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AUSTRALIAN Pork

Review of the scientific literature and the international pig welfare codes and standards to underpin the future Standards and Guidelines for Pigs

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Executive Summary

All pigs farmed in Australia are governed by the Australian Model Code of Practice for the Welfare of Animals – Pigs, which was approved by the Primary Industries Ministerial Council on April 2007. The original Model Code of Practice was approved by the Australian Agricultural Council in 1989 and the code has been subsequently updated in 1998, 2001, 2004 and 2007 to incorporate the latest research findings and new technologies in the area. This review is a comprehensive documentation of recent findings on pig welfare at all stages of their production cycle. Furthermore, comparisons are made between the current Australian Model Code of Practice for the Welfare of Animals – Pigs and the current Codes or Standards in Canada (Code of Practice for the Care and Handling of Pigs, 2014), the United Kingdom (UK, Codes of Recommendations for the Welfare of Livestock: Pigs, 2002), the European Union (EU, Council Directive 2008/120/EC) and New Zealand (Pigs – Animal Welfare Code of Welfare, 2018). These countries were selected because their high standards of pig welfare have been widely recognised.

Pig farming is one of the most intensive of all the livestock production systems; animals are commonly housed in large buildings, with a high degree of automation to supply feed, water, heat and ventilation. Whilst the increased intensification of animal production methods has reduced or removed a range of welfare problems, such as predation, thermal stress, some infectious diseases and nutritional stress, it has also created or exacerbated other welfare problems such as restricted space and social contact, lameness and barren environments. Extensive livestock production systems are generally thought to be less restrictive, however they do still impose restrictions on animals, albeit with considerable freedom and there are different welfare risks including frequency of inspections, climatic conditions and natural disasters.

All aspects of pig production are attracting welfare concerns; sow housing, growing-finishing pig housing, transport and slaughter. In pig production, the most contentious welfare issues involve indoor housing (close confinement and barren environment), particularly of breeding sows, however potential welfare issues do also exist in outdoor pig systems, including the implications of nose-ringing, shelter, litter desertion, pre-weaning piglet mortality, wallow design and management, thermoregulation in winter, heat stress in summer, any implications of lower back fat, and the suitability of different genotypes.

The following review provides conclusions, recommendations and future research for the following issues relevant to the Australian pig industry:

Gestating sows (including gilts)

- There are some obvious gaps in our knowledge on safeguarding the welfare of gestating sows and these obviously are topics for future research.
- The most obvious weakness in our knowledge on safeguarding the welfare of gestating sows is strategies for effective environmental enrichment in intensive, indoor and non-bedded systems. Together with the practice of restricted feeding of gestating sows, strategies for example to increase foraging and feeding times in feed-restricted gestating sows will reduce hunger and the likely development of oral stereotypies.
- Research on space allowance indicates that a space allowance for gilts and sows of 1.4 m^2/animal is likely to be too small and that significant improvements in welfare, in terms of aggression and stress, are likely to be achieved with space allowances for gilts and sows in the range of 2.0–2.4 m^2/animal.
- The effects of space on aggression and stress are most pronounced soon after mixing, highlighting the importance of floor space at mixing. Indeed, a strategy of staged gestation penning, with more space immediately after mixing and less space later in gestation may provide distinct animal welfare and economic advantages, but this requires investigation.
- While floor feeding is generally viewed as the most competitive feeding system, accessing feeding stalls or an electronic sow feeder (ESF) system also leads to competition between group-housed sows. A better appreciation of the positioning of resources and barriers in pens to facilitate access to important resources, such as feed, water and a comfortable lying area, and allow escape opportunities from others, is important in reducing aggression and stress and thus minimise risks to sow welfare.

Research recommendations: areas for future research to safeguard gestating sow welfare include effective environmental enrichment for gestating sows in intensive, indoor and non-bedded systems; opportunities to increase foraging (which clearly also provides environment enrichment); feeding times in feed-restricted gestating sows; and the use of stage gestation penning.
S&G recommendations: increasing the space allowance guidelines for gilts and sows in the range of 2.0–2.4 m^2/animal is likely to result in significant improvements in welfare (and productivity) with regard to aggression and stress. It is also important to monitor ongoing research investigating effective environmental enrichment for intensive, indoor and non-bedded systems in order to use outcomes to inform S&G on enrichment for not only gestating sows but pigs in all stages of production.

Farrowing/lactating sow and piglets, including painful husbandry practices

- Housing pre-parturient sows in farrowing crates without bedding/nesting material reduces their level of maternal behaviour in comparison to sows in more enriched environments.
- While confining sows, at least primiparous sows, at farrowing and/or denying them access to bedding/nesting material may induce acute stress, the limited evidence suggests that housing sows in farrowing crates without bedding is not a potent stressor for at least 3 weeks of lactation. However, housing beyond 3 weeks of lactation in farrowing crates may be stressful for sows.
- Alternative loose farrowing and lactation environments can provide sows with bedding and thus increased opportunity to perform maternal behaviours (including nest building and interaction with their piglets). However, these loose farrowing and lactation systems require extra floor space and can lead to an increased risk of piglet crushing.
- Total overall piglet losses (stillbirths and live born deaths) may be similar with loose farrowing and lactation pens and farrowing crates, however crushing of live born piglets is often higher in loose pens.
- Many causes of piglet mortality are a welfare concern because asphyxiation, starvation and physical trauma are likely to lead to negative affective states such as pain, fear and suffering.
- Piglets that develop full breathing but descend quickly into hypothermia and thus unconsciousness and, to a lesser extent, piglets that never develop full breathing are less of a welfare concern. However, piglets that develop full breathing, are not hypothermic, but suffer deaths from hunger, injury or disease are a greater welfare concern. Thus, any farrowing and lactation housing system needs to safeguard liveborn piglet mortality during the first few days post-partum when liveborn piglet mortality is at most risk.
- Maternal characteristics of sows and the quality of stockmanship will be integral to the success of loose farrowing and lactation systems.
- The on-going development of loose farrowing and lactation systems needs to be cognisant of minimising piglet mortality; current hybrid systems in which sows are confined at parturition and during the first few days post-partum when liveborn piglet mortality is at most risk, provide at least in the medium term an alternative system that addresses many of the most serious sow and piglet welfare concerns with farrowing crates and loose housing.
- Research indicates that castration in young pigs results in a short-term moderate acute stress response and that castration is likely to be painful for piglets at any age. Alternatives to surgical castration include immunocastration, genetic selection against boar taint compounds, and raising entire males slaughtered at lower body weights before they reach sexual maturity.
- The EU, Canada and UK have all mandated the use of anaesthetics for surgical castration, and also recommend the use of prolonged analgesics. Amongst different options of pain-relief available, the most promising ones are NSAID drugs, however the literature in support of NSAID drugs is still in its infancy and insufficient to make their use mandatory.
- Future research needs to focus on evaluating efficacy of pain relief using wider range of pain assessment markers as well as a non-invasive mode of delivery of pain relief in order to avoid double handling of piglets.
- Physiological and behavioural responses to tail docking of piglets vary according to the method used to perform the procedure. While tail docking piglets using either the clipper or cauterisation method caused increases in cortisol concentrations and behavioural indicators of pain, the cauterisation treatment resulted in a lower stress response compared to those in the clipper treatment. Furthermore, based on electroencephalographic (EEG) responses, tail

docking using clippers appears more painful than tail docking using cautery iron and that tail docking within the first few days of birth may be less acutely painful than at a later age.

- Whilst there is evidence that tail docking causes acute, short-term behavioural and physiological responses, there is also concern that tail docking may cause chronic, long-term pain in pigs since neuromas have been found in the tail stumps of tail docked pigs.
- The use of pain-relief such as meloxicam for tail docking looks promising, especially if the method of trans-mammary delivery meloxicam is refined.
- The implications of teeth clipping and teeth grinding on piglet health and in turn welfare require more extensive study.

Research recommendations: areas for future research to safeguard the welfare of sows and piglets during farrowing and lactation include examining the implications of confinement in a farrowing crate without bedding/nesting material on stress physiology of multiparous sows; opportunities to facilitate sow maternal behaviour, particularly sow-piglet interactions in crates, because providing opportunities for increased sow-piglet interactions may be beneficial for both sow and piglet welfare; sows' experience with farrowing and lactation housing system and the subsequent effect on the welfare of both the sow and the piglets; long-term effects of group lactation housing on both sows and piglets; the effect of early experience on stress resilience, emotionality and welfare in pigs later in life; evaluating efficacy of pain relief using wider range of pain assessment markers as well as a non-invasive mode of delivery of pain relief in order to avoid double handling of piglets during husbandry procedures.

S&G recommendations: if farrowing crates are to remain a feature of intensive housing systems, then increasing minimum dimensions of the crate and the provision of nest building materials (straw) around parturition need to be seriously considered in order to improve sow welfare. Whilst further research is still needed (particularly around pain-relief), it could be recommended that husbandry practices are performed on piglets of a young (less than seven days) and pain-relief should be administered for the duration of the procedure.

Weaner and growing-finishing pigs

- Space allowance for growing-finishing pigs is less contentious than for breeding sows; the literature indicates that current Australian space allowance requirements of 0.14 m^2 to 0.74 m^2/pig (weight: 10-120 kg) are likely to be sufficient. However, improvements in welfare (in terms of aggression and stress) and productivity (with regard to growth rate) are likely to be achieved with space allowances greater than the current Australian requirements.
- The effect of space allowance (and pen design and features) on the aggressive behaviour of growing pigs in the period immediately following mixing requires further investigation.
- There is considerable evidence in the young pig indicating that aggression is not affected by group size; other factors such as floor space and competition for feed or feeding space may have a greater impact on aggression, injuries and stress than does group size.
- Enrichment suitable for growing-finishing pigs is likely to be one that they can root, chew and manipulate. Novelty appears important in maintaining interest, but there should also be diversity in the materials at any one time. Furthermore, desired environmental enrichment needs to be targeted to be most effective.
- While the utilisation of environmental enrichments has been investigated, the effects of enrichment on stress adaptability and indicators denoting poor welfare have not been extensively studied.
- Straw has been widely accepted as an effective form of enrichment for pigs of all stages, however further research is needed to enable its use in systems with slatted or partially-slatted floors.
- At present it is not possible to identify point-source objects that can be recommended as effective enrichment.
- Further research is required to evaluate the effectiveness (type and placement within pen) of enrichment strategies for growing-finishing pigs, particularly when housed on slatted floors.
- Early weaning is considered one of the main welfare challenges for weaner pigs, further research to examine the effects on welfare and productivity of weaning alternatives is required. In addition, further understanding on the effect of weaning on the sow would be beneficial.

Research recommendations: areas for future research to safeguard the welfare of growing-finishing pigs include examining the effect of space allowance (and pen design and features) on the aggressive behaviour of growing pigs in the period immediately following mixing; the effectiveness (type and placement within pen) of enrichment strategies for growing-finishing pigs, particularly when housed on slatted floors; and the effects on welfare and productivity of weaning alternatives.

S&G recommendations: current Australian space allowance requirements of 0.14 m^2 to 0.74 m^2/pig (weight: 10-120 kg) are likely to be sufficient, however, improvements in welfare (in terms of aggression and stress) and productivity (with regard to growth rate) are likely to be achieved with space allowances greater than the current requirements.

Boars

- There is no specific research on the housing requirements of mature boars, although it is reasonable to infer information on requirements such as space, flooring, temperature, lighting and social stimulation from guidelines for sows.
- Research on boar housing requirements and the implications for boar welfare is required.

Research recommendations: whilst it may not be viewed as a high priority, research on boar housing requirements and the implications for boar welfare is required.

Outdoor housing

- The limited literature suggests there are no large differences in risks to sow welfare in indoor and outdoor systems, based on the variation in a number of selected variables.

Research recommendations: areas for future research regarding outdoor housing include nose-ringing, predator control, shelter, litter desertion, selection and training of stockpeople, wallow design and management, overgrown claws, avoidance by pigs of others at feeding time, thermoregulation in winter, and any implications of lower backfat.
S&G recommendations: the provision of huts for farrowing and lactation are currently a recommendation, however consideration should be made to make them a requirement to ensure protection for sows and the piglets during sensitive period of their life cycle.

Specific physiological and behavioural problems in pigs

- Finely grounded pelleted feed is a risk factor and provision of straw can reduce the prevalence of gastric ulceration.
- Lameness is a major welfare concern because of the likely pain and discomfort for extended periods. Quality of flooring is widely considered to be essential to pig welfare as it is likely to have a direct effect on foot health. In slatted floor areas, the slat and gap widths should be appropriate to the claw size of the pigs to prevent injuries, while in solid floor areas, the surface should not be too smooth, but sufficiently rough to provide some abrasion to avoid excessive hoof growth.
- Stereotypies may develop in long-term conflict or thwarting situations, and there is evidence that stereotypies can develop in response to barren or restricted environments as well as feed restriction and restricted foraging opportunities.
- The implication of stereotypies on pig welfare is contentious; a major review of the extensive literature on human and animal stereotypies and their links to welfare found evidence that increased stereotypies can be associated with reduced welfare, increased welfare or no change in welfare. Nevertheless, stereotypies generally indicate either a present problem for the animal or a past problem that has resolved.
- With the practice of restricted feeding of gestating sows, strategies to increase foraging and feeding times will reduce hunger and the likely development of oral stereotypies, such as oral stereotypic licking, bar-biting and sham chewing or vacuum chewing. With intensive, indoor and non-bedded systems in current pig production systems, providing opportunities to forage in terms of searching and chewing for example with straw has been shown to reduce oral stereotypies.
- With the extensive use of fully- or partially-slatted, non-bedded and non-enriched environments in Australian pig production, further research is clearly required to investigate functional and effective enrichment. Recommendations can then be made regarding appropriate S&G for environmental enrichment for all stages of pig production.
- Tail biting is likely to cause both acute and chronic pain in the short-term in the recipient due to the actual tail biting and consequently weight loss and infection in the longer term is a potentially serious welfare problem for growing-finishing pigs.
- Tail biting is believed to be a multi-factorial syndrome factors influencing tail-biting appear to include external factors such as manipulable objects or substrates that can be chewed and manipulated, and particularly straw, space, stocking density and group size; indoor and outdoor climate; crowding, flooring, and food and feeding system; and internal factors such as genetics, gender, age and weight, gastrointestinal discomfort and health status.

Research recommendations: areas for future research regarding specific physiological and behavioural problems in pigs include investigate strategies to increase foraging and feeding times to potentially reduce hunger and the likely development of oral stereotypies; and functional and effective enrichment, the outcomes of which recommendations could then be made regarding appropriate S&G for environmental enrichment for all stages of pig production.

S&G recommendations: once functional and effective enrichment strategies have been identified recommendations need to be updated to include appropriate S&G for environmental enrichment for all stages of pig production

General management practices of pigs

- The current focus of pig breeding programmes is largely driven by market needs and economic benefit, however, future research needs to include welfare-relevant traits to help counter the effects of productivity-based genetic selection.
- Anaesthetic overdose is effective for a painless death in all classes of pigs, but euthanasia may be delayed because veterinary supervision and administration is required, and it is expensive.
- When applied with sufficient force, blunt trauma and non-penetrating captive bolt are effective methods of euthanasia for piglets and result in immediate unconsciousness and death.
- Penetrating captive bolt is effective as a single step method for euthanasia of pigs under 120kg. For mature sows and boars, penetrating captive bolt causes loss of consciousness, but a secondary step (e.g. exsanguination) is necessary to ensure death.
- Blunt trauma, non-penetrating and penetrating captive bolts are all safe for the stockperson and cost effective, however highly dependent on the training and skills of the operator. Furthermore, blunt force trauma is likely to be unpleasant for some stock people to perform, and as such it may result in a delay in the euthanasia of compromised piglets.
- Electrocution for pigs less than 2.3kg causes immediate death; an electric current flows through the brain resulting in unconsciousness and through the heart leading to cardiac arrest. Cost and maintenance of equipment may limit this euthanasia method.
- Carbon dioxide (CO_2) is the most commonly used gas for gas inhalation euthanasia in piglets. Exposure to carbon dioxide (>80% CO_2), to a mixture of CO_2:Argon, argon gas (90%) or nitrous oxide in either pre-filled chamber or with a high flow rate have all been found to be effective methods to kill pigs.
- However, CO_2 inhalation is highly noxious and causes signs of distress until loss of consciousness which may occur as long as 2 minutes following exposure to the gas. Piglets exposed to alternative gases or gas mixtures also show some signs of distress.
- A lack of conclusive outcome-based evidence means that further research is required to determine the most effective and humane gas or gas mixture for gas inhalation euthanasia of piglets.

Research recommendations: further research is required to determine the most effective and humane gas or gas mixture for gas inhalation euthanasia of piglets.
S&G recommendations: the different methods of euthanasia for piglets, growing-finishing pigs and adult pigs are highly dependent on the training and skills of the operator, and as such appropriate training and support should be a primary component of the human resource management practices at a farm.

