Beef cattle welfare in the United States: Identification of key gaps in knowledge and priorities for further research

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Introduction
Animal welfare plays an increasingly important role in decisions and attitudes about animal agriculture in the United States. For example, because of pressure from consumers and advocacy groups, foodservice and retail organizations have begun to require their suppliers to pass animal welfare audits on a regular basis. Although this auditing process was initially limited to highly centralized aspects of food production, such as slaughter plants, foodservice and retail organizations face growing pressure to provide evidence that animal welfare is considered from the farm to the plate. Indeed, the consumer perception of animal welfare can drive the sustainability of the production method, as in the egg industry, where concerns about animal welfare have led to proposed national legislation banning conventional cages for laying hens (Mench et al., 2011; Greene and Cowan, 2012).

Animal welfare is likely to continue to play an important role in agriculture. The scientific study of animal welfare can inform best practice on farm and, in many cases, provide a basis for animal care, thus contributing to the public discussion about these issues. Sufficient scientific information will allow decisions to be made based on evidence and measured outcomes, rather than solely on perceived ethical concerns. Throughout this review, emphasis is placed on the empirical evidence informing the three main aspects of animal welfare: 1) physical functioning, in that animals should be healthy and thriving, such that one function should not be enhanced to the detriment of another, 2) naturalness, meaning that animals have the ability to engage in behaviors they are strongly motivated to perform, and 3) subjective states, in that animals can enjoy life; that is to say, they experience positive states and negative states (e.g. pain) are minimized (Fraser, 2008). Empirical evidence about these issues comes from literature about cattle, both dairy and beef. Information from the dairy literature is included in this review when relevant and is identified it as such.

The objective is to strategically review scientific information about the welfare of beef cattle in the United States to identify key gaps in knowledge and priorities for further research. Comprehensive reviews are available for many of the topics covered. This review is broader than a single-topic review in scope. It is targeted in approach, providing a critical review of existing knowledge in order to identify where additional information is needed. Beef production has been divided into the following sections: nutrition and growth, health, painful procedures, environmental and housing conditions, social interactions, transport, handling, and slaughter. Key issues and future research needs are highlighted within each section; a summary and ranking is provided at the end of the document.

1. Nutrition and growth
Several areas of nutrition have received either considerable attention within the scientific literature or have been identified as key animal welfare concerns: weaning, feeding high-concentrate diets, using body condition as a tool for assessment and production-related technologies, such as antibiotics, ionophores, hormones (both fed and as implants), and β-adrenergic agonists.

Weaning
In the United States, weaning is practiced by beef producers at an average calf age of 207 d (Reinhardt and Reinhardt, 1981; USDA, 2007a). The majority of producers (54%) pick the weaning date based on age or desired weight, while some producers wean based on tradition (12%), the physical condition of the cow (9%), forage availability (8%), or other reasons (17%). Choosing a specific age or weight to wean may directly avoid other problems including: lower body condition of cows, poor forage availability, and the rare but potential risk of an un-weaned older offspring causing starvation of the newer offspring if weaning occurs naturally. The timing of weaning is similar to or shorter than in feral cattle, where it occurs naturally between 7 and 14 months (Reinhardt and Reinhardt, 1981). The duration of the cow-calf relationship is substantially different in feral versus commercial situations. Under natural conditions, the cow never completely or abruptly abandons the calf (Reinhardt and Reinhardt, 1981) and the pair maintains a lifelong relationship of social contact and companionship even when new offspring arrive (Reinhardt, 2002).

The loss of milk and social contact associated with weaning creates a stressful situation for cows and calves (Weary et al., 2008), and increases the risk of sickness, particularly when it is coupled with other stressors such as transport. A number of studies have found that calves weaned and immediately transported to a new location and co-mingled with unfamiliar calves have a higher
mortality rate and decreased weight gain compared to calves weaned and left at home (e.g. Step et al., 2008; Edwards, 2010); however, one study found no differences (Boyles et al., 2007). Currently, half (50%) of producers wean and ship calves the same day (weaning on the truck, USDA, 2007b).

Preconditioning, a protocol that requires vaccinations and starting calves on feed and avoids immediate transportation after weaning among other practices, offers a consistent health advantage to the calf (Peterson et al., 1989b; Schipper et al., 1989), but there is not always a financial advantage to the producer (Peterson et al., 1989a). The majority of producers (61%) never vaccinate calves for respiratory diseases before sale and only 34% of producers hold calves for more than 31 d after weaning and before sale (USDA, 2007b). This indicates a disconnect between the ideal management of calves from a welfare perspective before sale and the strategies that many cow/calf producers follow.

Abrupt weaning and separation of cow/calf pairs results in the absence of adults among calves, which may be a psychological stressor. However, adding adult cows to the pens of abruptly weaned calves does not improve their health or performance within the first few weeks of arrival at the feedlot (Gibb et al., 2000). It appears that the presence of an unfamiliar adult is of little or no comfort to a newly weaned calf, though visual contact between the calf and its own dam does appear to alleviate some of the stress of weaning. Calves weaned and allowed fence-line contact with their dams gained more weight the first week following weaning, were still heavier than traditionally weaned calves after 10 wk (Price, 2002), and displayed fewer behavioral signs of stress post weaning compared to controls (Boland et al., 2008).

The most recent method developed to minimize stress at weaning has been the 2-step (or 2-stage) weaning procedure (Haley et al., 2005). In 2-step weaning, nursing is prohibited by a plastic anti-sucking device, which is inserted into the calf’s nose. The cow-calf pair remains together during the first phase for 4 to 7 d, but without nursing while weaning occurs. Following step 1, the plastic anti-sucking devices are removed and the pairs are separated. Calves weaned in 2 steps display favorable changes in behavior with fewer vocalizations and spend more time eating and less time walking in the first week following separation compared to abruptly weaned calves (Haley et al., 2005; Boland et al., 2008; Loberg et al., 2008). Two-step weaned calves also gain more weight compared to abruptly weaned calves in the first week following separation (Haley et al., 2005). At least one study did not show behavioral advantages in 2-step weaned calves compared to abruptly weaned calves (Enríquez et al., 2010), perhaps because 2-step weaned calves wore the anti-sucking devices for 17 d, at least 10 d longer than recommended by Haley et al. (2005). The short-term benefits of this practice seem robust, but the long-term health and economic implications are unknown.

Future research
Research is needed to determine best management practices for non-abrupt weaning methods (e.g. duration of fence line and flap insertion in 2-step) and to quantify the effects of these practices on calf health at the feedlot. This additional information will inform a cost/benefit analysis for producers considering these practices.

High-concentrate feeding
High-concentrate feeding is common. Upon arrival at the feedlot, 58% of US cattle are fed a diet that is at least 50% concentrates; 83% of cattle in the finishing phase are fed this type of diet (USDA, 2011b). High-concentrate feeding has been associated with nutritional disease, the most common of which include acidosis, liver abscesses and laminitis; the latter two occurring secondary to acidosis (Nocek, 1997; Galyean and Rivera, 2003; Nagaraja and Lechtenberg, 2007a). Acidosis is the result of excessive acid production in the rumen (Owens et al., 1998; Penner et al., 2011) and can be defined as either acute (clinical acidosis) when the pH is less than 5.0 or sub-acute ruminal acidosis (SARA) when ruminal pH is less than 5.8 for more than 12 h/d (Schwartzkopf-Genswein et al., 2003). The welfare issues related to acute acidosis include observable illness and mortality, while SARA is associated with variable feed intake and reduced weight gain, rumenitis (lactate-induced thickening of the statum cornea of the rumen mucosa causing mucosal lesions; Owens et al., 1998), liver abscesses (Nagaraja and Lechtenberg, 2007b) and laminitis (Cook et al., 2004; Nordlund et al., 2004). At this time, the prevalence of acidosis in feedlots is not known; however the incidence of liver abscesses has been reported to range between 12 and 32% (Nagaraja and Lechtenberg, 2007a), but can be as high as 56% (Fox
et al., 2009). American and Canadian beef quality audits found that liver abscesses account for 54 and 64% of all condemned livers, respectively (Van Donkersgoed et al., 2001; Garcia et al., 2008).

