary for the prevention and management of these welfare-compromising diseases. (2) Sheep that are kept in predominantly uncomfortable conditions are generally ill thrifty due to altered feeding behaviour and increased metabolic requirements for maintenance, while predisposed to build up of infectious challenge causing physical insult and lameness or respiratory disease. Common examples of uncomfortable conditions causing poor sheep welfare include grazing on permanently wet pastures without a dry lying area; feeding on standing root crops without the provision of a suitably drained hard run-off area; and housing in poorly designed, overcrowded and inappropriately bedded...
buildings. (3) Failure to provide freedom from pain or injury has obvious production consequences, while physical harm and many chronic infectious diseases are painful. (4) The production success of sheep management systems such as those allowing sheep to select where they graze on extensively managed Scottish hills, referred to as hefting, or easy care sheep management founded upon avoidance of disturbance of lambing ewes, depends on enabling animals to express natural behaviour. Animals that are not free to express innate behaviour are often unhealthy, for example goats are natural browsers, but when kept intensively are forced to graze, introducing helminth parasite health challenges while reducing natural protection through natural plant secondary metabolites in browsed herbage. (5) Animals that are frightened or distressed do not eat and are predisposed to stress-related metabolic and infectious diseases.

Welfare encompasses both physical and mental health (Webster et al., 2004), and while good physical health is essential, it alone does not necessarily lead to good mental well-being, as in the case of sheep that are intensively managed in uncomfortable accommodation, which may be healthy and productive, but may not experience a ‘good life’ (Yeates, 2012).

**Importance of small ruminant welfare within the primary context of global food security**

Continuing improvement of the efficiency of food production through the 21st century is a global priority to meet the needs of the world’s growing population. Climatic conditions impact upon the seasonal availability of energy, nitrogen, phosphates, organic manure and water. The temporal opportunities for and constraints to agricultural production imposed by these climatic factors tend to be greatest in those regions where increased food production is most needed to alleviate poverty. In these regions, seasonally available natural resources generally cannot support efficient production of crops for direct human consumption, but are suited to the growth of herbage that can be utilised by food-producing ruminant livestock.

Goats are generally more efficient than other domesticated ruminants in their metabolism and tolerance of poor quality and potentially toxic nutrients and conversion into food products, while sheep are adapted to convert short herbage to milk or meat. Different small ruminant breeds and production systems have been developed to suit local resources and exploit the complementary benefits of co-management in seasonally biodiverse environments. Consequently small ruminants have become the main livestock economic resource in those impoverished regions where improved food production efficiency is most urgent, and discussion of animal welfare is arguably most relevant within this context.

When addressing efficiency and sustainability of small ruminant production, resources must be utilised and food produced in a manner that minimises environmental footprints, meets high animal welfare standards and is socially acceptable. However, global small ruminant livestock production is inherently inefficient with regard to utilisation of seasonally available herbage and the goal of small ruminants playing a role
in alleviating poverty in a welfare-friendly manner is seldom achieved. Unproductive animals must digest and metabolise more nutrients than their efficiently managed counterparts to produce the same yield of meat or milk product. Thus, in addition to compromising animal welfare, inefficient small ruminant farming causes unsustainably high levels of greenhouse gas production, arising from the level of forestomach microbial digestion per unit of food produced. Failures of small farming to sustainably alleviate poverty must, therefore, be investigated and addressed through interdisciplinary research before it can become a solution to the challenge of socio-economically and environmentally sustainable global food security.

The current inefficiency of global small ruminant agriculture in terms of conversion of natural resources into human food, especially when compared to pig, poultry and fish production, presents important opportunities to translate research findings and development of sustainable husbandry and health management into efficient utilisation of natural resources in target environments. Improved sheep management through the application of precise strategies to make more efficient use of natural resources in seasonally limited environments and/or as an integrated part of general agricultural systems, is needed for increased food production and socio-economic development in response to population growth. This provides a platform for better animal welfare.

Non-productive growing animals may be slower to reach finishing or breeding weights, and are consequently more susceptible to secondary diseases than their productive counterparts. For example, lambs that are slow to finish are predisposed to further production and welfare-limiting helminth parasitism, trace element deficiencies, lameness and mange. Conversely, attempts to improve productivity can introduce disease risks and compromise welfare if they are not accompanied by appropriate disease risk management. For example, grain feeding introduces the risk of ruminal acidosis, while genetic improvement may result in selection of animals that are less able to cope with nutritional and environmental constraints or endemic disease threats.

Management of disease risks with reference to improved food production

There has been a tendency to promote genetic improvement as the foremost solution to redress failures of sheep production to meet global needs for food security. However, sheep breeding and genetic selection technologies will only succeed if the animals are first kept alive, in a good state of welfare and productivity. Breeding selection criteria have generally focused on particular production traits such as prolificacy and milk production, but have often failed to consider the suitability of individual improved animals to their target environment, with reference to nutritional and disease constraints. Genetic improvement in sheep kept in seasonally resource-limited regions has generally not been matched by a corresponding improvement in nutrition, health and welfare management. There are notable exceptions such as selection of animals that are resistant to blowfly strike, endoparasitic infections or foot rot. There has been a secondary focus on technological advances, for example developing sheep-housing design.
Resistance to anthelmintic drugs has become problematic in the control of nematode and trematode sheep parasites, threatening sustainable production and animal welfare. There has been a focus on the selection of animals that are resistant or resilient to helminth parasites, albeit this cannot afford a solution unless undertaken along with the adoption of new technologies. These include the utilisation of electronic identification devices and automated weighing and shedding systems, linked to models of predicted animal performance under specific herbage growth conditions, to precisely target anthelmintic drug treatments only towards animals requiring it (Greer et al., 2009). This addresses both the welfare needs of individual animals and the epidemiological principles underpinning helminth management at a group level while reducing the rate of selection for anthelmintic resistance.

Thus, for extensive, low input environments, while animal health problems are not the only cause of low production and poor welfare, planned sheep flock health management affords greater opportunities for rapid improvement than genetic selection for production traits or technological advance. Equally, in intensive production systems, technological advance and genetic improvement achieves little unless undertaken in conjunction with planned flock health management. The sheep flock prevalence of a range of production-limiting pathogens is generally very high, hence the development of pragmatic, problem-focused approaches to diagnosis and management of disease and control of the infectious diseases that they cause are important in ensuring good productivity. The epidemiology of most disease outbreaks depends upon environmental, climatic and animal management factors, and basic animal husbandry and health management problems are often the primary causes of failure to meet global food security needs. For example, the requirements of lambs for an early colostrum feed and hygienic environment are often overlooked in situations where the first priority of their owners is to ensure adequate nutrition for the dam to be productive. The consequences of this scenario are neonatal diseases and mortality, which are inefficient and impart obvious welfare problems.

The application of scientific health planning principles to integrate animal genetic selection with good nutrition, husbandry and disease management is a prerequisite for improved sheep productivity and welfare to meet global needs for food security. Production of food from livestock is important: first to feed the animals’ keepers and second to address the need for global food security. The latter relies on trade and the ability to market animals, which necessitate demonstration of high standards of animal welfare.

**Promotion of animal welfare within the context of food production efficiency**

Animal welfare is sometimes perceived as being the preserve of affluent society, but less relevant to uncompromising agribusinesses or impoverished individuals caring for small numbers of animals. However, the need for demonstrably good standards of animal welfare is important, regardless of the economics of livestock production.
Convincing large-scale livestock agribusinesses of the need to provide assurance of high standards of animal welfare is generally supported by the positive impact of promoting such action on trade and product marketing. Sheep products are now sold in developed countries with an audit trail linking to the farm of origin, or to the nature of the resource on which the animals were reared in a welfare-friendly manner. However, promotion of the relevance of animal welfare to individual sheep keepers who care for their animals, but struggle to feed and house their families is potentially awkward. It is commonplace for impoverished people to live in close contact with their animals with human welfare standards that are lower than those expected of their animals by meat consumers in developed countries.

Impoverished people living in seasonally resource-poor environments have a close cultural relationship with small ruminant livestock, which they depend upon for their livelihood. People living in these environments are aware of the zoonotic disease risks associated with close contact with animals, for example swine flu, avian influenza and Kyasanur forest disease. Small ruminant-specific zoonotic health risks are generally more insidious or less well known. Examples include chlamydial abortion, orf, cryptosporidiosis, hydatid disease, fleas and scabies. Hence, improved animal health and welfare has multiple benefits to human well-being, potentially addressing challenges of food security and animal welfare needs, having obvious socio-economic and environmental benefits, and improving human health standards through the control of zoonotic diseases and by ensuring a healthy diet.

Primary concern for animal welfare ahead of consideration of animal production is a luxury that can only accompany a relatively high level of affluence. Poor people probably care deeply for their animals, but may not feel that animal welfare is affordable. In fact, their own welfare often reflects that of their animals and vice versa. The need to focus on keeping small ruminants alive as short-term cash reserves surpasses investment in animal welfare. Nevertheless, ensuring the best welfare standards of animals that are subject to human care or influence is a fundamental creed worldwide. In these scenarios in which many of the world’s small ruminants are kept, the most pragmatic means of addressing animal welfare is to focus on animal production and management of disease risks.

The OIE prioritises animal welfare standards with an important agenda of maintaining international trade (Bayvel, 2002). Consumers in relatively affluent countries now demand reassurance that their food is produced in a welfare-friendly manner irrespective of whether they understand the principles underpinning good animal welfare. Meat and meat products are now sold in a way that provides reassurance about good welfare standards. This has given rise to the inclusion of welfare in the concept of quality assurance both to promote products and in certain circumstances to regulate farmer suppliers. Suppliers must provide assurance that they comply with farm animal welfare requirements to competitively market their products. Traditionally, this was limited to proxies for welfare, irrationally focusing on the physical environment in which the animals were kept and not the animals themselves. However, increasingly, the disease status of slaughter animals and health status of the flocks and herds from which they originate are used as animal indices of welfare. Slaughter sheep are inspected ante-mortem. Identification of signs of systemic disease, local
disease such as lameness or injury is clear evidence of poor welfare and may result in exclusion from quality assurance schemes, slaughterhouse rejection and/or prosecution. Post-mortem identification of signs of systemic disease may result in carcase condemnation, while signs of disease in offal results in their rejection. These findings are recorded and can provide indices of animal welfare. For example, persistent high levels of rejection of livers in animals consigned from a holding provides evidence of production-limiting disease and pain. Although cases of fasciolosis may be unavoidable, failure to instigate appropriate planned preventive measures is a tangible indication of poor welfare standards. In this regard, abattoir feedback provides both an index of animal welfare and the basis upon which intervention can be planned.

Although some of the constraints to improved productivity can be addressed by prescriptive methods, most cannot. Instead, improved productivity requires a holistic, iterative veterinary health planning approach, based on rational, problem-focused diagnosis, management, prevention and control of disease, with responsible and sustainable use of remedies, rather than dependence on pharmaceutical treatments.

**Clinical evaluation of individual animals**

Sustaining good states of sheep welfare depends upon the ability to recognise signs of abnormal behaviour indicative of disease, injury, stress or discomfort in individual animals. This requires a sound individual animal-focused clinical diagnostic approach. Conversely, the reward gained from clinical examination and successful treatment of individual sheep is not necessarily matched by a positive impact on animal production, and the cost of treatment often outweighs potential production benefits. For example, some injuries take a long time to heal during which time the animal is suffering, while many diseases have lasting impact visible in terms of the animal’s productivity. In these cases, treatment fails to provide freedom from discomfort, pain or disease, or to express normal behaviour. The animal’s welfare state associated with prolonged recovery may be less acceptable than the option of timely euthanasia to avoid further suffering. Hence, while saving a life may be rewarding, it is not necessarily the same thing as affording an animal a ‘life worth living’.

It is therefore important to ensure optimal treatment success through the prompt identification of individual sick or injured sheep, assimilation of a relevant disease history, rational clinical examination and the implementation of effective treatment regimes. The process of clinical examination must be methodical, first establishing characteristics such as the animal’s breed, sex, age and size. It is next necessary to attempt to identify any abnormal behaviour, with reference to the normal appearance and behaviour of adult sheep and lambs within comparable environments. Sheep are flock animals and will usually move as part of the group. Any animal which is separate from the rest of the group is acting abnormally. At pasture, sheep spend the majority of their time actively grazing, or lying and chewing the cud. The majority of sheep managed under commercial conditions regard humans as predators and will move away if approached closely. The flight response will vary with the degree of human contact the sheep are accustomed to, the breed, the age of the animal and
between individuals. Normal lambs, when roused from lying, will stand, stretch and then move freely. Lambs over several days of age will show play behaviour such as jumping and racing with other lambs. Normal lambs will suck vigorously once the teat is located and will shake their tails during this process and butt the udder to stimulate milk let down. Lambs which are reluctant to stand, or stand hunched, are lame or do not suckle vigorously are exhibiting abnormal behaviour. Sheep behaviour indicating pruritus, lameness or respiratory distress is abnormal and may occur with a variety of diseases.

Having first gathered a relevant disease history and observed the animal’s behaviour, the next component of the diagnostic process is to undertake a detailed physical clinical examination. This begins with assessing rectal temperature, heart rate, character of respiration and the colour of mucous membranes as indices of the systemic state. Next, the animal must be examined in a methodical stepwise manner, integrating the findings with the disease history and behavioural observation to localise problems to specific body systems. Having localised the problem, further physical examination of the locomotor, respiratory, cardiovascular, digestive, reproductive, nervous and urinary systems, mammary gland or skin can help to characterise any lesions that are identified. The diagnosis can be further supported using ancillary tools and methods (Sargison and Scott, 2010).

The objectives of individual animal examination are to decide upon the most appropriate treatment and to instigate suitable control measures to ensure adequate productivity and good welfare of others at risk in the group or flock. These objectives are only possible if an accurate diagnosis of the problem is first reached. Clinical signs identified following examination undertaken at clinics or treatment centres away from the farm or environment in which the sheep are kept are useful for the diagnosis of some specific individual animal diseases or injuries. However, the examination of animals out of context may fail to identify the primary causes of production-limiting disease or management problems, and is a poor platform for improvement of animal welfare.

**Individual animal disease management**

Failure to manage pain, injury or disease due to the administration of inappropriate or ineffective remedies is a global welfare concern, frequently reflecting a lack of proper veterinary examination and diagnosis. This situation arises in commercially farmed small ruminants in particular due to frequently erroneous perceptions that market forces dictate that the value of individual animals does not warrant the cost of veterinary examination or intervention. In many poor rural regions of the world, a comparable situation arises due to circumstances whereby veterinary visits to examine individual sick or injured animals are impossible or impractical, or clinical examinations are performed out of context at veterinary treatment centres. The problem is often compounded in these regions by the widespread availability of potentially poor quality medicines, and a generally poor level of understanding of appropriate medicine storage and administration.
Traditional approaches to veterinary clinical diagnosis that are based on pattern recognition and dependence on pharmaceutical drugs to treat individual animals have a limited impact on animal health and welfare because they generally fail to address the needs of the larger groups to which the individuals belong, or to identify opportunities to promote the well-being of ruminant livestock. Regardless of the reasons for the lack of proper veterinary examination and diagnosis, the greater use of individual cases as sentinels for national, regional, group or flock problems affords an opportunity to reduce the high prevalence of endemic diseases, with positive welfare benefits to greater numbers of animals.

Disease management to achieve good states of animal welfare depends on sustainable use of effective anti-microbial and anthelmintic drugs, appropriate pain management, availability of vaccines, and correction and maintenance of fluid and electrolyte balances. Management of pain includes the administration of proven anaesthetic treatments. Consideration must be given to the nature of the pain involved, whether adaptive pain, involving mechanisms that protect the animal from injury and promote healing, or maladaptive pain created by a pathological process that results in persistence of pain long after the initiating causes have been removed. Steroid drugs and non-steroidal anti-inflammatory drugs (NSAIDs) can be useful for the short-term mitigation of adaptive pain, by lessening swelling and diminishing inflammation, although it must be acknowledged that their efficacy in longer-term pain management and control of maladaptive pain is unproven (Scott, 2013). High-profile reports of catastrophic population declines of vultures throughout the Indian subcontinent associated with the accumulation and toxic effects of the NSAID, diclofenac, acquired by scavenging of cattle carcases (Oaks et al., 2004), have served to draw worldwide attention to the manner in which there has been a perceived need for such widespread and long-term use of NSAIDs to control pain and prevent suffering in animals with poor prognoses for recovery, and to question the effectiveness of this approach.

Limited availability of vaccines, and of NSAIDS and anti-microbial drugs that are licensed for use in small ruminants, is an issue in different parts of the world and a potential threat to good animal welfare. Similarly, the emergence of anthelmintic and ectoparasiticidal drug resistance, and the spectre of anti-microbial drug resistance, has inevitable adverse animal welfare consequences.

Planned animal health as a means of ensuring a good state of welfare

Robust promotion of the concept of welfare-friendly ruminant livestock agriculture in isolation, while subsistence farmers still struggle to feed, clothe and house themselves, and before they see the economic returns of sustainably improved productivity would be inapt. It is first necessary to address these human requirements by improving the economic returns from keeping ruminant livestock, for example by creating micro-finance, supply chains and access to markets. Once these prerequisites are in place, the foremost opportunity to achieve sustainable improvement in production of safe food is
afforded by the promotion of planned animal health. Thus, sustainable improvements in the productivity and profitability of ruminant livestock can address the quality of life of people who own and care for farmed animals, and provide a pragmatic means of both engendering concern for and ensuring high standards of welfare.

Livestock management systems that compromise welfare are seldom efficient or sustainable with reference to ruminant production, while economically efficient and sustainable systems are also generally welfare friendly. However, while improved animal health arguably affords the most tangible means of improving animal welfare, it is important to acknowledge differences between animal health and animal welfare. Welfare encompasses both physical and mental health, and while good physical health is essential, it alone does not necessarily lead to good mental well-being, as in the case of sheep that are intensively managed in uncomfortable accommodation, which may be healthy and productive, but may not experience a good life. Conversely, poor productivity may not always cause suffering. Discussion of sheep welfare should, therefore, include consideration of the extent of poor welfare, the intensity and duration of suffering, the number of animals involved, the alternatives available and the opportunities to promote the well-being of small ruminant livestock.

When considering the welfare state of food producing animals, it is necessary to understand the fundamental principle that most small ruminants are kept to convert primary forage, natural herbage or cereal crops into a marketable product; hence the profitability and sustainability of sheep production are influenced by the efficiency of conversion of primary crops to meat, wool or milk. The feed conversion efficiency is greatest, and net greenhouse gas emissions lowest, in animals that achieve maximal productivity from the available resources, hence a major aim of health planning is to ensure an optimal balance between economic inputs and outputs. The major opportunities for improved sheep productivity through planned animal health are the same, regardless of the production system (Scott and Sargison, 2007). These are in the fields of reproductive performance, neonatal survival, lamb growth, unexpected deaths and adult survival. Optimal productivity in these areas is inextricably linked to good standards of animal welfare.

**Sheep flock health and welfare planning**

The clinical examination and treatment of individual sheep within the context of their environment is important to ensure an adequate state of animal welfare, albeit the net benefits are small when compared to planned flock or group health management. The health of individual animals needs to be determined and then assessed along with that of the whole group to which they belong and other co-managed animals, within the context of the disease history, their husbandry, the environment in which they are kept and contemporary agriculture.

Some causes of poor production and welfare are suited to preventive control strategies. For example, psoroptic mange (sheep scab) can only be controlled by planned whole group acaricide treatments coordinated between neighbouring farmers and based on disease risk assessment and appropriate choice of drugs use or treatment methods. However, a one-fits-all health plan for sheep flocks would be inappropriate
due to the diversity of breeds, production systems, nutritional resources and environmental constraints.

In most cases planned animal health needs an iterative approach, rather than prescriptive control strategies. For example, the principles of helminth control are not constant because the parasites evolve in response to climatic and management factors, with one consequence being the emergence of anthelmintic resistance.

The list of measurable targets from which key indices for sheep production can be deduced includes (1) lambs reared per ewe, (2) lamb growth rates, (3) mating weights, (4) adult weights, (5) lambing patterns and (6) involuntary culling rates. Few managed sheep flocks meet production targets that are commensurate with their genetic potential. Hence, while further genetic selection, or the capture of de novo mutations associated with production traits or disease tolerance offers the potential meet these targets, the strategies will only succeed if corresponding necessary improvements are made in nutrition, health and welfare management. An integrated approach founded on robust scientific principles is therefore required to combine genetic potential with appropriate feeding strategies and planned animal health management.

Improved productivity requires a holistic approach based on rational, problem-focused diagnosis, management, prevention and control of disease, with responsible and sustainable use of remedies, rather than dependence on pharmaceutical treatments. This involves the iterative application of planned animal health principles (Fig. 10.1):

![Figure 10.1 Iterative principles of planned sheep flock health management.](image-url)
Managing disease risks

(1) first determine if individuals or groups of animals are performing to tangible targets; (2) next, identify any constraints and rationally investigate their causes; (3) next, ensure that the most appropriate remedies are used efficiently, based on assessment of the individual circumstances; (4) next, evaluate the response to and cost–benefits of whatever management or remedies are employed and then (5) surveillance and continuing to monitor and address issues, repeating the process as indicated to ensure on-going improvements in productivity and welfare.

Without accurate disease surveillance information, it is difficult to make specific recommendations regarding immediate improvements to the health and welfare of sheep and goats. However, based on general observations, a reduction in the severity of common, chronic, debilitating diseases could afford a useful starting point for improvement. The immediate priorities for most flocks would arguably be for improvements in the care and disease management of neonatal animals, and more rational approaches to lamb growth within the context of pervading agricultural conditions.

Investigation of flock failures to meet pragmatic targets starts with a relevant problem history, concentrating on the common causes that manifest in the production system, local region and at the relevant time of year. Clinical examination of individual animals is often misleading within the context of flock or group problems because there is a temptation to examine the worst affected individuals, which may be suffering from longstanding conditions that are irrelevant to the investigation, or may show clinical signs that have arisen as a result of, rather than due to, the primary problem. The physical examination should therefore be focussed on the group as a whole, looking at the variation between animals and the prevalence of clinical signs. These are generally easier to appreciate when examining the group at a distance. In many circumstances, the actual diagnosis may be less relevant than the identification of predisposing factors, so an assessment must also be made of the animals’ environment, including their management and husbandry.

The combination of a relevant disease history, general physical examination and detailed examination of the affected body system is often sufficient to reach a useful diagnosis of the cause of production-limiting disease and poor welfare. However, in many situations, ancillary microbiological, parasitological, haematological, biochemical or serological diagnostic tests are required to support the involvement of specific body systems, or to provide evidence of exposure to specific pathogens. The value of on-farm post-mortem examination must not be underestimated.

As the iterative health planning process advances, diagnostic tests become more important to allow the application of state-of-the-art scientific research, for example concerning genetic selection for production and resistance to disease constraints, or use of genomic markers to monitor and develop treatment or management strategies.