Human resource management

- Irrespective of the housing system, the skills, knowledge and motivation of stockpeople to effectively care for and manage their animals are integral to the standard of welfare experienced by their animals.
- Attitudes influence not only the manner in which stockpeople handle pigs, but also their motivation to care for their pigs. Thus, training targeting technical skills and knowledge as well as the attitudes and behaviours of stockpeople should be a primary component of the human resource management practices at a farm.
- As has occurred in the Australian pig industry in the past, this cognitive-behaviour training needs to remain an integral element in the industry's stockperson training priorities.

1. Animal welfare and its assessment

1.1 Animal ethics and animal welfare

Ethics is concerned with the principles of right conduct, that is, the moral aspect of behaviour (Levy, 2004). Thus, when we reflect upon ethical standards for animals, we ask how people ought to behave towards animals, in general or in relation to a specific domain. In any ethical analysis though, science can provide facts that need to be utilised to remain rational, and when combined with other beliefs and principles, facts can yield behavioural guidance (Levy, 2004). Therefore, in an ethical analysis of an animal use, science may provide the factual basis of the impact of this animal use on the animal, in particular its impact on the welfare of the animal.

It is widely acknowledged that most of the animals that society uses can suffer. Mellor et al. (2009) argues that in using these animals for our purposes we implement varying degrees of control over the quality and duration of their lives, which consequently provides us with the opportunity to manage them humanely. Furthermore, using these animals for our own purposes rather than theirs, requires us to manage them humanely. We therefore have an ethical 'duty of care' towards the animals under our care and this translates into a practical obligation to ensure their welfare is maintained at acceptable levels.

There are a number of recent reviews on animal welfare, its assessment and the strengths and weakness of the assessment (for example, Broom (1986), Boissy et al. (2007), Fraser (2008), Mellor et al. (2009), Hemsworth and Coleman (2011), Mellor (2012), Hemsworth et al. (2015), Tilbrook and Ralph (2017), Hemsworth (2018a)), which can be summarised as follows.

1.2 Animal Welfare

Animal welfare is a state and it is largely agreed that animal welfare relates to experienced sensations, that is, how the animal feels (Hemsworth, 2018a). How an animal feels develops from the integrated outcomes of the current sensory and other neural inputs from within the animal and from its environment, which are processed and interpreted by the animal according to its species-specific and individual nature, and its past experience. It is these integrated outcomes that represent the animal's current experience (i.e., its welfare status), and this changes as the balance and nature of the inputs change. These experiences are subjective and will differ in their affective or emotional contents: negative affective experiences include thirst, hunger, nausea, pain and fear, and positive affective experiences include satiety, contentment, companionship, curiosity and playfulness. As a result, the welfare state of an animal can vary on a continuum from very poor to very good (Hemsworth, 2018a). Whilst conscious emotional experiences cannot be assessed directly; neural, behavioural and physiological indicators of emotion can be measured. Researchers have employed these measures to describe how animals respond to situations assumed to cause discrete affective or emotional states.
Most animal welfare research during at least the last four decades has concentrated on preventing animal suffering. However, attitudes toward animal welfare have moved beyond whether the animal is suffering and there is increasing societal interest in providing domesticated animals with the opportunity for positive affective experiences (Tannenbaum, 2001, Mellor, 2012, Hemsworth et al., 2015, Lawrence et al., 2017). Consequently, there is an increasing research focus on positive welfare states in captive animals.

1.3 Conceptual frameworks for assessment of animal welfare

Understanding animal welfare and its assessment requires the use of multiple indicators from multiple disciplines (Hemsworth et al., 2015, Tilbrook and Ralph, 2018) particularly since individuals vary in the manner in which they cope with stressors (Broom, 1986, Koolhaas et al., 1999). The conceptual framework of 'biological functioning' is commonly used to infer compromised animal welfare on the basis that difficult or inadequate adaptation will generate welfare problems, while the framework of 'affective state' is based on the concept that the welfare of an animal derives from its capacity for affective experiences. The principle underlying the concept of 'natural living' is that animals should be raised in 'natural' environments and allowed to behave in 'natural' ways. However, this third conceptual framework has the least scientific credibility because the concept of natural is usually too poorly defined to provide a sound basis for animal welfare assessment. The rationale for and the approach of these three conceptual frameworks in assessing animal welfare will be briefly considered now.

1.3.1 Biological functioning

Difficult or inadequate adaptation will create welfare problems for animals. Animals use a range of behavioural and physiological responses to assist them in coping with challenges, and while biological regulation in response to challenges occurs continuously, successful adaptation is not always possible (Hemsworth, 2018b). Serious challenges can limit an animal's ability to adapt and as such lead to its death. Less severe challenges which can have significant biological costs, resulting in growth, reproductive, health and other impairments, which also reflect and/or result in welfare problems for the animal. Thus, animal welfare is at risk in environments in which adaptation is difficult for the animal (Hemsworth, 2018b). The rationale for the biological functioning approach is therefore that difficult or inadequate adaptation will generate welfare problems for the animal and that the risks to welfare can be assessed at the following two levels: first, the magnitude of the behavioural and physiological responses to the challenge and, second, the biological costs of these responses (Hemsworth, 2018a).

It is the biological cost of stress that is the key to understanding the associated welfare implications. The success of an animal in coping with its environment will be reflected in the normality of its biological functioning and fitness, with severe risks to welfare associated with the most extreme coping attempts. The normality of biological functioning can be studied using an animal's behavioural responses to the challenges such as stereotypies, redirected behaviours and displacement activities as well as the animal's physiological stress responses to challenges such as the activation of the sympatho-adrenal-medullary (SAM) system and the hypothalamo-pituitary-adrenal (HPA) axis, with the subsequent increase in synthesis of catecholamines and glucocorticoids, respectively. For many stressors, the first and, at times, the most biologically economical and effective response is a behavioural one. In concert with the behavioural responses, the activation of the SAM system and the HPA axis can be highly effective mechanisms to assist the animal in adapting to changes in its environment. In addition to behavioural responses, physiological outcomes include adjustments in metabolic rate, cardiac function, blood pressure, peripheral circulation, respiration, visual acuity and energy availability and use that allow the animal to meet physical and/or emotional challenges (Sapolsky, 2002, Kaltsas and Chrousos, 2007, Moberg, 2000). Long-term activation of the HPA axis can have marked effects on efficiency of growth with for example the breakdown of muscle protein under the catabolic effects of ACTH and glucocorticoids (Sapolsky, 2002, Kaltsas and Chrousos, 2007). Stress-induced secretion of these stress hormones have also been implicated in failed reproduction (Clarke et al., 1992, Tilbrook et al., 2000) and immune competency (Blecha, 2000). How serious these costs are, depends on how long the animal is required to divert physiological resources to maintain homeostasis. Thus, the extent to which these coping attempts are succeeding or failing is reflected in the biological costs to the animal, such as deterioration in growth efficiency, reproduction and health (injury or disease).

This conceptual framework has been predominantly used in assessing risks to animal welfare (i.e. negative welfare states). Research has largely used the biological functioning framework to imply compromised animal welfare on the basis that suboptimal biological functioning accompanies negative affective states, such as hunger, pain, fear, helplessness, frustration and anger (Hemsworth, 2018b). The measures used in studies in pigs have included behavioural variables, such as aggression and stereotypies; physiological variables, including circulating concentrations of cortisol and neutrophil to lymphocyte ratio and immunoglobulin A; and health variables, such as lameness, skin lesions, live weight change and reproductive performance.

1.3.2 Affective state

The second framework emphasises that the welfare of an animal stems from its capacity for affective experiences, that is, experienced sensations of the animal and thus how it feels. An animal's welfare state is therefore likely to be in a negative state when the predominant affects they experience are predominantly unpleasant, and vice versa. Affective experiences are generated by both sensory inputs that reflect the animal's internal functional state and by other sensory inputs that reflect the animal's perception of its external circumstances (Hemsworth, 2018b).

Preference research (the measurement of animal preferences), in which the strength of the animal's preference for a chosen environmental option or the motivation to perform a type of behaviour is measured, has been used by scientists to make inferences about animal welfare (Hemsworth, 2018a). The rationale for these inferences is that an animal's preferences are influenced by either the animal's emotions, which have evolved to motivate behaviour to avoid harm and facilitate survival, growth and reproduction, and these emotions reflect important biological requirements of the animal. Furthermore, it has been suggested that animals make choices that, for the most part, are in their best interest: animals will likely avoid aversive stimuli and choose rewarding stimuli (Hemsworth, 2018a). To determine the question of the strength of an animal's preference, experiments have incorporated varying levels of cost (e.g., work effort, time and relinquishing a desirable resource) associated with gaining access to a resource or avoiding aversive stimulation. These 'behavioural demand' studies have been used to investigate the animal's level of motivation to access or avoid the situation being tested and the strength of the motivation provides a quantitative measure of how much the animal 'wants' to access or avoid the situation.

Further approaches that have been used to assess affective experiences, particularly negative affective experiences, include measures of behaviour, such as fear, pain and illness behaviours, cognitive bias, such as deviation in judgement, and physiology, such as activation of the sympatho-adrenal medullary system and the hypothalamo–pituitary adrenal axis (Hemsworth, 2018a). While there are inconsistencies in the literature, behaviours such as play, affiliative behaviours and some vocalizations appear to be the most promising current behavioural indicators of positive affective experiences in animals.

A promising area of research is the study of changes in cognitive function as indicators of affective state. For example, in tests of 'judgement bias', in which one cue predicts a positive event while another predicts a less positive/negative event, animals in a negative affective state when presented with ambiguous (intermediate) cues are more likely to respond to these ambiguous cues as if they predict the negative event (a 'pessimistic' response), than animals in a more positive state (Mendl et al., 2009).

1.3.3 Natural living

The final conceptual framework, although not often well articulated in the literature, is based on the view that the welfare of animals is improved when they can express their normal behaviour. This also often implies that the animal should be raised in a 'natural' environment and allowed to behave in 'natural' ways. The general idea that we can improve animal welfare by providing more 'natural' environments and thus allowing animals to perform their full 'repertoire' of behaviour is intuitively appealing. Though, both the concept of natural and the behaviours that are desirable or undesirable in terms of animal welfare are usually too poorly defined to provide a sound basis for animal welfare assessment. However, there is an increasing research focus on those behaviours that are highly-motivated, for example those that are strongly preferred.

In conclusion, the interpretation of the physiological and behavioural indices of both biological functioning and affective states provide the basis for inferences regarding an animal's welfare state. Although the biological functioning and affective state frameworks were initially seen as competing, a more unified orientation has now emerged where biological functioning is taken to include affective experiences, and affective experiences are recognised as products of biological functioning.

As mentioned the majority of studies on pig welfare have employed the biological functioning framework to infer compromised pig welfare on the basis that suboptimal biological functioning accompanies negative affective states, such as hunger, pain, fear, helplessness, frustration and anger (Green and Mellor, 2011, Mellor, 2015a, 2015b). Few studies have used preference and motivation tests to investigate what resources or behaviours are important to pigs, and which, by implication, might provide "relief" by reducing the intensity of some negative effects or "benefit" by increasing opportunities to experience positive affects (Mellor, 2012, Mellor, 2015a, 2015b). For example, motivation tests have been used to assess sow hunger (see Bergeron et al. (2000) and the strength of sow preference to gain access to a pen from a gestation stall (Kirkden and Pajor, 2006b). These three frameworks, particularly biological functioning, are used in this review of the literature to assess the welfare implications of common practices in the pig industry.

1.4 Assessment of welfare in the field

The assessment of welfare in a livestock production system can be used to demonstrate compliance with policy, law, and regulatory standards, and to assure the community (both consumers and non-consumers) that welfare standards are being met. Welfare assessment in a production system can also be used to assist owners and managers to monitor and improve the welfare of their livestock. Welfare assessment in the field requires practical and effective welfare measures and two types of measures are used: environmental and management components (input measures); and validated, repeatable and feasible animal-based welfare indices (outcome or output measures). In recent years, the assessment and monitoring of animal welfare has moved from the conventional approach of evaluating the environment and resources required to ensure good welfare, to focussing on animal-based measures of welfare. Examples of this are, AssureWel, Real Welfare, PigCare™ and the animal welfare assessment at a farm or on-site level in the European Union Welfare Quality® project (Botreau et al., 2009).

Animal-based measures can provide a direct assessment of the animal's welfare state, and while environmental parameters will offer information regarding potential or current welfare risks, they fail to directly reflect the welfare state of the animal (Colditz et al., 2014). Nevertheless, Main et al. (2014) suggest that outcome measures are unlikely to replace all environment measures, particularly where welfare science has shown that the resources provided contribute to genuine welfare benefits. In addition, it is widely recognized that there are some challenges in assessing some animal-based measures, particularly behaviour measures, in a reliable, consistent and time-efficient way (Main et al., 2014).

It has been argued that compliance and market assurance schemes might measure compliance with certain aspects of the welfare of animals, but they do not provide clear directions on how to improve animal welfare (Butterworth et al., 2011, Colditz et al., 2014, Main et al., 2014). Indeed, these authors propose a continuous improvement approach utilizing both regular monitoring of pre-defined welfare criteria (input- (environmental and management) and outcome-based), benchmarking performance to identify targets for improvement and a management system to ensure preventive and corrective action to maximize levels of these criteria. Furthermore, it has been suggested that such an animal welfare risk assessment and management scheme lends itself to providing evidence for compliance and assurance schemes. In addition, production variables should be utilised, many of which farmers already collect such as growth, reproduction, health, mortality and culling statistics and environmental measures. Thus, this multi-pronged approach provides opportunities to benchmarking livestock welfare, both within farms and within the livestock industry for use by individual farmers, industry and stakeholders, to provide compliance evidence and market assurance and, probably most importantly, to assess animal welfare and risk in order to continuously improve animal welfare (Hemsworth, 2018b).

As outlined previously, a multidisciplinary approach is necessary in the assessment of pig welfare, including measures of behaviour (e.g. fear, pain, aggression, play and stereotypic behaviour), physiology (e.g. circulating concentrations of cortisol and neutrophil, lymphocyte ratio), health (e.g. lameness, skin lesions, body condition score) and production (e.g. live weight change, reproductive performance). A range of animal-based measures of pig welfare are currently used in the field, at an individual level including body condition score (individual), lameness (individual), injury score (individual), shoulder lesions (individual), vulva lesions (individual), tail lesions (individual), bursitis (individual), leg swellings (individual), and manure on the body (individual); and at a group-level such as enrichment use (group/pen), tail docking (group/pen), ear/flank biting (group/pen), use of nose rings (group/pen), pigs needing further care (group/pen), hospital pen (group), panting (group), huddling (group), coughing (group), sneezing (group), pumping (laboured breathing; group), rectal prolapse (group), scouring (group), constipation (group), metritis (group), mastitis (group), uterine prolapse (group), rupture and hernia (group), local infection (group), social behaviour (group), stereotypies (group), exploratory behaviour (group), fear of humans (group), qualitative behavioural analysis (QBA) (group), mortality (group), neurological disorder (tremor in piglets; group), splay leg (group), castration (group), and teeth clipping (group).

2. Purpose of this Review and the Australian Model Code of Practice for the Welfare of Animals – Pigs

All pigs farmed in Australia are governed by the Australian Model Code of Practice for the Welfare of Animals – Pigs, which was approved by the Primary Industries Ministerial Council on April 2007. The original Model Code of Practice was approved by the Australian Agricultural Council in 1989 and the code has been subsequently updated in 1998, 2001, 2004 and 2007 to incorporate the latest research findings and new technologies in the area. This review is a comprehensive documentation of recent findings on pig welfare at all stages of their production cycle. Furthermore, the current Australian Model Code of Practice for the Welfare of Animals – Pigs (Appendix IV) is compared to the current Codes or Standards in Canada (Code of Practice for the Care and Handling of Pigs, 2014; Appendix V), the United Kingdom (UK, Codes of Recommendations for the Welfare of Livestock: Pigs, 2002; Appendix VI), the European Union (EU, Council Directive 2008/120/EC; Appendix VII) and New Zealand (Pigs – Code of Welfare, 2018; Appendix VIII). These countries were selected because their high standards of pig welfare have been widely recognised. Major differences in the Codes of Practice and Standards of these other countries and that of Australia are listed below and throughout the review at the relevant sections.

NB: at the time of this review the United Kingdom Codes of Recommendations for the Welfare of Livestock: Pigs (2002) was in the process of being reviewed (updated version expected to be released in early 2019), and as such the revised recommendations are likely to differ from those reported below.

2.1 Major differences in the Codes of Practice and Standards

2.1.1 Housing in stalls

- Australia: By 2017 sows must not be housed in stalls for more than 6 weeks during any gestation period.
- Canada: Sows or gilts can only be housed in stalls for up to 5 weeks after mating.
- UK: Sows and gilts cannot be housed in gestation stalls but can be housed in farrowing crates during the period between 7 days before predicted farrowing time and the day of weaning piglets.
- EU: Ensure that sows and gilts are kept in groups during a period starting from four weeks after the service to one week before the expected time of farrowing. Shall not apply to holdings with fewer than 10 sows provided that they can turn around easily in their boxes.
- New Zealand: Sows or gilts can only be housed in stalls for the purpose of mating, for no longer than seven days per reproductive cycle. The pigs should be released from stalls as soon as practicable after mating.