Factors contributing to acidosis include: the length of time to adapt to high-concentrate feeding (Beaver and Olson, 1997; Owens et al., 1998; Schwartzkopf-Genswein et al., 2003; Nagaraja and Titgemeyer, 2007); the amount and fermentability of concentrate and fiber in the diet (Campbell et al., 1992; Yang and Beauchemin, 2006, 2007); feed intake (Schwartzkopf-Genswein et al., 2003); feeding behavior and competition (Gibb et al., 1998; Schwartzkopf-Genswein et al., 2003; 2011; González et al., 2012a) and the individual’s ability to cope with high acid production (Goad et al., 1998). Other risk factors include an animal’s capacity for fermentation, acid absorption, epithelial molecular level adaptation and epithelial proliferation (Penner et al., 2011).

Strategies to reduce the incidence of acute and sub-acute ruminal acidosis include feeding diets containing adequate amounts of fiber (Nagaraja and Lechtenberg, 2007a) or ionophores which are believed to alter ruminal fermentation and feeding behavior (Nagaraja and Lechtenberg, 2007a; González et al., 2009; 2012a). Gradual adaptation over a 3 to 4 wk period from high-forage to high-concentrate diets facilitates establishment of healthy ruminal microbe populations (Vasconcelos and Galyean, 2007) and allows the ruminal epithelium to adapt (Aschenbach et al., 2011; Penner et al., 2011). Although buffers, such as sodium bicarbonate and seaweed, or direct-fed microbials such as yeast cultures and bacteria, have been used to mitigate acidosis and SARA, their effects have not been consistent (Enemark, 2008). Several studies provide evidence that feeding antibiotics decreases the incidence of liver abscesses (Nagaraja and Lechtenberg, 2007b; Wileman et al., 2009) and increases weight gain (Nagaraja and Lechtenberg, 2007b). At this time, no information has been published assessing whether clinical or sub-clinical acidosis causes pain per se in cattle.

In addition to the health concerns associated with feeding high-concentrate diets, other aspects of welfare, such as motivation to consume forage and ruminate, may also be affected. However, little work has addressed this issue in beef cattle. In a single study, beef cattle preferred to spend time at pasture, particular for lying behavior, but preferred the feedlot during feeding times (Lee et al., 2013). In this type of work, it is unclear which motivation drives these results, as microclimates and the comfort of lying surface, as well as the type of feed available all differ between environments, and thus do not provide direct evidence about the motivation for forage. No work has identified how much forage or what particle size/length is required to stimulate rumination. Anecdotally, geophagia or pica may indicate that beef cattle are motivated to consume forage and/or ruminate, but no studies to date have quantified this response to high-concentrate diets.

Future research

Epidemiological analysis is needed to both understand the prevalence of acidosis and the risk factors (e.g. diets resulting in least digestive disturbance and best performance, optimal transition strategies and relationships between animal feeding behavior, ruminal physiology, metabolism and genetics) that contribute to this problem in commercial feedlots. Further work is needed to understand the non-health implications of high-concentrate feeding, from whether acidosis and/or sub-clinical acidosis are painful for cattle (e.g. the extent of the welfare concern) to a better understanding of the motivation to consume forage and to ruminate. Finally, the economic implications of high concentrate feeding (e.g. mortality, morbidity, growth efficiency and carcass quality) requires more attention.

Body condition score

Body condition score (BCS) is currently assessed in the Beef Quality Assurance (BQA) program as an indirect evaluation of adequate nutrition or disease. Body condition scores range from 1 (extremely thin) to 9 (very obese). The ideal BCS for all cows is 5-6. There are biological implications of low BCS. For example, in beef cattle, reproductive performance is lower in cows with suboptimal BCS below 4.5 and in cows whose BCS has lowered between calving and breeding (Spitzer et al., 1995; Kasimanickam et al., 2012; Soca et al., 2013), unless they had been reared on extensive rangeland (Mulliniks et al., 2012). Indeed, while there is a long history of use of such scoring systems in beef cattle with suboptimal BCS below 4.5 and in cows whose BCS has lowered between calving and breeding (Spitzer et al., 1995; Kasimanickam et al., 2012; Soca et al., 2013), unless they had been reared on extensive rangeland (Mulliniks et al., 2012). Indeed, while there is a long history of use of such scoring systems in beef cattle and the score’s relationship to fertility and the number of days to estrus postpartum, relatively little research has evaluated the other, non-health-related implications of body condition, such as hunger. In addition, retailer and industry welfare-assessment schemes include BCS as an outcome measure, but face the challenge of determining a threshold of acceptability. To date, there seems to be
agreement that extreme thinness is undesirable. For example, it is not recommended that these animals be shipped to slaughter, because time at assembly points and while in transit can be long, putting extremely thin cows at a higher risk of becoming non-ambulatory.

**Future research**

If body condition scores are used as an outcome measure in welfare-assurance schemes, additional research is needed to understand if and when animal welfare implications arise.

**Production-related technologies**

Several technologies are commonly used for either health or management reasons in beef cattle: antibiotics (48% of feedlot beef cattle are given treated feed), ionophores (90% of feedlot beef cattle are given treated feed), and hormonal treatments (either as implants or in feed, 84 to 85%) and β-adrenergic agonists (57% of beef cattle are given treated feed; USDA, 2011b). Antibiotics are used in feed to both prevent and treat illness and to improve weight gain (for an overview of labelapproved uses see Gadberry [2011]). Ionophores are used to reduce SARA by altering ruminal fermentation and feeding behavior (Nagaraja and Lechtenberg, 2007a; González et al., 2009; 2012a). Melengestrol acetate (MGA) is fed to 85% of heifers to both improve feed efficiency and suppress estrus in feedlots (Gadberry, 2011; USDA, 2011b) and is discussed further in the section on painful procedures. Hormonal implants are used to increase average daily gain and improve feed efficiency (Stewart, 2013). β-adrenergic agonists are fed to feedlot cattle in the latter stages of the finishing period to increase average daily gain, improve feed efficiency, and maximize lean muscle growth (Miller et al., 1988; Moloney et al., 1990; Avendaño-Reyes et al., 2006; Vasconcelos et al., 2008).

Research has primarily focused on the health or growth benefits of these technologies. The non-health related effects of these technologies on animal welfare have received less attention, with a few exceptions examining effects of hormonal implants. Some research has evaluated the effect of hormonal growth-promoting agents on responses to hot weather. These studies report either no change (Kreikemeier and Mader, 2004; Mader and Kreikemeier, 2006; Mader et al., 2008) or an increase (Gaughan et al., 2005) in physiological indicators of heat stress such as panting score or body temperature compared to animals without implants. Another body of work has evaluated the effects of hormonal implants on sexual and social behavior in feedlots. Use of implants is thought to either increase (estrogen) or decrease (androgens) buller steer syndrome (Blackshaw et al., 1997). Experimental studies have found that implants either have no effect (Baker and Gonyou, 1986; Newman et al., 1990; Godfrey et al., 1992) or decrease aggression and/or sexual behavior (O’Lamhna and Roche, 1983; Vanderwert et al., 1985; Unruh et al., 1986; Hawkins et al., 2005). Only a single study found that implants (Synovex-S) increased mounting behavior in females (Lesmeister and Ellington, 1977). The majority of these studies have examined Zeranol, an estrogenic implant. These results are likely dependent on the type of implant used, the age and sex of the animal implanted, the dose as well as aspects of experimental design, such as sample size.

β-adrenergic agonists also have not been well studied from an animal welfare perspective. In an unpublished thesis, Vogel (2011) reported that there were signs of heat stress associated with certain combinations of either ractopamine or zilpaterol with implants. Although the animal welfare implications of these compounds have not been well studied in cattle, experiments with pigs report a high dose of β-adrenergic agonists (ractopamine) can make pigs more difficult to handle (Marchant-Forde et al., 2003). Other problems observed in pigs include increased prevalence of non-ambulatory animals, aggression in gilts, and hoof cracking (Poletto et al., 2009; 2010). The ractopamine label clearly states that non-ambulatory animals may be more common. Although cattle may respond differently to these components, the work in pigs provides insight into factors that may be important to examine. In ruminants, zilpaterol has been associated with increased skin temperature in sheep (Macías-Cruz et al., 2010). Baszczak et al., (2006; 200 mg/steer per d#) reported a slight increase in speed when cattle entered the squeeze chute.