Planned animal health with the objective of disease prevention requires prompt identification of sick or injured animals to enable timely diagnosis of infectious causes. The treatment response is generally better and recovery is quicker in animals that are identified promptly as part of the health planning process than in the case of animals only seen once they are obviously sick or injured.
Biosecurity with reference to infectious diseases compromising animal welfare

It is not possible to sustain gains in small ruminant productivity and welfare without also having good biosecurity. The introduction of many diseases to an individual sheep flock has direct effects on production and welfare, for example causing abortion, lameness, skin disease, ill thrift and deaths. Introduction of anthelmintic-resistant nematode and trematode parasites impacts upon production efficiency and welfare by complicating the control of endemic helminth parasites. Introduction of zoonotic diseases such as orf, chlamydial abortion, Q fever, salmonellosis, tuberculosis or ringworm has potential consequences on the health of those working with the animals, and may have direct production and welfare consequences, as well as an indirect economic impact through effects on quality assurance or trade.

Effective biosecurity to prevent the introduction of new diseases or problems necessitates a combination of (1) isolation and quarantine; (2) assessment of the risk of introduction of specific problems; (3) appropriate treatments on arrival; (4) sourcing animals from flocks with similar or higher status for freedom from specific diseases and (5) preventing disease in the introduced animals that is already endemic in the main flock. The period of time for which animals are kept in quarantine should be sufficient to allow them to be clinically examined for the presence of identifiable disease and successfully treated as required. The threat of introduction of anthelmintic-resistant helminths is always present, hence animals should be treated with a combination of anthelmintic drugs that are likely to be effective against resistant parasites on arrival. Effective treatments to remove contagious ectoparasites should be given, depending on the risk assessment. Knowledge of the disease freedom status of source flocks depends on the availability of diagnostic tests with known sensitivities and specificities. Knowledge of the prevalence of the diseases is also required to allow validated health accreditation schemes to be developed. Control of endemic diseases might involve vaccination and strategic treatments.

Good biosecurity is threatened by effects of climate change, as shown by the creation of opportunities for the spread into northern Europe of Culicoides midge vectors of welfare compromising diseases such as bluetongue and Schmallenberg virus infection.

Control of highly contagious endemic diseases depends on good biosecurity and management at each of individual flock, regional and national levels. Control of exotic arthropod vector-borne viral and protozoal diseases depends on national biosecurity and disease management. The potential solution to some exotic disease plagues may lie in their eradication involving testing and vaccination protocols. Surveillance is critical to regional and national disease control, reiterating the importance of availability of reliable diagnostic tests in animal welfare management. The incorporation of serological tests such as the sheep scab ELISA (Nunn et al., 2011) into pen-side lateral flow devices, therefore, has potential benefits for disease control and animal welfare.

Transhumance sheep farming is common in poorly developed countries, whereby flocks move between regions, grazing on roadsides, common land and crop aftermaths.
Sick and pyrexic animals, showing signs of inappetence and respiratory disease, are commonplace and, in the absence of access to veterinary services, are treated symptomatically with whatever drugs are available. The opportunity is generally lost to consider these individual animals as sentinels for endemic diseases such as peste des petits ruminants (PPR).

In October 2016, an announcement was made by the Food and Agriculture Organization of the United Nations and the OIE of an ambitious global plan to eradicate PPR by 2030 (Veterinary Record, News and Reports, 2016). However, consideration of the welfare of animals in transhumance farming systems raises questions about how to instigate a rational disease control programme without access to veterinary diagnostic or vaccine distribution infrastructures. Consideration of PPR in the context of transhumance sheep farming raises concerns over biosafety and the spread of other unrecognised production-limiting diseases causing poor welfare. Furthermore, the close contact between shepherds and their animals highlights the potential to improve human health standards through the control of zoonotic diseases.

**Welfare education focused on managing disease risks**

Animal welfare education in isolation from the objectives of animal production generally lacks impact with the target audiences of agricultural businesses and smallholder livestock farmers alike. Motivating behavioural change in livestock keepers towards the health and welfare of their animals is most likely to succeed when the primary focus is on improved production and infectious disease control, based on the pragmatic, problem-focused principles of sheep flock health planning.

Animal welfare concerns may be overlooked due to a tendency to fail to recognise abnormal animal behaviour and poor health because the signs are perceived to be normal by observers with little or no experience of different scenarios. However, when ruminant livestock is observed by outsiders with different points of reference, then several obvious animal welfare concerns may be immediately apparent. Education must therefore engender a fresh perspective of states of animal welfare and well-being. Most of the publicly obvious animal welfare concerns are consequences of failure to manage or effectively treat poor nutrition, infectious diseases or traumatic injury. Education based on listing these concerns in a descriptive and judgmental manner is unhelpful without first considering how they may have arisen and then identifying practical solutions.

The management solutions to many disease constraints to production and welfare are already known, for example the importance of simple environmental hygiene and colostrum management in the prevention of neonatal diseases and mortality, but their uptake is poor. Hence, there is a requirement for the development of tools and systems, such as the ‘train the trainer’ concept, use of locally respected sheep keeping leaders by example, or application of innovative digital technologies and media aimed at translation of knowledge of good animal husbandry and health management.
Conclusions

Good welfare of farmed animals is essential, not least within the context of global food security. Effective management of disease risks is a necessary prerequisite for the achievement of good animal welfare. This process is underpinned by the clinical evaluation and disease management of individual animals. However, the greatest gains are achieved when this is integrated into planned animal health management, undertaken within the context of contemporary agriculture. Good biosecurity is necessary in the management of production-limiting and welfare-threatening diseases. Development of planned sheep flock health and welfare requires education, focused on managing disease risks, which must be delivered in a sympathetic and impactful manner.

References


Scott, P.R., 2013. The challenges to improve farm animal welfare in the United Kingdom by reducing disease incidence with greater veterinary involvement on farm. Animals 3, 629–646.


Livestock farming requires appropriate management of animals so as to optimise their production and health. This management includes regular handling and a number of husbandry procedures. The latter may be fairly innocuous (e.g. backlining with an ectoparasiticide for lice) or painful (e.g. castration). These husbandry procedures are carried out so as to reduce health problems, to increase productivity, to facilitate management or as a means to harvest a particular product. A number of husbandry and veterinary procedures are routinely carried out on sheep (Table 11.1).

Most of these procedures are time consuming and costly and they are carried out because they are necessary and usually not optional. Sheep farmers would prefer not to have to dock, mules, dag or crutch lambs but the breeding of wool sheep with wool free rear ends is still in its infancy (Scobie et al., 2007). The option to use hair breeds (e.g. Dorper) or wool losing breeds (e.g. Wiltshires) is still unattractive to those farmers for whom wool is a valuable product.

The development of alternatives to these husbandry procedures has been a focus of research for many years. The removal of wool by chemical means rather than shearing is possible but has not become a widespread practice. Some husbandry practices (e.g. tooth grinding) have come and gone and others such as foot trimming for the treatment of foot rot have become less important, whilst in contrast, scanning for pregnancy diagnosis is now becoming standard practice.

Procedures which involve the removal or destruction of tissues are painful while others, such as shearing, may not cause pain but may still be stressful for the animal.

Pain

The assessment and alleviation or elimination of pain in sheep caused by husbandry procedures has been the focus of research for several decades. This research has been stimulated by public concerns about the pain caused by more invasive practices that might impact negatively on the trade in sheep products (Sneddon and Rollin, 2010) and by a desire to minimise the pain and distress caused by these procedures.

Most of the research has focussed on acute pain, that is the pain experienced during the procedure and in the hours afterwards. The identification and assessment of long-term pain is controversial as pain may be replaced by irritation and what is experienced by an animal over days and weeks after a procedure such as castration is difficult to assess. Production parameters, such as weight gain, are not usually affected significantly by the procedures performed on sheep. This may be interpreted to indicate that these procedures do not cause long-term severe pain such that it impacts on feeding behaviour and rumenation.
Pain in sheep has usually been assessed using experimental protocols in which the behaviour or physiological responses to a particular husbandry procedure are monitored before and after the procedure (Kent et al., 1998; Lester et al., 1996). The better experimental protocols include positive and negative controls and control for the effects of the analgesics or anaesthetics used (Table 11.2). Some published papers do not have sufficient treatment groups to allow effective comparisons. Positive controls in which the husbandry procedure is carried out without analgesia is often unacceptable to animal research ethics committees and may be unacceptable to the editorial boards of some veterinary journals. This is unfortunate as it lessens the value of the research findings.

The alleviation or elimination of pain caused by different procedures can be approached in different ways. There is no pain if the procedure is not carried out and so implementing farm management or breeding programmes where or in which the procedure is unnecessary is the best way to eliminate pain. This should be the focus of all research looking at husbandry procedures. The elimination of pain is also possible with the use of various analgesic regimes using general or local anaesthesia.

### Table 11.1 Routine husbandry and veterinary procedures carried out on sheep

<table>
<thead>
<tr>
<th>Procedures</th>
<th>Frequencies</th>
<th>Level of pain</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Castration</td>
<td>Once</td>
<td>+++</td>
<td>Worldwide common practice</td>
</tr>
<tr>
<td>Short scrotum</td>
<td>Once</td>
<td>++</td>
<td>New Zealand practice</td>
</tr>
<tr>
<td>Docking</td>
<td>Once</td>
<td>++</td>
<td>Worldwide common practice</td>
</tr>
<tr>
<td>Mulesing</td>
<td>Once</td>
<td>+++</td>
<td>Australian practice, Merino sheep only</td>
</tr>
<tr>
<td>Ear notching</td>
<td>Once</td>
<td>++</td>
<td>Worldwide common practice</td>
</tr>
<tr>
<td>Ear tagging</td>
<td>Once</td>
<td>++</td>
<td>Common, sometimes mandatory</td>
</tr>
<tr>
<td>Teeth grinding</td>
<td>Once</td>
<td>++</td>
<td>Rare practice, banned in some countries</td>
</tr>
<tr>
<td>Daggerring</td>
<td>As needed</td>
<td>−</td>
<td>Common practice on wool sheep</td>
</tr>
<tr>
<td>Crutching</td>
<td>As needed</td>
<td>−</td>
<td>Common practice on wool sheep</td>
</tr>
<tr>
<td>Shearing</td>
<td>Once yearly</td>
<td>−</td>
<td>Necessary practice to harvest wool</td>
</tr>
<tr>
<td>Vaccination</td>
<td>As needed</td>
<td>−</td>
<td>Worldwide common practice</td>
</tr>
<tr>
<td>Drenching</td>
<td>As needed</td>
<td>−</td>
<td>Worldwide parasite treatment</td>
</tr>
<tr>
<td>Bolus administration</td>
<td>As needed</td>
<td>−</td>
<td>Worldwide parasite treatment</td>
</tr>
<tr>
<td>Dipping/shower</td>
<td>As needed</td>
<td>−</td>
<td>Ectoparasite control when necessary</td>
</tr>
<tr>
<td>Spraying/backlining</td>
<td>As needed</td>
<td>−</td>
<td>Ectoparasite control when necessary</td>
</tr>
<tr>
<td>Foot trimming</td>
<td>As needed</td>
<td>−/+</td>
<td>Prevention or treatment of foot rot</td>
</tr>
<tr>
<td>Artificial insemination</td>
<td>As needed</td>
<td>−/+</td>
<td>Specific situation</td>
</tr>
<tr>
<td>Embryo transfer</td>
<td>−/+</td>
<td>Specific situation</td>
<td></td>
</tr>
<tr>
<td>Electroejaculation</td>
<td>−/+</td>
<td>Semen collection and analysis</td>
<td></td>
</tr>
<tr>
<td>Pregnancy scanning</td>
<td>−</td>
<td>Becoming common practice</td>
<td></td>
</tr>
<tr>
<td>Vasectomy</td>
<td>Once</td>
<td>+</td>
<td>To produce teaser rams</td>
</tr>
</tbody>
</table>

+++ Very painful; ++, painful (minor pain); −/+ may be painful; −, not painful but may be stressful.
plus systemic analgesics. These are costly protocols, the drugs are often veterinary
use drugs only and not available to farmers, the delivery of anaesthetic drugs may be
difficult, time consuming and dangerous, and techniques for rapid effective delivery
of anaesthetics to large numbers of sheep are in their infancy. The alleviation of pain
may be brought about by selecting the least painful technique, and or by using local
anaesthesia or systemic analgesics.

The experience of pain may be influenced by individual and environmental factors.
Age may affect the behavioural response to a husbandry procedure such as castration
and ideally, these procedures should be performed early in life. Lambs handled gen-
tly in early life may show less signs of pain (Guesgen et al., 2014). Male lambs may
show a weaker response to a painful stimulus as they age over the first 12 days of life
whereas female lambs do not (Guesgen et al., 2011). This suggests that the pain expe-
rienced by ram lambs can decrease over this time period and perhaps they should be
castrated at 10 rather than 2 days.

### Distress

The distress that sheep experience when being mustered (collected), yarded and then
handled (restrained) will differ depending on flock size, how familiar the sheep are
with people (Hargreaves and Hutson, 1990) and the facilities available, plus the effect
of the procedure itself (Hutson, 2014). Thus sheep that are farmed in small flocks and
are hand-fed regularly may not fear humans as much as sheep that live in large flocks,
are mustered infrequently by dogs and when yarded, usually experience something
which is stressful (e.g. weaning or shearing), irritating (e.g. vaccination) or painful
(e.g. docking). Sheep that are fed supplements (Hutson, 1980) or housed, probably
see humans as a positive component of the environment and may not be so badly af-
fected when caught and treated as compared to those sheep that rarely see humans in
the enviroment but a negative context. Sheep that follow a shepherd and are watched
over every day by a shepherd are less likely to be afraid of humans than sheep that are
free grazing and mustered infrequently using dogs. In the latter, fear is a component
of mustering. Lambs handled gently in early life may be less fearful from humans
(Markowitz et al., 1998).

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive control</td>
<td>Castration</td>
</tr>
<tr>
<td>Negative control</td>
<td>Handling—sham castration</td>
</tr>
<tr>
<td>Analgesia control</td>
<td>Administer local anaesthetic</td>
</tr>
<tr>
<td>Analgesia</td>
<td>Administer local anaesthetic followed by castration</td>
</tr>
</tbody>
</table>
The physical and/or emotional distress that sheep experience when subjected to any husbandry procedure is difficult to assess and will vary widely between farming systems. The impact of mustering, yarding and being caught and processed is probably unpleasant especially if dogs are used during mustering and in yards (Hutson, 2014). The physiological responses to these management practices usually indicate stress. However, as fear of dogs or humans is probably essential to moving large mobs of sheep, this stress is impossible to eliminate. Small flocks that follow the shepherd may not be stressed during movement but shearing and other practices involving restraint will still be stressful (Hargreaves and Hutson, 1990). When lambs are subjected to ‘marking’, which often includes a number of procedures such as castration, docking and ear tagging, in a pen with their dam present, the distress they experience is probably much less than that experienced by lambs mustered into a yard with hundreds of ewes and lambs. The latter are separated from their dam and surrounded by the noise of a mob of ewes looking for their lambs. They are caught and ‘marked’ and then placed in a pen or paddock where they have to find their dam.

The layout of farms, farm tracks, yards and woolsheds are important as good design will minimise the effort needed to muster sheep and move them through yards, races, dips, showers and into the catching pens adjacent to the shearing board (Barber and Freeman, 2014). Well-trained dogs also facilitate these movements of sheep. Easy movement probably reduces the stress experienced by sheep during the standard procedures. Familiarity with yards and feeding sheep in yards may make movement easier and less distressing (Hutson, 1985).

The rationale and techniques for carrying out different husbandry procedures and ways to alleviate or eliminate the pain and stress are discussed later.

**Marking**

Lambs are marked in the first 2 months of life. It is usually recommended that lambs are ‘marked’ as early as possible, preferably in the first few days of life to minimise pain. This may require refinement following work by Guesgen et al. (2011) which showed that male lambs became more tolerant of a thermal pain stimulus up to 12 days of age but female lambs did not. Lambs born indoors may be marked before they are moved outdoors. Lambs born outdoors in small flocks of ewes used to human contact may be caught in the first few days or weeks of life and be marked individually or in small lots in the paddock or in small pens. Within the sheep breeding sector, lambs are typically given an ear tag in the first day after birth to match them to their dam.

Lambs born to ewes in large flocks grazed extensively will usually be mustered into yards at 3–6 weeks of age and be marked. Lambs being yarded en masse need time to form a strong bond with their dam before being mustered to minimise ‘mismothering’. Ewes may be mobbed in groups according to mating cycle and thus in each mob, they will lamb over a 3 week period. Lambs born in week three of the mating cycle need time to bond with their dam and if they are ‘marked’ at 2 weeks of age, their flock mates will be 5 weeks old. For many lambs marking is the most painful husbandry practice they experience as most will be sent for slaughter at 3–6 months of
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age. Between marking and transport to slaughter or a saleyard, they may be drenched and perhaps dagged (removal of faecal pads from the breech) or shorn. Merino lambs kept for wool production may be mulesed during marking which adds to the pain experienced.

**Castration**

The majority of male lambs (rams) are slaughtered by 6 months of life; a proportion are reared further and killed before they are 1 year old. Merino rams lambs may be castrated and held for wool production as adults. Ram lambs are castrated to prevent them from mating with post-pubertal female lambs, eliminate ram taint in meat, promote a fatter carcass, reduce homosexual behaviour and make management easier. Rams on reaching puberty become more difficult to manage in yards. The scrotum can be quite woolly on some breeds and its removal, which usually occurs with castration, results in a cleaner animal requiring less crutching or dagging to minimise the risk of flystrike. The removal of the scrotum is also important as it reduces the likelihood of faecal contamination of the carcass during slaughter and processing.

Ram lambs are castrated in many ways including the application of a rubber ring, surgical removal of testes or application of a bloodless castrator (Burdizzo) (Stafford and Mellor, 2015; Table 11.3). All physical methods of castration cause injury and pain (Mellor and Stafford, 2000). There are serious potential side effects to castration including tetanus and haemorrhage. Ewes should be vaccinated against clostridial diseases before lambing to prevent tetanus, or lambs should be given tetanus antitoxin at castration. Marking should be carried out in dry clean conditions to minimise the risk of tetanus. Haemorrhage is not usually a problem in small younger lambs but in older rams when surgical castration is necessary, it should be controlled by using an emasculator or ligating the cords.

In New Zealand, ram lambs may have the scrotum removed by placing a ring across the scrotum distal to (below) the testicles (short scrotum) and the testicles remain positioned close to the abdominal wall (Stafford and Mellor, 2015). The acute pain caused by this procedure is less than that caused by ring castration per se (Dinniss et al., 1997). In New Zealand, the ‘short scrotum’ is carried out on about 40% of ram lambs, 40% are left intact and 20% are castrated. Ram lambs left intact are usually slaughtered early in life but short scrotum lambs may be held longer as store lambs and killed anytime, even after puberty. Short scrotum lambs grow faster and leaner than castrated lambs (wethers). A small proportion of short scrotum lambs may be fertile and ram like in behaviour. Late born ram lambs and smaller ram lambs are generally castrated because they will take longer to reach slaughter weights and will be held as stores over the autumn and winter and killed after they would have reached puberty if left intact.

Leaving ram lambs intact is the best way to eliminate the pain caused by castration. This is followed by the short scrotum procedure. Both should be encouraged if farm management and lamb finishing times allow them and if there is no market resistance to meat from intact or short scrotum lambs.
It is often suggested that the earlier lambs are castrated the better, but there is evidence that pain perception may actually decrease in ram lambs as they age over the first 12 days of life (Guesgen et al., 2011). Ring castration within 3 days of birth may cause less acute pain than castration later in life but castration on day one of life may make lambs more sensitive to tail docking carried out 10 days later (McCracken et al., 2010). This possibility needs further investigation as does the possibility that male and female lambs may develop pain perceptions differently over the first few weeks of life (Guesgen et al., 2011).

On farms where lambs are born indoors, it is possible to castrate lambs during the first few days of life and this is recommended to minimise the handling of lambs after they are put out to pasture. Ram lambs born outdoors in extensive farming systems cannot generally be castrated until they are some weeks of age. Marking should only be carried out when the youngest lambs are bonded with their dams and capable of maintaining this bond through the marking process. Using ram markers to identify ewes bred over the two breeding cycles and stocking them separately allows marking to be done on younger lambs. Scanning ewes for pregnancy allows the identification of not-in-lamb ewes that can be culled, and ewes with single, twin or triplet lambs.

### Table 11.3 Methods of castrating lambs

<table>
<thead>
<tr>
<th>Methods</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber ring</td>
<td>A rubber ring placed above the testes which causes anoxia with the scrotum and testes sloughing off after some weeks.</td>
</tr>
<tr>
<td>Surgical castration</td>
<td>The distal scrotum is either incised over both testicles or removed using a scalpel blade and the testes are physically drawn out and torn off. They may be pulled out and cut or scraped through.</td>
</tr>
<tr>
<td>Bloodless castrator</td>
<td>The blade of the bloodless castrator (Burdizzo) is closed over each spermatic cord in two movements leaving a space between the cuts. The blade is closed and left on each cord for a minute or so. The testes shrivel and the scrotum shrinks over a few weeks.</td>
</tr>
<tr>
<td>Short scrotum</td>
<td>A rubber ring is placed below the testes which are pushed up against the abdominal wall. The scrotum sloughs off after a few weeks but the testes remain in the inguinal area.</td>
</tr>
<tr>
<td>Bloodless castrator + rubber ring</td>
<td>Combination technique which may reduce pain experienced by lambs.</td>
</tr>
<tr>
<td>Physical destruction</td>
<td>Testicles are destroyed by blunt trauma—not recommended.</td>
</tr>
<tr>
<td>Immunocastration</td>
<td>Possible and painless but not done; there may be farmer and meat market resistance.</td>
</tr>
</tbody>
</table>

It is often suggested that the earlier lambs are castrated the better, but there is evidence that pain perception may actually decrease in ram lambs as they age over the first 12 days of life (Guesgen et al., 2011). Ring castration within 3 days of birth may cause less acute pain than castration later in life but castration on day one of life may make lambs more sensitive to tail docking carried out 10 days later (McCracken et al., 2010). This possibility needs further investigation as does the possibility that male and female lambs may develop pain perceptions differently over the first few weeks of life (Guesgen et al., 2011).
These pregnant ewes with different litter sizes can be managed separately and marked when it is thought lambs are capable of finding their dam after marking.

If marking is done outdoors then it should only be carried out on a fine day with dry conditions underfoot to minimise the possibility of wound infection. Using temporary yards on clean dry pasture is a good way to minimise danger of infection. Moreover, temporary yards can be shifted to the flock to minimise the need for mustering over long distances.

If no form of analgesia is used, then the acute pain caused by castration will differ according to techniques used (Kent et al., 1998; Lester et al., 1991; Molony et al., 2012). Rubber ring castration causes a smaller plasma cortisol response than surgical castration but lambs castrated by ring are more active than those castrated surgically. This has led to some disagreement about which is more or less painful but as behaviours may be specific to a particular method it may be inappropriate to compare different behaviours in assessing pain. The plasma cortisol response to castration is shorter and smaller following ring castration than surgical castration which suggests that the acute pain is less during and immediately following application of the ring (Paull et al., 2009). Wound healing following ring castration is slower than following surgery, and lambs castrated by ring are still turning to look at their scrotal area 6 weeks after castration unlike surgically castrated lambs which suggest that the scrotal area is at least irritating and at worst, still painful.