2.1.2 Space allowance

- Australia*:* Sows and gilts mated or selected for breeding**.** Sows - 1.4m^2, Gilts - 1 m^2 and stalls 600mm x 2200mm
- Canada: Sows - 1.8 to 2.2 m^2, Gilts - 1.4 to 1.9 m^2.
- EU*:* Sows - > 2.25 m^2, Gilts - > 1.64 m^2
- UK: Sows - 2.25 m^2, Gilts - 1.64 m^2.
- New Zealand: A specific space allowance is not specified, for sows and gilts, rather there is a requirement that all group-housed pigs must be able to stand, move about and lie down without undue interference with each other in a space that provides for separation of dunging, lying and eating areas. For growing-finishing pigs there is a formula for calculating space allowance requirements: Area (m^2) per pig = 0.03 x liveweight 0.67 (kg).

2.1.3 Husbandry procedures

- Australia: Castration performed after 21 days of age should be done under analgesic to control procedural pain.
- Canada: Castration performed at any age should be done under analgesic to control procedural pain.
- EU: If castration is performed after 7 days of age it should be done by a veterinarian using anaesthetics. Tail docking performed after 7 days of age should only be done under anaesthetics and additional prolonged analgesia by a veterinarian. The method of castration must not involve tearing of tissues.
- UK: If castration is performed after 7 days of age it should be done by a veterinarian using anaesthetics. Tail docking performed after 7 days of age should only be done under anaesthetics and additional prolonged analgesia by a veterinarian. The method of castration must not involve tearing of tissues.
- New Zealand: Castration of piglets is not performed under commercial conditions in New Zealand but can be performed in pigs on smallholdings. If castration is performed at any age, then it must be carried out by a veterinarian and the pig must be given pain relief at the time of the procedure. Tail docking after 7 days of age can only be performed by a veterinarian and pigs must be given pain relief at the time of the procedure.

2.1.4 Enrichment (including nesting materials)

- Australia*:* In the current Australian Model Code of Practice for the Welfare of Animals – Pigs there is no requirement to provide environmental enrichment. There are recommendations that boars and gestating sows should be provided with bulky or high fibre feed to satisfy appetite (Recommended practice 3.1.9) and that the provision of straw or other suitable materials to permit foraging behaviour is encouraged (Guideline 4.1.18).
- Canada: The Canadian Code of Practice for Care and Handling of Pigs stipulates that all classes of pigs must be provided with multiple forms of enrichment that aims to improve the welfare

of the animals through the enhancement of their physical and social environments (Requirement 1.8).

- New Zealand: 'Pigs – Animal Welfare Code of Welfare 2018' states that all classes of pigs must be managed in a manner that provides them with sufficient opportunities to express and satisfy their normal behaviours. These include, but are not limited to, feeding, drinking, sleeping, dunging and urination, vocalisation, thermoregulation, and social contact (Minimum Standard No 9 – Behaviour). This does not explicitly state foraging behaviour or the use of environmental enrichment, although the incidence of stereotypic behaviour, aggression, and tail, ear and vulva biting (as specified in example indicators of normal behaviour) may be reduced by providing environmental enrichment.
- EU: The EU Council Directive 2008/120/EC states that all class of pig must have permanent access to a sufficient quantity of enrichment materials that does not compromise their health and enables them to carry out proper investigation and manipulation activities and fulfil their behavioural needs. Additionally, in the week before the expected farrowing time, sows and gilts must be given suitable nesting material in sufficient quantity unless it is not technically feasible for the slurry system used. Furthermore, countries within the EU may have more specific standards regarding the provision of enrichment for pigs at different stages of production.
- UK: The UK Codes of Recommendations for the Welfare of Livestock: Pigs state that to enable proper investigation and manipulation activities, all classes of pig must have permanent access to a sufficient quantity of material such as straw, hay, wood, sawdust, mushroom compost, peat or mixture of such which does not adversely affect the health of the animals. Additionally, in the week before the expected farrowing time, sows and gilts must be given suitable nesting material in sufficient quantity unless it is not technically feasible for the slurry system used.

3. Housing and management of pigs

Whilst the increased intensification of animal production systems has reduced or removed a range of welfare problems, such as predation, thermal stress, some infectious diseases and nutritional stress, it has also created or exacerbated other welfare problems including restricted space and social contact, lameness and barren environments (Cronin et al., 2014). Extensive livestock production systems are generally thought to be less restrictive, however they do still impose restrictions on animals, albeit with considerable freedom and there are different welfare risks including frequency of inspections, climatic conditions and natural disasters. For pigs, modern indoor intensive production systems are considered by some sections of the community to be inherently bad due to a perceived lack of space, barrenness of the environment and a reliance on technology (Barnett et al., 2001, Mellor et al., 2009). On the other hand, outdoor housing is usually extensive and as such thought to be inherently good as it provides animals with a more 'natural' environment, the opportunity to perform a greater range of behaviours, and the use of fewer technological inputs reduces the likelihood of equipment breakdowns that may adversely affect welfare (Hemsworth, 2017).

For livestock, the primary focus of welfare concerns has been on intensive production systems. These concerns have led to a varied range of responses, however most commonly they have resulted in the development of alternative systems, sometimes based on previous, more traditional farming practices, such as free-range pig systems. These alternative systems often merely replace one set of welfare problems with another, due largely to an insufficient understanding of the animals' requirements, including those for space, social contact and environmental enrichment, and without this understanding it is difficult to design appropriate housing systems. In pig production, the most contentious welfare issues involve indoor housing, particularly of breeding sows, however potential welfare issues do also exist in outdoor pig systems, including the implications of nose-ringing, appropriate shelter, litter desertion, pre-weaning piglet mortality, wallow design and management, thermoregulation in winter, heat stress in summer, any implications of lower back fat, and the suitability of different genotypes (Barnett et al., 2001, Marchant-Forde, 2009).

While there remains a focus on intensive indoor housing systems, research has indicated that the design and management of both indoor and outdoor housing systems is probably more important for animal welfare than is generally recognised (Barnett et al., 2001, Rushen and Passillé, 1992, Hemsworth, 2018a).

3.1 Gestating sows (including gilts)

There are a number of recent comprehensive reviews on the effects of housing on the welfare of gestating sows, such as (Hemsworth, 2018a, Hemsworth et al., 2013, Hemsworth, 2017, Verdon et al., 2015) and this section of the present review adds to these recent reviews.

3.1.1 Space allowance

According to the standards in the Australian Model Code of Practice for the Welfare of Animals – Pigs, the minimum space allowance for group-housed gestating gilts is 1m^2/gilt, and for gestating sows it is 1.4m^2/sow. The Canadian Code of Practice for the Care and Handling of Pigs requires gilts housed on partly-slatted floors to have a minimum space allowance of 1.4 to 1.7 m^2/gilt, whereas those housed on solid-bedded floors must have a minimum space allowance of 1.5 to 1.9 m^2/sow. The Canadian code also specifies that sows housed on partly-slatted floors should have a minimum space allowance of 1.8 to 2.2 m^2/sow, and those housed on solid bedded floors should have a minimum space allowance of 2.0 to 2.4 m^2/sow. The UK Code of Practice states that gilts should have a minimum access to 1.64 m^2/gilt of space, whereas sows should have minimum space allowance of 2.25 m^2/sow. The EU's Council Directive 2008/120/EC requires all member states to provide > 1.64 m^2 and > 2.25 m^2 of total unobstructed floor area for gilts and sows, respectively. There are also additional requirements in the EU and UK about pen dimensions and amount of solid flooring per sow/gilt. New Zealand uses the formula Area (m^2) per pig = 0.03 x liveweight 0.67 (kg) to calculate the space allowance for housing of pigs.

Reducing floor space for gilts and sows in the range of 1.0–3.0 m^2/animal has been found to increase aggression and plasma cortisol concentrations and reduce reproductive performance. For example, in gilts, aggression was higher at a space allowance of 1.0 than at 2.0 m^2/gilt (Barnett et al., 1992, Barnett et al., 1997) and stress was higher at 1.0 than at 1.4, 2.0 or 3.0 m^2/gilt (Hemsworth et al., 1986, Barnett et al., 1992, Barnett et al., 1997). In sows, aggression was generally higher at 2.0 than at 2.4, 3.6 or 4.8 m^2/sow (Weng et al., 1998) and at 2.25 than at 3.0 m^2/sow (Remience et al., 2008). Within the range of 1.4–3.0 m^2/sow, significant negative relationships have been shown between space allowance and aggression, stress and farrowing rate in sows (Hemsworth et al., 2016, Hemsworth et al., 2013).

Floor space has affected the prevalence of skin injuries in some studies (Weng et al., 1998, Salak-Johnson et al., 2007, Remience et al., 2008) but not in others (Barnett et al., 1992, Barnett et al., 1997, Hemsworth et al., 2013). These findings on the effects of space, particularly those on aggression and stress, indicate that a space allowance for gilts and sows of 1.4 m^2/animal is likely too small and significant improvements in these respects are likely to be achieved with space allowances for gilts and sows in the range of 2.0–2.4 m^2/animal. Furthermore, space effects on aggression and stress are most evident shortly after mixing (Hemsworth et al., 2013, Hemsworth et al., 2016), which highlights the importance of floor space at mixing.

Reducing floor space for gilts and sows has been found to decrease immunological responsiveness and reproduction. Immunological responsiveness in gilts, assessed on the basis of a cell-mediated response to a mitogen injection, was reduced in gilts with a space allowance of 0.98 m^2 rather than 1.97 m^2/gilt (Barnett et al., 1997) and immunological responsiveness in sows, assessed on the basis of neutrophil to lymphocyte ratio was reduced with 1.4 and 2.3 m^2 than 3.3m^2/sow (Salak-Johnson et al., 2012). Reduced expression of oestrus in gilts was found with a floor space 1 m^2 than 3 m^2/gilt (Hemsworth et al., 1986a), while reducing floor space in the range of 1.0–3.0 m^2/sow reduced farrowing rate (Hemsworth et al., 2013) and litter size (piglets born alive) were reduced with 1.4 and 2.3 m^2 than 3.3m^2/sow (Salak-Johnson et al., 2007).

In contrast to the above studies, (Greenwood et al., 2016) found no effects of floor space allowances of 2, 4 or 6 m^2/sow on agonistic behaviour, including aggressive behaviour, and injuries at mixing and the following 4 days, although salivary cortisol concentrations were higher in the 2m^2/sow treatment. There were no effects of the previous treatments on any of these measures when sows in all treatments were provided with 2 m^2/sow.

The use of dedicated mixing pens has been proposed by several authors on the basis that providing features that allow avoidance by less aggressive sows while enabling the social hierarchy to quickly form will reduce aggression and, subsequently, injuries and stress at mixing (Verdon et al., 2015). Although there is evidence that pre-mixing of sub-groups before introduction to large dynamic groups appears to reduce contact and aggression between new and resident sows (Durrell et al., 2003), surprisingly there has been no published research on the effects of mixing pens on the long-term effects when sows are subsequently placed in gestation group systems. An obvious design feature of a mixing pen that would allow avoidance by less aggressive sows while enabling the social hierarchy to quickly form is increased floor space. Since a sow's requirement for space appears to be less once the group is established (Hemsworth et al., 2013), with its animal welfare and economic implications, a strategy of staged gestation penning, with more space immediately after mixing and less space later in gestation, warrants further investigation. In their review of the literature on other possible design features, Verdon et al. (2015) suggest that a mixing pen with increased floor space, barriers and feed supplied *ad libitum* is likely to reduce aggression, injuries and stress at mixing. However, further research is required, particularly on the long-term consequences when sows are subsequently introduced to a gestation housing system in which there may be changes in the design features, such as less floor space, another feeding system or introduction to a dynamic group.

3.1.2 Group size during gestation

No difference in the stress of sows based on cortisol concentrations has been found in groups of 10, 30 or 80 (Hemsworth et al., 2013), but reports on effects of group size on aggression and injuries are contradictory. Aggression, but not the prevalence of injuries, increased in larger groups in one large study (Taylor et al., 1997), whereas injuries, but not aggressive interactions and stress, increased in larger groups in another (Hemsworth et al., 2013). The latter authors suggested that fast movement and, therefore, the opportunity to sustain injuries through slipping and contacting with pen features might be inhibited in small groups. Neither Taylor et al. (1997) nor Hemsworth et al. (2013) found any effects of group size on reproductive performance (farrowing rate and litter size (total and born alive)).

There is a considerable body of research in the young pig indicating that aggression is not affected by group size in the range of 6 to 80 pigs (Turner et al., 2000, Turner et al., 1999, Samarakone and Gonyou, 2009). Other factors such as floor space and competition for feed or feeding space may have a greater impact on sow aggression, injuries and stress than group size.

3.1.3 Feeding system during gestation

The type of feeding system affects the level of aggression related to competition for feed (Spoolder et al., 2009). Although floor feeding is competitive, accessing feeding stalls or an electronic sow feeder (ESF) system also leads to competition between group-housed sows. Andersen et al. (1999) (p. 102) stated that, "the feeding arrangement may influence the nature of the aggressive encounters as well as the amount of aggression."

Floor feeding is one of the simplest and cheapest methods of feed delivery, with feed delivered either manually or automatically, directly onto the pen floor. Feed droppers are normally spread to accommodate approximately 6 to 8 sows per feeder (Rizvi et al., 1998; Marchant-Forde et al., 2009), allowing sows to feed simultaneously, which may be an advantage to pigs in general. In comparison to concurrent feeding and fixed schedule sequential feeding, feeding grower pigs over 4 weeks in a random order increases plasma cortisol concentration and decreases immunological responsiveness based on a cell-mediated response to a mitogen injection (Barnett and Taylor, 1997). These results suggest that an unpredictable schedule of feeding may compromise pig welfare.

With restricted feeding, group-housed sows compete, consuming as much feed as possible until all the feed is gone. Consequently, variation in feed intake between sows is seen in floor feeding systems (Mendl et al., 1992, Brouns and Edwards, 1994). Spreading feed over a greater area can minimize aggression and allow subordinate sows greater access to feed (Gonyou, 2005). Providing the daily ration over multiple feed drops per day can reduce skin and vulva injuries and structural problems with feet and legs in gestating group-housed sows (Schneider et al., 2007), although duration of agonistic behaviour was unaffected in young prepubertal gilts. Recent research has shown that 'dominant' sows (i.e., those that delivered more aggression than they received) spent the most time feeding where the majority of feed was distributed, while all other sows fed opportunistically, consuming what they could from between and around other sows (Verdon et al., 2018). However, 'subordinate' sows (i.e., those that delivered very little or no aggression relative to the aggression they received) spent more time than 'subdominant' sows (i.e., those that received more aggression than they delivered) and dominant sows avoiding where most of the feed was delivered. Clearly further research is necessary on the management and design of floor feeding systems to ensure that all sows are able to feed with minimise risks to their welfare.

In comparison to floor feeding, the provision of a feeding stall for each sow in the group, particularly full-body length stalls, reduces aggression and plasma cortisol concentrations in the long term in group-housed gestating gilts (Barnett et al., 1992, Barnett and Taylor, 1997, Andersen et al., 1999). Furthermore, as discussed earlier, even when feeding stalls are provided floor space, either total space or the space outside the feeding stalls, independent of the feeding system affects stress (Barnett and Taylor, 1997, Barnett et al., 1992).

However, it has been shown in some experiments that full-body length stalls do not affect aggression or skin injuries in the 90 minutes after mixing or skin injuries in the long term (Barnett et al., 1992, Barnett et al., 1997). Andersen et al., (1999) found increased vulva bites in pens with full-body feeding stalls and suggested that feeding arrangement influences the nature as well as the amount of aggression. Indeed, although floor feeding is competitive, gaining access to feeding stalls can also lead to competition and aggression between group-housed sows (Bench et al., 2013). Continuous access to feeding stalls in comparison to allowing access only around feeding, reduced aggression and skin injuries, but not salivary cortisol, in group-housed sows (Wang and Li, 2016).

While not extensively studied, the position of resources and barriers in pens to facilitate access to important resources, such as feed, water and a comfortable lying area, and allow escape opportunities from others, may also reduce aggression and minimise risks to sow welfare.