**Future research**

A number of studies are underway examining the effects of β-adrenergic agonists on morbidity and mortality are underway. Additional work is needed to understand the more nuanced effects of both hormones (implanted and fed) and β-adrenergic agonists on beef cattle welfare. In addition to the unknown effects of these components, dosage may present unique challenges when delivered via feed, as it will be dependent on the amount of feed consumed by each individual.
2. Health

Attention to cattle health begins with a documented, valid veterinary-client-patient relationship and many animal welfare schemes, including BQA, require documentation of this agreement. Managing health is a multifactorial challenge. Preventing disease and injury in cattle on the ranch or feedlot requires focus on the animal's age and physiological state, infectious agents, the environment, weather patterns, and management practices. Signs of illness or injury in cattle include anorexia, decreased weight gain or low BCS, abnormal behavior, or abnormal physical appearance (Blecha, 2000; Webster et al., 2004) and all of these changes play a role in disease detection. Cattle are affected by a number of diseases. Rather than review all literature in these areas, this review focuses on two problems, Bovine Respiratory Disease (BRD) and lameness, as examples of health issues that are well and less understood, respectively.

BRD is the most costly disease for the beef industry (Smith, 1998). Loneragan (2005) estimated that BRD caused 67% of total mortalities in US feedlots. BRD is associated with decreased feedlot performance and diminished carcass qualities (Smith, 1998; Larson, 2005) and decreases cattle productivity while increasing treatment and death loss (Galyean et al., 1999; Irsik et al., 2006). BRD research can be divided into two categories: prevention and detection/treatment.

The risk factors for BRD are well understood. Cattle at the highest risk for morbidity and mortality are light weight, commingled, immunologically naive, hauled long distances from the farm of origin and are not used to being fed or watered from bunks or troughs (Duff and Galyean, 2007). A number of management procedures can prevent BRD, often referred to as “preconditioning” calves for transition to the feedlot. These pre-arrival practices include introduction to the feed bunk, vaccination, treatment for parasites, weaning, castrating, and dehorning well before transport (Shipper et al., 1989). More than 80% of large feedlot operators recognize the value of these practices, but only 35% always had access to this information when calves arrived (USDA, 2011b). The disconnect between the value of these practices and their implementation requires attention.

Detection of BRD and other illnesses is more challenging, particularly in extensive environments or in large feedlot groups. Specificity and sensitivity of BRD detection by pen riders, compared to post-mortem lung lesions, is relatively poor, 60% (White and Renter, 2009). Using aspects of the sickness response, such as changes in behavior, is a promising way to improve detection (e.g. Weary et al., 2009). For example, previous research has demonstrated that GrowSafe®, a tool used to automatically record feeding behavior, can be used to detect BRD earlier than observation by feedlot personnel (Sowell et al., 1999; Quimby et al., 2001). These tools also may aid evaluation of treatment outcomes, although little work has addressed this idea at this point in time. Additional research with this type of technology, taking into account the financial feasibility of such methods, is needed.

In contrast to BRD, other health problems have received considerably less attention within the published literature. For example, the causes, prevention, detection and treatment of lameness in beef cattle are not well understood, nor has the national prevalence been documented. Lameness is important for several reasons. Of primary concern, it is known to be painful. Generally, anti-inflammatories such as flunixin meglumine have provided pain relief in induced lameness models. These found improvements in gait and pressure placed on the affected foot and claw; however, in field trials, anti-inflammatories have yielded variable results with mild improvement to locomotion score and other measures of pain sensitivity (Kotschar et al., 2009; Schulz et al., 2011). Differences between these studies may be a result of variation in the causes of clinical lameness, the sensitivity of experiments to detect differences in treated animals, or the inherent difficulty in controlling pain in lame animals because of changes in their processing systems (Whay et al., 1998; Anderson and Muir, 2005). Additional studies are needed to further evaluate pain mitigation in both induced lameness models and field studies. In addition, lameness is costly. Involuntary culling of lame cattle continues to be an important reason for losses in both the dairy and beef industries (USDA, 2010, 2011a). Finally, the evaluation and prevalence of lame cattle is one of the primary factors in third-party welfare audit programs including National Dairy FARM (Farmers Assuring Responsible Management) Program, Validus, New York State Cattle Health Assurance Program (NYSCHAP), and others (NYS Department of Agriculture and Markets, 2002; National Milk Producers Federation, 2012; Valdus Ventures LLC, 2012). It is possible that
similar parameters could be included in beef evaluation schemes. An understanding of risk factors, prevalence and treatment of specific causes of lameness will improve the value of these audits.

**Future research**

For diseases that are well understood, additional research is required to improve uptake of preventative management strategies and validate automated ways to improve disease detection. For diseases where less is known, information is required about prevalence, risk factors and evaluation of treatment effectiveness (e.g. lameness, SARA, as described in the nutrition section). Epidemiological studies at the feedlot or slaughter level would be useful starting points for these types of health concerns.

**3. Painful procedures**

Beef cattle undergo a number of painful procedures, including castration, dehorning and branding. Other painful procedures that are less prevalent in beef cattle include spaying heifers, wattling and ear notching. The focus of this review will be on the most prevalent management procedures associated with pain in cattle, but the general principles can be applied to other procedures as well. In many cases, the focus will be on what is known about how to manage or eliminate pain associated with these procedures, such as anesthetics, non-steroidal anti-inflammatory drugs (NSAIDs), opioids, α2-agonists, and N-methyl D-aspartate receptor antagonists (Thurmon et al., 1996). This review will also discuss the challenges associated with providing adequate pain relief.

**Castration**

Castration of male calves destined for beef production is one of the most common livestock management practices performed in the United States amounting to approximately seven million procedures per year (USDA National Agricultural Statistics Service, 2009). Methods of castration are typically associated with physical, chemical or hormonal damage to the testicles such as occurs with immunological castration (Stafford and Mellor, 2005a). In most production settings, physical castration methods are the most common. These can be subdivided into procedures involving surgical removal of the testes or methods that irreparably damage the testicles by disruption of the blood supply using a rubber ring or latex band (AVMA, 2009) or a castration clamp (Burdizzo castration). Surgical and band castration are the most common methods in the United States at 49% and 47%, respectively (USDA, 2007a). In this study, most operations either castrated none of their bull calves before sale (41%) or all of their bull calves before sale (50%). Of those operations that castrate before sale, most (75%) performed the procedure at an average age of less than 93 days (USDA, 2007a).

Benefits of castration include a reduction in aggression and mounting behavior of males resulting in fewer injuries in confinement operations and reduced dark-cutting beef (Tarrant, 1981). Steers also have higher meat quality with increased tenderness and marbling. Carcasses from steers therefore command higher prices at market when compared with bulls (AVMA, 2009). Castration also prevents physically or genetically inferior males from reproducing and prevents pregnancy in commingled pubescent groups (Stafford and Mellor, 2005a).

Although the benefits of castration are widely accepted in most countries, all castration methods have been demonstrated to produce physiological, neuroendocrine, and behavioral changes indicative of pain and distress (Fisher et al., 1996; Stafford and Mellor, 2005a; Pang et al., 2006; 2008; Stilwell et al., 2008; Currah et al., 2009; González et al., 2010).

Administration of a local anesthetic alone effectively mitigates acute distress associated with castration (reviewed by Coetzee, 2013a) but the integrated cortisol response (as measured by the area under the time-cortisol concentration curve) is only modestly reduced. NSAID administration alone is not effective in reducing acute distress associated with castration. However, the reduction in integrated cortisol response reported is greater in NSAID-treated calves compared with calves receiving only local anesthesia. The combination of local anesthesia and an NSAID achieved the greatest reduction in cortisol response in published reports, suggesting that a multimodal analgesic approach is more effective in mitigating pain associated with castration than use of a single analgesic agent. Lidocaine and flunixin meglumine are the only compounds with analgesic properties that are approved by the United States Food and Drug Administration (FDA) for use in cattle. Flunixin requires intravenous administration and at least once daily dosing to be effective. In the absence of compounds specifically licensed for pain relief in cattle in the United States, extra-label drug use (ELDU) regulations codified in the Animal
Medicinal Drug Use Clarification Act (FDA, 1994) allow for unapproved analgesic drugs to be administered by or under the supervision of a veterinarian, provided such use does not result in a tissue residue violation. Accordingly, a combination of local anesthesia with oral administration of a long-acting NSAID like meloxicam may provide the optimum balance of convenience and analgesic efficacy at the time of castration.