Castration by bloodless castrator (Burdizzo) causes a similar cortisol response to the rubber ring (Dinniss et al., 1997) but less than surgical castration (Mellor and Stafford, 2000). Combining rubber ring and Burdizzo may reduce the pain experienced by 1-week-old lambs during castration but not older lambs (Dinniss et al., 1997; Mellor and Stafford, 2000). Castration by short scrotum probably causes less acute pain than rubber ring, surgical or Burdizzo castration and is to be recommended if no analgesic is available. Castration by destroying the testicles physically is not recommended.

The plasma cortisol response to ring castration and by inference, the acute pain caused by it can be reduced by injecting local anaesthetic into the scrotal neck, the spermatic cords and the testes some minutes before castration (Dinniss et al., 1997; Kent et al., 1998; Molony et al., 2012). Injecting local anaesthetic into the testicles is simple and technically easy. Local anaesthetic is less effective against the pain caused by surgical or Burdizzo castration (Dinniss et al., 1997) and using a non-steroidal anti-inflammatory agent along with local anaesthesia may be needed to eliminate the pain caused by them. Injecting a non-steroidal anti-inflammatory agent before castration will not eliminate the pain caused by castration but will reduce the pain experienced afterwards (Paull et al., 2009, 2012).

Tools to administer local anaesthetic into the testes and apply rubber rings are available but more efficient tools are required. Local anaesthetic administered topically by squirting it into the scrotal neck onto the spermatic cords either before or after they are severed reduces the pain experienced following surgical castration (Lomax et al., 2010; Paull et al., 2009). To minimise any pain experienced after the effect of local anaesthetic wears off after 2 h, an injection of a non-steroidal anti-inflammatory agent could be used. General anaesthetic is not appropriate for lamb castration.
Castration wounds need to be treated for screwworm in areas where this parasite exists.

It is not necessary to castrate ram lambs that are likely to be killed with in the first 4 or 5 months of age; those likely to be killed later but before puberty could castrated by short scrotum and those left could be castrated. To a great extent this is done in New Zealand where 40% of ram lambs are not castrated, 40% have a short scrotum and 20% are castrated. Those subject to the latter procedures should be given local anaesthetic into the scrotal area if possible in combination with a non-steroidal anti-inflammatory drug (NSAID) to eliminate or at least minimise pain. Developing effective tools for administering a combined local anaesthetic/NSAID easily and efficiently to large numbers of lambs is the future for large extensive farms on which large numbers of lambs are castrated. Immunocontraception may become the preferred method of castration in future but at present it is not popular probably due to a lack of promotion and market concerns or misconceptions about the use of hormones in meat production. There may be concerns also about the safety of staff administering these vaccines.

Docking

Most wool sheep have their tails shortened as lambs. This practice called docking is carried out to reduce the likelihood of sheep getting flystruck (French et al., 1994) as docked sheep are less likely to develop faecal pads (dags) on the wool surrounding the perineal area than sheep with long tails. Thus docking reduces the risk of flystrike and also the need for removing dags and or wool from the perineal area (dagging or crutching). Moreover, dagging or crutching has to be done before shearing if there are dags. Lambs with dags have to be dagged before they are sent for slaughter and often before they are sent to sale yards. It is an additional stress to lambs and older sheep as they have to be mustered, yarded, fasted and put through the shearing shed and onto the shearing board for dagging/crutching. Sheep with tails take longer to shear as their tails have to be shorn.

The length of the tail after docking may vary depending on tradition or practice. Tails should be docked below the third palpable joint so that the tail covers the vulva in the ewe lamb and anus in ram lambs (Munro and Evans, 2009). Longer tails may not be lifted as high and result in urine staining and dags (Fisher et al., 2004). Slaughter lambs are often docked short to minimise the need for dagging before slaughter and to make it and crutching easier. Very short-docked tails may result in more dags, more flystrike and also in other problems such as rectal prolapse (Fisher et al., 2004). When lambs are not docked, shearing and crutching can take longer to perform. Hair sheep are not docked and some wool shedding breeds (e.g. Wiltshires) are also not docked.

In lambs, tails are docked by hot knife (cautery), cold knife or rubber ring (Sutherland and Tucker, 2011). The bloodless castrator (Burdizzo) can be used but is not recommended. The plasma cortisol responses to docking using a ring or hot cautery are similar, suggesting similar acute pain is experienced. Lambs are more active after ring than cautery docking which suggests that the former might be more painful.
The plasma cortisol response to docking using a cold knife is much greater than the response to docking by ring or cautery so it is certainly more painful and should not be done. The least painful technique for docking is probably cautery of the tail between the joints of young lambs when the tail is soft and easily burned through.

The administration of a ring block of local anaesthetic to the tail is difficult but done correctly it reduces the behaviours indicative of pain (Kent et al., 1998); the administration of local anaesthetic topically after docking by cautery is also recommended to reduce pain (Lomax et al., 2010) but its effect is debatable (Paull et al., 2009). After docking, the perianal area should be sprayed with anti-flystrike and screwworm medication in countries where these pests exist.

Docking is essential in most wool sheep breeds to reduce flystrike. The alternatives are to breed sheep with no wool in the perianal area as suggested by Scobie et al. (2007) or to use alternative breeds that shed wool or hair sheep. In the near future, it may be possible to delete the genes responsible for long tail length and thus remove the need to dock lambs.

**Mulesing**

In Australia, fine-wool Merino sheep are mulesed to reduce the incidence of flystrike. In mulesing, two strips of skin are cut from the breech and one strip from the tail (Fisher, 2011). This allows a bare area to develop in the perianal area, reduces wrinkly wooled covered skin and thus reduces the pre-disposition of sheep to flystrike. It is usually done by skilled contractors. It may be carried out when marking lambs.

It is a painful procedure (Fisher, 2011) and has been criticised as an unnecessary mutilation. But it is a very efficient way of reducing flystrike and since its development, it has been accepted by the majority of Australian Merino sheep farmers. In the last two decades criticism of this procedure (Sneddon and Rollin, 2010) has prompted attempts to make it unnecessary by breeding sheep with less wrinkly skin around the perianal region, developing analgesic protocols to reduce the pain experienced by lambs (Lomax et al., 2013; Paull et al., 2008), developing other ways of reducing the amount of wrinkly skin or increasing the use of insecticides and crutching to more effectively prevent flystrike (Rothwell et al., 2007). None of the alternatives have been widely adopted in the short-term by wool producers.

Breeding sheep with less wrinkly skin in the perianal area so that they do not require mulesing, is the most sustainable option for flystrike control without mulesing (Fisher, 2011) but it will take a decade or more to take effect within flocks. An integrated parasite control programme of crutching and treatment with long acting fly control chemicals is effective but time consuming and expensive. Alternative methods of reducing wrinkly skin include the use of clips or topical or intradermal injection of chemicals to cause skin scarring and depilation are painful and not very effective (Fisher, 2011). Alleviating the pain caused by mulesing is possible by the topical administration of local anaesthetic after the procedure plus injecting a NSAID but this will not eliminate the pain experienced during the procedure (Paull et al., 2008).
**Ear tagging and notching**

Lambs are earmarked by farmers for several reasons including to identify farm of origin, year of birth, dam and make identification of sex easier during drafting. The marks are made with various types of ear notching devices. Ear tags are widely used and in some countries, sheep may have to be identified using them (Edwards et al., 2001). Ear tags with electronic chips to allow automatic identification are becoming more practical and will be used on farm to identify sheep and facilitate weighing, body condition scoring, longevity etc. Fly deterrent ear tags are also available. Ear tags to identify sheep and transmit information on movement and location may become common in future.

Ear notching is usually done to lambs during marking but ear tags may be placed after weaning. Notching devices are usually used to cut small triangle shape out of the ears and different patterns of notches are used to indicate the year of birth. Round or other shaped punches may be used for farm of origin identification. Notching is painful and there may be some haemorrhage.

There are many types of ear tags used on sheep (Edwards et al., 2001). They are usually one or two piece tags. One piece tags such as metal loop tags are placed on the edge of the ear while polyurethane loop tags are pushed through a slit cut into the body of the ear. Two piece tags, usually of polyurethane are placed by punching a stem through the body of the ear and fitting the second piece over the stem of the first. All ear tags cause damage to the ear but metal loop tags caused the most severe and persistent damage (Edwards et al., 2001). Single loop tags were difficult to fit through the slit and caused more haemorrhage, and lambs vocalised and shook their heads more following this than following placement of other tags (Edwards et al., 2001).

Fitting of two piece polyurethane ear tags is least painful and damaging than metal loop tags or single loop polyurethane tags. Placing large polyurethane ear tags in lambs during marking is not really feasible due to them being lost, so either notching or smaller plastic two piece tags are preferable to metal loop tags. Ear notching lambs and then placing one tag after weaning or after drafting replacement ewe lambs may be preferable to replacing tags at this stage.

Analgesics are not used when ear notching or tagging is done and it is difficult to administer local anaesthetic to the ear. Using NSAIDS when marking lambs might reduce the pain caused by ear notching or tagging but would not eliminate it. It is possible that microchips will become the mode of identifying sheep in future but in the meantime ear notching and tagging will continue.

**Marking**

Marking lambs is a process when several things are done at one time to lambs. Attempts to minimise pain experienced during castration, docking, mulesing and ear notching means that several analgesic processes might need to be done at one time. This is difficult and time consuming when working with hundreds or thousands of lambs simultaneously.
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It is likely that in the future, the administration of local anaesthesia and an NSAID to the testes and tail can be achieved practically using an automated administration device (e.g. NUMNUTS). Perhaps the NSAID will be within the lamb vaccine for clostridial diseases and local anaesthetic will be administered topically in anti-flystrike medication. Any one of these processes or a combination will not eliminate pain but together they would substantially reduce it. The use of these medications in this manner will require new formulations by drug companies plus changes to legislation and/or regulations governing the application of analgesics by non-veterinarians.

A better regime might to be place lambs for marking in a herringbone type holding device. This would allow lambs to be given local anaesthetic/NSAID into the scrotum and tail before the other procedures. They could then be vaccinated, ear notched, docked, sprayed with anti-fly medication so that by the time they are castrated the local anaesthetic is working. This would make the process time efficient and allow for effective pain relief.

There are attempts to breed wool sheep with little wool in the perineal area which do not require docking and there may be an increase in hair or wool shedding breeds in some countries. Castration may be reserved for ram lambs that will be kept past puberty before slaughter. The short scrotum procedure might become more common worldwide. Microchips may replace ear tags and notching on larger farms where identification and drafting will become more automated.

Foot trimming

Foot trimming was a common practice for the diagnosis, treatment and prevention of foot rot (West et al., 2009). It is probably unnecessary as a treatment and sheep affected with foot rot should be given antibiotics rather than have feet trimmed. After treatment with antibiotics, the feet of affected sheep return to normal shape after some months. Severe foot trimming will cause pain and haemorrhage and it must be done under controlled restraint. Modern sheep handling devices capture and turn sheep over making foot trimming easier to do and under more controlled circumstances.

Sheep severely affected by foot rot should be identified, treated and if possible culled and sheep should be bred for resistance to foot rot as it is a particularly painful disease and one of the major welfare problems in many sheep flocks. Foot bathing may be used in the prevention and treatment of foot rot.

Shearing, crutching or dagging

Sheep may be covered with hair or wool. Hair sheep (e.g. Barbados Blackbelly) and some breeds of wool sheep that shed their wool (e.g. Wiltshires) do not need to be crutched, dagged or shorn. Wool may be fine as on Merino sheep or coarse as on New Zealand Romney and British breeds. Fine wool, especially very fine wool is valuable, but coarse wool is not worth much.

Wool has to be removed once a year as it acts as insulation and sheep with too much wool may overheat. Shearing patterns vary widely between production systems. Sheep
are generally shorn in early summer but Merinos are usually shorn in autumn. Some flocks are shorn twice yearly (summer and winter) or three times every 2 years. Winter shearing of pregnant ewes is done with a special comb to leave some wool on the sheep to act as insulation. Winter shearing is dangerous as newly shorn sheep may be exposed to inclement weather and die of exposure. Shelter is required as is adequate feed if sheep are shorn in winter. Winter shearing may reduce the percentage of cast ewes in a flock and make lambing easier.

Wool may be a valuable product or a less valuable by-product. Wool in the perivulvular region may be removed (crutching) to assist mating and birth. Before birth, wool may also be removed from the belly area to assist lambs in finding the teats.

Sheep are often crutched or dagged before shearing to make it easier to remove a clean fleece. All these processes are stressful with shearing being the most stressful (Hargreaves and Hutson, 1990). Specially designed shears are used for these procedures and sheep are usually shorn either in purpose built wool sheds or for smaller flocks, specially designed trucks or mobile facilities. To shear sheep, they have to be caught, upended and then moved through a series of positions as the wool is removed. In addition to shearing being stressful, sheep may be cut during shearing and poor handling skills may result in sheep becoming difficult to handle during the process. Wounds are frowned upon by skilled shearers and farmers and poor handling skills are definitely *infra dig*. Very large sheep such as rams may be sedated to assist shearing. Some breeds of sheep are reported to be more difficult to shear than others.

The physical process of shearing is hard work and shearers aim to minimise unwanted behaviours in sheep during the process by good handling. Skilled shearers minimise the hard work involved and probably also reduce the stress experienced by the sheep. Alternatives to shearing have been sought for decades. Chemical wool removal is possible but the wool may have to be caught in ‘wool nets’ or left to fall off. If sheep lose all their wool outdoors then exposure to cold weather or sunburn may be problematic (Hutson, 2014). Mechanically assisted or robotic shearing may become possible in future but remains a work in progress.

Simple sheep restraint devices now allow sheep to be dagged standing up. More complicated often hydraulically driven devices allow sheep to be caught and tipped over thus allowing dagging, crutching, foot paring and other procedures such as vaccination, drenching and bolus administration with minimal physical effort by humans. The relative stress experienced by sheep when restrained by human handling and machine restraint has not been compared but the latter is certainly less stressful for humans.

**Health treatment (vaccination, drenching, bolus administration, dipping, showering and backlining)**

Flock management involves preventative health programmes which include parasite (external and internal) control, vaccination against infectious disease and trace element supplementation. Vaccination programmes involve injections which are mildly painful but the vaccination against Johnes disease may cause abscess formation
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(\text{West et al.}, 2009) as may the use of dirty needles. Needles should be replaced frequently and the use of clean and sharp needles will reduce problems with injecting medications and vaccines. Needleless syringes for vaccination are available but are quite expensive and not widely used in sheep farming.

Internal parasites are controlled by drenching or injecting with anthelmintics or giving anthelmintic intra-rumenal boluses. Sharp projections on the tip of a drenching gun may cause intra-oral injuries and abscessation in the mouth. Banging the drench gun against teeth may be painful. Well-maintained drench guns will minimise problems. Intra-rumenal boluses are large and need to be administered by skilled personnel to minimise the likelihood of them being place in the trachea.

Dipping for external parasites may be frightening as sheep do not swim well. Showering for external parasites is probably less stressful than dipping but is probably stressful. Showering in a race and backlining are probably less stressful and easier than dipping.

These procedures require yarding and restraint in a race. Sheep tightly packed in a race are easier to drench or inject. Specially designed hydraulic and electrically driven sheep holding devices are now available to facilitate these processes. They may reduce the time required and thus reduce the stress experienced by sheep but this has not been quantified.

\textit{Breeding practices}

Modern breeding practices include artificial insemination, embryo transfer, pregnancy diagnosis by scanning and vasectomy for producing ‘teaser’ rams. Ram semen is collected by electroejaculation or artificial vagina. The use of an artificial vagina to collect semen has probably limited negative welfare impacts but electroejaculation is stressful. It causes similar stress to part-shearing (\textit{Stafford et al.}, 1996) and rams are often sedated before electroejaculation.

Conception rates in ewes inseminated with frozen semen are higher if semen is placed in the uterus rather than the vagina. Intrauterine insemination requires laparoscopy with abdominal inflation. Embryo transfer involves the collection of embryos from a donor ewe and intrauterine placement in the recipient ewes. Laparoscopy is required for these processes. Laparoscopy is usually carried out on ewes that have been sedated and are then held in a cradle with their head lower than the abdomen. The abdomen is inflated with some air to make insemination and embryo transfer easier to do. Sedated ewes experience some distress during laparoscopy and this can be alleviated by injecting a NSAID or eliminated by using detomidine (\textit{Stafford et al.}, 2006). In some countries laparoscopy and vasectomy can only be carried out by veterinarians. Rams are sedated and given local anaesthesia when being vasectomised so no acute pain is experienced.

Pregnancy diagnosis is carried out by scanning ewes restrained upright in a crush. It is probably not very stressful and is done rapidly. Pregnancy diagnosis has some very positive welfare outcomes in that ewes with triplets or twins can be identified and managed separately from single lamb bearing ewes. Moreover, non-pregnant ewes can be identified and culled so that pregnant ewes will get more feed.
**Electro-immobilisation**

Electro-immobilisation is used to immobilise animals including sheep without sedating them. It immobilises but does not prevent pain. It is probably not necessary to immobilise sheep using electro-immobilisation.

**Teeth grinding**

It was suggested that teeth grinding, that is shortening and levelling the incisor teeth of sheep using an angle grinder with a cutter might prolong their lives by allowing them to graze effectively for longer. This was never confirmed and several reports showed no positive effect on productivity of ewes subjected to teeth grinding (Denholm and Vizard, 1986; Orr et al., 1991). When done correctly and not too severely, tooth grinding may cause minimal distress (Denholm and Vizard, 1986) but if done too severely, it can cause acute pain and distress. Tooth grinding is a painful practice that should not be undertaken routinely and the practice is now generally discontinued and is banned in some Australian states.

The removal of long teeth from old sheep with periodontal disease is done to allow them to graze easier and fatten up before culling. Pulling long teeth which are mobile is painful but grazing with loose teeth may also be painful. Whether it is better or worse to leave or remove loose teeth is open to debate.

**Conclusions**

Sheep are subject to a number of husbandry procedures which are carried out to reduce disease and optimise productivity. These procedures take time and cost and if they could be done without these procedures this would be better for farmers and sheep. Some are likely to continue (e.g. pregnancy scanning), others may be or have been banned (e.g. teeth grinding) while others which are painful but important (e.g. tail docking) may continue to be carried out but with analgesia becoming mandatory. Breeding sheep to minimise the need for shearing, docking or mulesing may become economically or socially necessary. In the near future the widespread use of sedatives, local anaesthetics and systemic analgesics will become more common practice to alleviate or eliminate the distress and or pain experienced by sheep during some husbandry practices. Equipment is available or being developed to administer these drugs to sheep. Finally, legislative changes are required in many countries to enable farmers, perhaps under veterinary supervision, to administer these drugs to their livestock.

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Further reading


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Introduction

Live animals have been traded for thousands of years, and this is set to continue. However, unlike the simple exchange of animals between neighbours that exists as an image of pastoral utopia in the minds of many consumers, modern trade in live animals can span vast distances, across regional, national and continental boundaries. The nature of modern commercial livestock production and trade is such that animals must, at some point, undergo transportation from the farm of birth to a finishing system; to and from markets or saleyards; to the abattoir for slaughter. Livestock production systems are becoming increasingly more stratified, with a number of steps in the basic chain from production to slaughter (Miranda-de la Lama et al., 2010). An efficient, well-structured supply chain, planned using a logistical approach, can minimise the risk to animal welfare.

The welfare of animals during transport and slaughter is a point of concern to consumers, and media coverage of poor conditions and animal abuse results in public outrage (Nocella et al., 2010, 2012; Phillips et al., 2009; Tiplady et al., 2013). Welfare aspects of transport of livestock have recently been reviewed by Norris (2005), Broom (2005), Trentini et al. (2008) and Fisher et al. (2009), while humane slaughter practices were extensively reviewed by the European Food Safety Authority Animal Health and Welfare Panel (EFSA, 2004) and again by von Holleben et al. (2010). This chapter builds on this body of knowledge, presenting recent advances in sheep transportation, pre-slaughter management and slaughter to maximise welfare.

Preparation of sheep for transportation

Fitness to travel

No animal should be loaded for transportation if it is likely that the animal is unable to cope with the journey as a result of illness, injury or physiological state (e.g. late pregnancy and early neonatal). Chapters 7.2, 7.3 and 7.4 of the OIE Terrestrial Animal Health Code (OIE, 2015) and the International Air Transport Association (IATA) Live Animals Regulations give clear and detailed guidance on assessing an animals fitness to travel. Although there is little published research underpinning these guidelines, the rationale for most is generally self-evident.
**Acclimation periods and curfews**

For short journeys, by road, rail or air, it is common practice to withdraw feed and water for a period of time prior to transport (curfew), whereas for long journeys, for example sea transport undertaken as part of the livestock export supply chain, it is vital that animals are acclimated to the feed offered on-board prior to loading, as inanition is one of the predominant contributors to mortality in sheep undergoing sea transport (Richards et al., 1989). However, under commercial conditions, sheep commonly spend a mere 5 days in the assembly depot (Phillips and Santurtun, 2013), and little recent research has explored potential aids to feed acclimation, subsequent to the work investigating the effects of feed type, virginiamycin and dexamethasone on feed acceptance and intake carried out in the early 1990s (Adams and Sanders, 1992; Bailey and Fortune, 1992; McDonald et al., 1994; Norris et al., 1992).

In ruminants, the removal of water prior to transport poses little welfare risk, as long as the climatic conditions and overall deprivation period do not result in dehydration (Fisher et al., 2009). Without the additional stress of transport, sheep can be deprived of water for up to 72 h in mild conditions (Cole, 1995, 2000), however, when high temperatures prevail, dehydration can occur rapidly (Lowe et al., 2002). Short-term feed deprivation (up to 34 h) has little effect on blood glucose, meat quality and yield (Fisher et al., 2015), although the welfare effects of subjective experiences such as hunger are unknown.

**Loading**

Loading and the initial movement of the container or vehicle are known to cause physiological stress responses in sheep (Broom et al., 1996; Parrott et al., 1998a,b), and livestock transporters consider that the main factors affecting the ease of handling sheep are the facilities and the naivety of the animals to handling (Burnard et al., 2015). Livestock transporters also expressed the importance of handler experience and attitude, concurring with the findings of Hemsworth (2007), Hemsworth and Barnett (2001) and Hemsworth et al. (2011). However, little recent research has explored new strategies to improve transport loading and unloading practices.

**Transport of sheep by road, rail and air**

Where animals are transported short distances to slaughter, measures of short-term effects on animal welfare such as increased physiological responses (Cockram et al., 2000), behavioural responses (Wickham et al., 2012), injuries (and mortality) and carcass quality (Dalmau et al., 2014), are most commonly used. Sheep show less obvious signs of distress during road transport than other species of farm animals (Broom, 2008). However, it is still likely to be an aversive experience, resulting in similar plasma cortisol and plasma adrenaline responses to other known psychological stressors such as isolation (Cockram, 2007; Parrott et al., 1994). Conditions within vehicles during transportation can also affect the stress response in sheep, with particular stressors including exposure to high levels of noise, handling by humans, flooring,
vibration and altered thermal environment (Broom, 2008). There has been little research to identify the importance of each of these individual components during prolonged transportation.