While electronic sow feeder (ESF) systems provide sows with the opportunity for protection from others at feeding, aggression and displacement occurs at the entrance of the ESF (Anil et al., 2005, Scott et al., 2009, Olsson et al., 2011, Bench et al., 2013). In fact, some authors have suggested that strategies to prevent queuing would improve sow welfare in these systems (Anil et al., 2003). Some ESF systems allow sows to re-enter after they have consumed their daily ration, allowing dominant sows to repeatedly re-enter the ESF (Hunter et al., 1988, Olsson et al., 2011), placing pressure on the ESF and restricting others from accessing the feeder (Durrell et al., 2002). Vulva biting is also more prevalent in ESF systems than floor-feeding systems (Scott et al., 2009, Jensen et al., 2012) and Scott et al. (2009) in a survey of injuries in farms with different feeding systems reported that prevalence of severe vulva lesions in sows at farms with different feeding systems was highest in those with ESF systems. In a study of seven different types of group-housing systems for pregnant sows across 55 herds, Leeb et al. (2001) found vulva lesions in up to 62% of sows on one farm. Furthermore, (Rizvi et al., 1998) using a postal survey on 410 pig farms in south-west England reported vulva lesions in 70% of farms with ESFs.

As discussed earlier, there is evidence in grower pigs that feeding in a random order increases stress and decreases immunological responsiveness (Barnett and Taylor, 1997). These results suggest that an unpredictable schedule of feeding may compromise pig welfare. While feeding schedules were only studied over 4 weeks in this experiment, the stress and immune responses seen in grower pigs may have implications for the welfare, health and reproductive performance of sows recently introduced to ESF systems and thus research on this aspect is warranted, particularly those sows displaced from the ESF when the system is first active each day.

Verdon et al. (2015) in reviewing the literature on feeding systems for gestation sows suggested that feeding stalls may be the compromise, allowing sows to simultaneously feed while offering some form of protection against aggressive animals and reduced feed intake, although sows in these systems could be at greater risk of vulva injuries than either ESF or floor feeding systems. It is difficult to conclude on the optimal feeding system because first, research directly comparing aggression, stress, injuries, and feed intake (i.e., weight gain) between floor feeding, feeding stall, and ESF systems is lacking and second, of the research that has been conducted, the comparison of the feeding system (or housing type) is often confounded by design features such as space, group size and bedding.

3.1.4 Time of mixing

The results of the limited number of studies that have examined the effects of the stage of the reproductive cycle at mixing on aggression, injuries and stress are inconsistent. Higher levels of aggression and cortisol concentrations early after mixing have been observed in sows mixed in the week after insemination (early gestation) than 5 to 6 weeks after insemination (Stevens et al., 2015). Since there were no differences in aggression and cortisol 7 days after mixing either early or later in gestation, these effects seem to be acute. The effects of the stage of reproduction at mixing on injuries also appears to be a short term effect since sows mixed early in gestation had more skin injuries at 7 days after mixing than those mixed later in gestation (Stevens et al., 2015). More skin injuries, more vulva injuries and a greater incidence of lameness were also observed by Knox et al. (2014) in sows mixed early after insemination than in those mixed later in gestation.

In contrast to the effects on aggression and stress found by Stevens et al. (2015), Strawford et al. (2008) and Knox et al. (2014) found that aggression early after mixing was similar for sows mixed at 2 to 9 days after insemination and those mixed 35 to 46 days after insemination and Knox et al. (2014) found that sows mixed early after insemination had a smaller increase in serum cortisol from a baseline measure than sows mixed later in gestation.

The effects of the stage of the reproductive cycle at mixing on reproductive outcomes support the findings of Stevens et al. (2015) that mixing sows earlier after insemination results in higher levels of aggression and cortisol concentrations than mixing later in gestation. Conception rates were lower for sows mixed early in gestation than for those mixed later in gestation or those housed in stalls for the entire gestation (Knox et al., 2014), and farrowing rates were lower for sows mixed early in gestation than for those mixed later in gestation (Li and Gonyou, 2013, Knox et al., 2014).

It is relevant in this discussion of the effects of the stage of the reproductive cycle at mixing to consider the very limited data on grouping sows at weaning. While group housing may overall facilitate the sexual behaviour of sows (Barnett and Hemsworth, 1991), there is evidence that grouping of sows stimulates the sexual behaviour of dominant sows but suppresses that of subordinate sows (Pedersen et al., 1993, Peterson and Lee, 2003). Social stress, arising from both social restriction with individual housing (Barnett and Hemsworth, 1991) and social submission with the presence of a dominant sow, may be implicated in these effects on sexual behaviour and thus raise welfare concerns with grouping of sows at weaning. Furthermore, there is evidence that the onset of oestrus may be delayed and variation in the onset of oestrus may be increased with grouping of sows at weaning (Langendijk et al., 2000, Rault et al., 2014), although with high levels of boar stimulation, neither the detection nor duration of oestrus differed between weaned sows in stalls and those in groups (Langendijk et al., 2000). Cortisol concentrations one day after mixing was higher for sows mixed at weaning than those housed in stalls after weaning but mixed within 2 days after insemination (Rault et al., 2014), which could be due either to the stage of reproduction or the accumulation of various stressors when weaning sows into groups.

While the literature is inconsistent, possibly because of differences between studies in intrinsic sow factors, such as genetics, size, familiarity and experience, and design features of the housing systems, such as feeding system, pen design and group size, it nevertheless appears that the challenges associated with aggression, stress, and injuries at mixing may have the greatest implications for sows mixed early after insemination. Further research on the effects of the stage of the reproductive cycle at mixing on sow welfare is required.

3.1.5 Static and Dynamic groups

Static groups are normally formed within a few days of insemination or after pregnancy has been confirmed for the remainder of gestation. In contrast in dynamic groups, unfamiliar sows within a few days of insemination or after pregnancy has been confirmed are frequently introduced to the group so that they experience between 3 and 12 mixings per gestation (Marchant-Forde, 2009). Since sows are introduced to a group and within the group may experience regular introductions of unfamiliar sows, it is not surprising that some authors have proposed that aggression may be greater and persist for longer in dynamic groups of sows (Barnett et al., 2001, Arey and Edwards, 1998). Only a few studies have compared the welfare implications of static and dynamic groups. Anil et al. (2006a) found that although skin injury scores were higher in dynamic groups, there were no differences between the two groups in aggression, cortisol concentrations, farrowing performance, and longevity, while Strawford et al. (2008) found no differences between the two group types in aggression, skin injuries, and cortisol concentrations. In the most recent and most substantial study, involving 1,569 sows over 5 reproductive cycles and 2 years, Li and Gonyou (2013) found increased chronic skin injuries (e.g., cuts, swellings, and wounds) and lameness in the dynamic group, although there were no effects on farrowing rate, weight gain, or litter size. Interestingly, sows introduced into either group system between 2 and 9 d after insemination had a lower farrowing rate than those introduced into either group system between 35 days later. These studies differed markedly in a number of design features (e.g., the provision of bedding, flooring, and space allowance), however the findings of Li and Gonyou (2013) raise welfare concerns with dynamic groups. Thus, research on the effects of design features, such as space, both amount of floor space and quality of space in terms of escape opportunities to reduce agonistic behaviour, group size and bedding, is required to safeguard sow welfare in dynamic groups.

3.1.6 Restricted feeding of gestating sows

The feed intake of breeding sows is commonly restricted during gestation for productivity and lameness reasons (Meunier-Salaün et al., 2001). While this feeding level is sufficient for maintenance, and for some growth and foetal development, it leads to hunger (Barnett et al., 2001a). Behavioural demand or operant conditioning (motivation) tests have generally been used to assess sow hunger and are considered an effective way of measuring feeding motivation (Kirkden and Pajor, 2006a, D'Eath et al., 2009a, D'Eath et al., 2017), and such studies have shown that conventional restricted feeding during gestation results in sows being hungry for a considerable period of the day (Hutson, 1991, Lawrence and Terlouw, 1993). In behavioural demand tests, Bergeron et al. (2000) found that sows fed a control diet (5% crude fibre), *ad libitum* 'worked' to obtain less feed rewards than restrictively-fed sows on either high levels of high fibre diets (3.5 kg/day (18% crude fibre) and 4.5 kg/day (23% crude fibre)) or the control diet (2.5 kg/day). While working for feed in itself may be rewarding because even those sows fed *ad libitum* worked to obtain some feed reward, restrictive feeding results in gestating sows experiencing hunger.

Increasing the amount of roughage and daily feed allocation generally reduces stereotypies and increases the time spent feeding (Appleby and Lawrence, 1987, Robert et al., 1993, Bergeron et al., 2000, Terlouw and Lawrence, 1993, Spoolder et al., 1995, Whittaker et al., 1998, Ramonet et al., 1999, Holt et al., 2006). While high-fibre diets increase the time sows spent feeding and reduce stereotypies as long as the animal's nutrient requirements are met (Robert et al., 1993, Brouns and Edwards, 1994, Ramonet et al., 1999), increased feeding time accounts for much of the reduction in stereotypy level associated with high-fibre diets (Robert et al., 1997). Bergeron et al. (2006) in an extensive review of the literature proposed that for sows (as with other ungulates), low fibre, high-concentrate diets that require little food-searching behaviour and consummatory behaviours such as chewing, result in unfulfilled motivations to perform these natural foraging activities, leading to increased oral stereotypies (including oral stereotypic licking, bar-biting and sham-chewing or vacuum-chewing).

In a review of the literature, (Meunier-Salaün et al., 2001) concluded that there is no consistent evidence of increased stress, based on plasma and urinary cortisol concentrations, in sows individually housed and restrictively fed, and this is supported by more recent studies (De Leeuw and Ekkel, 2004, Toscano et al., 2007). However, since glucocorticoids can be affected by metabolic rate, glucocorticoids may not be an appropriate physiological measure of stress associated with hunger (De Jong et al., 2002).

Therefore, regardless of the feeding system, gestating sows on a restricted diet experience hunger, however, while this feeding practice has and will continue to raise welfare concerns, the implications of hunger on the welfare of feed-restricted sows is unclear. The addition of roughage to the diet of feed -restricted sows increases the time spent feeding and reduces stereotypies compared to feeding a concentrate diet at a restricted level. Interestingly though, while roughage increases feeding and reduces stereotypies, these effects are less pronounced than those arising from a concentrate diet fed ad libitum (Bergeron et al., 2000).

3.1.7 Barren environments

It remains difficult to clearly define what constitutes a 'barren' environment, however it is believed to be an environment that does not allow animals to perform 'highly motivated behaviours' that if deprived cause biological disruption (and potentially a welfare concern) (Mason, 2006). Most indoor farm animal production systems are considered by some to provide barren environments for animals (Barnett et al., 2001). Stereotypies may develop in long-term conflict or thwarting situations, and there is evidence that stereotypies can develop in response to barren or restricted environments (Mason, 1991, Würbel et al., 1998). Stereotypies may originate from redirected behaviours (and other abnormal behaviours including displacement, redirected and vacuum behaviours) if the conflict or thwarting persists (Hemsworth, 2018b). Once developed, stereotypies can become part of the animal's behavioural repertoire and therefore may persist in the absence of the original eliciting, stimuli/conditions (Mason, 1991). The implications of stereotypies on animal welfare is highly controversial, and Broom (1983) argued that the welfare of the animal is at risk if stereotypies occur for 10% of an animal's waking life, and Wiepkema (1983) suggested that animal welfare is at risk if stereotypies occur in more than 5% of all animals (Wiepkema, 1983).

Pigs have evolved to root and investigate their environment with their snout and specialised rostral disc to obtain a balanced, nutritional and satiating diet (down to specific amino acids). This behaviour can account for 10–20% of their active time (Stolba and Wood-Gush, 1989). Modern systems of intensive pig production thwart the expression of key behaviours such as exploration and foraging. Enrichment suitable for pigs is therefore likely to be one that they can root, chew and preferably ingest with some nutritional benefits. Effective enrichment should decrease the incidence of abnormal behaviour and increase the performance of behaviours such as exploration, foraging, play, and social interaction, which are within the range of the animal's, normal, species-specific behaviour (Chamove, 1989, Mench, 1994, Markowitz et al., 1995, Van de Weerd and Baumans, 1995).

Stereotypies have been reported in sows in a range of indoor housing systems including tethered, stall-housed and group-housed sows (Barnett et al., 2001, Schouten and Rushen, 1992, Vieuille-Thomas et al., 1995). Lack of stimulation in the pig's environment may lead to boredom and stereotypies, but the welfare implications of intensive, indoor and non-bedded systems common in current Australian pig production systems are poorly understood. The EU Council Directive 2001/93/EC states 'pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, sawdust, mushroom compost or a mixture of such that does not compromise the health of animals.' However, the extent to which this provides effective enrichment has been questioned by many (Marchant-Forde, 2009, van de Weerd and Day, 2009).

A well-accepted definition of environmental enrichment in the scientific literature is an increase in the biological relevance of captive environments by appropriate modifications (Newberry, 1995). In other words, enrichment is an environmental change that improves or enhances animal welfare (Mills and Marchant-Forde, 2010). However, the term enrichment is often used loosely to denote any environmental change without an understanding of its impact on the animal. Some environmental enrichment strategies have been shown to assist animals in adapting to barren environments. For example, provision of objects or conditions which stimulate exploration, foraging, manipulation, social behaviour and problem solving, particularly when combined with diversity of opportunities, may mitigate deleterious stress effects on neurobiological systems and endocrine profiles and promote stress adaptability in rodents (Lehmann and Herkenham, 2011, Abou-Ismail et al., 2010, Abou-Ismail and Mendl, 2016, Greenwood and Fleshner, 2008). While the utilisation of the enrichments has been investigated, the effects of enrichment on stress adaptability and indicators denoting poor welfare have not been extensively studied in pigs (van de Weerd and Day, 2009), particularly gestating sows. The provision of straw that elicits foraging behaviour in terms of searching and chewing, has been shown to reduce oral stereotypies, such as bar biting and sham chewing, in gestating sows housed in stalls and groups (Sambraus and Schunke, 1982, Spoolder et al., 1995, Bergeron et al., 2006). While the utilisation of the enrichments has been studied, the effects of enrichment on stress adaptability and indicators denoting poor welfare have not been extensively studied in pigs (Van de Weerd and Day 2009). De Jong and colleagues (De Jong et al., 1998, 2000; de Groot et al. 2000) compared the effects of two rearing environments on pig behaviour and stress physiology; an 'Enriched' environment, in which pigs were reared in large farrowing pens followed by large growing and fattening pens with provision of straw, and a 'Barren' environment, in which pigs were reared in smaller farrowing pens in which sows were crated, followed by smaller growing and fattening pens with partially slatted solid floors. While pigs reared in the Enriched treatment had higher baseline salivary cortisol concentrations at 14–22 weeks of age, but not at 9 weeks of age, the pigs reared in the Barren treatment environment had a blunted circadian rhythm in salivary cortisol at 14–22 weeks of age. De Jong et al. (2000) proposed that since blunted circadian cortisol rhythms are often recorded during states of chronic stress in pigs and rats or during depression in humans, the blunted circadian rhythm in cortisol in the Barren treatment pigs may reflect decreased welfare. Pigs reared in the Barren treatment also displayed more manipulative behaviours directed towards pen-mates, such as massaging and nibbling (De Jong et al. 1998).

A further advantage of the use of straw as environmental enrichment is that it may reduce gastric ulceration (Scott et al 2006; Herskin et al, 2016). Both hunger and gastric ulcers are thought to be possible causes of sham chewing in sows (D'Eath et al. 2009). A high fibre diet and access to straw (Steward et al, 2011), and provision of silage in addition to straw bedding has been shown to reduce sham chewing. Other than straw or objects, pens can be enriched with barriers or hiding areas to reduce the frequency and type of aggressive interactions (Van de Weerd and Day, 2009). This can be used for example to mix sows in a dedicated mixing pen where barriers are provided.

With the extensive use of fully- or partially-slatted, non-bedded and non-enriched environments for gestating sows, further research is clearly required to examine the extent to which this provides functional enrichment. This research should identify objects or situations that have functional relevance to the animal and act with a foreseeable rewarding outcome and improves or enhances animal welfare (Newberry, 1995). This is a topic that has been neglected for the breeding sow.

3.1.8 Conclusions, recommendations and further research on gestating sows

There are some obvious gaps in our knowledge on safeguarding the welfare of gestating sows and these obviously are topics for future research. The most obvious weakness in knowledge is strategies for effective environmental enrichment in intensive, indoor and non-bedded systems. Together with the practice of restricted feeding of gestating sows, strategies for example to increase foraging and feeding times in feed-restricted gestating sows will reduce hunger and the likely development of oral stereotypies such as oral stereotypic licking, bar-biting and sham chewing or vacuum chewing.

Research on space allowance, particularly recent research indicates that a space allowance for gilts and sows of 1.4 m^2/animal is likely to be too small and that significant improvements in welfare, in terms of aggression and stress, are likely to be achieved with space allowances for gilts and sows in the range of 2.0–2.4 m^2/animal. The research also indicates that the effects of space on aggression and stress are most pronounced soon after mixing, highlighting the importance of floor space at mixing. Indeed, a strategy of staged gestation penning, with more space immediately after mixing and less space later in gestation may provide distinct animal welfare and economic advantages, but this requires investigation. Mixing pens with increased floor space, barriers and feed supplied *ad libitum* have been advocated by many authors.