**Dehorning/disbudding**

Dehorning/disbudding is a commonly performed practice in both beef and dairy cattle industries for a variety of reasons including: safety for handling, decreased incidence of carcass wastage due to bruising, less feeding-trough space needed, decreased risk of injury to other cattle, increased value of the animal, and fewer aggressive behaviors exhibited (AVMA, 2012a). Disbudding is a method of removing horns in calves up to around 8 weeks old when horn buds are 5 to 10 mm long and can be removed via a heated disbudding iron (Stafford and Mellor, 2005b). Once horns grow longer, they become attached to the underlying frontal sinus and must be removed by amputation (dehorning). Three primary methods remove or prevent horn growth in cattle: 1) amputation using scoop dehorners such as Barnes, Keystone, gauges, saws and gigli wire; 2) cautery using an electrical, gas-powered or battery-powered hot iron and 3) chemical application of caustic paste usually consisting of a strong alkalotic agent such as sodium hydroxide or calcium hydroxide. Use of these methods varies among regions (USDA, 2007b). Regardless of the method, changes following the procedure are consistent with an acute stress response (Reviewed by Stafford and Mellor, 2011; Stock et al., 2013).

The use of analgesics such as local anesthesia, systemic anti-inflammatories, and sedatives with analgesic properties have been investigated by several studies using behavioral, physiological, and neuroendocrine biomarkers for assessment of pain following dehorning/disbudding (Stafford and Mellor, 2011). For example, when using cortisol concentrations as an indicator of stress and pain, evidence exists of a rapid cortisol increase following the procedure, peaking within the first 30 minutes. Cortisol concentrations then plateau from 1 to 6 hours and then decline, returning to baseline 7 to 8 hours following the procedure. Local anesthetics mitigate the cortisol response for their respective duration of action (i.e. lidocaine: 2 hour; bupivacaine: 4 hours) following the procedure but a delayed cortisol response is observed, presumably once sensitivity returns to the anesthetized area (Petrie et al., 1996; McMeekan et al., 1998; Sutherland et al., 2002). Anti-inflammatories have aided in the reduction of this delayed cortisol response (McMeekan et al., 1998; Sutherland et al., 2002; Milligan et al., 2004; Stilwell et al., 2009). Additionally, the use of sedatives with suggested analgesia can contribute to the reduction of the initial cortisol response, improving procedural success (Stafford et al., 2003; Stilwell et al., 2010). Recent reviews of this and other evidence suggest a multimodal approach using local anesthetics, NSAIDs and, when possible, sedatives with analgesic properties to best provide analgesia to cattle following dehorning/disbudding. Local anesthetics and sedatives/analgesics aid in the attenuation of the acute response, and NSAIDs mitigate the observed inflammation-associated pain (Coetzee, 2011). Most studies evaluating stress and pain changes in dehorned cattle investigate the acute response; however, very few studies have examined chronic pain or stress responses following dehorning/disbudding.

**Branding**

Branding is accomplished by subjecting the skin to extreme temperatures to bring about a permanent thermal injury to the skin or hair follicles (AVMA, 2012b). Hot-iron branding induces scarring—a permanent alopecia. Freeze branding kills the pigment in the hair follicles resulting in the regrowth of depigmented hair (AVMA, 2012b). Although many states have brand registries, inspection services, and regulations related to branding livestock, only four states currently require that cattle be hot-iron branded (AVMA, 2012b). Indeed, in 2007 hot-iron branding as a method of herd identification was most common in the western United States and least common in the east (83 and 9% of cattle and calves, respectively, USDA, 2007a). Overall, hot-iron branding was used by 24% of operations and is more common as herd size increases (USDA, 2007a).

Both hot-iron and freeze branding are considered painful procedures (Lay et al., 1992b; Schwartzkopf-Genswein and Stookey, 1997; Schwartzkopf-Genswein et al., 1998). Hot-iron branding is associated with an increase in mean plasma epinephrine concentrations compared with freeze- or sham-branded animals (Lay et al., 1992b). An increase in plasma cortisol concentrations in hot-iron-branded animals compared with sham-branded animals has also been demonstrated (Lay et al., 1992a). Hot-iron
branding causes pronounced behavioral responses at the time of iron application as assessed using exertion force measurements against the headgate (Lay et al., 1992a; 1992c; Schwartzkopf-Genswein et al., 1997). Image analysis of behavior has also been used to demonstrate that hot-iron-branded animals have higher maximum, average, and cumulative head movement distances and increased head velocity compared with freeze- or sham-branded animals. Similarly, freeze branding is associated with increases in plasma cortisol concentrations when compared with sham branding (Lay et al., 1992a). Freeze branding has also been associated with increased tail-flick frequencies compared with sham branding (Schwartzkopf-Genswein et al., 1997). Freeze-branded animals also apply a greater amount of exertion force for longer periods of time against the headgate load cells than sham-branded animals. However, the magnitude and duration of this exertion was not as great as in animals that were hot-iron branded (Schwartzkopf-Genswein et al., 1997; 1998). In the course of this review we were unable to find references to studies that specifically evaluate analgesic interventions at the time of branding, indicating that this is a deficiency in the published literature.

Age
The age at which these procedures are performed likely plays a role in the pain involved. Comparisons between ages are difficult, as the behavioral repertoire of the animal also changes with age, creating an inherent confound in these questions. Thus, the clearest arguments for performing painful procedures at a younger age are about minimizing either the invasiveness or tissue damage of the procedure. For example, the American Veterinary Medical Association (AVMA) recommends disbudding before the horns attach to the skull (around 8 weeks of age; AVMA, 2012a), as this procedure is less invasive than dehorning. Regardless of the age the procedure is performed, effective analgesia is still needed. In addition, further work is needed to understand the effects of performing multiple painful procedures at the same time. Many experiments focus on a single procedure in order to control other factors, but in reality, these management practices occur at the same time.

Challenges in providing analgesia
There are several challenges associated with providing effective analgesia in food animals in the United States (reviewed in Coetzee, 2013b). First, there are currently no analgesic drugs specifically approved for the alleviation of pain in livestock (North American Compendiums, 2010). Therefore, use of any drug for pain relief constitutes extra-label drug use (ELDU) (Smith et al., 2008). Under the Animal Medicinal Drug Use Clarification Act (AMDUCA) 14, ELDU is permitted for relief of suffering in cattle provided specific conditions are met (Coetzee, 2013b). A second challenge to providing effective analgesia in cattle is the delay between the time of drug administration and the onset of analgesic activity. For example, local anesthetics require 2 to 5 min before a maximal effect is achieved (Lemke and Dawson, 2000; Spoormakers et al., 2004). This may slow animal processing as producers must wait for local anesthesia to take effect. This delay may serve as a disincentive for them to provide routine preemptive analgesia. Furthermore, the requirement for large numbers of animals to be processed quickly may result in procedures being initiated before optimal analgesia is achieved. A third challenge is that the route or method of analgesic drug administration may require specialized training and expertise or may be hazardous to the operator. For example, the NSAID flunixin meglumine is only approved for intravenous administration in the United States (Smith et al., 2008). Therefore, administration requires the animal to be adequately restrained and the operator to be proficient in intravenous administration. Similar issues are encountered with epidural analgesic drug administration and administration of local anesthesia into the scrotum. The latter procedure is also considered especially hazardous by many livestock handlers. In addition, the majority of analgesic drugs available in the United States have a short elimination half-life necessitating frequent administration in order to be effective (Smith et al., 2008). This increases the stress on the individual animal and increases labor and drug costs. For all of these reasons, less that 20% of US veterinarians currently report using analgesia routinely at the time of dehorning and castration (Coetzee et al., 2010).

Studies examining the health and performance effects of newer drugs with extended duration of activity are also needed. Regulatory approval of safe, cost-effective and convenient analgesic compounds will support the implementation of practical pain management strategies as a part of standard industry practice at the time of castration, dehorning/disbudding and/or branding.

Alternatives to painful procedures
Eliminating the need for a given procedure is the most straightforward way to manage pain. For example, using
polling genetics has successfully reduced the number of animals undergoing dehorning; this approach has resulted in a 58% reduction in beef calves born with horns from 1992 to 2007 (USDA, 2007b). There are also alternatives for both spaying heifers and castration of bulls.

Heifers may be spayed to prevent estrus and the resulting mounting and general unrest in the pen. Rather than surgically spaying females, orally administered estrus-suppressing compounds can be fed to heifers to prevent them from cycling. Approximately 85% of heifers on feed were fed MGA to suppress estrus (USDA, 2011b).