**Transport of sheep by sea**

Australia is the world’s largest exporter of sheep by sea (Schipp, 2013), with 2.18 million head exported in 2014–15, 97% of which were destined for the Middle East (Meat & Livestock Australia Ltd, 2015). Long sea journeys generally require holding animals in pens constructed on each deck, where they are provided with feed, water and sometimes artificial ventilation for the duration of the journey, which may be up to 34 days for some journeys from Australia to the Middle East. The average voyage from Australia to the Middle East is 25 days, with a range between 14 and 34 days dependent on distance between port of origin and destination and ocean/weather conditions. Long-distance transport of livestock by ship poses a unique set of challenges to welfare compared to intra-EU transport which involves the use of roll-on roll-off truck transport. When sheep are transported long distances by sea, there is a greater risk of a poor welfare outcome; however, the risk of an adverse animal welfare outcome is ultimately determined by a range of animal, management and environmental factors (Marahrens et al., 2011).

The World Organization for Animal Health (Office International des Epizooties, OIE) has established standards for the health and welfare of animals being moved across national boundaries (Schipp, 2013). Mortality rate is the main measure of welfare used by the Australian live export industry for shipments of livestock by sea and air (Phillips and Santurtun, 2013). The main cause of death during sea transport is the inanition/salmonellosis complex which consistently accounts for about 75% of all sheep mortality on-board the vessel (Norris, 2005). However, for animals transported long distances, or retained on farms and feedlots for long periods after transport, measures such as increased disease incidence and reduced productivity can also provide an insight into the long-term welfare effects of the journey (Broom, 2005). Long-distance sea transport exposes livestock to similar stressors to those experienced during road, rail or air transport; however, there are few independent peer-reviewed studies of the increased risk of cumulative stress during the extended transport period. The recent reviews by both Phillips and Santurtun (2013) and Caulfield et al. (2014) highlight the paucity of data in this area. Given the prominence of inanition and outbreaks of disease, particularly salmonellosis, as primary causes of shipboard mortality in sheep, increased focus on animal preparation prior to the journey would be worthwhile.

**Transport practices**

*Journey duration*

Studies of the impacts of transport on the stress responses in sheep have shown that loading and the initial transport phase caused a significant increase in plasma cortisol
and lactate dehydrogenase which diminished over the course of the transport period (De la Fuente et al., 2010). This supported the work of Cockram (2007), who showed that plasma cortisol concentration declined within a few hours and was often near to, or at, pre-transport values by the end of a 24-h journey. After the initial psychological stressors of loading, increasing transport duration may present a challenge to welfare. As journey length is increased, exertion and potentially fatigue during transport may result from long periods of standing rather than lying down, requiring muscular tension to balance the body during vehicle motion (Terlouw et al., 2008).

Physiological effects of increasing transport duration by road (where feed and water are withheld) include increased live weight loss, in older lambs (Sarozkan et al., 2009) and in suckling lambs (Tadich et al., 2009). In older lambs, most of the reduction in weight was attributed to loss of gut fill which is recovered after feeding upon arrival (Fisher et al., 2010). The findings of Fisher et al. (2010) indicate that healthy adult sheep, transported under favourable conditions, can tolerate road transport durations of up to 48 h. It is difficult to find data to support prescribed maximum journey times, applicable to all transport types and conditions, and more emphasis should be placed on the quality of the journey rather than focusing exclusively on duration.

**Space allowance**

Space allowance (or stocking density) during transport is regarded as one of the most important factors influencing animal welfare (Broom, 2005). There are generally two views about the space required for sheep during transport. The first is that sheep should be transported at high stocking density (low space allowance) so that they can brace themselves against each other and avoid significant movement in the vehicle (Cockram et al., 2004). The second is that they should be transported at low stocking density (high space allowance) to allow them to adopt an independent brace against the motion of the vehicle, avoiding contact with other animals (Jones et al., 2010). The OIE Terrestrial Animal Health Code (OIE, 2015) recommends that the space provided on a vehicle or in a container (during land transport) is determined by the need for livestock to lie down or to stand during the transit process. Cockram et al. (2004) found that sheep spend most of a 7-h journey standing rather than lying down, but the amount of lying behaviour increases with journey duration. High stocking density does not allow animals to lie down (Knowles et al., 1995), but when animals travel at low stocking density, they can lie down and move, but their welfare may still be at risk if driving techniques are poor.

The majority of recommendations for space allowance provided to adult sheep in transport are defined according to weight ranges. Cockram et al. (1996a,b) identified that space allowances that make it possible for sheep to lie down in transit should be approximately 0.25–0.27 m² per sheep of 35 kg live weight, while De la Fuente et al. (2010) indicated that for lambs of 12–14 kg live weight, reducing space allowance to 0.12 m²/lamb did not affect physiological responses or meat quality, as compared to the EU minimum space requirement per head of 0.20 m² for lambs over 26 kg live weight, on journey times <5 h. Similarly, Cozar et al. (2016) indicated that there were no significant differences in physiological indicators in lambs of approximately...
28 kg live weight, transported at a range of space allowances between 0.16 and 0.30 m². For small lambs, recommendations tend to focus on space allowance per animal. This is inadequate as it does not take into account variation in animal weight and may lead to large numbers of sheep per pen. For sheep, it is therefore recommended that space allowances should be calculated according to an allometric equation relating size to body weight (Jones et al., 2010; Petherick and Phillips, 2009).

During long-distance transport by sea, the space allowance also needs to take into account an animal’s ability to access feed and water. The Australian Standards for the Export of Livestock (ASEL) includes minimum space requirements for sheep, which are lower than those required by domestic codes of practice for confined sheep (Caulfield et al., 2014). Ferguson and Lea (2013) investigated the impact of the ASEL space allowance on animal welfare, concluding that the existing allowances were sufficient. However, it was suggested that a 10% increase in space allowance during the early part of the journey could have some benefits and should be investigated further.

**Thermal environment during transport**

Transportation of any type involves a change to an animal’s thermal environment. Ruminants have a wide range of thermoneutrality from about 10 to 30°C (Webster, 1983), enabling them to tolerate moderate fluctuations in temperature quite adequately. In ewes, transportation by truck was seen to produce a significant increase in rectal temperature which declined following unloading (Ingram et al., 2002). Mortality from heat stress during road transport rarely occurs in sheep, though it is essential that adequate ventilation is maintained on-board the vehicle (e.g. reducing the amount of time that the vehicle is stationary). For a given stocking density and vehicle design, the temperature–humidity index inside the transport vehicle generally increases when vehicles are stationary in proportion to the duration of the stop. Fisher et al. (2005) reported that during journeys in summer, the stationary periods and an increase of external ambient temperature (>25°C) could induce thermal stress and be detrimental to sheep welfare.

During long-distance transport by sea, heat stress often presents a challenge to livestock when they are transported from cold to hot regions with little diurnal temperature fluctuation. Generally, sheep cope with heat stress better than cattle (Caulfield et al., 2014), though the risk and rate of dehydration occur with increased thermal panting. A heat stress model was developed for the Australian livestock export industry in 2003 to estimate (and subsequently) minimise the incidence of heat stress mortality in livestock during voyages to the Middle East. The review and refinement of the model are described in the Meat & Livestock Australia publications (Eustace et al., 2009; Ferguson et al., 2008).

**Provision of feed and water**

Water deprivation is considered to be a more significant risk to welfare than food deprivation, given the risk of dehydration. Krawczel et al. (2007) studied water deprivation in continuously transported lambs. Results did not indicate that the lambs were dehydrated at the conclusion of 22 h transport and they were reluctant to drink when
offered water on the trailer after 14 h transportation. However, the effect of water deprivation on suckling lambs could be different from that described in older lambs and sheep, even for short journeys. De la Fuente et al. (2010) showed that suckling lambs show symptoms of dehydration when transport times are increased from 30 min to 5 h. In contrast, when feed is withdrawn, research suggests that healthy, untransported sheep can tolerate long periods (2–3 days) without food before undue compromise to their welfare (Cole, 1995).

During sea transport, feed and water are provided (usually ad libitum); however, inanition can occur in sheep that fail to adapt to the shipboard ration (Phillips and Santurtun, 2013). Inanition is common in over-fat sheep, which have depressed appetites (Higgs et al., 1991). The ASEL addresses the issue of inappetence in sheep, and it contains requirements for a feed transition period, monitoring and management of affected livestock (Schipp, 2013). Inappetence and inanition in sheep during live export remain a key problem, and research is required to further identify the factors that predispose certain sheep to this condition and develop mitigation strategies.

Rest stops

For long-distance transport of animals, rest stops are mandated within certain jurisdictions, however, a shorter supply chain may also involve stopovers, for example at saleyards, classification centres or pre-export collection centres. Each stopover involves the unloading, and subsequent re-loading of animals, contributing to the compounded stress levels of the journey (Grandin, 1997). Within the European Union, a 24-h stopover is mandated after 29 h of transport (EC, 2005), but research underpinning this duration of stopover is lacking, and there is industry pressure to reduce the duration of the rest period, and to remove the requirement for animals to be unloaded for the rest period. Messori et al. (2015a) investigated physiological and behavioural responses of sheep unloaded and reloaded for an 8-h stopover after the first 29 h of a total journey duration of 35 h, as compared with an untransported group and a group that remained on the truck during the stopover. Those that remained in the truck performed less lying and feeding during the stopover period, but there were no significant differences in physiological measurements between the two transported groups. On completion of the journey, those that have been unloaded and reloaded showed greater creatine kinase levels than the control group that remained on farm, indicating that they had suffered some muscle damage and had lost on average 2 kg of bodyweight as compared with the group that remained on the truck. The authors concluded that avoiding the unloading and reloading aspects, when the rest stop was as short as 8 h, gave no clear improvement in welfare. Another study (Krawczel et al., 2007) considered road transportation of lambs for a 22-h journey, either as a single continuous stage, or as three stages, with rest periods between each stage. The first rest period was 6 h and the second was 24 h. Although the lambs receiving rest stops maintained bodyweight and showed little physiological evidence of food deprivation as compared to the continuous journey group, there were no positive impacts on immunosuppression and stress, as measured by cortisol levels. Researchers in Spain have been investigating the sheep welfare and meat quality impacts of interrupted journeys,
incorporating stopovers of varying durations at a classification centre (Miranda-de la Lama et al., 2009, 2012a,b). However, they have found a strong interaction with season, or climatic conditions, so again no clear conclusions on welfare aspects could be drawn.

**Saleyards and markets**

During the marketing process from farm to slaughter, some sheep will be sold through livestock saleyards (auction markets). There is a perception that the welfare of livestock sold through markets is poorer than those animals sold directly to the abattoir. However, a study by Gregory et al. (2009) questioned whether the perception that sheep markets have poor welfare standards was justified, as the prevalence of handling difficulties at the sheep markets was found to be low. There have been no recent studies to support or refute earlier findings which showed that marketing via saleyards results in increased dehydration and fatigue (Kim et al., 1994), increased carcass bruising (Knowles et al., 1994a) and increased mortality during transport and in lairage (Knowles et al., 1994b).

**Post-transport conditions**

**Lairage environment and pre-slaughter considerations**

Animals that have been transported long distances will be tired, may be hungry and thirsty if they have undergone pre-transport feed and water restriction, and feed and water were not provided during the journey, and may experience unfamiliar climatic conditions. Heat stress is an important consideration in sheep exported from cooler areas to hotter climes, for example in the case of sheep exported to the Persian Gulf from Australia. In a high heat load situation, not only do the animals require more water, but their willingness to drink is also affected by the water temperature. Appetite and feed intake are suppressed by high ambient temperatures, and this can impact on body condition and growth rates (Alamer, 2011; Alamer and Al-Hozab, 2004; Marai et al., 2007; Savage et al., 2008). To optimise growth rates in sheep arriving in hot climates, pen space allowances should be greater than 1.2 m² per sheep, water trough allocation should be a minimum of 1 cm per head and feed trough space 5 cm per head if the animals are on a structured feeding programme, or 10 cm per head for ad-lib feeding (Dundon and Mayer, 2015).

Immediately on arrival, the animals are unloaded, an operation that could be assumed to be stressful, as in the case of loading. However, it seems that no significant increase in body temperature or cortisol response occurs in sheep (Broom et al., 1996). Thereafter, the animals are moved to holding pens to rest. This could take the form of a feedlot, or yards, from which they will be moved on after a period of time, or could be the lairage of a slaughter facility. Research into the impact of rest post transport has focused predominantly on the lairage, particularly in relation to the impact on meat quality attributes.
There is an underlying assumption that the longer the rest period, the better. However, for pre-slaughter lairage it appears that a period between 6 and 12 h may be optimal (Liu et al., 2012), when comparing white blood cell counts and differentials, plasma cortisol, creatine kinase and glucose of sheep transported for 8 h, then laired for 0, 2, 6, 12, 24 or 48 h with untransported sheep. Similarly, Ekiz et al. (2012) found that cortisol levels in sheep that allowed a 30-min rest period were not significantly different from those that allowed an 18-h rest period, but meat quality attributes (tenderness, colour, water holding capacity and cooking loss) were better in the group held for 18 h. Liste et al. (2011) also found elevated plasma cortisol, lactate and glucose levels in lambs slaughtered immediately after arrival compared to lambs rested for 12 h, while Leme et al. (2012) confirmed that even a short, 3-h lairage period can reduce the cortisol response in sheep, suggesting a recovery from transport and handling stress.

Animal handling

There is an abundance of scientific evidence to demonstrate that stress during animal movement and the risk of physical injury can be minimised by ensuring that the animal handling facilities are well designed. The impact of poorly designed or constructed handling facilities on the welfare of livestock has been studied extensively (Grandin, 2009). Provision of non-slip floors, well-designed races and even lighting throughout the movement areas, together with the elimination of distractions, have been shown to improve the movement of sheep in abattoirs. Movement difficulties are mostly created by poor physical conditions such as inappropriate flooring or raceways. This can be assessed practically in a processing plant by recording slips, falls and baulking as livestock are moved through the handling system (Grandin, 2012). Stockperson behaviour during handling such as frequency of touching, pushing and whistling influences cortisol concentration (Hemsworth et al., 2011). Similarly, the use of dogs has a pronounced effect on stress indicators in sheep. Grandin (2009) recommends that dogs should be limited to pastures, large pens and other open areas where animals have room to move away. Stockpersons who believe that electric prodders or goads and dogs are appropriate methods for moving animals and that the use of goads does not stress animals, may use goads more frequently (Coleman et al., 2012). In Australia, electric prodders are still widely used in the sheep transport industry (Burnard et al., 2015) and permitted in most jurisdictions. Within the abattoir, their use is usually limited to moving reluctant sheep into restraint (Grandin and American Meat Institute Animal Welfare Committee, 2013).

Lairages can be relatively noisy, especially when compared with most farm environments. Weeks (2008) found noise levels in sheep lairages to be lower than in pig and cattle lairages, but higher than sheep would normally be accustomed to if out in a paddock. Noise, such as banging gates, use of rattles, dogs barking and whistling, can have a profound effect on animal movement and stress levels (Kim et al., 1994). Unlike cattle, sheep generally do not vocalise in response to an aversive stimulus; therefore, this is not a measurable indicator of stress during handling. Apart from vocalisation between ewes and their lambs, or vocal communication between sheep, there has been little research in this area.
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Restraint for stunning and slaughter

The main purpose of restraint is to restrict the movement of an animal, holding it in the correct position, so that a procedure (e.g. sticking or stunning) can be carried out accurately. Restraint in itself is stressful for the animal, however, when restraint is combined with isolation, this can evoke a more substantial stress response (Apple et al., 1993). Systems used to convey animals to the stunning and slaughter point have to work at high speeds. For example, lamb abattoirs in New Zealand slaughter up to 24,000 animals per day. Systems must allow for animals to move in a continuous flow to the point of slaughter, without interruptions on the slaughter chain. Many establishments have automated this part of the process, through the installation of devices designed to move animals and restrain them for stunning. V-shaped conveyor restrainers, which deliver sheep in a continuous flow, are commonly used in high throughput abattoirs. They are designed in such a way that sheep remain in visual, audio and tactile contact with each other, avoiding isolation of individual animals which is known to be stressful (Parrott et al., 1994).

In Europe, there is a requirement for sheep slaughtered without stunning to be individually and mechanically restrained. This has been interpreted by some regulatory authorities as a requirement to load individual animals one at a time onto the V-restrainer, effectively isolating them from other animals. Bates et al. (2014) found that lambs handled in this manner showed an increase in cortisol and lactate (possibly indicative of struggling behaviour) as compared with sheep allowed to sequentially enter the V-restrainer. Separating sheep and loading individually into V-restraint works against the design principles of the equipment and the animal’s natural following behaviour. Anil (2012) confirmed that sheep do not appear distressed when loaded sequentially with other sheep and it is more beneficial to move them as a group.

Humane slaughter

Animals have been slaughtered for human consumption for thousands of years, but in recent generations, it has been considered ethical to render the animal insensible prior to slaughter by exsanguination. The body of knowledge on commercial slaughter practices for sheep was extensively reviewed by von Holleben et al. (2010), and this information will not be reiterated here. Both electrical stunning and mechanical stunning have long been practised in commercial slaughterhouses, and recent research has focused on optimising electrical stunning, improving methods for assessing insensibility and the development of new methods of rendering the animal insensible prior to slaughter.

Emergency procedures

When moribund or non-ambulatory animals (animals that are unable to walk or stand, or exhibit signs of distress, with little chance of recovery) are identified on the farm, truck or in the lairage, they should be humanely destroyed immediately. The ideal method used for emergency slaughter depends on the type of species and category of animal. Industry has expressed a need for a humane killing method that does not require the animal to be pithed or bled post-stunning. Pithing is a technique whereby
the brainstem is physically destroyed by passing a rod through the hole produced by
the penetrating captive bolt or free bullet, into the brain and down the first part of the
spinal column. Destruction of the brainstem ensures death, but exposes the operator
to central nervous tissue and associated health hazards. The need to avoid pithing
and bleeding is particularly important when the procedure needs to be performed on
a truck or in a lairage pen. Research by Gibson et al. (2012) made welfare-based rec-
ommendations for gun/cartridge combinations and shot positions to ensure the death
of sheep (horned/polled rams and ewes) without the need for pithing or bleeding.
Similarly, a euthanasia kit (Cash Dispatch Kit) based on the Cash Special captive bolt
pistol has been developed and trialled as a one-step killing method for cattle (Gilliam
et al., 2012), and work in this area is still on-going.

Assessment of insensibility

To safeguard animal welfare at slaughter, it is important to be able to assess insen-
sibility after application of the stun, and prior to exsanguination, such that a semi-
conscious animal does not suffer the painful process of exsanguination, rather that
it can be re-stunned before the incision is made. Similarly, post incision, it is im-
portant to be able to identify returning consciousness prior to death and to re-stun if
required. The gold standard method of assessing lack of consciousness is by electro-
cephalogram (EEG), however, the recording of EEG in real-time on every animal
processed in a commercial slaughterhouse is not practicable, and proxies such as re-
flex responses and behavioural indicators are used. This has been a routine practice
for many decades, but until recently, scientific validation of these proxy indicators of
unconsciousness has been lacking (Verhoeven et al., 2015a). A structured comparison
of the EEG pattern and behavioural indicators in sheep subjected to chemical anaes-
thesia, and sheep that were exsanguinated without prior stunning, was undertaken by
Verhoeven et al. (2015b). In the anaesthetised sheep, absence of rhythmic breathing
and absence of menace reflex indicated unconsciousness. Both were present during
induction of anaesthesia, while in the exsanguinated sheep, the EEG pattern indicated
unconsciousness prior to the loss of rhythmic breathing (15–39 s post-EEG changes)
and loss of blink reflex (42–76 s post-EEG changes). It was concluded that absence
of rhythmic breathing and loss of blink reflex, both used extensively in commercial
slaughterhouses as indicators of unconsciousness, are conservative indicators, provid-
ing confidence that those animals are indeed insensible.

Optimisation of electrical stunning

Electrical stunning parameters have been laid down in legislative instruments
around the world, but the basis for selection of the particular values prescribed is
often not clear. It may be based on a belief that longer application duration and
higher current will result in a ‘better’ stun, although this is not supported by re-
search (Cook et al., 1995). Associated with electrical stunning in sheep is the meat
quality issue of ‘blood splash’—petechial haemorrhages or ecchymoses in muscle
(Gregory, 2007), which may be associated with ‘over-stunning’, particularly in small-
er animals. Therefore, research interest has turned to optimising the parameters for current flow and duration of application as a potential means of reducing any meat quality problems while ensuring a good stun, and thereby protecting animal welfare. Llonch et al. (2015) demonstrated that currents as low as 0.3 A, applied for 3 s could induce effective stunning in lambs and goat kids (weight range 7–16 kg), by either head-only or head-to-body application, while Berg et al. (2012) found that a head-only application of 0.6 A for 10.5 s was insufficient to stun lambs in the range of 10–15 kg, but 1.25 A resulted in a 92% effective stun rate in a commercial slaughterhouse. They then altered stun duration, comparing 1.25 A, applied for either 14 or 3 s. No significant differences were found in the incidence of blood splash, but the short stun duration increased the likelihood of a poor quality stun, that is incomplete unconsciousness, based on assessment of reflexes and behavioural indicators.

**New methods for rendering sheep insensible prior to slaughter**

Carbon dioxide (CO$_2$) mixtures have long been used for pre-slaughter stunning or killing of pigs and poultry. Recently, investigations into the use of CO$_2$ mixtures in sheep slaughter have been carried out. A 90% concentration of CO$_2$ with 60 s immersion time resulted in between 90% and 100% of lambs being stunned, whereas increasing exposure times increased the proportion of animals killed, and decreasing the gas concentration increased the proportion of animals rendered semi-conscious rather than fully stunned (Bornez et al., 2009b, 2010). When compared with electrical stunning, the CO$_2$ system produced comparable meat quality, endocrine and haematological outcomes, leading the authors to conclude that CO$_2$ stunning was a suitable alternative stunning method for sheep (Bornez et al., 2009a,b, 2010; Linares et al., 2008; Vergara et al., 2009). However, lambs exposed to progressive immersion to 90% CO$_2$ do show aversive behaviour and breathlessness (Rodriguez et al., 2016), which may be considered to be a negative welfare outcome.

A new technology, trademarked DTS: Diathermic Syncope, is under development in Australia. This technology applies electromagnetic energy (922 MHz) to the forehead of the animal, held within a restraint device, to selectively and rapidly raise the temperature of the brain to a point at which neurotransmission fails, and the animal falls unconscious. To date, the DTS technology has been tested on a small sample of anaesthetised sheep and the results showed that the required brain temperature was reached and that unconsciousness was achieved based on EEG traces (Small et al., 2013).

**Conclusions**

Live animals are transported by road, rail, air and sea, and this is set to continue as developing countries improve and expand their livestock agriculture industries, developed countries trade superior genetics, and the physical distance between the consumers (increasingly urbanised) and the primary production of livestock increases. Supply chains are becoming increasingly complex, with animals transiting through a number
of ‘hubs’ or collection points between origin and destination, and it is evident that each stage of the overall journey brings its own challenges to welfare.

Our understanding of the factors contributing to physical and physiological stress is developing, and research is ongoing into mitigation strategies and optimisation of individual components of the supply chain (e.g. the sea journey, or the road journey, or humane slaughter). However, the attention of the consumer is shifting towards the ‘whole of life’ welfare of animals rather than merely the individual steps, and also away from merely ensuring the Five Freedoms are met, and that animals live a ‘good’ life. Therefore, to meet consumer expectations, future research needs to take a through-chain approach, considering the cumulative impact of multiple stressors, and also the cognitive or emotional impacts of such cumulative stress on the welfare of animals. Indeed, a through-chain approach to welfare management is being taken, and a welfare assessment tool for sheep transportation has been developed, and evaluated on a pilot scale by Messori et al. (2015b).