While floor feeding is generally viewed as the most competitive feeding system, accessing feeding stalls or an electronic sow feeder (ESF) system also leads to competition between group-housed sows. However, irrespective of the housing and feeding, a better appreciation of the positioning of resources and barriers in pens to facilitate access to important resources, such as feed, water and a comfortable lying area, and allow escape opportunities from others, is important in reducing aggression and stress and thus minimise risks to sow welfare.

This review of gestating sow housing highlights the importance of the design of the system on sow welfare. It highlights the need for research on animal welfare in new and modified housing systems, as well as current but contentious systems, to be attentive to the design contributions of these systems to animal welfare. This review also highlights areas for future research to safeguard gestating sow welfare: effective environmental enrichment for gestating sows in intensive, indoor and non-bedded systems; opportunities to increase foraging (which clearly also provides environment enrichment) and feeding times in feed-restricted gestating sows.

3.2 Farrowing/lactating sow and piglets, including painful husbandry practices

The Australian Model Code of Practice for the Welfare of Animals – Pigs states that farrowing crates must have minimum dimensions of 0.5m x 2m, and overall dimensions of farrowing crate and the creep area must be at least 3.2m^2. Recent comprehensive reviews on the effects of farrowing and lactation housing on the welfare of sows and piglets, include Baxter et al. (2011) and Baxter et al. (2017).

Individual housing in farrowing crates for parturient and lactating sows has been a controversial issue for many decades (Singh et al., 2017). As in the EU, USA, NZ and Canada, the majority of sows in Australia are housed in farrowing crates during parturition and lactation (Baxter et al., 2012). However, the use of loose farrowing systems (both single-litter and multi-litter) is increasing (Baxter and Edwards, 2017, Baxter et al., 2017). Farrowing crates save space and labour, and facilitate ease of inspection and intervention, however, they were also designed to reduce piglet mortality (Barnett et al., 2001, Johnson and Marchant-Forde, 2009). Because the sow's position is fixed, the footprint of the farrowing crate is minimal; typically, 1.23 m^2 crate within 3.6 m^2 pen (Baxter et al., 2012). The primary criticism of the farrowing crate is the behavioural restriction of the sow and the subsequent impact on sow welfare. Farrowing crates limit the movement of sows and the opportunity for sows to perform natural behaviour, such as nest building, and to be able to freely interact with their piglets (Barnett et al., 2001, Singh and Hemsworth, 2013, Pedersen et al., 2015) and a restricted choice of stimuli to interact with such as other pigs and additional features of the physical environment (Barnett et al., 2001). Additionally, the physical aspects of restriction associated with farrowing crates have become more relevant as sow size has increased considerably over the last 30 years; genetic improvement and breeding for hyperprolificacy has resulted in a 55% increase in sow weight (Moustsen et al., 2011). The significant increase in sow weight has implications for sows fitting in farrowing crates that have not been adapted to account for sow size increase and consequently may be non-compliant with welfare regulations, for example, in the EU and UK regulations require sows to be able to stand up and lie down without difficulty.

Farrowing crates were developed largely to reduce high piglet mortality, primarily through reducing accidental crushing by the sow, and the data on whether farrowing crates have contributed, at least in part, to a general reduction in piglet mortality are equivocal (see Barnett et al., 2001). Criticisms of the farrowing crate have generally focused on sow rather than piglet welfare, which is perhaps surprising considering the far greater incidence of piglet deaths from various causes (a critical measure of welfare) compared with sow deaths in farrowing crates. As Baxter (1984) notes, the visible nature of the farrowing crate, with its explicit function of confining the sow and restricting her movements may be responsible for this greater criticism.

Alternative loose farrowing environments such as the PigSafe pens (Piglet and Sow Alternative Farrowing Environment) (Edwards et al., 2012) provide sows with bedding and thus increased opportunity to perform nest building and to freely move about and interact with their piglets during farrowing and lactation (Verdon and Rault, 2018). However, these loose-farrowing and lactation systems require extra floor space and can lead to an increased risk of piglet crushing (Morrison et al., 2011), which has limited their uptake by pork producers.

3.2.1 Implications of confinement on sow welfare

While there is little evidence that domestication has resulted in the loss of behaviours from the species' repertoire or that the basic structure of the motor patterns for such behaviours has been changed, behavioural differences between wild and domestic stocks in nearly all cases are quantitative in character and best explained by differences in response thresholds of behaviour, such as to sexual stimuli, novel stimuli, humans and environmental conditions (Price, 2002). Certainly, in relation to maternal behaviour, domestic sows have retained a strong motivation to build a nest before parturition (Gustafsson et al., 1999) and studies in semi-natural conditions indicate that sows have retained the need to express maternal behaviour (Stolba and Wood-Gush, 1989, Špinka et al., 2000, Damm et al., 2002). From about 24 hours before parturition, nest building starts and becomes more intense between about 12 and 6 hours prepartum (Algers and Uvnäs-Moberg, 2007, Wischner et al., 2009a). Thus, the obvious welfare risk for the sow is confinement *per se*. While entry to either farrowing crates or farrowing pens results in an acute stress response in gilts based on cortisol concentrations (Cronin et al., 1991), gilts housed in farrowing crates had increased stress during the 24 h pre-partum period and parturition (Lawrence et al., 1994, Jarvis et al., 1998), but not the day following parturition (Cronin et al., 1991, Lawrence et al., 1994, Jarvis et al., 1998). In contrast, (Oliviero et al., 2008) found that multiparous sows in crates had similar cortisol concentrations prior to and during parturition.

Some authors, for example, Lawrence et al. (1994) proposed that this increased stress around parturition in farrowing crates is a consequence of the inability of sows to fully perform natural behaviours such as nest-building. However, it is difficult to determine the welfare consequences of an acute stress response around parturition, since parturition *per se* is associated with an increase in cortisol concentrations. While both Cronin et al. (1991) found no effects of housing gilts in farrowing crates during the first 3 weeks postpartum, they found higher concentrations at 4 weeks postpartum in farrowing crates than farrowing pens. This finding was supported by Jarvis et al. (1998). At least in gilts, any effects of farrowing crates on stress may be limited to the period around parturition and the later stages of lactation (that is, the 4th week post-partum). While concern for sow welfare has been linked with farrowing crate confinement because of a restriction in nest-building opportunity (Lawrence et al., 1994, Jarvis et al., 2002), there remains a lack of comparative data on multiparous sows.

It is clear that housing pre-parturient sows in farrowing crates without bedding/nesting material reduces their level of maternal behaviour, in particular pre-farrowing nest-building behaviour, compared with sows in more enriched environments (see Barnett et al., 2001). A major function of maternal behaviour in naturalistic environments is to minimise piglet mortality by providing a comfortable, thermally insulated environment for the sow and her litter that may also provide a degree of protect from predators. Thus, it could be argued that nest-building behaviour may be irrelevant to piglet survival in farrowing crates as the beneficial elements of a nest are also provided by an indoor crate, i.e. shelter, warmth and protection. Although the expression of maternal behaviour can vary between sows (Špinka et al., 2000, Andersen et al., 2005), it has been shown that sows with lower piglet mortality rates expressed more nest building behaviour (Andersen et al., 2005, Wischner et al., 2009b), were calmer during farrowing (Andersen et al., 2005) and were more careful during lying down movements (Burri et al., 2009). There is limited evidence that primiparous sows in loose farrowing and lactation housing systems have improved maternal behaviour, based on increased interactions with their piglets and increased responsiveness to piglet vocalizations (Cronin and Smith, 1992, Cronin et al., 1996, Thodberg et al., 2002b). An increase in maternal behaviour observed in loose farrowing and lactation housing systems may have welfare benefits for piglets because nest-building activity, response to piglet distress calls, nose contact with piglets during posture changes and restlessness when piglets are removed are reported to negatively correlate with risk of piglet crushing (Andersen et al., 2005).

Furthermore, several authors have proposed that a function of nest-building behaviour is to influence the course of parturition and thereby the survival of piglets (Cronin et al., 1993, Cronin et al., 1996). In a review of the literature, Yun and Valros (2015b) proposed that nest-building behaviour appears to be positively related to the parturition process and post-partum sow behaviour and piglet survival. Longer farrowing durations in sows in crates have been reported to be associated with higher stillborn rates in some but not all studies (see review by Baxter et al. (2017)). Higher incidences of savaging of piglets are reported when sows are confined in crates (Lawrence et al., 1994) and there is limited evidence suggesting that increased nest-building is associated with a faster farrowing process with fewer complications (Morrison et al., 2011). Higher oxytocin levels have been reported in sows provided with greater nest-building opportunities (Yun et al., 2013) with this research demonstrating greater suckling success for piglets as evidenced by greater IgG levels in piglets from loose-housed mothers (Yun et al., 2015a). Depriving or limiting sows of the opportunity to freely interact with their piglets appears to reduce their maternal responsiveness to piglets. In comparison to multiparous sows and their litters remaining in farrowing crates, transferring sows from farrowing crates to pens at 2 days post-partum resulted in increased sow–piglet interactions and increased maternal responsiveness based on the behavioural response of sows to audio recording of unfamiliar piglet screams (Singh et al., 2017). Similarly, Cronin et al. (1996) found that crated sows vocalise less towards their piglets when presented with an audio recording of a screaming piglet while (Thodberg et al., 2002b) found that sows in crates took longer to react as they moved to a lying position when an audio recording of a screaming piglet was played.

Therefore, confining primiparous sows at farrowing and/or denying them access to bedding/nesting material may induce an acute stress response, but the available evidence suggests that housing in a farrowing crate without bedding for at least for 3 weeks of lactation is not a potent stressor for sows. Research on the longer-term effects of housing in crates on stress physiology of multiparous sows is inadequate. However, depriving sows of opportunities to perform behaviours that appear to be highly motivated such as nest building and opportunity to freely interact with their piglets, presumably deprives sows of increased opportunity for positive emotional experiences. Thus, the housing of sows and piglets in farrowing crates is likely to remain contentious for some of the public.

More comprehensive research on sow welfare post-partum is required. One of the main difficulties in reviewing research on loose farrowing and lactation housing is the considerable variation in housing design features, including space and bedding, which may markedly affect sow welfare. In addition, this variation in housing also has the potential to impact significantly on the welfare of piglets. Furthermore, if farrowing crates are to remain a feature of intensive housing systems, then increasing minimum dimensions of the crate and the provision of nest building materials (straw) around parturition need to be seriously considered in order to improve sow welfare.

3.2.2 Implications of confinement of the sow on piglet welfare

While there is often discussion about the welfare implications of mortality *per se,* many causes of piglet mortality are a welfare concern because asphyxiation, starvation and physical trauma are likely to lead to negative affective states such as pain, fear and suffering (Edwards, 2002). Since sentience and consciousness are prerequisites of suffering (Mellor and Diesch, 2006), there is debate about piglet welfare when considering mortality associated with the birth process and the newborn piglet (Baxter and Edwards, 2017). Based on research by David Mellor and others, (Mellor and Diesch, 2006) it has been concluded that the embryo and fetus cannot suffer before or during birth because suffering can only occur in the newborn when the onset of breathing oxygenates its tissues sufficiently to substantially reduce the dominant adenosine inhibition of brain electrical activity. Therefore, as reviewed by Baxter et al. (2017), the least welfare concerns relate to those piglets that never develop full breathing (i.e., never gain full consciousness because they die during labour or immediately after), intermediate concerns relate to piglets that develop full breathing but descend quickly into hypothermia (and thus unconsciousness) and high concern relates to piglets that develop full breathing, are not hypothermic, but suffer deaths from hunger, injury or disease. It is this third group of piglets that have the potential to suffer for a considerable period. While stillborn piglets that are intrapartum deaths occurring just before expulsion is initiated, during expulsion or just after being born are of intermediate concern, it is particularly the third group of piglets that have the potential to suffer and to suffer for a considerable period.

While the design of alternate farrowing and lactation housing (loose housing) has largely focused on improving sow welfare by reducing confinement, there is increasing concern for how the different loose housing systems affect piglet welfare, as well as piglet performance (Ahmadi et al., 2011, Baxter et al., 2012). Pre-weaning piglet mortality has dropped from over 25% 30 years ago to less than 10% today (Garcia and McGlone, 2018). However, even at 10% pre-weaning mortality, over 100 million piglets die before weaning each year. Larger litters have been shown to have a greater number of smaller, at-risk piglets and crushing is a major cause of pre-weaning mortality (Nuntapaitoon and Tummaruk, 2015, Westin et al., 2015, KilBride et al., 2012). Solutions to reduce pre-weaning mortality have focused on the farrowing environment, sow genetics and management practices such as cross-fostering piglets among sows (Garcia and McGlone, 2018).

While there are concerns about the variability in pre-weaning piglet mortality in loose farrowing and lactation housing systems (Baxter et al., 2012, Moustsen et al., 2013), a contentious point with these housing systems is that live born piglet mortality is generally higher than in farrowing crates (Cronin et al., 2014). However, recent reviews of the literature have concluded that comparable levels of total piglet survival, one of the main economic parameters for evaluating alternatives to farrowing crates, have been achieved in some non-crate farrowing systems (Baxter et al., 2012, Morrison et al., 2011). A collation of a large database of literature by Baxter et al. (2012) indicates that pen systems designed to meet the animals' biological needs, such as separate dunging and lying areas and rails or sloped walls to assist sow posture changes and protect piglets, had a similar total piglet mortality (16.6%) to conventional farrowing crates (18.3%) and modified farrowing crates, such as turnaround/ellipsoid (16.3%) and hinged/swingside crates (17.4%). In a large comparative study in Switzerland (655 farms comprising 63,661 litters), (Weber et al., 2007) found no difference in total piglet mortality (stillbirths and live born deaths) between loose farrowing pens and farrowing crates (17.2% and 18.1% total mortality, respectively), but crushing was higher in loose pens and mortality due to other causes was higher in farrowing crates. Similarly, in a cohort study of 112 breeding farms in England (2143 litters, with 6.5% of piglets stillborn and 12% live born pre-weaning mortality), KilBride et al. (2012) found no difference in pre-weaning mortality or numbers reared between non-crated and crated systems. As in the study by Weber et al. (2007), more piglets were crushed when reared in non-crated systems and more piglets died of other causes in crated systems. It is difficult to make comparisons of systems in industry because of variation within systems in design features and variation both within and between systems in management, however these findings indicate that total piglet mortality in loose housing systems can be similar to that in conventional crated systems.

Since the majority of pre-weaning piglet mortalities occur within the first 2–3 days postpartum and are mainly caused by crushing (Johnson and Marchant-Forde, 2009, Cronin et al., 2014), there is interest in brief confinement of sows during parturition and early lactation. Recent research has shown that confinement only in early lactation is effective in maintaining the survival of live-born piglets (Moustsen et al., 2013, Pedersen et al., 2015, Hales et al., 2015, Singh et al., 2017, Condous et al., 2016); in comparison to confinement during parturition and the entire lactation, similar piglet survival was achieved when sows were confined either for parturition and the first 3–7 days postpartum or only during the first 3–7 days postpartum.

Transitioning to less restrictive systems means that loose farrowing and lactation housing systems may be used alongside farrowing crates within the same herd, which may result in sows being housed interchangeably between farrowing and lactation systems. There is evidence that interchanging sows between different farrowing and lactation systems affects maternal behaviour, however the subsequent effect on piglet mortality remains poorly understood (King et al., 2018). Whilst sow productivity is considered an individually stable trait, sow maternal behaviour is believed to develop over consecutive parities, with the previous farrowing environment influencing subsequent maternal behaviour (Jarvis et al., 2001, Thodberg et al., 2002b, a). A recent study by King et al. (2018) reported that inter-parity farrowing consistency is important for sow performance; returning sows to the same farrowing and lactation system reduced piglet mortality during second parity, whilst farrowing in a loose farrowing and lactation system during first parity significantly increased second parity litter size without increasing piglet mortality. Sows' experience with farrowing and lactation housing system and the subsequent effect on piglet welfare requires further investigation.

As discussed earlier, sows in loose farrowing and lactation systems show increased interactions with their piglets and responsiveness to piglet vocalisations (Cronin and Smith, 1992, Cronin et al., 1996, Thodberg et al., 2002b), which may have welfare benefits for their piglets. Maternal behaviour, such as nest-building activity, behavioural response to piglet distress calls, nose contact with piglets during posture changes and restlessness when piglets are removed, has been shown to be negatively correlated with the risk of piglet crushing (Andersen et al. 2005). Piglets reared in loose farrowing and lactation housing systems show more play behaviour and less injurious behaviour, such as nibbling, sucking or chewing another piglet (Oostindjer et al., 2011, Singh et al., 2017) and piglets reared in multi-litter group lactation systems are less aggressive post-weaning (Li and Wang, 2011, Verdon et al., 2016). Thus, rearing in farrowing crates, either directly or more likely indirectly through the maternal behaviour of the sow, may adversely affect the social development of piglets.