Chemical castration is also an option. Gonadotropin-releasing hormone (GnRH) vaccines induce neutralizing antibodies, resulting in immunocastration in bulls characterized by suppression of luteinizing hormone (LH) and testosterone (Amatayakul-Chantler et al., 2012). In some cases, there are production benefits associated with immunocastration. For example, the combination of vaccination with anabolic implants increased bodyweight, average daily gain and hot carcass weight (Amatayakul-Chantler et al., 2012). Although there are benefits of this non-surgical approach to castration, one of the challenges with immunocastration is that vaccination protocols require the administration of two injections, 42 d apart. This strategy will present logistical challenges to beef producers in extensive range conditions especially in areas with inadequate cattle handling facilities. Vaccine approval by the United States Department of Agriculture (USDA) also presents limitations on current use.

Future research

Research is needed to facilitate regulatory approval of analgesic compounds within the United States. Furthermore, studies investigating the potential health and performance benefits of providing analgesia at the time of dehorning and castration are critical to determine if the cost of analgesia can be offset by production benefits in beef systems. This work would complement efforts to improve use of analgesia with beef cattle. Most studies are confined to investigating the effect of either dehorning or castration or branding separately when these procedures are typically conducted at the same time. Finally, specific research investigating the effect of analgesic administration at the time of branding is missing in the published literature.

4. Environmental and housing conditions

**Mud and winter conditions**

According to the National Beef Quality Audit in 2011, 49% of beef cattle had no mud or manure on their bodies at the time of slaughter (McKeith et al., 2012). These findings indicate that beef cattle are exposed to environments with mud or manure before processing. In addition, cattle kept in open lots have dirtier hides than those reared indoors (Honeyman et al., 2010). However, there is little evidence documenting environmental conditions (e.g. depth of mud, % of days with mud or rain present, average temperature) during rearing for either cow-calf operations or feedlots.

There is some evidence that muddy conditions affect performance. For example, milk production in dairy cattle is reduced in months with precipitation, particularly on farms providing less shelter (open corrals, lots) (Stull et al., 2008). Mud also reduces growth rate in beef steers (Morrison et al., 1970), although the environmental conditions are poorly described in this study. Decreased productivity may be mediated by additional energy requirements associated with thermoregulation in wet environments (Degen and Young, 1993) and walking in mud (Dijkman and Lawrence, 1997). Finally, mud is thought to increase health problems such as lameness (see research needs in health section of this paper), as exposure to moisture can weaken the integrity of the hoof (Borderas et al., 2004).

Wet lying areas are also undesirable. When given a choice, dairy cattle clearly avoid wet sawdust in freestalls (86 vs. 27% DM, Fregonesi et al., 2007). Lying times are also lower when the only option is wet freestall bedding (Fregonesi et al., 2007); evidence suggests that this relationship is dose-dependent (Reich et al., 2010). In addition, lying times are lower when dairy cattle are housed in rainy winter weather, where underfoot conditions are also wet (e.g. Fisher et al., 2003; Tucker et al., 2007; Schütz et al., 2010). Similar patterns are seen in beef cattle; they spend less time lying in cold conditions, particularly when housed outside (Gonyou et al., 1979; Johnson et al., 2011). Exposure to wet conditions and/or deprivation of lying time cause a cascade of physiological responses, characterized by an initial up regulation of the hypothalamic-pituitary-adrenal (HPA) axis (Fisher et al., 2002; Tucker et al., 2007; Webster et al., 2008). Other changes associated with exposure to wet, winter weather include lower white-blood cells (WBC) counts, higher non-esterified fatty acids (NEFA) and thyroxine (T4) levels and lower body temperature (Tucker et al., 2008).
et al., 2007; Webster et al., 2008). Others have found minimal changes in physiological function with exposure to mud (Wilson et al., 2002). In feedlots, mounds of bedding and/or dirt are often used to provide a dry-lying areas (61% of feedlots, USDA, 2000), but little is known about appropriate stocking density (m² of mound/animal), nor the effectiveness of this management strategy. In addition, little is known about other management strategies used to manage mud in feedlots including changes in stocking density, pen scraping and addition of bedding. To date, most of the work looking at the behavioral responses to mud and wet conditions has been conducted in dairy cattle and rarely encompasses the combination of wet and cold conditions seen in many feedlots in winter, nor the effects on rangeland. This literature also neglects calves, a vulnerable population on rangeland in winter.

In addition to wet conditions, beef cattle are often reared and managed in environments with severe winters. Rangeland cattle will use protected areas in colder conditions (Houseal and Olson, 1995; Beaver and Olson, 1997; Rubio et al., 2008; Graunke et al., 2011). This pattern is apparent if animals are older and more experienced (Beaver and Olson, 1997), but not in all cases (Graunke et al., 2011). Cattle will also use man-made windbreaks (Olson and Wallander, 2002) and shelters that provide protection from rain (Vandenheede et al., 1995). Windbreaks can result in mixed effects on production and measures of growth or body condition (e.g. Olson et al., 2000), as the energy saved by improved thermoregulation can be offset by reduced time spent feeding. Indeed, cattle on range will often alter their time spent feeding and lying in response to winter conditions (e.g. Malechek and Smith, 1976; Redbo et al., 1996; Graunke et al., 2011). Windbreaks are used in 44% of feedlots (provided to most pens, USDA, 2000). Little experimental evidence exists evaluating how to best provide and manage protection from winter weather in this phase of the production cycle. In addition to use of windbreaks, cattle also use other cattle for protection; they are more likely to have other individuals within a 5-m radius in inclement weather on range (Graunke et al., 2011). In addition to seeking shelter, cattle will also orient towards the sun in cold winter weather (Gonyou and Stricklin, 1981). Finally, beef cattle shiver in response to cold conditions; this response becomes less marked when animals have more exposure to winter weather (Gonyou et al., 1979). Together, these behavioral changes may provide insight into when cattle begin to perceive the adverse effects of winter weather and when protection may be needed, although more work is needed in this area.

In addition to the direct effects of winter weather, other resources, such as water, are also affected by cold conditions. For example, water availability may be affected by freezing temperatures. Cattle will use snow as a water source (Degen and Young, 1990a, b) with limited effects on production parameters, but little is known about how other aspects of animal welfare respond to limited availability of fresh water.

**Future research**

Research is needed to evaluate methods used to provide dry-lying areas in winter (e.g. mounds, changes in stocking density, addition of bedding, pen scraping) in terms of both short-term behavioral responses and longer-term health and production outcomes in both feedlots and cow-calf operations. Research is also required to inform when protection from winter weather is needed from an animal welfare perspective, both in feedlots and cow-calf operations. An improved understanding of how to best provide and manage windbreaks and overhead shelter (e.g. type and amount of shelter) and how cattle adapt to snow as a water source would also be beneficial.

**Heat**

Heat load affects cattle in a number of ways, from changes in behavior, physiology, production and in extreme cases, death. Physiological changes include an increase in respiration and eventually panting, increase in body temperature and sweating (e.g. Brown-Brandl et al., 2003). Behavioral responses include shade seeking and an increase in time spent standing overall and near water sources (e.g. Widowski, 2001). Multiple weather factors contribute to heat load including ambient temperature, humidity, wind speed and solar radiation (Mader et al., 2010). In addition, the duration and previous acclimation to heat are also thought to contribute to animal response to heat waves. However, much of this evidence is based on experiments in environmentally controlled chambers without solar radiation (Brown-Brandl et al., 2005) and retrospective analysis of death events (as reviewed by Nienaber and Hahn, 2007).

Two management strategies are commonly used to reduce heat load in beef cattle: shade provision and cooling with water. Neither option is particularly common in feedlots,
with only 14 and 13% of feedlots providing either method of cooling to all or most pens (USDA, 2000), and little is known about how either are used on cow-calf operations. In addition, other factors, such as air flow, may influence heat load, but are not easily documented in surveys of management practices, nor in on-farm assessment of animal welfare.