It is evident that, when considering the ‘farm-gate to slaughter’ section of the supply chain, there has been a paucity of new developments in recent years that continue to mitigate the negative welfare impacts of transportation and handling. Implementation of existing knowledge may have advanced, as indicated by the plethora of international standards and guidelines, but research has tended to focus more on human–animal interactions, or scientific validation of existing industry know-how under specific supply-chain situations, than on the development of alternative mitigation strategies. A major deficit in progress is evident in the preparation and selection of animals prior to transport such that the animals loaded for transport are prepared to cope with physiological, health and psychological challenges of the journey.

References


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Advances in Sheep Welfare


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Introduction

The principles of precision farming

The information technology revolution is impacting on most aspects of modern life, and this includes agricultural production. In its broadest sense, ‘precision agriculture’ is about managing variability. The approach was first adopted in arable farming where ‘Site-Specific Crop Management’ involved ‘matching resource application and agronomic practices with soil and crop requirements as they vary in space and time within a field’ (Whelan and McBratney, 2000). This can be achieved by measuring and mapping crop growth or yield at harvest and then apply fertilizer (and/or herbicides/pesticides) only when and where needed. Precision agriculture is also called ‘smart farming’ or, more recently, ‘Farming 4.0’ or ‘Agriculture 4.0’ (Weltzien, 2016). All these terms refer to the same concept: the use of information technology and sensor data to improve the efficiency of resource utilisation in farming systems.

The development of precision livestock farming (PLF)

Although the application of precision approaches to agriculture were originally associated with arable farming, the approach can also be applied to livestock production (Berckmans, 2015). Indeed, one could argue that, by monitoring and measuring variability the level of the biological unit that is the individual animal, precision livestock farming (PLF) is in many ways more advanced than precision arable farming as the latter does not yet measure and manage variability at the level of individual cereal plants.

Fig. 13.1 shows a simplified control diagram for the application of the precision farming concept to livestock production. Manual data input (which is prone to human error) is increasingly being replaced by automatically sensed data. These data are integrated and analysed along with external data (e.g. weather forecasts, commodity prices etc.) to help the farmer, aided by external advisors (e.g. veterinarians, nutritionists etc.) make more informed management decisions. It is important to emphasize that the PLF approach is a tool to support farmers and not to replace them or their skills as a good stock person. The management decisions of the farmer or their professional advisors are then implemented, with increasing levels of automation being used to achieve this. A key concept of the precision approach is that the outcomes of the
analysis-decision-control stages are integrated, monitored and documented and this stage feeds back into the data integration/analysis stage. This feedback loop enables the control systems to ‘learn’ and optimise the data processing algorithms for the specific conditions, not only for that particular farm but also for each animal on that farm. Different farmers will also have different requirements for the way they balance the needs to be economically and environmentally sustainable whilst also maintaining animal welfare standards, and the algorithms can be tuned to meet each farmer’s specific needs and goals. The recorded data and documented outcomes are also of value to the farmer as they can be used to demonstrate compliance with, for example farm assurance schemes and animal welfare standards and so help to add value to the product. This information is of interest to retailers as it can be used to help link consumers with the source and provenance of their food.

**Current PLF technologies deployed on farms**

To date, the majority of PLF technologies have been developed for and are used in intensive livestock production systems. In ruminant production systems, the dairy cow has, so far, been the main beneficiary of PLF technologies (Rutter, 2012). The comparatively high value of the milk produced over the lifetime of a cow means that even quite expensive technologies can still give a good economic return on their investment through improvements in production efficiency. As well as automatic systems that can identify, weigh and segregate cows, a variety of sensors are used to detect when dairy cows are in oestrus. Oestrus detection is crucial in production systems that rely on artificial insemination and this helps in explaining the initial focus on technologies that help in this area. Cows show an increase in activity during oestrus, and this extra movement can be detected by accelerometers mounted on one of the cow’s legs or around her neck. Cows also eat less during oestrus, and this reduction in intake is followed by a reduction in time spent ruminating. This is used by other oestrus detection
Advanced livestock management solutions

systems which monitor rumination, either using bioacoustic sensors around the animal’s neck or an accelerometer in the cow’s ear. External sensors can also be used to monitor the animals, with 3D cameras able to automatically body condition score cows that walk under it. Recently, systems that can determine each cow’s location and track her movement in the barn have become available to dairy farmers. Although these have initially been used to help to locate a cow that requires artificial insemination, the movement data could also give invaluable insight into other conditions, for example detecting when an animal is diseased or injured. Indeed, technology companies see automated health and welfare monitoring as the next important area beyond oestrus detection, and many are working to integrate data from a variety of sensors and sources as they try to detect the subtle changes in behaviour associated with the onset of disease. Finally, robots are taking over many of the management duties on an increasing number of dairy farms. This includes robotic milking systems, robotic slurry scrapers and robotic feeding systems.

Compared with intensive dairy cow farmers, sheep farmers (especially those producing meat and wool rather than milk), have, to date, comparatively few PLF technologies available to assist them. The subsequent section will review the existing sheep PLF technologies.

Current sheep precision livestock farming technologies

Electronic identification (EID)

Given a major objective of the PLF approach is to measure and manage variability at the level of individual animals, the ability to automatically identify individual animals is arguably the core technology within PLF systems. Although image recognition systems have the potential to identify individuals of some breeds of farm animals that is those with individually different coat patterns, the development of low cost radio-frequency identification (RFID) technology [now more widely known as electronic identification (EID)] has revolutionised automated animal identification. There are essentially two types of RFID system—passive and active. In a passive system, the tag does not contain a battery or any other independent power source. Instead, the electronics in the tag are energised and powered externally by electromagnetic energy transmitted by the reader, at which point the tag transmits a radio signal that contains the tag’s unique identifier. This is picked up and decoded by the RFID receiver. In contrast, active tags contain their own power source that is a battery. Although this enables them to operate over longer ranges compared to passive tags, they are generally larger, more expensive and the battery has a finite life. Given the low cost, small size and long (effectively indefinite) life of passive tags, they have come to dominate animal EID systems.

The RFID tag needs to be attached to the individual it is intended to identify, and three methods are available. Although injectable, subcutaneous, glass-encapsulated tags are ideal for the use with pet animals, the difficulty in safely removing them after slaughter generally precludes their use in the majority of farm animals. The small size
of passive RFID tags means that they can be easily incorporated into traditional numbered ear tags. Alternatively, the RFID tag can be incorporated into a ceramic bolus which, following oral dosing, resides in the reticulo-rumen in sheep, cattle and goats. Different methods have their advantages and disadvantages, respectively. Fitting an ear tag is less likely to injure the animal compared with oral dosing where improper administration can result in serious injury such as entering the trachea or oesophageal rupture. Ear tags are more likely to be lost compared to boli, although the size of the bolus is important, and small (20 g) boli are more likely to be lost compared with large (72 g) ones (Cappai et al., 2014). EID boli have one advantage over ear tags that can be important in some countries and that is they are very difficult (if not impossible) to remove without killing the animal. This makes it difficult for the identity of stolen animals to be removed or for unscrupulous farmers to swap animal IDs as part of fraudulent record keeping or subsidy claims.

**Automatic weighing systems**

Liveweight is a useful indicator of nutritional status, and regular automated measures of liveweight are a potentially useful management tool. By linking an EID reader to an electronic weigh platform, it is possible to record a liveweight estimate for each animal as it walks over the platform, known as walk-over-weighing (WOW) (Morris et al., 2012). Note that each WOW reading is an estimate, as weight readings from a moving animal are not as accurate as those obtained in a static crush. In order to improve the reliability of the individual weight data, a number of WOW readings need to be taken. This requires getting the animals to voluntarily walk over the platform on several occasions each day, and this is usually achieved by strategically positioning the WOW platform between two important resources, for example the paddock and a water trough (Fig. 13.2). In practice, Brown et al. (2014) found that they were unable to get sufficiently reliable WOW data within a suitable timeframe and as a result they could not recommend the approach for the on-farm management of individual sheep. Hopefully, future improvements in the reliability of RFID technology, in-paddock filtering of spurious weight measurements and methods to increase the frequency of weight readings will result in WOW systems that can provide useful on-farm management data for individual sheep.

**Automatic shedding gates**

Automatic shedding gates (also known as automatic sorting or drafting gates) allow animals to be automatically segregated as they move down a raceway. Typically, pneumatically driven gates direct the sheep into two or three groups as they exit a crate. A gate at the entrance to the crate prevents the next sheep from ‘rushing’ through the segregation gate. The shedding gate can be linked to an EID system allowing farmers to select specific sheep based on their EID number. Alternatively, the gate can be linked to an automatic weighing system and programmed to select sheep based on their liveweight, either their absolute weight or, in conjunction with EID, some threshold changes as their previous weight was recorded.
Domestic sheep suffer attacks from wild, feral and domestic carnivores, usually canids, in most parts of the world, although the Australian sheep industry has a particular problem with predation by wild dogs (Allen and Fleming, 2004). Such attacks have a direct negative impact on sheep welfare as well as a detrimental economic impact on the farmer. A number of digital technologies have been developed to help livestock farmers to manage the negative impact of predators.

Traps can be used to capture predators, with live capture in cages preferred to snares or leg-hold traps which can kill non-target as well as target animals and can result in any trapped animal suffering a slow and painful death. Any animal caught in a cage trap is deprived of food and water and will find confinement stressful, so traps need to be regularly inspected to minimise the amount of time animals are trapped. Trap alert devices (Larkin et al., 2003) can alert farmers or their pest control operatives to the fact that an animal has been caught in a trap, facilitating rapid intervention to reduce the suffering experienced by the trapped animal. Research by Woodford and Robley (2011) found that such systems were generally reliable, although alerts failed to be delivered on 6 of their 45 tests.

Figure 13.2 Sheep crossing a walk over weighing platform as they exit a controlled traffic zone where they were accessing a watering point. 
Source: Photograph by Kemmis, L., Sheep Cooperative Research Centre, Australia.
Digital technologies are also alerting farmers to the presence of predators on or near their farm. ‘Wild Dog Alert’ (Invasive Animals Cooperative Research Centre, 2015) uses remote camera ‘traps’ that is digital cameras at that are activated by a movement sensor and have infra-red illumination so that they can work at night. The images from the cameras can be automatically processed to identify wild dogs and alert farmers to their presence, although this does not yet appear to be been subjected to scientific validation. An alternative approach allows farmers to use a website or smartphone ‘app’ to report and share sightings, impacts and control measures for wild dogs and other pests in their local area (Invasive Animals Cooperative Research Centre, 2016). Although this latter approach does not facilitate automatic predator detection, it uses information technology to help farmers quickly and easily share their predator and other pest sightings.

Future sheep PLF technologies

Advanced EID systems

The next generation of EID tags currently (2017) being developed operate at ultra-high frequencies to increase the reading speed, distance and the number of tags that can be read simultaneously (Umstatter, 2014). These ultra-high frequency-EID tags can also include digital memory that allows the tag to store management information, for example when the animal received veterinary treatment, its liveweight history and so on. Although local data storage on the animal can overcome data capture issues where mobile data access (e.g. over Wi-Fi or cellular network) is unavailable, it limits the ability to integrate data from the whole flock across time. The integration of data from a variety of sources, including different animals, is one of the key strengths of the PLF approach, and so local data should be seen as an interim store until data from the farmer’s EID reader can upload the data into the ‘cloud’ that is central data servers located away from the farm.

Applying dairy cow technologies to sheep production

PLF technologies that have been developed for intensively-managed dairy cattle could, with some adaptation, be applied to intensify various aspects of sheep production, particularly for dairy sheep. Indeed, dairy sheep already benefit from EID-facilitated milk metering, individual feeding and automated sort gates. Oestrus detection systems based on behaviour monitoring (as discussed earlier) could facilitate artificial insemination to improve sheep genetics, and robotic milking systems could be adapted for use with dairy sheep. Neck and/or ear mounted accelerometers are also able to detect rumination and eating behaviour in cattle, and these should in principle work with sheep. Note that eating time is not very well correlated with food intake as animals spend variable amounts of time searching through mixed feeds as they select specific dietary components. However, time spent ruminating is closely linked with fibre intake, so can be used to help estimate intake. As well as helping to optimise feeding,
these data can also help to detect the changes in behaviour such as a reduction in food intake associated with the early stages of many diseases. Leg-mounted accelerometers can detect changes in cow activity associated with the early onset of lameness in dairy cattle (Thorup et al., 2015) and could be adapted to detect foot health problems in sheep. Physiological monitoring (e.g. boli to detect rumen pH) can also be used to help and optimise the diet and detect rumen disorders. However, PLF technologies could also be applied to more extensive sheep systems, not to make them more intensive but to make them more efficient, and these possibilities are covered in the remainder of this section.

**Animal location**

Although global navigation satellite system (GNSS) receivers were first used to record the position and track free-ranging sheep in the early 1990s (Rutter et al., 1997), the technology has not yet been adopted as part of commercial PLF systems due to several barriers. Although the cost of early receivers was prohibitively high, the widespread adoption of GNSS chipsets in smartphones and other consumer electronics had brought the production cost down to under 5 US dollars by 2007 (GPS Business News, 2007). While cost is no longer a major barrier, the comparatively high power requirements of GNSS receivers (Paek et al., 2010) is still an issue. Tracking sensors based on current GNSS chipsets require the batteries to be replaced or recharged at regular intervals and this impracticality currently precludes their use in animal monitoring as part of PLF applications.

Another limitation of consumer-grade (i.e. cheap) GNSS receivers is their comparatively poor performance in buildings due to impaired signal reception (Kjærgaard et al., 2010). As discussed earlier, the initial focus for the development of PLF technology has been intensively managed that is housed dairy cow, and the commercial on-farm dairy cow positioning systems developed to date use radio location rather than GNSS to determine the cow position. Cows carry a radio transmitter, typically on a collar, and a number of receivers around the building are used to triangulate the cow’s position. These local tracking systems overcome the twin problems associated with GNSS receivers that is a short battery life and poor indoor performance. Whilst these radio-location tracking systems could be used with sheep, the need for a network of receivers across the field for extensive sheep systems is likely to make this solution comparatively expensive. Of course indoor performance would be less of an issue in extensive sheep production systems when the sheep are outdoors for most of the year, so future improvements in low-power GNSS receivers may result in practical, on-farm sheep tracking systems in the future. An alternative approach to determine the location of free-ranging livestock could be to use image recognition from unmanned aerial systems (UASs, commonly known as ‘drones’). This could use a variety of technologies (e.g. infra-red cameras, image recognition algorithms) to detect where sheep are, and then the drone could fly down and use, for example medium range EID to identify individuals. Whether sheep are frightened by drones flying above them requires further research, but a small, quiet drone that maintained a minimum altitude might not even be detected by the animal.
Notwithstanding the technical challenges of acquiring position data from farm animals, knowing the location and movements of individual animals opens up a number of novel management solutions. One potential use of sheep position data is to help detect attacks by predators. Manning et al. (2014) showed that, compared with before or after, the velocity of sheep movement was higher during simulated predator attacks, and centripetal rotation also occurred during 80% of the simulated attacks. This shows the potential to automatically detect and alert the farmer to an attack by predators on their flock based on the movement of the sheep. However, this approach would, at best, allow a farmer to intervene to limit an ongoing attack rather than prevent an attack from starting in the first place.

Animal position data could also be valuable in monitoring and managing sheep grazing behaviour, and the following sub-sections explore the possibilities in this area.

**Controlling pasture access**

An important part of the management of grazing systems in controlling where the livestock have access to graze. Historically, this was achieved through direct supervision by a human shepherd, often a child (Umstatter, 2011) and children still ‘shepherd’ flocks of sheep and/or goats in many parts of the world. The introduction of compulsory child education in other parts of the world in the 19th century led to the development of fixed ‘barbed’ wire fences, and then more temporary ‘electric’ fences were developed in the 1930’s. These fences allowed some control over where animals could graze, but although electric fences allow more dynamic control of grazing compared with fixed fences, they need to be moved on a regular basis and this requires labour.

Several technological solutions in facilitating more dynamic control of pasture access have been developed. The simplest of these are timed and/or remote release gate handles which are already commercially available (e.g. ‘Batt-Latch Gate Release Timer’, Novel Ways, Hamilton, New Zealand). These are typically used to open (release) a ‘spring’ gate in an electric fence to allow animals to access the next paddock or feeding area at a specific time without the need for human intervention. A more sophisticated approach is a fully robotic fence which can move across the paddock, and such a system was brought to market in 2007 (‘Voyager’, Lely S.à.r.l., Maassluis, The Netherlands). Although this system no longer appears to be available, it demonstrates the potential to bring highly dynamic control of grazing where the terrain is sufficiently flat to accommodate the robots.

**Virtual fencing**

The concept of virtual fencing (also known as ‘invisible’ or ‘geo-fencing’) proposes a radically different approach in controlling where animals can graze. Rather than relying on physical barriers, virtual fences rely on other means to control access to pasture. Virtual fences, such as electric fences, rely on reinforcement and animal learning to control the movement of livestock. In traditional electric fences, animals have to learn that if they touch the wires that make up an electric fence they will get an unpleasant stimulus (an electric shock). This effectively punishes the act of touching the wires,
and the animals have the opportunity to learn through trial and error that they can avoid the unpleasant stimulus (the shock) if they avoid contact with the wires. One approach to virtual fencing utilises an electric stimuli (shock) as a punishing stimulus but replaces the physical electric wire barrier with auditory cues. The concept is that as the animals approach the ‘virtual’ boundary they are given an auditory cue that is a sound. If they turn away from the virtual boundary the sound is switched off, but if they continue towards the boundary they receive the punishing stimulus when they reach the boundary. The animals can learn, through trial and error, that they can avoid the punishing stimulus by changing their direction of movement such that the auditory cue is switched off. This requires fitting each animal with a device that can administer the punishing electric shock and also determine where the animal is in relation to the virtual boundary, and two approaches have been used to determine the animal’s relative position. The first utilises a signal cable that is laid on the ground. Sensors on the animal detect the proximity of the animal to the signal cable and activate the ‘warning’ sound, and if the animal continues to try to cross the signal cable it receives an electric shock (Umstatter et al., 2015). The second approach in determining the animal’s position relative to the boundary is to fit the animal with a GNSS receiver, in which case the boundary is simply defined by a series of latitude and longitude coordinates. Again, when the animal approaches the boundary it receives a warning signal, and then if it continues to cross the boundary it receives the electrical stimulus. Whilst the ‘signal-cable’ approach is comparatively simple, it still requires labour to lay down and, if required, move the signal cable. Although the ‘GNSS’ approach is technically more challenging (given the power requirements of GNSS receivers discussed earlier), one major advantage is that it does not have the labour costs associated with installing and moving a signal cable, and allows for a more dynamic boundary. This dynamic boundary can be reset, should the animal break through the original boundary, with the animals being guided back using cues based on their behaviour rather than their location (Lee et al., 2009). This can help overcome the issue of animals getting ‘trapped’ on the wrong side of a signal cable virtual fence should they manage to cross it.

A commercial ‘signal-cable’ virtual fence system (Boviguard, Lacmé, La Fléche, France) was shown by Umstatter et al. (2015) to be effective with cattle, with the authors also noting that the cattle were wary of crossing the signal cable when the system was switched off. From this it appears likely that the cattle were using the signal cable as a visual cue to determine the location of the boundary, and this may have helped them learn to avoid it when the system was active. To date (2017), there is not yet a commercial GNSS-based virtual fencing system available for on-farm use, although an Australian company (eShepherd from Agersens) have indicated they are close to bringing a new product to market.

The use of an electric stimulus in ‘punishment’ based virtual fencing systems raises ethical concerns. Although other potentially punishing (aversive) stimuli, for example the sounds of dogs barking have been tested, the animals quickly habituated and the stimuli stopped being aversive (Umstatter et al., 2009). Another likely issue with electric stimulus-based punishment in sheep is that, unlike cattle, they often have a thick fleece. So, whilst neck-mounted collars can effectively deliver an electric stimulus to cattle through their comparatively short coats, neck-mounted electric stimulus collars
will probably be less effective on sheep. Indeed, the majority of research into virtual fencing to date has been in cattle (Umstatter, 2011), and more research is needed to look at the effectiveness of the approach in controlling sheep movement.

**Reward-based virtual fencing**

An alternative to using punishment to control animal movement is to use positive reinforcement that is rewards. Rather than punish an animal for going in the ‘wrong’ direction, an animal can be rewarded for going in the ‘right’ direction. Anyone that has shaken a bag of food pellets to get sheep to follow them will be familiar with the concept. This will initially involve some training, but just as animals can learn to use an acoustic stimulus to avoid an electric shock, they can also learn that an acoustic signal is associated with a reward, for example getting access to some feed pellets. This is the basis of clicker training in pet and zoo animals, where a previously neutral signal (the clicker) becomes associated with a reward (typically a small food treat). The signal can then be used to guide the sheep towards the desired location. Once trained, following the acoustic guide to fresh pasture should be sufficiently rewarding to help in maintaining the animal’s response. In practice, a combination of both reward and punishment-based virtual fencing may be needed. The animal would be guided with rewards for most of the time and punishment only used if the animal fails to respond to the reward signal but, perhaps for its own safety, still needs to be moved, or if the farmer wants to prevent grazing on areas the sheep would find attractive.

It is likely that both punishment and reward-based virtual fence systems will fail at some point and so it is unlikely that virtual fences will completely replace the need for physical fences. A traditional outer boundary fence will still be required to prevent the livestock from completely leaving the owner’s fields or rangeland, and to avoid them wandering onto busy roads or railways should the virtual fence fail. Consequently, it is likely that the main aim of virtual fence systems will be to move animals around within an outer physical boundary, making reward-based virtual fencing a more viable proposition.

**The ‘Virtual Shepherd’**

The integration of virtual fence technology with other sensors, both on and off the animal, along with external data such as weather forecasts, should allow smart systems to be developed that dynamically monitor and control grazing in a way similar to traditional, human-based shepherding. Such a system could act as a ‘virtual shepherd’ (Rutter, 2014). The availability of herbage could be monitored using remote sensing that is satellites or unmanned aerial systems, and animals guided to the next area to be grazed using reward-based virtual fencing. Changes in animal behaviour indicative of injury or disease, such as reduced locomotion and reduced feed intake could be automatically detected as discussed earlier, and the farmer alerted so that rapid treatment could be provided. The potential animal welfare benefits of such a virtual shepherd system are explored in the subsequent section.
Impact of PLF on sheep welfare

Potential positive welfare impact of PLF in extensive sheep systems

PLF technologies have the potential to improve animal welfare, especially the free-ranging livestock (Rutter, 2014). Under traditional rangeland management, as well as having to find their own feed and water, stock do not typically receive regular that is daily health checks. However, as discussed earlier, virtual shepherd technologies have the potential to bring to rangeland systems a level of individual animal monitoring and control that was previously only achievable with intensive management. Although commercial virtual shepherd systems have not yet been developed, the component technologies already exist and the potential welfare benefits of such an approach can be assessed. The following subsections use the Five Freedoms (FAWC, 1979) as a framework to assess the welfare benefits of a virtual shepherd approach, looking at each freedom in turn.