Multi-litter group lactation systems, which utilise a "two-stage farrowing system", may provide the benefits of a loose farrowing housing (single-litter) whilst also protecting piglets when they are at the greatest risk of crushing (Marchant-Forde et al., 2000). In a two-stage farrowing system sows and their litters are transferred to group lactation pens after an initial period of single-litter housing, Verdon et al. (2016) found that in comparison to single-litter lactation piglets, group lactation piglets had reduced aggression and skin injuries post-weaning, however they also had a lower growth rate during lactation. Li and Wang (2011) found that piglets raised in multi-litter group lactation systems were less aggressive than those raised in single-litter systems after being mixed post-weaning into small groups containing familiar and unfamiliar piglets. Grimberg-Henrici et al. (2016) reported that group-housed lactating sows had stronger maternal reactions in their home pen to distress calls from their separated litter and fewer crushed piglets. Recently, (van Nieuwamerongen et al., 2015) found that when compared to single-litter farrowing crate piglets, multi-litter (group-housed) piglets showed greater feed-directed behaviour during early lactation, had a higher feed intake in the early post-weaning period, had a more solid fecal consistency after weaning, showed a higher post-weaning weight gain, and displayed more play behaviour and less damaging oral manipulation of other pigs (including tail biting and ear biting). Thus, while two-stage farrowing systems provide sows with greater opportunity for movement, interactions with their piglets and social interactions with other sows, there is also limited evidence suggesting that these systems may benefit piglet survival and behavioural development. Long-term effects of group lactation housing on both sows and piglets needs further investigation.

The benefits of improved piglet welfare during lactation may well persist beyond weaning (Chaloupková et al., 2007, Oostindjer et al., 2011, Martin et al., 2015). However, Verdon et al. (2016) found that piglets reared in enriched single litter, loose sow pens were just as aggressive in the 2 h post-mixing at weaning as those reared in farrowing crates. The long-term effects of sow lactation housing on piglet social behaviour may benefit from more research.

Whilst the literature is lacking in pigs, there is increasing evidence of the importance of early experiences, such as maternal behaviour, on an animal's stress resilience later in life. The review by McEwen (2007) outlines the profound long-term effects early maternal care in rodents and non-human primates has on the offspring. In summary, strong maternal behaviour, which may include interactions such as licking and grooming of the offspring, produces a "neophilic" animal that is more exploratory of novel environments, less emotionally reactive and produces a lower and more contained glucocorticoid stress response in novel situations; poor maternal care leads to a "neophobic" phenotype with increased emotional and HPA reactivity and less exploration of a novel situation. Maternal behaviour has been found to affect offspring cortisol and serotonin levels in non-human primates (Maestripieri et al., 2007, Onyango et al., 2008) and experiences in early life can have lasting implications for later temperament measures in rodents, such as stress reactivity and fear (Meaney et al., 1988, Davis et al., 2004), and cognitive skills, such as spatial memory (Liu et al., 2000). The effect of early experience on stress resilience, emotionality and welfare in pigs later in life warrants further examination.

3.2.3. Barren environments

Environmental enrichment and alternative housing systems can provide benefits for both sows and piglets (see review by Vanheukelom et al. (2012)). As discussed in sections 3.2.1. and 3.2.2, providing opportunities to engage in explorative behaviour, nest-building and social interactions and improving maternal responses provides enrichment for both sows and their piglets. Social enrichment, increased space allowance and/or straw provide positive welfare outcomes, however they are not always practical to implement and raise other potential risks and concerns. Little is known about the effectiveness of enrichment using point-source enrichment-objects in the farrowing housing.

Pre-weaning feeding of piglets can be stimulated using a specially designed feeder for unweaned piglets (Kuller et al., 2010) or by intermittent suckling by removing the sow for several hours per day (Berkeveld et al., 2009). Alternative farrowing systems that provide enriched environments for both the sow and the piglets are multi suckling and get-away systems, with the former reducing stress and aggression around weaning due to the improvement in social skills of the piglets but little effects on feed intake (Bohnenkamp et al., 2013). The PigSAFE system, which provides additional space and straw bedding, increases play behaviour, social behaviour and sow-piglet interactions in piglets and reduces chronic aggression post-weaning (Martin et al, 2015). Increasing interaction of piglets with the sow, especially around a communal feed, and access to enrichment such as straw, both stimulate post weaning feed intake (Oostindjer et al., 2014).

Recently, (van Dixhoorn et al., 2016) compared disease development between piglets reared in environmentally and socially enriched pens (10m^2 pen, partly slatted (40%) and partly solid (60%) floor) and piglets reared in barren, stimulus-poor housing conditions (5 m^2 pen, 100% slatted floor with a 100x45cm solid rubber floor mat); enriched pens were provided with rooting substrate (1 kg straw, 160 L of moist peat and 180 L of wood shavings), jute bags, branches of a broom, and chains with blocks, while the barren pens were only provided with the chains with blocks. Enriched rearing led to a less severe onset and outcome of Porcine Reproductive and Respiratory Virus (PRRSV) and Actinobacillus pleuropneumoniae (A. pleuropneumoniae) co-infection, with enriched pigs showing reduced impact of infection and were less prone to develop clinical signs of disease. Furthermore, when compared to the barren housed piglets, piglets provided with enrichment performed less stress-related behaviour and had lower skin lesion scores (van Dixhoorn et al., 2016).

Research on the effects of environmental enrichment during the farrowing and lactation period with regard to both the sow and her piglets is still required.

Conclusions, recommendations and further research on farrowing/lactating sows and their piglets

As with housing sows during gestation, some of the inconsistencies in the literature on the effects of farrowing and lactation systems may be due to differences among studies in intrinsic sow factors as well as differences in the specific design of the systems. Nevertheless, it is clear that housing pre-parturient sows in farrowing crates without bedding/nesting material reduces their level of maternal behaviour, in particular pre-farrowing nest-building behaviour, in comparison to sows in more enriched environments. While confining sows, at least primiparous sows, at farrowing and/or denying them access to bedding/nesting material may induce acute stress, the limited evidence suggests that housing sows in farrowing crates without bedding is not a potent stressor for at least 3 weeks of lactation. However, housing beyond 3 weeks of lactation in farrowing crates may be stressful for sows.

Alternative loose farrowing and lactation environments can provide sows with bedding and thus increased opportunity to perform nest building and to freely move about and interact with their piglets during lactation. However, these loose farrowing and lactation systems require extra floor space and can lead to an increased risk of piglet crushing.

Many causes of piglet mortality are a welfare concern because asphyxiation, starvation and physical trauma are likely to lead to negative affective states such as pain, fear and suffering. While there is evidence that total overall piglet losses (stillbirths and live born deaths) may be similar with loose farrowing pens and farrowing crates, crushing of live born piglets is often higher in loose pens. Piglets that develop full breathing but descend quickly into hypothermia and thus unconsciousness and, to a lesser extent, piglets that never develop full breathing are less of a welfare concern. However, piglets that develop full breathing, are not hypothermic, but suffer deaths from hunger, injury or disease are a greater welfare concern. Thus, any farrowing and lactation housing system needs to safeguard liveborn piglet mortality during the first few days post-partum when liveborn piglet mortality is at most risk.

While there will be continuing development of the farrowing and lactation housing systems during parturition and early in lactation, as well as the remainder of lactation to safeguard sow and piglet welfare, any farrowing and lactation housing system will need to be economical for large-scale commercial production. There is general agreement in the literature that the maternal characteristics of sows and the quality of stockpersonship will be integral to the success of loose farrowing and lactation systems. Thus, from a welfare perspective, farrowing crates and loose housing systems have both advantages and disadvantages. Further research examining the implications of confinement in a crate without bedding/nesting material on stress physiology of multiparous sows is required. Furthermore, opportunities to facilitate sow maternal behaviour, particularly sow-piglet interactions in crates requires investigation, since providing opportunities for increased sow-piglet interactions may be beneficial for piglet welfare.

Clearly the likely on-going development of loose farrowing and lactation systems, both single and group litters, needs to be cognisant of minimising piglet mortality. So-called hybrid systems or temporary crate systems such as SWAP Pens in which when used correctly the intention is that sows are loose for nesting but then confined at parturition and during the first few days post-partum when liveborn piglet mortality is at most risk, provides at least in the medium term an alternative system that addresses many of the most serious sow and piglet welfare concerns with farrowing crates and loose housing systems.

3.2.4 Painful husbandry procedures: Piglets

Newborn piglets reared in commercial production experience a number of painful husbandry practices early in life, including castration, tail docking, tooth clipping, vaccinations and ear tagging or notching (Telkänranta and Edwards, 2018). These early procedures are some of the most significant interactions that pigs have with humans, however they are generally of a negative nature. Following these husbandry procedures, piglets demonstrate signs of distress as seen by extreme behavioural reactions and elevated levels of cortisol in the blood (Sutherland, 2015a). However, the extent to which these early-life stressors have long-term consequences is not well known. For example, piglets that have undergone tail docking show increased fearfulness to human in a voluntary human approach test carried out two weeks after the procedure (Tallet et al., 2016). In addition, there is increasing pressure from animal welfare groups to provide pain relief for these elective husbandry procedures in piglets. The Australian RSPCA's position is "that any procedure that may cause pain to the animals should be undertaken at the earliest possible age and only by competent and accredited operators. Appropriate pain-relieving products and treatments, and/or anaesthetics, must be used" (RSPCA, 2016).

Pain is difficult to study because it is an inherently subjective experience and only indirect indices of pain are available for use in animals. Like welfare, pain can be assessed in animals using a range of physiological and behavioural measures. The physiological response is measured by assessing total cortisol concentrations post-stressor to determine activation of the HPA axis (see review by Barnett and Hemsworth (2009)). Glucocorticoids are generally accepted as a measure of stress (Barnett, 2003), however, non-painful components of a surgical husbandry procedure such as restraint, isolation, and the presence of humans may also increase cortisol concentrations. Furthermore, glucocorticoids also have anti-inflammatory and immunosuppressive properties in response to tissue injury (Yeager et al., 2004). The behavioural response is assessed by behavioural indicators of pain such as vocalisation, escape attempts and standing with head lowered (Hemsworth et al., 2009, Hay et al., 2003). The neurophysiological responses (activity of the cerebral cortex) of the animal, recorded by electroencephalographic (EEG) responses recorded using a minimal anaesthesia model have been successfully used to assess nociception in a range of domesticated mammals (Johnson, 2007)(Johnson et al., 2005a; Johnson et al., 2005b) and are now used in combination with behavioural and physiological responses of the animals to measure pain.

The pain and welfare risks associated with performing elective husbandry procedures on piglets remain controversial and warrant further research into alternative strategies.

NB. Anesthetics are a diverse group of drugs that are used in the management of pain. The administration of anesthetics is necessary to provide inhibition of individual pain pathways (local anesthesia) or to render a patient unconscious to enable surgical procedures to be carried out (general anesthesia) (Rang et al., 2003). Analgesics (also known as pain-killers, OTC or NSAIDs) are medications designed to relieve the symptoms of pain.

3.2.4.1 Castration

3.2.4.1.2 Standards

	Castration Standards
Australia	Surgical castration of male pigs older than 21 days must be performed under anaesthesia and by a veterinary practitioner
Canada	Castration performed at any age must be done with analgesics to help control post-procedure pain, castration performed after 10 days must be done with anaesthetic and analgesic to help control pain
UK	Male pigs may be castrated provided the means employed do not involve tearing of tissues If castration is carried out after the seventh day of life it shall only be done by a veterinarian surgeon.
New Zealand	Surgical castration at any age must be carried out by a veterinarian
EU	If castration of piglets is carried out, pain relief must be administered prior to the procedure taking place within seven days of birth. Anaesthetic required for pigs castrated after seven days of birth

The Australian Model Code of Practice for the Welfare of Animals – Pigs requires the surgical castration of pigs older than 21 days of age be performed under anaesthesia and by a veterinarian. The New Zealand Animal Welfare (Care and Procedures) Regulations (2018) recommends that surgical castration should not be performed, however if it is (on pigs at any age) it must be performed by a veterinarian, and it recommends that pain relief should be provided (as with any elective husbandry procedure). The Canadian Code of Practice for the Care and Handling of Pigs states that as of July 2016, castration performed at any age must be performed with analgesics to help control post-operative pain. According to the EU Council Directive 2000/120/EC, surgical castration performed after 2012 should be done so with anaesthesia and/or prolonged analgesics and as of January 1st, 2018 surgical castration of pigs should be abandoned. However, the uptake of this directive has been inconsistent amongst different countries within the EU. The UK Codes of Recommendations for the Welfare of Livestock: Pigs requires castration to not involve tearing of tissues, and if performed in piglets older than 7 days of age it must be by a veterinarian. However, in the UK castration is generally not performed and pigs are slaughtered at a younger age to reduce the incidence of boar taint.

Castration of male pigs is a management practice widely performed as a preventative measure against boar taint (Lundström et al., 2009) and post-pubertal aggression in male pigs (Rydhmer et al., 2010). Castration prevents the production of androstenone and skatole, that are both linked to boar taint in pig meat (Čandek-Potokar et al., 2017). However, castration also stops the production of testicular hormones such as testosterone and estrogens, which negatively affects the feed conversion efficiency and lean tissue growth (Prunier et al., 2006). Most of the European countries, as well as the USA and China routinely perform surgical castration. Most commonly surgical castration is performed by farmers without the use of analgesics or anaesthetics (EFSA, 2004, Prunier et al., 2006). There is growing scientific literature on negative welfare implications of surgical castration due to the acute pain caused during the procedure and prolonged post-operative pain that can last for several days (Rault et al., 2011, von Borell et al., 2009, Prunier et al., 2006).

In both Australia and New Zealand male pigs are slaughtered at lower body weights before they reach sexual maturity in order to avoid the use of castration (Sutherland, 2015b). However, anecdotal evidence suggests that Australian farmers that castrate male pigs do so using surgical castration without anaesthetics or analgesics. Recent work on consumer attitudes, primarily from European countries has reported increasing consumer concern over the use of surgical castration due to the pain and stress associated with the procedure (McGlone et al., 1993, Sutherland et al., 2010, Rault et al., 2011). Whilst the continued use of surgical castration needs to be reconsidered, it is difficult to implement a cessation of the practice because at present none of the alternatives are economically viable at a commercial level.

The most common castration method is the surgical removal of the spermatic cord using a scalpel blade and the procedure takes approximately 1-2 minutes (Marchant-Forde et al., 2009). Surgical castration in young pigs generally results in a short-term moderate acute stress response and castration, based on behavioural indicators, is painful for piglets at any age. Castrated piglets vocalised more frequently during treatment than sham-castrated piglets (Taylor et al., 2001). Castration also reduces sucking and standing and increases lying for 6 hours (McGlone et al., 1993), increases standing or sitting and reduces lying for 2 hours (Taylor et al., 2001) and reduces sucking and massaging the udder for 2.5 hours, increases inactivity while awake for 2.5 hours and increases scratching and tail wagging for 24 hours (Hay et al., 2003). White et al. (1995) found piglets castrated without lidocaine had a higher heart rate and higher frequency of highest energy (HEF) measurements of vocalization than those castrated with pain relief, and that castration without anesthetic is of greater stress for pigs 8 d of age or older. Castration increases plasma ACTH and cortisol concentrations from 5 to 30 minutes and from 15 to 90 minutes, respectively (Prunier et al., 2005), while plasma cortisol concentrations were still elevated at 24 hours (Carroll et al., 2006). In contrast, no effects of castration have been found on nursing, lying, standing or sitting during the first 2 hours after treatment (Carroll et al., 2006) and on urinary corticosteroids and catecholamines concentrations from 1 to 4 days following castration (Hay et al., 2003). Age at castration within the range of 1 to 20 days appears to have little influence on behaviour (McGlone et al., 1993; Taylor et al., 2001) or cortisol concentrations (Carroll et al., 2006).

Most studies have shown little or no effects of castration on growth. McGlone et al. (1993), Hay et al. (2003) and Carroll et al. (2006) found no effect of castration on weight gain, but Kielly et al. (1999) found that castration at 3 days of age but not 10 days temporarily reduced weight gain in piglets.

3.2.4.1.2 Pain relief post-surgical castration

Whilst a number of anaesthetics and analgesics have been explored as potential pain-relief post-routine husbandry procedures, there are currently no effective and affordable options for use in a commercial setting (McGlone et al., 1993, McGlone and Hellman, 1988, White et al., 1995, Jäggin et al., 2006, Sutherland et al., 2010). Pain relief for castration can be divided into general anaesthetics, local anaesthetics and analgesics (von Borell et al., 2009). Several studies have explored the use of injectable general anaesthetics such as a cocktail of xylazine, ketamine and glyceryl guaiacolate injected intravenously (McGlone and Hellman, 1988), ketamine and azaperone injected intramuscularly (Schmidt et al., 2012), and intravenous injection of thiopentone (Waldmann et al., 1994). However, these studies reported a number of limitations for the use of general anaesthetics as pain-relief post-castration, including insufficient pain relief, time consuming, expensive and delayed piglet recovery. The long recovery period was also associated with increased piglet crushing and reduced feed intake.