Cattle are motivated to use shade in summer conditions (Schütz et al., 2008) and provision of this resource reduces both respiration rate and panting score, an indicator of heat load (e.g. Mitlöchner et al., 2002; Gaughan et al., 2010; Sullivan et al., 2011). Similarly, sprinklers or misters reduce heat load, in some cases, more efficiently than shade alone (Mitloehner et al., 2001; Kendall et al., 2007). While both dairy and beef studies demonstrate that shade and water cool cattle, the effects on production are mixed. For example, some studies show improved performance associated with shade provision (Mitlöchner et al., 2002), while others do not find any differences in final weight (Sullivan et al., 2011). These discrepancies may be explained by differences in both heat load and shade design between studies, as well as changes in production that occur relatively late in the physiological and behavioral response to heat. Animals attempt to thermoregulate through other means (e.g. respiration, sweating) before altering long-term feed intake and growth (Hahn, 1999). Despite the mixed evidence about production benefits of heat alleviation, cattle benefit from shade and water cooling well before changes in feeding behavior or body temperature occur (e.g. Chen et al., In press). More work is required to identify when heat abatement is needed and the best ways to both provide and manage these resources.

Determining when heat abatement is needed is challenging because of the number of weather parameters involved, effects of acclimatization, and individual differences in susceptibility (e.g. breeds differ in sensitivity to heat, Brown-Brandl et al., 2006; Gaughan et al., 2010). Previous attempts to set thresholds for “stress” (e.g. Armstrong, 1994) draw clear lines about when heat abatement would be beneficial, but the scientific basis for these categorizations are unclear and further complicated by the use of different measures of heat load (ambient temperature, THI, HLI). Growing evidence is emerging that heat abatement is beneficial in preventing an increase in body temperature or a drop in production, often at lower temperatures or heat indices than previously thought (e.g. Bryant et al., 2007; Chen et al., In press). These more recent papers treat heat load as a continuous variable (as opposed to categorical), lending themselves towards identification of thresholds based on biological responses. Secondly, additional research is needed in order to make recommendations about both the physical features of heat abatement (e.g. type of shade provided, droplet size of water used, air flow, space at the water trough) as well as the effects of management of these resources (e.g. m² of shade provided/animal) and other management decisions (e.g. movement of cattle or other factors that may increase risk). Recently, several groups have begun to address these questions (e.g. Eigenberg et al., 2009; Sullivan et al., 2011), but more work is needed in order to make industry-wide recommendations. These recommendations may play an important role in on-site animal welfare-assessments, as indicators of heat stress are weather-dependent (e.g. respiration rate, panting score), thus are difficult to include in single-time point audits. For example, in the European Union cattle welfare assessment tool, heat stress is the only welfare issue that does not have an animal-based measure associated with it (Welfare Quality®, 2009).

**Future research**

Research is needed to inform when heat abatement is needed from an animal welfare perspective, both in feedlots and cow-calf operations. An improved understanding of how to best provide and manage heat abatement (e.g. type and amount of shade, droplet size, role of air flow, effect of other management such as cattle movement, size and placement of water troughs) is needed and an epidemiological approach to addressing these questions would improve the industry-wide relevance.

**5. Social interactions**

Much of the work looking at social interactions in beef cattle has focused on “natural” conditions. Few populations of feral cattle exist, making studies on the natural social structure of cattle, without human intervention, rare. Feral island cows of all ages were found to socialize with both their yearling and newborn calves in small groups (10.5 animals per group) with some sub-adult males present in the group (Bouissou et al., 2001). Mature bulls were found with female groups primarily during mating season when group size increased to 18 animals per group, but bulls tended to be solitary or remain in small groups of other adult and sub-adult males during the non-mating
season (3.5 animals). These small group sizes are likely a reflection of the relatively small population of feral cattle studied and bigger groups would be expected with larger populations. The cohesiveness of adult females with their newborn and yearling female offspring is reflective of their long-lasting matriarchal social structure (Veissier et al., 1990). Calves also form long-lasting relationships with their age cohorts, starting before the calves are 3.5 mo of age (Raussi et al., 2010).

In natural conditions, dominance relationships among females are established very quickly, often without a fight, and tend to be very stable (Bouissou et al., 2001). Fights are usually limited to the first day of regrouping, but changes in behavior and avoidance among unfamiliar steers can last up to 5 d after regrouping (Patison et al., 2010). The stress from regrouping beef cows appears subtle, but is evident in dairy cows by the reduction in milk yield (as much as 4% for the first 5 d after mixing) (Jezirowski and Podluny, 1984).

In large groups, individual recognition is more difficult and the incidence of aggression increases (Stricklin et al., 1980). Under commercial conditions, aggression among unfamiliar cattle has been identified as a contributing factor in dark cutters arising from cattle that are regrouped prior to slaughter (Warren et al., 2010).

Mixing or co-mingling of unfamiliar cattle is a common practice in the feedlot industry where pens are often filled with animals from multiple sources. The large group sizes of unfamiliar steers in feedlots, as well as other contributing factors, may contribute to the emergence of the buller steer syndrome, a problem with an annual incidence between 2 and 4% (Brower and Kiracofe, 1978; Irwin et al., 1979). The buller steer syndrome is a behavioral problem among feedlot steers and is characterized by the repeated mounting of a steer (referred to as the buller) by a group of steers (known as the riders) who persistently follow and perform the mounting behavior. The buller steer becomes exhausted from the excessive mounting, often shows loss of hair, swelling and trauma on the rump and tail head, and in extreme cases can suffer broken bones. In addition, bullers were 2.5 times more likely to be reclassified as “sick” and 3.2 times more at risk to die than non-buller steers (Taylor et al., 1997).

Several causative factors of the buller steer syndrome have been suggested and include the use of anabolic agents, improper implantation, re-implantation or double dosing (Irwin et al., 1979; Voyles et al., 2004; Bryant et al., 2008), as well as changes in weather and seasonal factors, excessive mud or dusty pen conditions, entry weights, disease, group size, improper or late castration, feeding management, transportation, handling, mixing and aggressive social-dominance behavior (see review Blackshaw et al., 1997). The incidence of bullers tends to increase as the number of animals in the pen increases (Brower and Kiracofe, 1978; Irwin et al., 1979). For every 9.3 m2 increase in pen size, the buller rate decreased by 0.05% (Irwin et al., 1979). Preventative methods that tend to reduce the incidence of bullers includes forming feedlot pens with as few groups as possible, keeping the number of steers per pen below 200, and implanting on arrival (as opposed to delayed implantation). Some anecdotal evidence suggests overhead barriers that allow steers to escape mounting may have some benefit (Blackshaw et al., 1997).

In general, low space allowance results in slower rates of gain in heifers and bulls (Andersen et al., 1997; Mogensen et al., 1997). However, insufficient bunk space has a greater effect on cattle behavior, such as aggression and displacements, than does group size (Albright and Arave, 1997). Animals that are more competitive (win more aggressive encounters) ultimately gain more time at the feed bunk and have higher dry-matter intake when bunk space is limited (Zobel et al., 2011). Though agonistic behavior does increase as group size increases and as space decreases, distance between individual cattle remains constant (10 to 12 m between animals) after space reaches 360 m2/animal (Kondo et al., 1989). Relatively little is known about best management practices for group size nor for space allocation of key resources such as food or water.

Finally, social interactions may affect other aspects of the feedlot environment. For example, dust from dried manure may be exacerbated by restlessness and aggressive interactions within the pen. This is undesirable, as dust has been linked to respiratory diseases in feedlot cattle. Dust can be controlled through management practices such as sprinkling, removing manure from the pen, and changing stocking density in the pen (Loneragan and Brashears, 2005).

Future research

Research is needed to address several issues associated with social interactions. A body of work is required to generate science-based recommendations for key
resources, such as bunk space and water. More work is required to understand the health and performance effects as well as the best management strategy for grouping unfamiliar animals. Similarly, the effectiveness of overhead barriers and other protocols for preventing, eliminating and treating buller steer syndrome needs to be evaluated.

6. Transport

**Duration**

Transport regulations regarding travel duration and distance for cattle are less stringent in the United States than other countries, including the European Union (EU), Australia and New Zealand. According to the 28 Hour Law (USDA, 1997), American cattle can be in transport up to 28 h, while the maximum allowable transport duration in Canada, an important player in the North American beef system, is 52 h before cattle must reach their final destination (Canadian Agri-Food Research Council or CARC, 2001). A range of studies suggest that the vast majority of cattle transported in North America fall within the maximum regulated times specified by the United States and Canada of either 28 or 52 h, respectively (Warren et al., 2010; Cernicchiaro et al., 2012b; 2012a; González et al., 2012b). Less is known about the cumulative transport duration of cattle that are sold through markets or auctions, nor is there enforcement of the 28-h law within the US.