Freedom from hunger and thirst—by ready access to fresh water and a diet to maintain full health and vigour

In most rangeland systems, sheep have to find their own food and water for the majority of the time, and the available forage is usually variable in both quantity and quality. This is likely to result in periods when the sheep are hungry. Technologies that can monitor the sheep’s foraging behaviour could help to identify or even predict when and where forage is likely to be limited, and virtual shepherd technologies could move the animals to other areas of pasture, possibly identified using remote sensing, for example unmanned aerial vehicles or drones. If fresh pasture is not available, supplementary feed could be delivered, potentially by drone. Natural water sources can freeze in winter or can dry up in summer. A combination of weather forecasting and sensors at watering points could warn farmers if water points have or are likely to be frozen or have dried up in a drought, and the sheep either moved to areas with a more reliable water supply or water could be taken to the animals in tankers.

Freedom from pain, injury or disease—by prevention or rapid diagnosis and treatment

Sheep in rangeland systems are typically not inspected very frequently and consequently health problems or injury can go undetected for long periods of time. Research in dairy cows has demonstrated that behaviour monitoring using, for example a leg mounted accelerometer can detect the early stages of a number of health problems. Similar technologies could be used with sheep in rangeland systems to provide 24/7 monitoring and facilitating the rapid and remote diagnosis of disease or injury. Virtual shepherd technology could then guide the animal, along with some of its usual flock mates, to a handling area where it can be inspected by the farmer or a veterinarian. As discussed earlier, technologies that help to mitigate against predation risk should also help to reduce injuries to sheep.
Freedom from discomfort—by providing an appropriate environment including shelter and a comfortable resting area

In contrast to more intensively managed animals, sheep in rangeland systems have little if any shelter from the weather. By utilising short to medium term weather forecasting, a virtual shepherd system could move animals to areas with more shade when a prolonged hot and sunny period was forecast, or could guide them to more sheltered areas when prolonged rain or snow was forecast. This should help to reduce discomfort due to adverse weather.

Freedom from fear and distress—by ensuring conditions and treatment which avoid mental suffering

Animals in extensive systems have relatively infrequent contact with humans, and, when they do, this is often only when mustered (also known as gathering or being rounded up). This process uses the animals’ natural fear responses to dogs and humans which the sheep perceive as predators. Virtual shepherding technology could significantly reduce the fear associated with mustering by gradually guiding the sheep towards a handling area, possibly over a period of several days.

Freedom to express normal behaviour—by providing sufficient space, proper facilities and company of the animals’ own kind

Animals in rangeland systems are usually able to express a wider range of normal behaviour compared to their intensively reared counterparts, and the utilisation of precision technologies in their management should not necessarily change this. Indeed, PLF technologies have the potential to help and maintain the freedom to express normal behaviour under extensive management whilst increasing welfare across the other freedoms as outlined earlier. This could help to ensure that sheep in rangeland systems lead a good life rather than just a life worth living (FAWC, 2009).

Potential negative welfare impact of PLF

Although PLF technologies are already bringing improvements in animal welfare through more rapid detection of health issues (Berckmans, 2014), it is possible that the inappropriate application of the technology could result in situations where there is a negative impact on animal welfare. It is likely that most, if not all, technological systems will fail at some point. The welfare impact of such failures will, to some extent, depend on the number of animals affected, whether the failure results in the loss of access to critical resources, for example feed and water, and how quickly the failure is detected and rectified. Where possible, systems should be ‘fail-safe’ that is they should be designed in such a way that when they fail they do so in a way that minimises the negative impact on the animals. For example, a segregation gate should be designed so that if it fails it will open (or can be pushed open by an animal) to ensure the animals have access to an area where that have adequate food and water. PLF systems should
also incorporate monitoring systems so that if a fault does develop, part of the system can detect it and the problem can be reported to the farmer and perhaps even directly to a service provider.

In current sheep PLF systems, the loss of an EID tag by an animal would mean that its liveweight would not be recorded, and it might fail to be segregated into a group given, for example supplemental feed. This should not have a significant negative impact on the sheep’s welfare unless it is undetected by the farmer for an extended period of time. Whilst the loss of an EID tag could impact one animal, failures in other parts of more advanced PLF systems could impact the whole flock. For example, mechanical failure of robotic control systems or software ‘crashes’ in computer control and monitoring systems could result in the total failure of animal feeding systems, and this could quickly result in a significant negative impact on animal welfare. Farmers need to be aware of these risks and need to ensure that they continue to monitor their livestock and be vigilant and prepared to intervene when systems fail. Indeed, perhaps the greatest threat from the PLF approach to animal welfare is associated with an over-reliance by a farmer on technology. The farmer needs to maintain the capacity to manage their flock when the technology fails that is by retaining the ability to fall back on traditional, manual management when needed. The final potential risk of PLF technologies to animal welfare is that a farmer might decide to adopt a less hardy breed if they believed that the technology could help to support that breed in an otherwise challenging environment. Again, PLF technologies are intended to complement good animal husbandry and not replace it, and farmers need to be aware of the limitations as well as the benefits of PLF systems.

Barriers to technology adoption

Several factors can affect the speed of uptake of new technologies by farmers. A survey of Scottish sheep farmers (Morgan-Davies and Lambe, 2015) found that the cost of the equipment was the main barrier to the adoption of EID, but that farmers would consider adopting the technology if the financial benefits could be made clearer or if financial help was made available, for example from the government. The demonstration of technologies such as EID on monitor or demonstration farms should help to show how they can help farmers in cutting their costs by reducing the labour requirements. Research into PLF technologies could also include a cost-benefit analysis to establish the likely return the farmer can expect on their investment. It is also likely that the cost of technologies will fall in the future, driven by cheaper components and the economies of scale as more and more farmers adopt them. Sheep farmers will also likely benefit from technologies adapted from those originally developed for dairy cattle. Training is also important if farmers are to get the maximum benefit from the technologies that they do adopt. It is also crucial that the data are presented to the farmer in a clear and easily comprehensible way. Again, work done with dairy cow PLF systems should help here as technology companies now have a better understanding of how to integrate and present data to farmers.
The idea that farmers are ‘technology-shy’, either because of their age or due to cultural issues, is challenged by their general enthusiasm for other digital technologies, for example smartphones and computers. Indeed, their experiences with earlier technologies probably makes them justifiably wary of rushing to become an ‘early adopter’, with concerns that they may end up with buying into a technology that quickly becomes obsolete and is no longer supported. This is known as the ‘Betamax effect’, after the Betamax video cassette recording standard that was quickly made obsolete by the more successful (even though arguably technically inferior) VHS standard.

Another potential barrier to the uptake of PLF technologies by sheep farmers is the availability of reliable internet access, especially in the remote, rural location typical of many sheep farms. Many of the dairy PLF technologies now on the market rely on ‘cloud’ storage of the farm and animal data on remote servers. Cloud-based services offer two benefits. Firstly, unlike farm-based storage, cloud storage is reliably backed-up and storage hardware failures should not lead to the loss of historical data. Secondly, cloud storage can be reliably accessed by third parties, for example the farm vet or nutritionist. However, to access cloud services the farm needs reliable internet access, and more needs to be done to ensure rural communities can realise the benefits of fast and reliable internet access.

A final potential barrier to the adoption of PLF technologies by sheep farmers is the misconception that such technology is only applicable to intensive production systems. Although PLF systems were initially developed for use in more intensive systems, there is no fundamental reason why they should not be used in more extensive systems. Indeed, the likely benefits should be even greater in more extensive systems given that they largely lack the close monitoring and control typical of intensive production, and PLF technologies should help to make extensive systems more efficient without necessarily making them more intensive.

**Wider potential benefits of sheep PLF**

Although a farmer’s main goals in implementing PLF technologies are likely to be to improve the economic efficiency of production and to promote and maintain animal welfare, there are potentially some wider benefits. In many parts of the world, such as upland areas in the United Kingdom, sheep grazing is important in maintaining an open, grassland-dominated landscape that has important heritage, cultural and recreational value. Although these open landscapes were originally a by-product of commercial farming practice, there is usually a desire to maintain them rather than to see them become managed forest or have them revert to scrubland and, ultimately, natural woodland. These wider benefits are often supported as a part of government agri-environmental schemes which pay farmers to manage the land to deliver ecosystem services. These services include safe drinking water, flood mitigation, plant and animal biodiversity as well as recreation and tourism. Grazing animals are an important ‘tool’ in managing many of the landscapes that deliver these services, and PLF technologies
could help with this delivery. Firstly, by improving the economic efficiency of sheep production, PLF technologies can help to ensure livestock production is economically viable in areas where it is currently uneconomic without subsidies. Secondly, tools such as the virtual shepherd discussed earlier could include agri-environmental outcomes as a part of the overall management goals. These could help to ensure that sheep are kept away from environmentally sensitive areas at certain times of year and help to manage grazing pressure to deliver optimal biodiversity outcomes. As well as providing the farmer with the tools to help them in managing their flock to meet the requirements of agri-environmental schemes, PLF technologies could also monitor and help to demonstrate the farmer’s compliance (or not) with the schemes. Indeed, the need to both meet agri-environmental schemes and to demonstrate that they have been met could be the main factor driving the adoption of PLF technologies in many sheep farms in the future.

Another area where PLF technologies have the potential to deliver wider benefits is in helping to ensure the traceability and quality assurance of livestock products. PLF technologies capture a wide variety of data on the farm, and these data can be used to help to demonstrate compliance with the requirements of quality or other farm assurance schemes. Although the comparatively restricted quantity and range of data collected by current sheep PLF technologies limits this application at the moment, future systems should deliver more relevant data and in greater volumes. For example, animal movement data along with foraging data could demonstrate that a natural behaviour that is grazing was the predominant form of feeding. Such data can even be made available to the consumer, allowing them to scan a code on a livestock product to see information about the farm the animal was reared on as well as data about how as an individual it was managed. This direct link back to the farm and individual animals should help consumers better to understand where their food comes from, how it was produced, and generally help them to better appreciate the provenance of their food.

Finally, by improving the efficiency of resource use, PLF technologies will play an important role in feeding the growing human population in the future. Many argue that an expansion of ruminant livestock production is unsustainable, especially if it is based on an increased use of feeds such as cereals and soya that could be utilised more efficiently if consumed by people more directly. However, it is likely that cultural and recreational requirements for certain locations to be maintained by livestock grazing will ensure that sheep production continues in some areas, and PLF technologies have the potential to ensure that this production is as efficient as possible whilst still delivering the wider benefits discussed earlier in this section.

**Summary**

Precision approaches to farming are already having a big impact in many areas of agricultural production. Although dairy cattle farming has been at the forefront of developments in ruminant livestock production, technologies such as electronic identification,
WOW and automatic shedding gates are starting to have an impact in sheep production systems. A variety of new technologies are in development, and these have the potential to make a significant impact on sheep production systems in the future. These should not only improve the efficiency of production but also improve sheep welfare. Farmers need to be aware of both the limitations of these emerging technologies and also the fact they cannot replace good stockmanship.

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Optimised welfare for sheep in research and teaching

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Introduction

The use of animals in scientific research dates back to the writings of Aristotle and Erasistratus in the 4th and 3rd centuries BCE. Many of today’s advances in animal and human healthcare have been achieved as a result of animal research. Despite these advances, there is growing public awareness and debate regarding the use of sentient non-human animals as research subjects as well as the ethical and welfare obligations that researchers must consider when performing such work. Research involving animals is licenced in most countries and this chapter will illustrate some factors that need to be considered when performing or regulating sheep research.

When the general public thinks about animal use for human biomedical research, species that immediately spring to mind are small animals—rats, mice, guinea pigs, etc. With the use of primates for research purposes increasingly becoming limited by ethical considerations (Abbott, 2014), sheep are being increasingly recognised as a good paradigm for human biomedical research, particularly within reproductive science. Sheep research in other areas, for example Huntington’s disease (Jacobsen et al., 2010), has also been valuable and high profile.

In pregnancy studies, the size of sheep makes a broad range of maternal–placental–foetal instrumentation possible and their anatomy and physiology makes them very comparable to humans. The development of the ‘cooling coil’—a device which can lessen brain damage after ischaemic brain trauma, that is, cord occlusion during birth—was developed primarily through the use of research sheep (Gunn et al., 1997). Placental anatomy of sheep has an experimental advantage, as ovine pregnancies are a lot more resilient to surgical manipulation than humans, primates or pigs. Sheep of certain breeds can be selected to produce singleton foetuses; they have a relatively long gestation and their similar developmental and maturational trajectory to humans makes them suitable for work involving pregnancy and postnatal studies. In addition, postnatal development in sheep makes them excellent candidates for longitudinal studies (Donovan et al., 2013; Jaquiery et al., 2012; Oliver et al., 2005; Todd et al., 2009), and large amounts of paired data can be collected in the same animal from foetal life through to adulthood. Behaviourally, sheep can be appropriately managed in a laboratory setting; they respond positively to acclimatisation and routine and this can be very helpful for specific experimentation (Hernandez et al., 2009).
The vast amount of sheep research worldwide resides in the production sector. Sheep production industries are important contributors to the local and national economies of many countries, especially in the developing world.

Sheep are also frequently used for teaching and training within veterinary sciences, animal production and postgraduate medical education. The perspective guiding this chapter originates predominantly from sheep-based biomedical research on maternal and perinatal biology within a New Zealand-based university institution. In addition, both authors have research experience within production livestock biology and animal health. A key factor in our performance has been a drive to translate frequently back and forth between sectors. This drive underlies a commitment to the 3Rs, that is, principles of Replacement, Reduction and Refinement, which is a recurrent theme within this chapter. The more research can translate and be communicated across sectors, the more effective it can be and the likelihood for repetition and duplication is lessened. This, in turn, reduces welfare cost, all consistent with the 3Rs.

It is worth explaining the relevance of the 3Rs (National Centre for the Replacement, Refinement and Reduction of Animals in Research, 2017) briefly here. They are guiding principles for more ethical use of animals in research/testing and were first described by W.M.S. Russell and R.L. Burch in 1959 (Russell and Burch, 1959). They have now become embedded in legislation, covering animal use in research in many countries.

The 3Rs are:

1. **Replacement**: methods which avoid or replace the use of animals in research  
2. **Reduction**: use of methods that enable researchers to obtain comparable levels of information from fewer animals, or to obtain more information from the same number of animals, for example refined statistical modelling to establish numbers of animals required for an experiment  
3. **Refinement**: use of methods that alleviate or minimise potential pain, suffering or distress and enhance animal welfare for the animals used, for example modifications to housing (the use of pens instead of the usual caging systems)

The primary message to be conveyed in this chapter is that good research and teaching using sheep relies heavily on good welfare approaches and understanding of species-specific animal behaviour along with ethics. Superior animal care and understanding of sheep biology and behaviour are very important in ensuring sheep welfare which is paramount in research and teaching. All this requires a clear framework, starting with government legislation and codes that govern practice within a research and teaching organisation using sheep.

### Legislation and codes

**The five freedoms and legislative requirements**

To regulate animal use in research and teaching, the majority of developed countries have enacted overarching central government legislation to provide a framework for practice. The general theme is that experimental or teaching manipulations that impair the five freedoms [freedom from hunger or thirst, freedom from discomfort, freedom from pain, injury or disease, freedom to express (most) normal behaviour and freedom from fear and distress] of domestic or wild animals require that the justification for
doing so has undergone independent review via an institutional Animal Ethics Committee (AEC) or equivalent, operating under a legislative framework.

As an example, New Zealand’s main legislation is the Animal Welfare Act of 1999 (NZ-Government, 1999) followed by various subsequent amendments. Part 6 of the Act specifically deals with use of animals in experimentation or teaching. The United Kingdom (UK-Government, 2006) and the USA (USDA, 2013) also have similar central government legislation, although in the USA there is also individual state legislation. In Australia, legislation regulating animal use in research and teaching is state based, with an underpinning national code aimed at achieving national consistency.

As many farming activities involving livestock also impinge on some of the five freedoms, regulations often make some allowances for the use of production animals such as sheep in research and teaching, for example in teaching husbandry procedures to agriculture students. This may be achieved such as in New Zealand by the development of specific welfare codes for production livestock (MPI, 2016) that are developed in consultation with industry, the New Zealand Veterinary Association and two national animal welfare advisory committees. On careful inspection, the welfare codes are not mandatory in nature, to perhaps allow room for aspirational compliance as opposed to mandatory, for example usage of words like ‘should’ or ‘could do’ rather than ‘must’ or ‘shall do’ in documents. This also appears to be the case with other comparative codes in the United Kingdom, Australia and the USA; although with the latter two there is the complexity of individual state codes as well. In jurisdictions where they are not mandatory, the aspirational nature of farm animal welfare codes is often debated, and this debate is intensified where the government ministry responsible for enforcing animal welfare legislation is also the ministry responsible for supporting the agricultural industries This is the case in New Zealand and a number of states in Australia, but not in the United Kingdom where animal experimentation is regulated by the Home Office, which is separate from the Agriculture Ministries.

**Institutional codes of practice and animal ethics committees**

In countries such as New Zealand, Australia and the USA, regulatory approval of sheep research and teaching and associated personnel is currently undertaken by local committees operating under a centralised legislative framework. These committees are termed institutional animal care and use committees in the USA, animal care committees in Canada and AECs in Australia and New Zealand. Furthermore, institutions which undertake research and teaching involving sheep may be required to be licenced. In New Zealand, academic or commercial institutions that wish to undertake research and teaching using live animals are required to develop institutional codes of practice and recruit AEC members from a specified number of groups: researchers, the veterinary association, an independent non-governmental animal welfare organisation, lay members from the general public and an institutional animal welfare officer (AWO) who is a veterinarian. Equivalents to the AWO in the United Kingdom are named animal care and welfare officers. The roles of AECs and AWOS are similar across New Zealand and Australia and the two countries interact closely via trans-Tasman organisations such as the Australian & New Zealand Council for the Care of Animals.
in Research and Teaching (ANZCCART). Equivalents of the ANZCCART in other regions include the Canadian Council on Animal Care and the Office of Laboratory Animal Welfare in the USA. In turn there are international organisations that interact with and influence the national councils, in particular the Association for Assessment and Accreditation of Laboratory Animal Care International.

In New Zealand, an institutional code of practice is developed and the chairs of the AEC and the AWO report directly to the head of the organisation or their senior delegate. In the case of a university, this individual is usually the vice chancellor of research but in a non-academic organisation, he may be the CEO or general manager. The bottom line is while the head of the organisation is ultimately legally accountable, the individual researchers also bear accountability under the law.

In most of the large universities or institutions a broad range of vertebrate animals are used in research and teaching, ranging from fish and wild birds to sheep and pigs. Therefore every effort must be made to include enough researchers in an AEC with diverse enough background and experience to be able to enable thorough review of the applications from a welfare justification perspective. This is particularly important for sheep research as there are fewer investigators in many institutions, but a sound knowledge of sheep biology and normal husbandry practices (e.g. in farming and meat industry) is needed to assess and monitor the proposed work. External funding review should always be a preferred pre-requisite for all research applications but it is not always possible in the case of commercially sensitive research.

The AWOs or their equivalent in various countries are normally the institutional veterinarian and within their role they are required to be aware of upcoming and current research. They also have veterinary responsibility for the care of research or teaching animals alongside the researchers/academic staff. The role of AWO is essential and they can function optimally if researchers effectively use the office of the AWO (or their delegates within the AEC) to help develop protocols which minimise welfare costs and aim to accommodate the 3Rs as far as possible. In the case of research operations remote from the main institution and the AWO, a local large animal veterinarian with specialist knowledge and interest in sheep health and welfare may need to be contracted as a proxy. This arrangement works well in our research situation and has been especially useful in training new staff and integrating the veterinarian into regular farm operations such as health checks, preventative health programs, out-of-season breeding and pregnancy detection by ultrasound scanning. Proactive engagement and open communication means irregular call outs to the veterinarian are minimised, welfare is improved and very importantly, a useful contribution to the quality of research outcomes is gained.

The final step in the devolution from government policy to actual research practice is heavily compliant on adherence to the approved protocol. This should be managed by effective monitoring by the AWOs or their equivalent and AEC. Effective utilisation of animal usage returns at end of approval reporting is also important. This should not just be reliant on numbers but also on written reports that provide information and perceptions on welfare incidence reports and assessment of the effects of various manipulations. As animal usage returns and welfare incidence reports are self-reported, a diplomatic and savvy exercise carried out by the AWO and AEC is of paramount importance. Heavy-handed authoritarian approaches can be counterproductive,
especially in an academic environment as they tend to erode trust and persuade less compliant researchers to be more evasive, secretive and perhaps even obstructive.

For the AEC/AWO, a very good way to develop trust is to not only offer help with protocol development but also in the development of standard operating procedures (SOPs) and institutional drug administration orders (IDAOs). Developing these documents encourages effective communication and understanding while also providing useful teaching structures and also potential for streamlining AEC approval processes. There is also the benefit of sharing knowledge across research groups while establishing consistent standards of animal care and husbandry.

In New Zealand, USA and Australia the focus is on project approval and it encompasses assessing the capabilities of research staff and the suitability of their facilities. In the United Kingdom a licencing system looks at the three facets of approval, facility, project and personnel, in a three-stage process.

Sheep biology, health and interventions

Overview

There are some very good publications that deal specifically with sheep health and welfare in research and teaching (Aitken, 2007). ANZCCART provides very good guidance relating specifically to sheep research (ANZCCART, 2009) that references many useful publications. However, there are some important considerations from a research perspective where sheep may be managed in ways that deviate from normal husbandry practice, as detailed in the available farmed sheep welfare codes. This is particularly relevant where research extends to maintaining pregnant or lactating sheep indoors or perhaps involving maternal–foetal catheterisation and/or nutritional manipulation that is unusual from a farming perspective. Training of personnel responsible for sheep in research studies is dependent on conveyance of good principles of sheep biology, whether that involves nutrition, physiology or behaviour. In this section, the bias will be towards experiments involving more invasive mechanistic studies that usually involve indoor housing and some degree of instrumentation, as these often provide more of a challenge for sheep welfare.

For biomedical researchers in particular, sheep are often used as model for human conditions. Here, the term paradigm may be better suited as it allows better recognition of the similarities and differences of the species being studied, compared to the human. Many biomedical researchers do not have a background in ruminant biology and similarly in institutions where the majority of animals studied are not ruminants, animal care staff, veterinarians and technicians may not have a strong grounding in sheep biology within the broader meaning of the science. External consultation is very important if a knowledge base is lacking. This can lead to very positive developments for laboratory sheep welfare. As an example, our research group had the opportunity to set up a purpose-built facility for a research project that involved moving away from standard caging systems to more welfare-considerate pen systems for sheep, while still achieving experimental goals (NAEAC, 2009).
Advances in Sheep Welfare

Acclimatisation

As normal behaviour, nutrition and biology will likely be perturbed by experimentation, the selection and acclimatisation of sheep to their experimental surroundings is an important welfare and scientific consideration, especially when research is conducted indoors on concentrate feeds. Physical examination and health checks are useful and illustrated in more detail (Table 14.1). Some on-pasture assessment of how individuals manage increasing rations of indoor feed may also be useful; this can be done easily by body weight change trials. This can easily be done by monitoring weight during feed acclimatisation and we have used this for many of our studies where sheep have been maintained indoors from 2–3 months before pregnancy until after lambing (Bloomfield et al., 2003; Oliver et al., 2007). On occasions when we have new sheep on the property that are less used to concentrate feeds, we introduce small numbers of trainer sheep that are known for their fondness of our highly palatable feed. The naïve sheep copy the trainer sheep in consuming the laboratory feed, and this has proved to be a very effective means of getting sheep transitioned. Normally we can expect >95% of sheep to transition to our concentrate feed.