To overcome the limitations of general anaesthetics, a number of studies have explored the use of local anaesthetics injected directly into the testicles and subcutaneous tissues around it (White et al., 1995, Horn et al., 1999). However, most anaesthetic substances are governed by strict national regulations that mandate their administration by a certified veterinarian (Gottardo et al., 2016). The use of inhalant gases such as nitrous oxide (Rault and Lay, 2011), CO_2 (Kohler et al., 1998b, Gerritzen et al., 2008) and isoflurane (Walker et al., 2004) have been investigated, however, they provide limited post-operative pain relief. An in-depth review of literature on pain management practices for routine husbandry procedures in piglets suggested that the risks (including body weight dependant efficacy, inconsistent protocols, lack of applicator skills and the likelihood of anaesthetic overdose) associated with the use of CO_2/O_2 for general anaesthetics outweigh the benefits (O'Connor et al., 2014). In another study nitrous oxide was shown to be an effective anaesthetic during handling of piglets, however it provided limited post-operative pain relief following castration (Rault and Lay, 2011).

Non-steroidal anti-inflammatory drugs (NSAIDs) are becoming licensed for use in food-producing animals and are often the preferred option to address pain associated with elective husbandry procedures such as surgical castration. The relatively long-acting meloxicam is a NSAID that becomes effective approximately 30 to 60 minutes after administration. Meloxicam is registered and recommended for use in Canada and the EU for surgical castration of piglets (European Declaration, 2010). In Australia, meloxicam is registered for use in reducing symptoms associated with locomotor conditions and inflammation in pigs. Meloxicam has been shown to significantly reduce behavioural markers of pain in piglets one day post-castration (Keita et al., 2010, Hansson et al., 2011). Kluivers-Poodt et al. (2013) found meloxicam to be an effective form of pain-relief for castrated piglets even when the practice was performed without anaesthetics. This study also found that piglets given only local anaesthetics showed increased tail wagging in the days following castration, however, this effect was mitigated when meloxicam was given along with local anaesthetics (Kluivers-Poodt et al., 2013). The review by (O'Connor et al., 2014) suggests that NSAID's such as meloxicam, flunixin, meglumine and carprofen, pose minimal safety risk, however, there is limited evidence in the literature on long-term pain mitigation. Furthermore, the authors point out that limited markers have been used to test different pain-relief options following castration. For example: McGlone et al. (1987) used behavioural measures (nursing, standing, lying, coordination), Hansson et al. (2001) used behavioural measures (running, playing, sitting etc.), serum amyloid and skin temperature and Langhoff et al. (2009) measured cortisol at different timepoints until 24 hours post castration. This highlights the need for future research focusing not only on the long-term consequences of providing pain-relief but also evaluating its efficacy using a more comprehensive panel of stress markers (i.e. physiological, neurophysiological and behavioural). As such Coetzee (2013) reported that meloxicam acts on cytokines and hence is effective mainly in reduced inflammation related pain and would not work on procedural pain, which acts via nerves in the tissue.

3.2.4.1.3 Immunocastration

The most commonly available and effective alternative to surgical castration is an active immunisation against gonadotropin releasing hormone (GnRH); also referred to as immunocastration (Caraty and Bonneau, 1986, Dunshea et al., 1993). The main advantages of immunocastration include no pain or wound associated with castration, better production performance in terms of a more favourable feed conversion (Dunshea et al., 2001, Turkstra et al., 2002, Cronin et al., 2003, Jaros et al., 2005) and a higher percentage of lean meat (Jaros et al., 2005) compared to surgically-castrated pigs, reduced sexual and aggressive behaviour compared to entire males (Cronin et al., 2003, Velarde et al., 2007b), and the procedure is applicable to production systems with long fattening period (Thun et al., 2006). The most commonly used and effective vaccine for immunocastration is Improvac® (also referred to as Improvest® in the United States), which was developed in Australia (Zoetis, Parkville, Victoria, Australia). Improvac® was first authorized for commercial use in 1998 in Australia and New Zealand, and since then it has been used in many countries, including the EU which approved its use in 2009 (Batorek et al., 2012a). There are approximately 1.3 million pigs that are immunocastrated each month worldwide using the Improvac® vaccine (Zamaratskaia and Rasmussen, 2015a). Despite of the obvious benefits of immunocastration in place of surgical castration its adoption for commercial use in Australia and elsewhere remains modest (Dunshea et al., 2001). The limited commercial uptake may be due to vaccination costs (vaccine and labour), uncertainties regarding consumer/market acceptance of the method, the additional cost of screening at slaughter line to detect individuals with failed vaccination, accidental self-injection by stockperson, and lack of adequate return for boar taint-free pork (Prunier and Bonneau, 2006, Prunier et al., 2006, de Roest et al., 2009). Immunocastration may also adversely affect animal welfare, due to increased aggression and mounting displayed by pigs as they are physiologically entire males up until they receive the second dose of vaccination (Andersson et al., 2012, Rydhmer et al., 2010).

Research is ongoing in order to make immunocastration a reliable commercial alternative to surgical castration. A number of studies have investigated modified vaccination schedules, whereby pigs are vaccinated earlier (pre-pubertal or early-pubertal) in order to prevent farmers from handling heavy pigs (Einarsson, 2006, Andersson et al., 2012, Brunius et al., 2011). These studies have found no difference in the growth performance and carcass quality of early vaccinated boars to the entire males. Furthermore, Anderson et al. (2012) found that early vaccination may result in better welfare outcomes for pigs as the heightened aggression and sexual behaviour often seen in immunocastrates can be controlled earlier. Immunocastration increases feed intake post immunisation, which may lead to immunocastrates being fed a restricted diet to ensure carcass leanness. However, immunocastrates fed on a restricted diet have been found to have more carcass lesions than immunocastrates fed ad libitum (Batorek et al., 2012b).

Based on our current knowledge of immunocastration it can be suggested as a viable alternative to surgical castration, however further research is still needed on a range of factors; the vaccination regime to control aggression in boars prior to revaccination, increasing the quantity of lean meat, and as increasing cost efficiency facilitate use in a commercial environment.

3.2.4.2 Genetic selection

The levels of androstenone and skatole in adipose tissue is determined by both genetic factors and breed. Studies have shown that between 5-8% of purebred Hampshire, Yorkshire and Landrace boars and 50% of Duroc boars have high androstenone concentrations in adipose tissue (Zamaratskaia and Squires, 2009, Xue et al., 1996, Pedersen, 1998, Hortos, 2000, Doran et al., 2002). Tajet and Andresen (2006) showed positive genetic correlation between skatole and androstenone for both Landrace and Duroc, possibly due to the interaction between androstenone and skatole metabolism (Doran et al., 2002, Zamaratskaia and Squires, 2009). These findings suggest that genetic selection against one boar-taint compound may result in overall reduction of boar-taint in some breeds. Earlier attempts at selection against androstenone has resulted in overall reduction of androgens and estrogens, which lead to decreased performance and delayed sexual maturity (Willeke et al., 1987). A selection of boars with reduced capacity to accumulate androstenone in fat while maintaining normal levels of testosterone may be a more efficient way of selecting against boar-taint. In addition, further research to identify candidate genes for boar taint and to develop genetic markers for low boar taint would be beneficial.

3.2.4.3 Raising entire males

Entire males reportedly have a more efficient feed conversion as well as leaner carcasses, which in turn is economically beneficial. It is also believed that higher protein content in meat from entire males may be nutritionally better than that from castrates (Zamaratskaia and Rasmussen, 2015b). However, raising entire males is associated with poor pork quality as well as negative welfare outcomes. Increased aggression and sexual behaviour in entire males has been associated with increased skin lesions (and thus reduced market value) and management difficulties (Zamaratskaia and Rasmussen, 2015a). In countries such as Great Britain, Ireland and Spain where entire males are slaughtered at lower weight or before attaining sexual maturity, boar-taint is not a serious concern (de Roest et al., 2009). Even though Australia has a similar practice, studies from Australian commercial farms have found poor correlation between boar taint and weight at slaughter (D'Souza et al., 2011), and the prevalence of boar taint has been reported at multiple sites in Australia (Hennessy et al., 1995). In the face of a voluntary ban on castration in EU by the start of 2018, Borrisser-Pairó et al. (2016) conducted a survey of stakeholders in a Spanish pork supply chain and found positive attitude towards the voluntary ban as the use of castration was already decreasing. However, it was recognised that specialised breeds such as Iberian should be given an exception to the ban and alternatives to surgical castration should be explored in that breed. Most importantly for butchers that produce high quality traditional meat with high intramuscular fat content, it is essential to explore alternatives to surgical castration rather than banning it altogether (Borrisser-Pairó et al., 2016).

3.2.4.4 Tail docking

	Tail Docking Standards
*Australia**	Tail docking should be avoided wherever possible. *Where tail docking is practised as a preventative measure, it should be carried out before pigs are seven days of age.*
Canada	*Tail-docking performed at any age must be done with analgesics to help control post-procedure pain*
UK	Tail-docking shall not be carried out routinely but only where there is evidence that injuries to sows' teats or to other pigs' ears or tails have occurred: No tail docking may be carried out unless other measures to improve environmental conditions or management systems have been taken in order to prevent tail biting or other vices. *If docking of tails is carried out after the seventh day of life it shall only be performed under anaesthetic and additional prolonged analgesia by a veterinary surgeon.*
New Zealand	*Tail docking of pigs over seven days of age must be carried out by a veterinarian*
EU	Tail docking of piglets is allowed if there is documentation that tail injuries in the herd can be attributed to omission of tail docking. If tail docking is necessary, no more than half the tail may be docked and it must be carried out between the piglet's second and fourth day of life. *If docking of tails is practised after the seventh day of life, it shall only be performed under anaesthetic and additional prolonged analgesia by a veterinarian.*

*these are guidelines/recommendations

3.2.4.5 Teeth clipping

	Teeth Clipping Standards
*Australia **	Qualified advice should be sought to determine if teeth-clipping is necessary. This procedure should not be routinely required. If aggression between littermates or damage to the sow are a problem, this procedure should be carried out within three days of birth. It should only be done where unacceptable injury is occurring to littermates and the sow's udder. *Only the tips (no more than a quarter) of the teeth should be removed.*
Canada	*The need to clip piglets' teeth must be evaluated, and the procedure performed only when deemed necessary*
UK	Teeth grinding / clipping shall not be carried out routinely but only where there is evidence that injuries to sows' teats or to other pigs' ears or tails have occurred: Uniform reduction of corner teeth of piglets by grinding or clipping not later than the seventh day of life of the piglets leaving an intact smooth surface; *No tooth reduction may be carried out unless other measures to improve environmental conditions or management systems have been taken in order to prevent tail*
New Zealand	*Clipping or grinding of needle teeth must be carried out before five days of age.*
EU	If necessary, the eye teeth of the piglets may have their sharp point removed by grinding within the first three days of life *EU - a uniform reduction of corner teeth of piglets by grinding or clipping not later than the seventh day of life of the piglets leaving an intact smooth surface*

*these are guidelines/recommendations

3.3 Weaner and growing-finishing pigs

The weaner period is defined as a week or two post-weaning. Growing-finishing pigs are those pigs of a post-weaning age kept for slaughter. These pigs make up the majority of the world pig population of approximately 1 billion (latest figures from FAOstat accessed on 10 March 2018). There are a number of recent reviews on the welfare of growing-finishing pigs including O'Connell (2009), Amory (2018) and (Verdon and Rault, 2018).

3.3.1 Floor space and group size

Growing-finishing pigs are typically housed in groups on fully slatted pens or partly slatted pens with either dry feed ad libitum or liquid feed. At present the Australian Model Code of Practice for the Welfare of Animals – Pigs requires a space allowance of 0.14 m^2 to 0.74 m^2/pig (weight: 10-120 kg). The Canadian Code of Practice for the Care and Handling of Pigs stipulates that pigs require 0.16 m^2 to 0.95 m^2/ pig on fully or partially-slatted floors (weight: 10-150 kg) or 0.18 m^2 to 1.10 m^2 on solid bedded floor (weight: 10-150 kg). In accordance with the EU Council Directive 2008/88/EC, all growing-finishing pigs must have a space allowance of at least 0.1m^2 to 0.65 m^2/pig (weight: 10-110kg). In comparison, the UK's Codes of Recommendations for the Welfare of Livestock: Pigs standards require 0.15 m^2 to 1.0 m^2/pig (weight: 10-100kg and more). The New Zealand Animal Welfare (Pigs) Code of Welfare and Animal Welfare (Care and Procedures) Regulations require that at all times a grower pig has an unobstructed floor space in which it can lie down, of which the minimum lying space is no less than the area calculated from the following formula: $a=0.03xb^{0.67}$ where a is the minimum area (in m^2) and b is the weight of the pig in kg. Space allowance recommendations for growing-finishing pigs appear relatively consistent across countries.

Many of the welfare problems found in growing-finishing pigs can be attributed, either directly or indirectly, to inadequate space allowance (O'Connell, 2009). The relationship between animals and space can be defined in terms of space allowance per animal (m^2/animal) or stocking density (number of animals/m^2) (Petherick, 1983). Whilst both measures are mathematically equivalent, they may differ substantially in terms of the ethological impact on the animal. Pigs require sufficient space to lie down in a fully recumbent position, maintain discrete pen areas for feeding, lying and dunging, and be afforded opportunity to perform species-specific behaviours (Petherick, 1983; Baxter, 1984; O'Connell, 2009).

Space allowance for growing-finishing pigs is less contentious than for breeding sows, probably because the effects of inadequate space allowance on pig productivity are both well studied and easier to demonstrate (O'Connell, 2009). Spatial restriction of growing-finishing pigs can result in reduced access to feeders, increased stress and consequently reduced growth performance, and as such will also have adverse welfare implications.

Inadequate space allowance in growing-finishing pigs has traditionally been assessed by assessing effects on production. Bond et al. (1962) reported that rate and efficiency of weight gain increased as space allowance was increased from 0.45 to 0.90 to 1.80m^2/pig for groups of 3, 6 and 12 pigs. Similarly, Wingert and Knodt (1960) reported that during the finishing period pigs in groups of 49 provided with 1.32 and 1.76 m^2 of floor space/pig gained weight 24 and 31% faster, respectively than those allowed 0.88 m^2. More recently, Gehlbach et al. (1996) recommended minimum floor space allowance for growing pigs of 0.27 to 0.72 m^2 for pigs housed on slatted floors (weight: 11-95 kg) and 0.36 to 1.08 m^2 for pigs housed on solid floor (weights: 11–95 kg). A study by Jensen et al. (2012) also found that there was no evidence that productivity or pen hygiene were improved by increasing the space allowance of growing pigs from 0.67 m^2/pig to 0.79 m^2/pig in well-managed commercial pig systems (housed in non-bedded part-slatted pens, 1/3 solid floor, permanent access to wooden sticks as a manipulable substrate) and suggested that such an increase would be costly to producers. Turner et al. (2000) found no benefit in performance would be gained from increasing space allowance from 32 kg/m^2 for growing pigs housed on deep litter, however evidence for greater aggression and the depressed immune response to a novel antigen when housed at 50 kg/m^2, supports the use of a larger space allowance.

The literature indicates that space allowance and group size do not interact, suggesting that there is no need to specify different space requirements for growing pigs in large or small groups (Turner et al., 2000). It was suggested by Petherick (1983) that behavioural and performance indicators of stress attributable to a large group size would only become apparent when floor space allowance was below a threshold level. Evidence has been presented which suggests that stress was associated with a reduction in space allowance from 32 kg/m^2 to 50 kg/m^2 (Turner et al., 2000). McGlone and Newby

(1994) described mathematically the relationship between group size and unused space where the area of unused space per pig was found to increase in proportion to group size. From their calculation, animals in groups of 80 would be expected to have 36% more unused space per individual, then would animals in a group of 20. Thus, the stressful experience of being housed with many other individuals may have been minimised by the opportunity to avoid aggressive individuals provided by the greater pen dimensions and the greater free space which is actually available per pig in the large groups. Alternatively, the structure of social organisation in large groups may change from that based on a dominance hierarchy through physical assessment of fighting ability and individual recognition (Edwards and Turner, 2000).

Little is known about the relationships between aggression in recently weaned pigs and features of pen design or management (see review by (Verdon and Rault, 2018)). The limited literature suggests that aggression post-weaning is not affected by floor space allowance when pigs are mixed into pairs or small groups (0.35-0.72 m^2 per pig, Spicer and Aherne (1987)). However, group size was confounded with space allowance in this study. When space allowance is kept constant, increasing weaning group size from 6 to 12 pigs reduced the linearity of the hierarchy (Fels et al., 2014), however increasing group size to between 10 and 60 pigs had no effect on aggression for the 24 hours post-mixing (O'Connell et al., 2004).