Discussion will focus on transport duration instead of distance because it better defines the length of time cattle are confined on a transport vehicle. Indeed, the association between reduced welfare and increased transport duration is well established. Transport duration ranging between 2 and 48 h have been shown to result in shrink values between 0 and 8% of body weight (BW) (Lofgreen et al., 1975; Mayes et al., 1979; Jones et al., 1990; Zavy et al., 1992; Schwartzkopf-Genswein et al., 2007; Cernicchiaro et al., 2012b; 2012a). González, (2012c) reported that cattle in transport longer than 30 h had a greater likelihood of becoming non-ambulatory or lame, or dying. They also documented that shrink increased most rapidly in cattle transported for longer durations at higher ambient temperatures and concluded that transport durations greater than 30 h should be avoided during particular climatic conditions. Information on the effect of transport on unfit animals such as cull cows or very young calves is lacking but most likely is where the largest welfare issues exist.

**Space Allowance**

Space allowance (loading density) is the space available to an animal when placed into a trailer compartment calculated as kg of body weight per m2 or m2 per animal. In the United States and Canada, loading densities are not regulated but based on industry codes of practice guidelines which vary slightly between the two countries (USDA, 1997; CARC, 2001). Overloading or underloading on trucks may pose a risk to animal welfare and meat quality (Eldridge et al., 1988) (Tarrant et al., 1988; 1992). The most commonly used equation [\( A=0.01W^{0.78} \) where \( A = \) the area of the space m2 and \( W = \) the weight of the animal (kg)] to determine space allowance was developed by Randall (1993). An allometric coefficient (k-value) calculated as m2 per animal/ (body weight\(^{0.6667}\)) has been identified as a useful indicator of cattle space allowance in place of m2 per animal because animal weight does not have to be used to make comparisons within and between studies (Petherick and Phillips, 2009; EFSA Panel on Animal Health and Welfare (AHAW), 2011; González et al., 2012e).

The negative effects of high (0.89 m\(^2\)/animal) loading density [in comparison to medium (1.16 m\(^2\)/animal) and low (1.39 m\(^2\)/animal)] on animal welfare and carcass quality are well established. These effects include increased indicators of stress such as cortisol and glucose content in the plasma, reduced carcass weight, downgrading of carcasses, higher incidence of severely bruised cattle and increased risk of injury and mortality (Eldridge and Winfield, 1988; Tarrant et al., 1988; 1992; Grandin, 2007). Creatine kinase, a muscle enzyme, was found to increase with loading density, which suggests higher levels of muscle damage (Tarrant et al., 1988; 1992). In addition to determining the effects of stocking density overall, there is evidence that size of animal and location within truck affects outcomes. For example, González et al. (2012e) concluded that feeders and calves are at greater risk of being overcrowded due to their light weight, making it easier to load more animals before axle weight restrictions are exceeded. Location within the truck affects effective space allocation, cattle in the nose, back and doghouse were reported to have 44, 4 and 60% more space while cattle in the belly and deck had 8 and 6% less space than recommended by CARC (2001) and USDA (1997). More research will be required to assess if the loading densities used by the beef cattle industry are more or less favorable for welfare and meat quality than those recommended by CARC (2001) and USDA (1997).
Effects of feed and water withdrawal

During transport in the United States, cattle are not provided with feed or water. The majority of weight loss or shrink has been attributed to the effect of feed and water withdrawal accounting for 12 to 15% of the animal’s live weight and is both a welfare and economic concern (Grandin, 2007). Evidence of dehydration after transport includes increases in red blood cell count, hemoglobin, total protein and packed cell volume (Lambooy and Hulsegge, 1988; Tarrant et al., 1992; Warriss et al., 1995). Provision of ad libitum water to fasted livestock reduced shrink (Hahn et al., 1978) while access to water for 3.5 h or longer before slaughter increased muscle water content resulting in heavier carcass weights compared to those cattle that did not have water (Wythes, 1982). Food restriction also affects shrinkage. Steers fasted for 12, 24, 48 and 96 h were found to have live weight losses of 6, 8, 12 and 14%, respectively (Shorthose, 1965; Wythes, 1982; Lambooy and Hulsegge, 1988; Tarrant et al., 1992) and recovery to pre-transport body weights has been reported to take 5 d (Warriss et al., 1995). Self and Gay (1972) concluded that approximately half of the shrink observed in cattle transported an average of 1023 km, was due to loss of carcass weight. The rate of carcass weight loss in steers was documented to be 0.075%/d for transport and holding times lasting between 3 to 8 d (Shorthose, 1965).

Rest stops where cattle are unloaded can be used to provide cattle with both respite from standing, as well as provide opportunities to eat and drink. In addition, as of July 2013, truck drivers are required to stop for 30 min for every 8 h of driving (US Department of Transportation, 2011), but it seems unlikely that cattle would be unloaded during this type of stop. Little is known about the effect of providing rest stops, with or without unloading, on beef cattle welfare.

Effects of environmental conditions

Environmental conditions can vary greatly during a single journey. Variables include compartment, location within the compartment (depending on weather), whether or not the truck is moving and the type of passive ventilation (Mitchell and Kettlewell, 2008). Transport vehicles are not climate controlled, thus environmental conditions can influence animal welfare and meat quality (Schwartzkopf-Genswein et al., 2012). A number of studies have evaluated trailer/compartment/location temperatures and sought to link these parameters to either ambient weather conditions or management practices (Wikner et al., 2003; Bryan et al., 2010; Goldhawk et al., 2011; Stanford et al., 2011). In one of the few studies assessing the relationship between environmental conditions and animal welfare, González et al. (2012d) found that animal death increased sharply when ambient temperatures fell below -15 °C while the likelihood of becoming non-ambulatory increased when temperatures rose above 30 °C. There is also experimental evidence that mitigation at either extreme is beneficial. Improving airflow can reduce weight loss in summer (Giguere, 2006; Friend et al., 2007). Warren et al. (2010) reported that boarding (plastic, fiberglass or plywood pieces inserted to cover side perforations and alter air flow) reduced the incidence of dark cutters during winter transport. Beyond these few studies, little is known in this area. The relationship of design features including air flow and wind speed direction, ambient conditions, and perforation patterns with animal welfare outcomes such as cattle weight loss, morbidity, mortality, and injury due to extreme conditions such as frostbite need further study.

Effects of animal type and temperament on stress associated with transport and handling

Calves are believed to be more susceptible to the stresses of transport than mature cattle (>17 to 19 mo of age) due to their under-developed hypothalamic-pituitary system (Eicher et al., 2006), often resulting in an increased incidence of morbidity and mortality at the feedlot (Fike and Spire, 2006). Appropriate animal handling and management (i.e. use of bedding in the trailers) during transport of old or cull animals because of their relatively low economic value are also concerns (Grandin, 2001b). Handling stress due to loading and unloading has been shown to vary with such factors as animal temperament (Burdick et al., 2010), handling quality (gentle vs rough), experience of the handler and animal, the animal's condition, and the quality of the handling facilities (Grandin, 2001b). As an example, Lay et al. (1992b; 1992c) found that pasture-raised beef cattle unaccustomed to handling had higher heart rates and cortisol levels indicative of greater stress during restraint and handling compared to frequently handled dairy cattle.

Evidence that adverse effects of transport on animal welfare varies by animal type has recently been documented. González et al. (2012c, d) found that cull
cattle were at greatest risk of poor welfare during long-haul transport (≥ 400 km) as they were more likely to become lame at the time of loading and unloading and declared non-ambulatory or dead at the time of off-loading compared to fats, calves, and feeders. Likewise, calves were found more likely to become non-ambulatory and/or die compared to fat and feeder cattle (González et al., 2012d). Cernicchiaro et al. (2012a) reported that shrink increased the risk of BRD in lighter compared to heavier weight calves. González et al. (2012d) concluded that fat cattle are less susceptible to poor welfare because they have more robust immune systems, better body condition and therefore better health than calves, feeders, and culls, while Cernicchiaro et al. (2012a) concluded that heavier calves recover from transport more quickly due to their resilience to stress compared to lighter weight calves. At this time science-based information on the interrelationships between animal type (age, size and condition), temperament, and animal and handler experience as they relate to transport are scarce.

**Future research**

Research is required to answer a number of questions about transport. Topics include: optimal loading densities by animal type and weather, effect of transportation durations experienced by cattle sold and resold through the auction markets, effect of rest stops (with and without unloading), trailer design features that control environmental conditions (ventilation, use of bedding, boarding), and internal ramp and compartment construction. All of these features or management decisions need to be evaluated in terms of behavioral and physiological indicators of health and welfare and meat quality.