Regular weighing, handling and feed acclimatisation of sheep also allows familiarisation with human contact and including exposure to an indoor environment (e.g. during weighing or examination) can also be useful. In our experience farm dogs have no place in an indoor environment and are not used during acclimatisation. Acclimatisation to permanent indoor housing is best graduated with sheep initially being held in grouped pens where they can maintain some socialising behaviours. Much of our work requires individual feed management and various levels of instrumentation so individual pens are frequently used. It is important that pen design allows animals to have visual, auditory and olfactory contact with neighbouring sheep. Further acclimatisation to researchers entering the individual pens and handling the sheep is important and can be facilitated during feeding and pen cleaning. Related aspects of facility design will be dealt with later in more detail.

Acclimatisation for indoor study of sheep is an obvious requirement, but other aspects such as extended season breeding (i.e. extending the mating season beyond 1–2 months of the year) means that standard patterns of sheep husbandry practices

<table>
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<th>Table 14.1 Criteria for rejection on experimental recruitment</th>
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<tr>
<td>BCS &lt;2 or &gt;4 (see Appendix I, NAWAC Sheep &amp; Beef Code of Welfare, NZ, 2008).</td>
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<tr>
<td>Lameness and hoof health</td>
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<tr>
<td>Blind</td>
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<td>Wool break (or wool pull)</td>
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<td>Signs of metabolic imbalance (cold body temperature, ataxic behaviour, lethargy)</td>
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<td>Signs of infection or other sickness (abscess, febrile, restricted or laboured breathing)</td>
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<td>Abnormal vaginal discharges</td>
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<tr>
<td>Vaginal or anal prolapse</td>
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<td>Any degree of scouring</td>
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<td>Poor udder/milking potential for postnatal programme</td>
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need to be reconsidered. An obvious example is shearing. Under normal farming conditions, sheep may be shorn one or perhaps twice a year, usually at a date when that does not put them at too much risk of excess cold exposure in winter. There have been many sheep studies investigating the effects of shearing at certain times of pregnancy on lamb growth in utero. The findings are mixed and may be affected by geographic location and breeding factors (Kenyon et al., 2003). For staggered breeding systems it may be important to standardise time of shearing, especially when growth, metabolic and endocrine outcomes are of paramount importance to the research. For our studies we normally standardise shearing to around 90 days of gestation. Indoor photoperiod control is another important consideration as this factor affects the regulation of endocrine function, which may in turn affect experimental outcomes of interest directly or indirectly.

**Pre-experimental health testing and ongoing health programmes**

Health checks of sheep prior to experimentation should be part of a normal facility SOP and it is worth conducting them in the presence of the AWO and/or a veterinarian and/or experienced research staff with ample experience for sheep health and welfare. Apart from body condition score (BCS) and blood tests for liver function, our checks include hoof, udder and teeth checks (Table 14.1). As our research requires breeding 6 months of the year, we test our rams for a variety of sheep diseases, including brucellosis, and also for testicle calcification and general soundness. As we breed on an extended season, we need to be particularly vigilant and thoughtful about our sheep health program which has been developed with the help of our contracted sheep veterinarian. Sheep health and contingencies are a crucial component of funding applications we make. As part of our medicines SOP, there is a licenced staff member on site who maintains drug records under the supervision and audit of an institutional AWO. All drug use is recorded and if any drug is not associated with an approved AEC protocol, the incident associated with the event is fully described in an incident sheet for a check later by the AWO or contracted veterinarian.

**Nutritional considerations**

In terms of nutrition and metabolic physiology, sheep are quite different to predominantly omnivorous humans in terms of what they eat and how they process it. It can be amusing how the phrase ‘sheep are vegetarians’ is bandied around at medical research conferences or where research on monogastric animals predominates. Yes, sheep eat plant material but ruminant function ensures that only non-fermentable fibre, carbohydrate and non-rumen degradable protein pass through intact for primary digestion in the abomasum, intestine and perhaps further breakdown in the caecum. The microbes of the reticulo-rumen ferment the available carbohydrate to volatile fatty acids (VFAs) while the vast majority of protein found in a pasture-fed sheep diet is degraded into carbon skeletons (for fermentation) and ammonia which is often repackaged into microbial protein. VFAs are absorbed predominantly in the rumen and omasum while the microbial and non-rumen degradable protein is digested in the sheep’s equivalent
of our digestive system. As the carbohydrate and nearly all the free glucose and other simple sugars are fermented, there is hardly any available for direct uptake into the portal blood system. Apart from demonstrating that sheep are not classic vegetarians as in a human sense there are very important metabolic consequences of this digestive system for the sheep, especially if the animal is pregnant or lactating.

Fatty acids do not cross the sheep placenta in great quantities but glucose does cross the placenta by facilitated diffusion. Glucose and amino acids are the main fuels for placental and foetal metabolism (Cronje and Boomker, 2000). Similarly, carbohydrate sources such as lactose are important components within milk. The ewe, therefore, needs to make glucose and this is done by converting one of the VFAs (propionate), as well as glycerol and amino acids, into glucose and then into other sugars as required. This happens in the maternal liver, although the placenta is also very capable of amazing metabolic gymnastics to keep the pregnancy viable. This is not a model of human pregnancy and instead represents a different paradigm, which needs to be recognised by the researcher and sheep caretaker. Poorly conditioned or over-conditioned ewes are very vulnerable to a collapse of the ‘glucose supply train’ when they become unable to process enough metabolic precursors into glucose, often resulting in a condition termed metabolic ketosis. Ketosis can also occur in pregnant women but is much rare due to the ready supply of glucose that can be directly absorbed soon after oral ingestion.

The primary issue then is nutrition and ensuring that the pregnant ewe gets enough fermentable carbohydrate and fibre in her diet. The next issue is to ensure the ewe has optimal BCS for pregnancy (Kenyon et al., 2014), although the experiment may demand otherwise if the paradigm is nutritional restriction or an increasingly common maternal obesity. The two under and over scenarios require very good knowledge of how to formulate effective diets that allow the paradigm to develop while not causing collapse of the ewe or her pregnancy. It is also worth noting that ketotic state also has very adverse behavioural and welfare implications that are often accompanied by problems with calcium deficiency secondary to impaired magnesium supply. These metabolic states, once entered, are often self-perpetuating with the pregnant or lactating animal being unable to self-motivate her feed intake, thereby worsening the prognosis quickly. Effective monitoring of metabolic state during experiments involving pregnant sheep is very helpful to assess danger signs. The simplest measure is circulating blood glucose, although other metabolites such as non-esterified fatty acids and ketones (β-hydroxybutyrate) are often also measured. Other clues are variations in the normal posture of the animal, interest in food, temperature in the case of hypocalcaemia and taxic responses to stimuli. Diagnostic tools are very well covered in sheep health publications but the message to convey here is that investigators needs to be well prepared if they are disrupting normal ruminant nutrition and metabolism during experimentation. Ambulatory remedies for these metabolic conditions are also well described in the literature; however, prevention, wherever possible, is always best for sheep welfare during experimentation. Accordingly, given the significant role maternal hepatic metabolism plays in the ruminant, a screening measure such as a pre-study liver function test is useful, especially considering that sheep in countries such as New Zealand may be vulnerable to liver damage from pasture-borne mycotoxins.
such as sporidesmin (Di Menna et al., 2009; Oliver and Harding, 2009). These liver toxins can have profound effects on reproduction, general health and therefore well-being. We routinely perform spore counts on our research property for sporidesmin, although our area is not normally ‘hot with spore counts’. We increasingly perform BCS and screening blood tests for animal health prior to experimentation.

**Experimental manipulations and welfare considerations**

During the course of experimentation, it is sometimes necessary to perform procedures that affect the welfare of sheep apart from those that are part of normal farming practice. The most common of these is blood sampling. If not very frequently, blood sampling is most often performed by jugular venepuncture. However, if sampling must be frequently repeated, a jugular intra-catheter may be placed under local anaesthesia. The ultimate decision for choice between options is determined during submission to the AEC but more often in prior discussion with the AWO. The welfare cost of blood sampling and restraint while the sheep is conscious is an obvious consideration but the researcher should also consider whether the stress of venepuncture might affect the metabolites and hormones being measured (e.g. glucose, lactate and cortisol). This is especially important in the case of metabolic tests (Jaquiery et al., 2009) or tests of hypothalamo-pituitary-adrenal function, areas in which we routinely work (Jaquiery et al., 2006; Oliver et al., 2012).

For larger procedures such as foetal–maternal surgery, there are also real questions around effective induction, anaesthesia and post-surgical pain management. Within the ANZCCART publication, *The Sheep*, (ANZCCART, 2009) there is considerable detail, advice and references dealing with anaesthetic induction, maintenance and options for post-surgery pain management. The area of analgesia is well covered, ranging from the recommendation that everything that could possibly alleviate pain should be attempted, while others counter that measures should be shown to be effective. Assessment of pain and pain relief effectiveness in animals such as the sheep requires serious study and confidence that behaviours attributed to pain in sheep, for example bruxism (teeth grinding), lip curling (not to be confused with the Flehmen Response) and cessation of rumination, have a high certainty of accuracy (Mellor and Stafford, 1999). Human parallels do not often help, for example the efficacy of using opiates/opioid agonists for pain relief in sheep is uncertain but there are plenty of alternatives to explore including non-steroidal anti-inflammatory drugs (NSAIDs), \( \alpha_2 \) agonists and \( N \)-methyl-\( d \)-aspartate antagonists such as ketamine and various combinations (Lizarraga and Chambers, 2012). All these options have advantages and disadvantages. A particular problem with some approaches using opiates, ketamine or diazepam is that you can’t advise the sheep that they may feel rather odd physical and behavioural effects associated with the drug. Following surgery and drug administration, sheep need to be closely monitored, positioned in a recovery-type position—upright with their legs tucked underneath them—and assisted during recovery until they can regain balance on all four legs.

Given that many of these considerations only deal with pain relief of the ewe, it is appropriate to consider the possible needs of the foetus. The bulk of the evidence
suggest that the foetus remains in a sleep-like unconsciousness and is apparently not aroused by various stimuli including surgery (Mellor et al., 2007). This brings into question whether the foetus itself needs pain-relieving medication. However, as many drugs such as opiates and NSAIDs can cross the placenta, the question becomes second order. However, the metabolism, pharmacokinetics, actions and clearance of drugs, once they have crossed the placenta to the immature foetus, are very likely to be quite different to what happens in the mother. Drugs such as NSAIDs may have effects on foetal neural development, responses to experimental variables, for example ischemic brain injury (Wood et al., 2009) and, therefore, the relevance of experimental outcomes. The balance between providing pain effective relief and preserving the purpose of an experiment is important and needs to be continually debated so that invasive and potentially painful manipulations are justified and mitigated as much as possible.

**Euthanasia**

Euthanasia of animals may be an outcome at the conclusion of an experiment or in the case where welfare concerns dictate that it is necessary. As an example, within each AEC application we submit, the responsible investigator must outline the end points for humane euthanasia and link these to the required sheep monitoring sheets. For the most part this does not lead to many issues, as researchers are often well aware that compromised welfare also compromises science. However, there are always exceptions, and effective monitoring and audit procedures are an integral part of the AEC’s function and the AWO’s role. For actual euthanasia of sheep, it is very common that this is performed with the use of an intravenous anaesthetic overdose, as described in a specific IDAO. Species, dose, complications and carcass disposal requirements are included in the IDAO. More rarely, sheep are killed by exsanguination where the jugular and carotid are severed. However, the national and, therefore, institutional code on euthanasia for experimental animals (MPI, 2016) stipulates that sheep must undergo captive bolt stunning prior to exsanguination, that is this is a mandatory requirement. Interestingly, in the farming situation this requirement has recently become an aspirational suggestion for euthanasia of sheep and cattle as the science of domestic livestock slaughter evolves (Johnson et al., 2015).

**Sheep behaviour**

Some comments need to be made on sheep behaviour in relation to welfare in the experimental situation. Sheep are social animals and unless isolation stress is a desired manipulation, all measures should be taken to mitigate the effect this state has on sheep welfare or indeed the experimental outcome. It is also important to point out that both researchers and animal care staff should be aware that sheep can display distinct personalities, in our experience a ‘one size fits all’ way of treating sheep doesn’t always work. Being aware of the ‘individual’ is very important to ensure you provide the best standards of care. Sheep are highly social animals and should not be left alone for any length of time; they will vocalise and become distressed if left alone...
Optimised welfare for sheep in research and teaching

(Hernandez et al., 2010). Optimised pen and cage design are important to allow sheep to have visual contact with other sheep while also allowing for the importance of auditory cues for sheep.

In our current research setting it is easy to find companion sheep for an indoor experiment and these companion animals appear to respond positively to the palatable diet and sheltered laboratory environment, noting that these are only our human perceptions. In a biomedical laboratory, away from the source of sheep, finding companion sheep can be difficult but should always be a consideration for the investigator, laboratory manager and the AWO. The authors have observed the use of mock-up sheep in a metabolic crate to keep another sheep company, or the use of a full-length mirror facing a lone sheep’s cage. These are not described here as serious recommendations and as an alternative to actual companion sheep, but may be suitable as a last resort for no more than a few hours.

A sheep in a pen or metabolic crate is also unable to escape human presence; the investigator needs to take measures not to startle animals and also familiarise them to some degree of human contact. Handling of sheep is also another required skill of the sheep researcher. It is worth seeking advice from people that handle sheep for a job (e.g. existing or experienced research staff including animal care technicians and farm staff) to find the best way to calmly handle animals with minimal need for physical dominance. It is also important to be aware that sheep generally don’t like to be patted or touched on their heads. If handled correctly, there is no requirement for physical dominance or tugging on wool when handling sheep. Regular handling allows sheep to get into routines and can help minimise stress responses. The majority of sheep researchers are not formally trained in animal behaviour and often tend to judge animal behaviour from a human perspective, especially when it comes to stress. It should be pointed out that sheep are intelligent and are easily managed through routine activities. Sheep evolved as predated herd animals so they have very good flight responses that are quickly activated. To attempt to remove this behaviour completely is folly, unless the animal is a pet, but the minimisation of excitement and distress is a realistic and achievable objective.

The facility

The appropriateness of a facility for sheep research is a complex and subjective issue and open to a wide variety of perceptions. Welfare considerations must rank high for ethical reasons and for maximising the scientific quality of the output. Sheep research that largely serves pasture-based farm systems interests will heavily influence the facilities required, as there is a very strong imperative to allow relevant translation and implementation into industry practice. In this instance, best practice farming and codes will be very informative. For biomedical and indoor-based biotechnology research and teaching, it is important that the source of sheep also conforms to best practice principles. Unfortunately there are instances in sheep-based biomedical research in particular, that not much thought is afforded to best practice on the properties of sheep suppliers. The institutional AEC and AWO should mandate where are sheep
externally sourced, that the facilities and practice are of acceptable standard and that
the welfare of sheep meets the respective codes (MPI, 2016) that are derived from
the relevant legislation. ‘In the opinion of the authors’, adherence to welfare codes
in relation to sheep supply should always be mandatory for the research institution,
rather than aspirational, as it sometimes is in industry.

**Housing considerations**

In the case of biomedical or biotechnology research, it is very likely that sheep will
be housed indoors and in situations quite different to normal farm practice, or indeed
comparable with their normal biology. A fundamental requirement is that experienced
assistance is used to design an appropriate facility that meets the research require-
ments and most importantly best serves the welfare of the sheep. A useful approach
is to have a steering group that involves the sheep researchers from both within the
institution and external, management, the AWO and perhaps a specialist large ani-
mal veterinarian experienced in the research required. After visiting biomedical labs
around the world, it is clear that sometimes sufficient consultation and involve-
ment has not been sought before design and construction of indoor sheep research facilities.

Facility design is a subject in itself; however, there are several key considerations
for indoor-based sheep research. Flooring that allows weight displacement for the
sheep and limits the likelihood of conditions such as hoof laminitis developing is a
good start. The floor should also allow easy clearance of most dung and all urine.
Cleanable systems are important but also are the potential residual effects of a require-
ment for frequent cleaning (aerosol contamination and excess humidity). Sometimes
expensive facilities are built that require very frequent cleaning with high-pressure
water hoses and this can lead to animal health problems with infected hooves, wounds,
abscesses and respiratory infections. Also in such facilities, animals are not always
shifted during cleaning with the hoses. In our facility we have utilised a barn design
for our feedlot and main sheep housing area where the animal is positioned on a pur-
pose design wire lattice that allows effective weight dispersion and is several metres
clear from a porous and replaceable basement surface of pumice sand. Animals are
moved away when cleaning so they are not exposed to excessive aerosol contamina-
tion or stressed by high-pressure water hose use.

Pest control (insects, rodents and birds) needs to be managed by licenced con-
tractors, preferably with coverage over the whole parent institution rather than just
the facility.

**Pen versus crate/cage**

Pen design is important and should allow for group, individual and lambing, if re-
quired. Sides of the individual pens in particular should allow sheep to view each other
where possible. Our research sometimes involves maternal–foetal catheterisation pro-
tocols, and for a long time these experiments were conducted in metabolic cages. We
decided several years ago to conduct the vast majority of maternal–foetal catheterisa-
tion work in pens rather than in cages, only using metabolic cages for periodic studies
and infusion studies, for example following careful acclimatisation. Eventually we sourced backpack battery-driven pumps that decreased the need for cage use even further. Experimentation relying on large scale, expensive instrumentation (e.g. foetal EEG and EMG electrodes, infrared and ultrasonic blood flow probes) may still require cage use. Even facility managers, AWOs and AECs should encourage investigators to consider the huge increase in wireless telemetry technology as a means to get sheep out of metabolic crates and into pens for better welfare consideration. Another reason for using metabolic cages was the frequent use of radioactive isotopes for tracer studies, but fortunately ‘cold’ isotopes are becoming cheaper and more available, removing some of the containment requirements.

**Environmental management**

Ventilation, temperature and photoperiod control are further considerations for indoor housing of sheep. This begins to increase expense, but thoughtful use of a barn design that allows air to circulate under the grating and through roof fans can achieve a good result. The main message is to ask around and perhaps visit some facilities with the idea firmly ingrained that bigger and more expensive is not always better. Effective and smart design options may allow more budget to be spent on research and animal care.

Discussion of options for indoor feeding could easily occupy a chapter itself. There are some useful resources that give very good practical advice for sheep at different ages and stages of pregnancy or lactation (ANZCCART, 2009; Mellor, 1987). A ruminant nutritionist with experience in developing total rations for indoor housed sheep should certainly be consulted, especially if research, management or animal care staff do not have a postgraduate academic background in ruminant nutrition/digestive physiology or a great deal of practical experience.

Our facility uses custom-made pelleted diets based predominantly on lucerne (alfalfa) and barley and adjusts the composition according to the requirements of the experiment and characteristics of the sheep, that is, age and pregnancy/lactation state. This is facilitated by working with a boutique feed company (Dunstan Ltd., Hamilton, NZ) used to producing consistent batches of high quality feed from high quality ingredients. This is not cheap, but with managed acclimatisation we seldom have research animals exiting a trial due to feeding or digestive difficulties. The key components of our successful feed are quality ingredients; sufficient ‘scratch factor’ (fibre > 5 mm) from lucerne (60%) and meadow hay (5%), a limited amount of barley (30%, less likely to cause rumen acidosis than corn) and the balance composed of trace elements/mineral additives, limited molasses for binding and attraction, lime and a mould inhibitor. Around 8–10 MJ/kg is a good energy density to allow for good rumen function and stomach fill.

Once a relationship is developed with a supplier and a consistent product is assured it is possible to calibrate the performance of your sheep on the defined product. It is important to understand and use recommended nutritional guidelines for sheep (e.g. the National Research Council) (NRC, 2001). However, animal performance is affected greatly by breed, geography and the actual nutritional value of raw ingredients.
Advances in Sheep Welfare

(e.g. rumen degradable protein, bypass protein, fermentable and non-fermentable fibre and mineral levels) which can vary according to source. The best approach is to enlist the help of an experienced and qualified ruminant nutritionist rather than assume the product chosen actually meets the recommended guidelines.

While these recommendations involve maintenance feeding, much greater care is needed if feed restriction is used as part of the experimental treatments so as to investigate metabolic and endocrine regulation, particularly in the pregnant ewe and her late gestation foetus (Oliver et al., 2002). Bearing in mind the nutritional issues for the pregnant ewe that were addressed earlier (sections ‘Nutritional Considerations’ and ‘Experimental Manipulations and Welfare Considerations’), it is critical to monitor animals when using feed restriction. Some of the key variables to monitor are obvious such as maternal blood glucose and perhaps maternal urinary ketones; other key behaviours to observe are wool pulling and increased teeth grinding. Undernourished ewes can sometimes pull and ingest wool to increase bulk in their rumen.

For research requiring restricted concentrate feeding to reach target weights, it may be useful in our experience to supplement feeding with barley straw (Oliver et al., 2002). This provides bulk but does not deliver a great deal of metabolisable energy. A very strong caveat is required here for considering the use of barley straw; either get it analysed at a reputable laboratory for metabolisable energy or better still pilot the use of a batch first to make sure weight management targets can be achieved. In addition, the quality of the straw needs to be considered, as damp or incorrectly stored straw can contain moulds, spores and mycotoxins.

Training staff and students in Sheep Welfare 101

It is important not to assume a knowledge base regarding sheep welfare. Even in countries that are noted for their farmed sheep industries such as New Zealand and Australia a firm knowledge or background in sheep cannot be taken for granted, and certainly not for those from further afield. For those personnel who do have some experience, the welfare standards they are accustomed to may differ and need to be adjusted in line with up-to-date codes of practice and their interpretation. Biomedical academic staff and students, and sometimes their supervisors, tend to focus on the translatability to human medicine and do not necessarily understand the privilege and challenges of being able to conduct experiments using sheep. Medical students or practicing clinicians have distinct advantages with their knowledge of anatomy, physiology and medicines but they often need to be made aware that some aspects of sheep biology do not translate well from their knowledge, for example pain relief solutions, assumptions about stress exposure, animal behaviour, animal handling and above all nutrition, digestive and metabolic physiology. Careful questioning and testing during recruitment interviews is very important to establish background knowledge and a desire to fulfil welfare obligations.

From a facility management perspective, training new staff requires a plan to be developed and outlined clearly with the individual and their primary supervisor if it is third party. Rather than simply dropping a huge bundle of institutional and legislative
paperwork on the new staff member’s desk, an initial philosophical discussion about animal welfare and ethics is always a good start. With sheep the best approach is to address animal welfare by describing *normal* farm practice that informs relevant welfare codes and then explaining how the research manipulation is a progression away from that normal practice. The concept of cost benefit analysis and the important theme of the 3Rs must be made clear when describing AEC application procedures. For educating new staff on aspects of sheep biology, husbandry, health and specific manipulations, it is a good idea to recruit the relevant expertise of others such as experienced animal or research technicians, the AWO, or veterinarians. An added benefit of this approach is that the new person gets used to working with a range of people and it can be also a good developmental experience for those giving the training.

**Ongoing staff development**

With staff or students that are more established in their roles the next step is to get them involved in drafting SOPs, new ethics applications and ethics reporting (e.g. animal usage returns). Once again, it is useful to enlist the expertise of the AWO for information or preliminary evaluation. Senior technical staff should be encouraged to become responsible investigators on AEC applications where it is possible, as part of their career development. This can be empowering in itself, but also may have added benefits because the perspective of people performing day to day animal experimental tasks often leads to useful improvements in design and can make an application easier to understand and review by the AEC. Lastly, supporting senior students and staff to attend and present at conferences such as ANZCCART or its equivalents is also a good way of encouraging and developing compliance with sheep welfare and ethics. This is particular good for technical staff, as they will often have a chance to meet others engaged in similar roles at other research institutions. Technicians caring for and researching other species are often surprised and interested to hear about the sheep as a research animal.

An important role of training is to develop empowerment and independence in staff and students. Developing a degree of ‘redundancy’ in personnel roles in a sheep research facility or farm is good for sheep welfare, but also in terms of management, resilience and succession. However, that also needs to be moderated by developing a self-awareness of one’s own limitations and limitations of authority and responsibility as training progresses.

**Feedback**

Although seeking feedback following training sessions for research staff or graduate students may not be a formal institutional requirement, it can be very informative and useful. Often an experienced researcher will forget that they have been involved in projects for a long time and, therefore, not always understand that training needs to be graded and managed at the pace of those learning. As with any training situation, training needs to be tailored to the individual. In the case of AEC applications, in particular, the responsible investigators may also be too academic or removed in their thinking in
relation to what they see as *justifiable* research and in the process, forget that manipulations have not been described enough technically or in relation to the likely impact on the research animal. A student or learning staff member should never hesitate to ask their supervisor how they feel about the justification for a particular experiment and hopefully they should get a balanced and considered response.

**The personal cost of undertaking large animal research**

The emotional aspects of working with a large research animal such as the sheep need to be addressed. Contrary to societal opinion, sheep are extremely bright, routine driven and respond very well to being handled consistently by the same one or two people. They do make excellent pets and from personal experience, it is very difficult to conduct these sorts of experiments without developing attachment with sheep. At the end of a long-term experiment, lasting anywhere from weeks, months or even years, there is the always the dilemma of euthanasia of a long-term research animal. For medically trained students this can be difficult as those research animals have become de facto or proxy patients. For the research or animal care technician it can be very difficult to divorce from the idea that the animal is ‘merely’ a research subject or source for blood samples, longitudinal data, tissue samples, etc. In some situations a sole technician can be assisting a number of students or researchers, so they will be expected to be involved with potentially larger numbers of euthanasia as opposed to a sole PhD student or post-doctoral fellow. It is a firm belief of the authors that euthanasia of any research animal should never be ‘easy’; researchers should always be mindful of the privilege they have of being able to conduct research on sheep.

Lastly, while training should be empowering, the hierarchical preferences of facility management in a particular institution need to be taken into account. Hierarchical considerations can become quite a political issue in certain institutions, for example where medically or veterinary trained postgraduate students may have had previous supervisory experience in different situations. It is often very important to define roles within a facility; some medically trained PhD students may find it difficult to be under the day-to-day training or supervision of experienced research technicians. The hierarchical arrangement should be made clear by those responsible for the overall management of the facility, and the sheep in this case. Welfare of the research animal needs to be considered at all times. Redundancies in function in the case of absence also need to be clearly stipulated. In addition to well-conducted group meetings where these issues are discussed, well-developed facility SOPs will also help formalise hierarchal and functional arrangements.

**Concluding comments**

The predominant perspective of this chapter is from biomedical research, although many recent trials we have performed involve extended phases of work that rely on both pasture-based and laboratory-housed phases of sheep research. *(Bansal*
et al., 2015; Hancock et al., 2012). The findings from our research have also been useful when translated to agricultural research (Oliver and Harding, 2009) and from time-to-time we do get opportunity to focus on projects dedicated to that theme through collaborations with other groups or industries (McCoard et al., 2013; Oliver et al., 2014; Sales et al., 2013; van der Linden et al., 2013). Similarly our perspective on welfare and ethics is shaped by a New Zealand perspective and heavily influenced by current institutional codes and national legislation. However, there are many commonalities with other sheep research settings and the recommendations made are included as suggestions that can be fitted to the requirements of other research jurisdictions. Much of the success of our work has been developed by good farm practice and the experience of sheep research for sheep industries that has come from collaborators, advisors and some exceptionally good farmers and veterinarians.

In terms of new developments, an interesting possibility is that sheep use may be revisited more often as a large animal paradigm for human biomedical research as the use of primates becomes more controversial and restricted geographically (Abbott, 2014). This is particularly the case for research around pregnancy and foetal development as the sheep has many advantages over other species, as discussed earlier.

The development of new analogues of analgesic drugs that have lesser side effects (e.g. ketamine) would be welcome for sheep research. This type of development benefits both biomedical and animal production research, especially if recovery times and welfare are improved.

New remote and/or miniaturised technologies will revolutionise both production and biomedical sheep research over the next few years. Hopefully these developments will also minimise welfare burden for the sheep as a research animal.

In summary, the main message we wish to convey in this chapter is that good sheep welfare is conducive to good science. On occasion, however, as researchers, we may have a question that requires some compromise of sheep welfare. If this is unavoidable, we must make every effort to minimise the welfare cost through refinement, the number of animals required and where to possibly look for alternatives. This of course is the basis of the 3Rs of animal ethics and welfare in experimentation and teaching. From a teaching perspective there is an added challenge of students’ perspective of using animals within their training programmes. This requirement is very difficult for some students and we must be sensitive to that. However, in these days of increased urbanisation many people have less opportunity to have contact with animals, particularly domestic livestock like sheep. Teaching with animals is not always about vivisection and severe compromise of welfare. It is important that students have opportunity to interact with animals and understand different perspectives of people involved in animal industries and with those involved in biomedical research. Organisations like ANZCCART fill a very important role in informing society of the role of animals in research and teaching. From that perspective it is important that all sectors with an active stake in research and teaching using sheep attend these meetings so that we can assure that welfare standards are optimised and the species is adequately represented.
Jaquiery, A.L., et al., 2006. Fetal exposure to excess glucocorticoid is unlikely to explain the effects of periconceptional undernutrition in sheep. J. Physiol. 572 (Pt 1), 109–118.
Optimised welfare for sheep in research and teaching


National Centre for the Replacement, Refinement and Reduction of Animals in Research, 2017. Available from: http://nc3rs.org.uk/


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Part Four

Sheep Welfare Beyond 2020

15. Future challenges and opportunities in sheep welfare  285
Future challenges and opportunities in sheep welfare

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The changing face of sheep production

Looking towards 2050, it is clear that substantial increases in agricultural production efficiency are required to feed and clothe the projected growth in global population. To meet this need, we are likely to witness profound changes in sheep production systems and practices. These changes and associated challenges have been discussed in previous chapters. The expected main production trends include a decline in pastoralism and a commensurate intensification of the whole or part of the production system, along with an increase in the scale of individual sheep enterprises. Key drivers underpinning these trends include the need for increased output to meet consumer demand, increased capacity to mitigate and manage environmental variation in the quality of sheep products in the face of the effects of climate change, optimised labour and resource use efficiency, and a proactive response to societal expectations for good sheep welfare. These expected shifts in the way sheep are farmed have the potential to yield both positive and negative impacts to animal welfare (discussed further later). Getting the balance right in terms of on-farm productivity and sustainability will be a major challenge for sheep industries in the future.

Advances in technology

Technological advances across a broad range of farm practices are occurring at an unprecedented scale and speed. The application of these technologies in sheep production presents an exciting opportunity and in many respects will be germane to achieving a balance between productivity and sustainability of the farming system. Their application will also be paramount to achieving continuous improvement in animal welfare.

Genetic improvement

The application of DNA technologies and the increased emphasis on functional and resilience traits in sheep breeding programmes will have a positive impact on sheep welfare (Chapter 7). Selecting for functional and resilience traits is essential to mitigate the potential adverse effects that can result from an over-emphasis of breeding for increased production efficiency (Rauw et al., 1998).
To realise the full promise of genomic selection, large numbers of phenotypes (thousands) are required. Therefore, the development of measurement platforms and methods that enable cost-effective, large scale and, preferably, automated phenotyping of key traits in sheep is essential. Genetic strategies such as breeding less wrinkled (Merino) or polled sheep which obviate the need to perform painful procedures such as mulesing or dehorning are important long-term welfare solutions.

**Precision livestock monitoring and management**

The broad penetration of digital technologies in other sectors of agriculture such as broadacre cropping (e.g. GPS guidance systems, variable rate fertiliser application, yield mapping) has resulted in significant economic benefits (Koch et al., 2004). The application of similar technologies in livestock production has lagged, but is starting to gain some momentum (Rutter, 2014). Fixed and/or on-animal tracking and monitoring systems are rapidly emerging and may provide real-time data on the health and welfare status of not just the flock but also the individual animal. From an animal welfare perspective, autonomous animal monitoring offers real promise, particularly in extensive pastoral systems where the capacity to frequently inspect sheep is constrained. These digital technologies will also enhance genetic improvement through the collection of highly specified phenotypes/trait scale within the production environment.

**Advanced husbandry practices**

Sheep are subjected to many routine husbandry procedures throughout their lives, and as described in Chapter 12, husbandry procedures can have either negligible, moderate or quite severe impacts on animal welfare. Procedures that elicit moderate-to-severe welfare impacts are clearly at risk of community rejection given the increasing level of societal concern for good animal welfare. When a husbandry practice cannot be avoided but results in considerable pain, the research community and sheep industries must galvanise their efforts to develop and implement non-painful alternatives such as breeding solutions that obviate the need for the husbandry practice in question. However, if this approach is not feasible or is not currently available, the second priority must be to reduce the pain associated with the procedure. Fortunately, new analgesics and advances in the safe and practical administration of analgesics on-farm are becoming more available. Ensuring that pain management becomes mainstream on-farm will be a critical challenge for all sheep industries.

**Societal expectations**

**Intensive versus extensive**

As described in Chapter 3, societal expectations for animal welfare continue to broaden and increase. Although it is not possible to predict the future, in the absence of major societal or economic upheavals, war, famine, global energy shortage or
other catastrophe, it is reasonable to assume that the public’s expectations of livestock welfare will become greater. In recent decades, public attention on the welfare of farmed animals has focussed on intensive farming systems, especially for pigs and poultry, in what has been perceived as ‘factory farming’. As public interest in animal welfare grows, and societal expectations for rising standards increase, extensive farming practices employed in many sheep production systems are likely to come under increasing scrutiny. Furthermore, some aspects of sheep farming may come to be regarded as ‘intensive’ or sheep farming practices may move towards more intensive methods. An example is the increasing trend to feedlot sheep (Meat & Livestock Australia, 2007), either due to variable climatic conditions or to produce meat to meet specific market requirements.

In line with the theme of this chapter, developments in production systems present both challenges and opportunities for managing sheep welfare. The challenges arise because farmers and industry representatives will need to validate and provide assurance on sheep welfare for farming systems and practices that have traditionally been managed simply for productivity and profitability. Practices such as tail docking, which confer an undoubted long-term welfare benefit, may be increasingly questioned for their short-term welfare impact. This will mean that simply ‘business as usual’ will not suffice to meet public expectations, and alternatives to practices such as tail docking (pain-free methods of docking or leaving tails intact) will need to be adopted.

Intensification of sheep farming practices will prompt a need for more rigorous welfare evaluation, validation and assurance. Although it is obvious that extremes of confinement and behavioural restriction are detrimental to welfare, simply classifying extensive sheep farming as representing ‘good’ welfare and more intensive practices as ‘bad’ welfare is not supported by current evidence, as explained in relation to nutritional management (Chapter 8) and predation (Chapter 9). Sheep that are more closely husbanded may also benefit from the technological advances in monitoring and managing health and welfare that are described in Chapter 14.

Increased scrutiny of extensive sheep farming is likely to encompass public concern around impacts that may previously have been viewed as ‘natural’ and uncontrollable, such as mass weather-induced lamb mortalities and predation. Neonatal lamb deaths, which can be of the order of 20% (Hinch and Brien, 2013), are certain to receive much greater public questioning. This scrutiny may provide an opportunity to significantly improve a key area of sheep welfare by providing the incentive and market support for farmers, vets and industry advisers to improve lamb survival. There is the opportunity for implementation of known but not widely adopted strategies to improve lamb survival, and for researchers to develop new approaches (Chapter 8).

There are many examples where a farming industry becomes the sudden target of public criticism for its animal welfare practices, despite the practices in question having occurred over many years. This situation can arise from changes in societal expectations of how farm animals ought to be managed and the public acceptance of the level of risk to animal welfare is inherent in various farming systems. Extensive sheep farming, with inherent variations in feed availability and weather, is one production system that may need to respond to these societal changes in risk tolerance.
**Individual animal value and species comparisons**

It is important to remember that the experience of the individual animal matters, and thus animal welfare needs to focus on the individual animal through its experience of both positive emotions and its potential for suffering. In contrast, animal management is usually implemented through husbandry and economic decisions made at the group level. Although sheep in most farming enterprises are of higher individual economic value than say poultry or aquaculture species, sheep are usually not of such high individual value that each animal is able to receive specialised attention and treatment. As a consequence, welfare monitoring through technological innovation, and welfare assurance through flock health and welfare schemes, offers promising approaches to advance sheep welfare in the future. The economic drivers that underpin the increase in the number of sheep per stockperson will accentuate this need (Morris, 2013).

A looming challenge posed by societal expectations is the need to replace or mitigate painful husbandry procedures. In developed countries, people are well aware that their pet dog or cat receives pain control measures during surgery through the use of anaesthetic and analgesic drugs. In most sheep husbandry operations and in most jurisdictions, pain-free outcomes are commonly neither practised nor mandated. It is almost certain that future public concern will focus on the divergence between the way sheep are treated in comparison with dogs, cats and horses during painful husbandry practices. There is little evidence to support a contention that the perception of pain in farm animals, such as sheep, is any less biologically significant than it is for dogs, cats or horses (Dobromylskyj et al., 2000). Part of the challenge for sheep producers in responding to this welfare issue relates to the value of individual animals—a $5 anaesthetic–analgesic combination for a sheep may have a greater economic impact for the farmer than a $15 equivalent therapy for a dairy cow because of the relative difference in value between the two animals. Who pays for good welfare is a live-wire issue.

The solution is likely to have three components. Firstly, breeding strategies may reduce the need to perform certain practices, such as mulesing. Secondly, management practices may reduce or remove the rationale for some surgical husbandry procedures—for example, male lambs that are destined for slaughter as prime lamb ought to be able to be managed without castration. Third, if society expects sheep farmers to achieve certain standards of welfare with their animals, then there ought to be an aligned willingness of consumers to pay the price for those elevated welfare standards. As described in Chapter 3, public attitudes currently may make only a moderate contribution to public purchasing behaviour. The challenge and opportunity for sheep welfare, and indeed for welfare of other farmed species, is to develop regulatory, assurance and marketing frameworks that more closely align societal expectations of good farm animal welfare with a willingness to pay.

**Advances in animal biology and their implications for animal welfare**

New knowledge in animal biology provides a path to developing a more robust concept of what constitutes good welfare and can help us to design better measures and improved management practices for sheep. We see recent advances in three interrelated
areas as particularly pertinent to understanding and improving animal welfare: affective state, physiological regulation and resilience. Indeed, the growing knowledge of the interdependency of these aspects of the animal gives them added importance.

**Affective states**

The nature of affective states and how they arise in the brain is a long-standing question in neuroscience. The brain orchestrates the engagement of the animal with its external environment and management of its internal environment. To achieve these activities, the brain relies on information relayed via sensory receptors. Recent models of brain function suggest that rather than operating as a stimulus→response network, the brain generates internal models that draw meaning from sensory input via comparison of actual input with anticipated input inferred from prior experience (Barrett and Simmons, 2015; Barrett et al., 2016; Pezzulo et al., 2015). In describing this process, authors use the language of Bayesian inference, where predictions based on prior experience are updated by current information arriving from the sensory world. This model of brain function, termed active inference, has been very closely mapped to neuroanatomical pathways of communication within the brain (Barrett, 2017) and has very strong concordance with the large body of empirical evidence of the anticipatory nature of behavioural and physiological actions the animal employs when engaging with its environment (Dworkin, 2007).

In the active inference model, the current affective state of a sentient animal such as the sheep emerges from a comparison of the extent to which current sensory information resembles the internal models built on prior experiences from which pleasant or unpleasant events flowed (Barrett, 2017). Thus, the affective state arises from semblances to and discrepancies from prior experience, rather than being a hard-wired response to a specific challenge in a specific context, such as restraint in isolation, or escape from handling. Thus, the active inference model reinforces the prevailing viewpoint in animal welfare science that measurements of the animal, rather than the environmental context the animal is experiencing, are central to assessing its welfare. Prediction built on prior experience, as the basis of neural function, has implications for the design and interpretation of studies on affective states.

**Physiological regulation**

The active inference model also accounts for the predictive nature of physiological actions in the body. The influence of the brain over physiological functions was recognised very early in the science of physiology by Pavlov (1904) in his studies on classical conditioning. Recent accounts suggest that sensors termed interoceptors in blood vessels, tissues and organs continuously sense the physiological status of the body and directly influence affective state (Barrett, 2017; Barrett and Simmons, 2015; Pezzulo et al., 2015). Thus, the metabolic status and body condition of the sheep may generate a negative affective state and constitute a diminished welfare state when the animal cannot reconcile the discrepancy between the expected physiological state (e.g. satiety, energy balance) and actual physiological state (e.g. hunger and energy insufficiency) through actions such as eating or mobilizing tissue reserves (Stephan et al., 2016).
Resilience

A third area of growing interest in animal biology is resilience to environmental challenges. Resilience is a comparative measure of the difference between animals in their ability to cope with and return to normal when faced with an environmental challenge (Colditz and Hine, 2016). For example, weaning of lambs is accompanied by psychosocial and physiological challenges including disruption of the maternal-offspring bond, change of social grouping and change of diet. Evidence shows that in response to weaning, there is considerable variation between lambs in hypothalamic–pituitary–adrenal axis activity, growth rate and immune function. There is a heritable component of this variation between animals in stress responsiveness, growth rate and immune function during weaning, and heritable differences in temperament are also associated with resilience (Hine et al., 2015, 2016). Associations between these traits are also observed in studies that identify coping styles in livestock species (Koolhaas and van Reenen, 2016; Koolhaas et al., 1999), including sheep (Lee et al., 2014). Coping styles describe consistent behavioural and physiological responses to environmental challenges and are characterised as proactive and reactive. The estimation of breeding values for resilience traits offers the potential to include genetic selection for resilience into breeding programmes, so that sheep will be better able to cope with those stressors (such as weaning and transport) that are inevitably part of the farming environment (Hine et al., 2015). This ought not to preclude us from seeking to improve or minimise the impacts of current husbandry and management procedures on sheep welfare, but offers us (and the sheep) a powerful tool to achieve further gains in sheep welfare in relation to the unavoidable challenges of daily life.

In addition to the contribution of heritable effects to resilience, studies on affective processes and behavioural development indicate that prior experience can strongly influence resilience in both positive and negative ways (Crofton et al., 2015; Lyons et al., 2009). These advances in our understanding of animal biology create the opportunity to enhance the animal’s capacity for positively engaging with and responding to its environment (Boissy and Lee, 2014; Boissy et al., 2007). This can be achieved through the deliberate guidance of the animal’s interactions with its physical, social and human environments during its development, and through structured access to appetitive rewards and environmental complexity during everyday management. This strategy can be described as constructing a felicitous landscape of cognitive and affective experience that confers agency on the animal in a manner that lets the animal actively optimise its quality of life (Spinka and Wemelsfelder, 2011; Watters, 2009; Wechsler and Lea, 2007).

Assessment and management of welfare

To meet consumer expectations for more ethical sheep production, improved methods of assessing welfare and transparent demonstration of how these expectations are being met are needed. To determine whether the animal’s physical and emotional needs are being met requires assessment of a range of welfare measures. Chapter 6
describes recent developments in physiological indicators of welfare that can give new insights into welfare states. Although there are limitations to the application of these measures in certain contexts such as in extensive situations, there are opportunities for these physiological measures to be utilised in welfare studies in combination with affective state indicators (Chapter 5) and new technologies for behaviour monitoring (Chapter 14) to provide a more robust and objective assessment of the welfare status of sheep.

With the solid progress that has been made to develop better indicators of animal welfare, there is the opportunity to utilise this knowledge to provide a transparent way of reporting on animal welfare standards to consumers. Benchmarking animal welfare may enable monitoring and improvement of animal welfare to meet consumer demands for assurance of ethical products. For example, benchmarking of cow comfort has been demonstrated in dairy cows (von Keyserlingk et al., 2012). In their study, variation in the prevalence of lameness and leg injuries, lying behaviour, facility design and management practices were reported in dairy farms from three regions of North America. Considerable variation in some cow comfort measures was reported between farms, and individual reports were provided to producers to enable comparison of performance relative to others in their region. This feedback to producers may provide a means of sharing best practice between peers to facilitate improvements in welfare. Benchmarking of pig welfare has also been demonstrated in commercial pig finished farms in the United Kingdom using five animal-based measures of welfare (Pandolfi et al., 2017).

A framework for describing and measuring animal welfare performance across livestock industries has been proposed that may enable monitoring, reporting and benchmarking of sheep welfare (Colditz et al., 2014). The framework comprises three modules for assessing welfare with animal-, resource- and management-based measures and is designed for implementation through a process of on-farm assessment of welfare risks, development of management strategies for those risks, monitoring animals and annual review of data. In addition, across enterprise comparisons could provide the basis for benchmarking welfare performance on individual farms and providing feedback to producers to enable improvements in welfare performance. Output or animal-based measures are desirable to use in welfare assessment as they reflect the actual welfare status of the animal. But a key limitation is that there are very few practical output measures that can be readily implemented in extensive systems. In particular, more research to develop measures of affective state that can be easily performed on unrestrained animals in their production environment is needed.

Conclusions

Sheep will remain an important mainstay in global livestock production given their capacity to produce meat, milk and fibre, quite often in marginal pastoral land which would largely be unsuitable for other agricultural systems. In future, it is highly likely there will be changes in sheep production systems and practices, and the real and potential impacts on animal welfare will take on much greater significance given the
escalation of societal concerns and expectations regarding animal welfare. Advances in technology and the application of new biological insights to shape and direct demonstrable improvements in animal welfare will be central to guaranteeing the sustainability of future sheep production systems.

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Advances in Sheep Welfare examines the recent advances made in sheep welfare assessment, handling and management, providing state-of-the-art coverage of the welfare needs of one of the world’s most widely farmed animals.

The book begins with an introduction to sheep welfare in Part One, with chapters covering biology and natural behavior, sheep production systems, and consumer and societal expectations for sheep products. Part Two goes on to highlight new advances in sheep welfare assessment, and Part Three outlines a wide range of solutions to sheep welfare challenges. The final section looks ahead to the future, considering what sheep welfare will look like in 2030 and beyond.

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With its expert editors and international team of contributors, Advances in Sheep Welfare is a key reference tool for welfare research scientists and students, veterinarians involved in welfare assessment, and indeed anyone with a professional interest in the welfare of sheep.

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