**7. Handling**

Handling represents an area of considerable improvement in beef cattle welfare. Numerical scoring systems that assess handling in meat plants and in feedlots have been implemented on a wide scale. The scoring system for meat plants is fully described in Grandin (1998b, 2010a; 2012a). For example, baseline data collected in 1996 showed that the percentage of cattle moved with an electric prod ranged from 4% in the best plant to 90% in the worst (Grandin, 1998b). After four years of audits by retailers such as McDonald's and Wendy's (as part of the American Meat Institute audit; Grandin, 2012b), the average electric prod score was reduced to 15% (Grandin, 2005).

Vocalizations by cattle can be viewed as a reflection of the animal's commentary on aversive events (Watts and Stookey, 1999) and increase with use of electric prods, excessive pressure from a restraint device, and gates slamming on animals or falling (Grandin, 1998a). In addition, cattle that vocalized during restraint or were shocked with electric prods had higher cortisol levels (Dunn, 1990; Hemsworth et al., 2011). Bourquet et al. (2011) also found that 25% of vocalizations were associated with the use of a restraint device, possibly one that applied too much pressure. Measuring vocalizations during handling has also improved with the auditing process. For example, in 1996 the percentage of cattle vocalizing during handling ranged from 0 to 32%, with a mean of 7.7%. Grandin (2005) reported that the average vocalization percentage was 2% of the cattle averaged from four years of data. In addition, there is evidence that handling in non-slaughter situations can also be improved through similar means. For example, the percentage of cattle moved through the squeeze chute with an electric prod was 5% or less in 19 out of 20 feedlots in Colorado, Nebraska, and Kansas (Woiwode et al., In preparation).

Several mechanisms are available to improve handling, regardless of the situation. First, the physical environment can be altered to minimize balking and improve cattle flow. For example, cattle balked less when an entrance was lighted (Grandin, 2001a). Similarly, reducing pressure on the neck from a head restraint device decreased the percentage of cattle vocalizing from 23 to 0% (Grandin, 2001a). In the vast majority of plants, improvements were achieved without having to perform expensive renovations (Grandin, 2003). Secondly, low levels of electric prod use, vocalization and falling can be achieved by altering human behavior through better employee training, increased supervision, and moving smaller groups of cattle. Thirdly, several studies and reviews have shown that habituating cattle to handling procedures, such as being moved through chutes, can help reduce stress when the cattle are handled in the future (Fordyce, 1987; Grandin, 1997; Cooke et al., 2009; Petherick et al., 2009; Cooke et al., 2012). Finally, other animal factors, such as breed, can affect handling. For example, Brahman cross and continental cattle will run out of the squeeze chute faster compared to British cattle (Baszczak et al., 2006). Plasma cortisol levels were higher in Bos indicus calves compared to Bos taurus calves (Zavy et al., 1992).
The type of restraint can affect beef cattle welfare. For example, there has been recurrent interest in electrical immobilization. However, every scientific study on electrical immobilization has found that it is extremely aversive (Lambooy, 1985; Grandin et al., 1986; Pascoe, 1986). The AVMA states, “Electrical immobilization that paralyzes an animal without first inducing unconsciousness is extremely aversive and is unacceptable” (AVMA, 2013).

Future research
The effects of some management practices, such as feeding β-adrenergic agonists, on animal handling require additional research (see Nutrition section for more detail).

8. Slaughter
Reviews of welfare issues during slaughter have been recently covered in Grandin (2010b, 2013). Like handling, slaughter is an area that has undergone considerable improvement through programs like the American Meat Institute (AMI) audit of meat packing plants (Grandin, 2012b). Currently, problems at slaughter are focused on the animal’s lack of suitability for transport and the kill process, due to morbidity or poor body condition. The World Organization for Animal Health (OIE) has guidelines for suitability for transport (2012). When these guidelines are not met, euthanasia is the key alternative for animals not suitable for transport and the AVMA has recently revised their recommendations for these procedures (2013).

Animal welfare during religious slaughter is poorly understood and controversial. Discussions on this issue can be found in Grandin (2013), Rosen (2004), Gibson et al. (2009), AVMA (2013), Grandin (1994), Grandin and Regenstein (1994), Gregory (2007) and Anil (2012), and reflect different perspectives about these issues. When the animal is held in a well-designed restraint device for religious slaughter the vocalization score will be 5% or less (Grandin, 2012a). There are conflicting results between different scientific studies about the possible stress and pain that occurs when the throat is cut in a fully sensible animal (Grandin and Regenstein, 1994; Rosen, 2004; Gibson et al., 2009; Gregory et al., 2009; 2012). Grandin (1992) describes the operation of a well-designed restraint device for slaughter without stunning. Ultimately, the decision about the acceptability of these methods may lie in public discussion, rather than in scientific evidence.

9. Conclusions
This review has strategically covered existing scientific information about the welfare of beef cattle in the United States and identified key gaps in knowledge. Within the areas where more research is required, the authors offer their thoughts about priorities, based either on interpretation of the scientific importance or anticipation of issues that are likely to be the subject of public discussion, where evidence, rather than perceived ethical concerns, would be beneficial. Within their priorities, the authors identified two themes: areas where implementation is needed and issues where additional empirical research is needed.

For some topics, considerable research informs best practice, yet gaps remain between knowledge and implementation. BRD prevention provides a good example. As we reviewed, the risk factors and management strategies to prevent this disease are well understood, but only used by a relatively small portion of the beef industry. Yet, one of the most pressing welfare issues facing the beef industry is the high health risk to newly arrived feedlot cattle and the subsequent reliance on antibiotics to treat and prevent respiratory diseases at the feedlot. This is both a public relations and animal health issue that will require leadership, serious discussion, sincere effort and financial incentives across all segments of the beef industry to gain widespread adoption of practices that are in the best interest of the calves’ welfare. Other areas where empirical evidence does not limit decisions about how to improve animal welfare include use of analgesics and promoting alternatives for painful procedures. Animal welfare in these areas could be improved considerably and quickly with leadership and regulatory changes to improve the number and types of analgesics available. There is evidence of success when such actions are taken, as illustrated by the dramatic improvements in handling at slaughter facilities reviewed in this document.

In some cases, however, additional empirical evidence is needed to inform best practice. The summary provided here encapsulates many of the ideas laid out in the main body of this review. Here, the authors offer their thoughts about the most urgent of these issues, based on both scientific importance as well as their sense of what topics will be timely now or in the near future.
**Highest priority (immediate):**

- Evaluation of the animal welfare implications of technologies used to either promote growth or manage cattle in feedlots, particularly β-agonists, hormonal implants, immunocastration and MGA. In some cases, relatively little is known about the welfare implications of these technologies, while in others we anticipate continued public scrutiny and interest in these management tools.

- Understanding risk factors for health problems poorly studied at the population level, such as lameness, and the effect management has on both rare and more common diseases (e.g. SARA). Epidemiological work in this area is the first step to understanding how we may prevent these problems across the entire industry and would provide insight into both the long-term consequences of management decisions, such as weaning method and transition to high-concentrate diets, and the economic benefits of pain mitigation.

- Understanding the welfare implications of limited feed, water, and rest intervals (both with and without unloading) for cattle transported long durations under extreme climatic and management (too high or low loading density) conditions. Transport is a highly visible and important aspect of the cattle industry that has been poorly studied.

**Highest priority (longer-term):**

- Research is required to identify science-based recommendations about stocking density in feedlots for key resources: dry lying areas (mounds), shade and water, and feed year-round. This work is needed at a commercial scale, using industry-relevant group sizes and multiple measures of welfare, with particular emphasis on animal behavior, as these dependent variables provide insight into competition for and simultaneous use of these resources. This work is important to identify best management of summer and winter weather, as well as social interactions in feedlots.

- Understanding the welfare implications of aspects of trailer design, including optimal loading densities by animal type and weather, trailer design features that control environmental conditions (ventilation, use of bedding, boarding), and internal ramp and compartment construction. All of these features or management decisions need to be evaluated in terms of behavioral and physiological indicators of health and welfare and meat quality. Trailer design companies may be logical partners for this type of work over a number of years.

Investment in these research areas would advance science-based recommendations about beef cattle welfare.

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