The effect of space allowance on the aggressive behaviour of growing pigs in the period immediately following mixing requires further investigation. There is no evidence of increased aggression at mixing in large groups of growing pigs (5-20 pigs Nielsen et al. (1995); 10-80 pigs Schmolke et al. (2004)). Neither the provision of straw on the pen floor (Arey and Franklin, 1995) or the presence of food and/or water (McGlone, 1986) affect levels of aggression after mixing growing pigs.

Studies on the relationship between floor space allowance and aggression in growing pigs vary considerably in terms of the age and housing conditions of pigs (see review by (Verdon and Rault, 2018)). When group size is controlled for, general levels of agonistic behaviour between growing pigs increases as space allowance decreases (0.56-1.19 m^2/pig, Ewbank and Bryant (1972), but space allowance does not affect aggression related to competition for feed (Ewbank and Bryant, 1972, Meunier-Salaun et al., 1987, Scollo et al., 2014). As is the case with sows, space allowance (0.33-0.64 m^2/pig) has a greater effect than group size (range 5-20 pigs/pen) on the aggressive behaviour of growing pigs once the hierarchy has been formed, and there is no interaction between the two variables (Randolph et al., 1981). There is a considerable body of research in the young pig indicating that aggression is not affected by group size in the range of 6 to 80 pigs (Turner et al., 1999, Turner et al., 2000, Samarakone and Gonyou, 2009). As with gestating sows, in growing-finishing pigs other factors such as genetics, floor space and competition for feed or feeding space may have a greater impact on aggression, injuries and stress than does group size.

Space allowance has been reported as a crucial risk factor for tail biting (Schrøder-Petersen and Simonsen, 2001), however studies have produced inconsistent results, with most reporting no effect (D'Eath et al., 2014). (Munsterhjelm et al., 2015a) reported a more or less linear effect of space allowance, ranging from 0.7 to 1.5 m^2 on reducing the prevalence of tail damage, and Scollo et al. (2016) found a high stocking density increased the risk of tail biting damage in heavy pig production. Finnish farmers in the study by Valros et al. (2016) ranked restricting animal density as the 11th most important preventive measure for tail biting, while the Dutch farmers in the study by Bracke et al. (2013) rated space allowance as the second most important risk factor. With regard to group size, past research does not indicate a significant effect on tail biting (D'Eath et al., 2014), however a recent study on long-tailed pigs indicated that the risk for tail biting increased when pigs were housed in groups of more than 10 pigs per pen (Palander, 2016).

3.3.2 Barren environments

Effective enrichment should decrease the incidence of abnormal behaviour and increase the performance of behaviours such as exploration, foraging, play, and social interaction, which are within the range of the animal's, normal, species-specific behaviour (Chamove, 1989, Mench, 1994, Markowitz et al., 1995, Van de Weerd and Baumans, 1995) and, as has been found in rodents, promote stress adaptability (Lehmann and Herkenham, 2011, Abou-Ismail et al., 2010, Abou-Ismail and Mendl, 2016). As indicated earlier, pigs have evolved to root and investigate their environment, spending 10–20% of their active time in exploring and foraging in semi-natural conditions (Stolba and Wood-Gush, 1989). A series of experiments found that 'chewable', 'deform- able' and 'destructible' enrichment objects were most valued by growing pigs (Bracke et al., 2006). Although relatively common, the use of car tyres and chains are not effective forms of enrichment as pigs lose interest when the novelty wears off (Bracke et al., 2006). However recently Bracke (2017) has suggested that branched chains may in fact be a cost-effective way to tangibly improve pig welfare. Enrichment materials need to have sustained appeal rather than just an initial interest that diminishes over time (Van de Weerd et al., 2005). Novelty is important in maintaining interest (Trickett et al., 2009, Tarou and Bashaw, 2007), but the enrichment materials should be presented in a manner to provide diversity. For example, research with rats demonstrates that novelty *per se* in the absence of diversity of objects or materials at any one time seems to be less beneficial (Abou-Ismail and Mendl, 2016). It is important to note that environmental enrichment needs to be targeted to be most effective. For example, if exploration is the targeted behaviour, then changing the environment or introducing a novel object may be the best, while if foraging is the target, using feeding devices, changing the normal feeding regimen, or supplementing the diet may be more effective (Tarou and Bradshaw 2007).

Straw has been widely accepted as an effective form of enrichment for pigs of all stages (Tuyttens, 2005, van de Weerd and Day, 2009). It improves thermal and physical comfort, provides additional fibre when ingested and can be used for foraging and chewing (Fraser, 1975, 1985, Fraser et al., 1991). Many studies have shown that provision of straw reduces harmful social behaviours, including tail biting, even if straw was placed in a dispenser or rack (Van de Weerd et al., 2006, Zonderland et al., 2003). When straw is provided as bedding, it covers the whole floor area, which inevitably increases the proportion of time that pigs can spend manipulating the substrate, and results in higher levels of activity (McKinnon et al., 1989, Arey and Franklin, 1995, Lyons et al., 1995, Morgan et al., 1998, Kelly et al., 2000, Guy et al., 2002, Van de Weerd et al., 2006, Scott et al., 2006, Day et al., 2008). When pigs are provided with a full bedded environment, they spend about 25% of the active time interacting with the straw bedding (Beattie et al., 2000a, Beattie et al., 2000b). In addition, enriched housing has previously been shown to increase body weight and growth rate in growing-finishing pigs (Brown et al., 2018). Furthermore, the provision of straw bedding has been shown to be a significant factor in this increased average daily gain (Douglas et al., 2015), however there has been little research to determine why this may be the case.

When straw enrichment is compared with point-source enrichment-objects, studies report up to twenty times as much interaction with the straw in comparison with the objects (Ruiterkamp, 1987, Lyons et al., 1995, de Jong et al., 1998, Scott et al., 2006, Van de Weerd et al., 2006). Furthermore, straw is generally provided in much larger quantities than other forms of enrichment, which in itself increases the pig's opportunity to interact with it and potentially reduces competition among pigs to access it compared with point-source enrichment-objects. The effect on aggression is less clear, but this does not appear to be reduced in straw-based systems (van de Weerd and Day, 2009). Enriching the post-weaning environment with straw does not affect aggression at mixing (Melotti et al., 2011) but reduces aggression on the day after mixing, possibly by diverting piglet attention (Oostindjer et al., 2011; Melotti et al., 2011). As reviewed earlier, recent literature examining the effect of lactation housing on piglet aggression post-weaning, found piglets raised in group lactation housing had reduced aggression and skin injuries post-weaning when compared to single-litter lactation piglets (Verdon and Rault, 2018). Availability and cost may limit the use of straw in certain areas, while many systems with slatted or partially-slatted floors limit the use of straw.

Despite such strong benefits, the use of straw is often not applicable in many current production settings in Australia (and other parts of the world). This can be due to availability and cost, or in systems with fully- or partially-slatted flooring, the use of significant quantities of substrates such as straw block current waste handling-facilities. Alternative forms of enrichment are point-source objects, often called toys (van de Weerd and Day, 2009). To be effective these objects need to fulfil certain criteria. Housing of growing pigs in pens with multiple enrichment features has been shown to reduce fear in novel environments and increase ease of handling, reduce harmful social behaviour and aggression directed at pen mates and increase behavioural diversity (van de Weerd and Day, 2009). However, these studies combined several features (such as increased space, multiple levels and several objects) and many lacked proper control groups, therefore it is not possible to identify a single feature that can be recommended as effective enrichment.

While the utilisation of environmental enrichments has been investigated, the effects of enrichment on stress adaptability and indicators denoting poor welfare have not been extensively studied in pigs (van de Weerd and Day, 2009). Brown et al. (2018) reported that relative to piglets in barren environments, those in enriched environments may experience reduced anxiety, increased neuroprotection and synaptic plasticity, and an immune response consistent with reduced inflammatory challenge. The authors suggest that environmental enrichment may confer neuronal health benefits in growing-finishing pigs, through a potential relative reduction in neuroinflammatory process and increase in neuroprotection driven by an enrichment-induced increase in behavioural activity, such as interaction with the enrichment-stimulus and play behaviour. Clearly further research is required to evaluate the effectiveness of enrichment strategies for growing-finishing pigs, particularly when housed on slatted floors.

Enrichment suitable for pigs is likely to be one that they can root, chew and manipulate. Novelty is important in maintaining interest, but there should also be diversity in the materials at any one time. Furthermore, desired environmental enrichment needs to be targeted to be most effective, for example specifically targeting exploration or foraging.

3.3.3 Early weaning

Age of weaning		
Australia	For weaning of pigs under 3 weeks of age, management and nutrition needs to be of very high standard to prevent piglet mortality and ill-thrift	Guideline
Canada	Target an average weaning age of 3 weeks or older	Recommendation
UK	Piglets shall not be weaned from the sow at an age less than 28 days unless the health or welfare of the dam or piglets would otherwise be adversely affected	Standard
New Zealand	Piglets should be at least 28 days at weaning	Recommendation
EU	No piglets shall be weaned from the sow at less than 28 days of age unless the welfare or health of the dam or the piglet would be otherwise adversely affected	Standard

Early weaning is considered one of the main welfare challenges for weaner pigs (Pedersen, 2018). In domestic pigs, under semi-natural and wild conditions, there is a gradual separation of the sow from her litter prior to weaning. Sows have a natural tendency to spend time away from their piglets as lactation progresses and gradually reduce suckling frequency, which creates a gradual weaning process (Pajor et al., 1999). In conventional farrowing crates, the ability of the sow to moderate her own suckling frequency is reduced, and as such weaning becomes an abrupt event (de Ruyter et al., 2017). Abrupt weaning is typically associated with a reduction in growth, commonly referred to as a growth check, immediately post-weaning.

Common commercial weaning practices involve an abrupt early weaning at 3-4 weeks of age, when piglets may not be physiologically, immunologically or behaviourally ready to consume larger amount of solid feed (Heo et al., 2013). This can reduce the piglet's intake of metabolisable energy of up to 20% of normal intake. This reduced intake can last for several days and piglets have been found to not recover to pre-weaning energy (ME) intake levels until 2 weeks post-weaning (Pedersen et al., 2018). In suckling piglets, solid feed intake gradually increases in the fourth week of life (Bøe, 1991), although large individual differences have been reported. Pluske et al. (2017) reported that the percentage of piglets within a litter with little or none ingestion of solid feed before day 19 and day 27 was observed to be 51% and 16%. The daily feed intake of weaners was estimated to be on average 7-10 g/pig on day 18, increasing to 40 g/pig on day 25, and to 100 g/pig on day 31 (Pluske et al., 2017).

Farrowing housing that provides a sow only area has been shown to result in a more gradual weaning process, where suckling frequency can be reduced as lactation progresses (Pajor et al., 1999). This may benefit sow welfare by reducing confinement and allowing respite from piglets, but it may also affect the piglet's adaptability to weaning (Berkeveld et al., 2009). While gradually weaned piglets tend to be lighter at weaning (Kuller et al., 2004), the severity of the post-weaning growth check is reduced.

Several studies have examined the performance of piglets in response to intermittent suckling regimes (gradual weaning), in which the sow and piglets are separated for a defined proportion of the day and reported beneficial effects on piglet productivity post-weaning (Berkeveld et al., 2007, Berkeveld et al., 2009, Kuller et al., 2004, de Ruyter et al., 2017, Turpin et al., 2017). The observed improvement in piglet growth post-weaning has been attributed to increased creep feed ingestion in response to sow-piglet separation (Berkeveld et al., 2009; Berkeveld et al., 2007; Kuller et al., 2010; de Kuyker et al., 2017).

Growth performance post-weaning may be further affected as the weaning event is thought to be stressful, and stress and performance are strongly linked (Barnett et al., 2001). The removal of maternal contact, introduction of a new social and physical environment, and the changes in diet are all believed to contribute to the weaning stress response (Weary et al., 2008). de Ruyter et al. (2017) reported a reduced cortisol and stress physiology response to the weaning event in gradually weaned piglets compared to the response of abruptly weaned piglets.

Changes to behaviour and stress physiology of piglets at weaning are evident for different weaning ages (Colson et al., 2006). Negative piglet-directed behaviours are indicators of stress (Dybkjær, 1992) and increased incidences of these behaviours, such as belly nosing and aggression, are reported in abruptly weaned piglets when compared with gradually weaned pigs (Dybkjaer, 1992, Newberry et al., 1988, Worobec et al., 1999). de Ruyter et al. (2017) found that intermittent sow-piglet separation prior to complete weaning resulted in significantly shorter durations of belly nosing and aggressive interactions following the weaning event compared to abruptly weaned piglets. Belly nosing has been used as a key indicator for maladaptation in piglets post-weaning (Cox and Cooper, 2001, Straw and Bartlett, 2001, Jarvis et al., 2008, Widowski et al., 2008), and the repetitive nosing of another piglet's abdomen may be indicative of piglet nursing behaviour rather than consuming solid feed in the early post-weaning period (Widowski et al., 2008).

Short term separation (gradual weaning) during lactation reduces the piglet's response to the highly stressful event of weaning (de Ruyter et al., 2017; Turpin et al., 2017); the findings from these studies demonstrate that gradually weaned piglets exhibited fewer negative behaviours and a decreased cortisol response to weaning when compared to piglets that were abruptly weaned. These results suggest that in addition to previously reported increases in creep consumption pre-weaning, a reduction or change in stress experienced in response to weaning may help to explain differences in the performance of gradually weaned piglets.

On a side note, there has been limited investigation into the effect of weaning on the sow. Sows appear to experience a significant drop in feed intake and less activity after weaning than before weaning (Garcia and McGlone, 2018). Further research to examine the effects on welfare and productivity of weaning alternatives is required. In addition, further understanding on the effect of weaning on the sow would be beneficial.

Conclusions, recommendations and further research on weaner and growing-finishing pigs

Space allowance for growing-finishing pigs is less contentious than for breeding sows, probably because the effects of inadequate space allowance on pig productivity are both well studied and easier to demonstrate. The literature indicates that current Australian space allowance requirements of 0.14 m2 to 0.74 m2/pig (weight: 10-120 kg) are likely to be sufficient. However, improvements in welfare (in terms of aggression and stress) and productivity (with regard to growth rate) are likely to be achieved with space allowances greater than the current Australian requirements. The effect of space allowance (and pen design and features) on the aggressive behaviour of growing pigs in the period immediately following mixing requires further investigation. The literature indicates that space allowance and group size do not interact, suggesting that there is no need to specify different space requirements for growing-finishing pigs in large or small groups. Furthermore, there is considerable evidence in the young pig indicating that aggression is not affected by group size. As with gestating sows, in growing-finishing pigs other factors such as floor space and competition for feed or feeding space may have a greater impact on aggression, injuries and stress than does group size.

Spatial restriction of growing-finishing pigs is likely to result in reduced access to feeders, increased stress and consequently reduced growth performance, and as such will also have adverse welfare implications. Enrichment suitable for growing-finishing pigs is likely to be one that they can root, chew and manipulate. Novelty is important in maintaining interest, but there should also be diversity in the materials at any one time. Furthermore, desired environmental enrichment needs to be targeted to be most effective. While the utilisation of environmental enrichments has been investigated, the effects of enrichment on stress adaptability and indicators denoting poor welfare have not been extensively studied. Straw has been widely accepted as an effective form of enrichment for pigs of all stages, however further research is needed to enable its use in systems with slatted or partially-slatted floors. At present it is not possible to identify point-source objects that can be recommended as effective enrichment. Clearly further research is required to evaluate the effectiveness (type and placement within pen) of enrichment strategies for growing-finishing pigs, particularly when housed on slatted floors.

Early weaning is considered one of the main welfare challenges for weaner pigs. Common commercial weaning practices involve an abrupt early weaning at 3-4 weeks of age, when piglets may not be physiologically, immunologically or behaviourally ready to consume a larger amount of solid feed. Further research to examine the effects on welfare and productivity of weaning alternatives is required. In addition, further understanding on the effect of weaning on the sow would be beneficial.

3.4 Boars

Mating service is either carried out by natural mating with a boar or by artificial insemination (AI). In some countries with small-scale farms natural mating is most common, whereas in countries such as Australia AI dominates. However, most farms will keep boars to assist with oestrus stimulation and detection even if they are using AI. Breeding boars and boars used for oestrus stimulation and detection, begin working at about 6-7 months of age and are generally sold or culled after 2-3 years, when they have become too large and/or are replaced by genetically-superior animals.

Mature boars are generally housed individually to facilitate management and staff safety. Group housing is more common in outdoor systems, where service is often carried out by a number of boars living with a group of sows. In AI studs and farms using boars for oestrus stimulation and detection, boars are typically housed in individual pens or stalls. The keeping of boars in individual stalls where they cannot turn around was common in the past but is now prohibited in most countries under Codes of Practice or regulated standards.

There appears to be no specific research on the housing requirements of mature boars, although it is reasonable to infer information on parameters such as space, flooring, temperature, lighting and social stimulation from studies of pigs at other stages of production. Under natural conditions, mature boars are solitary for long periods of time and join sow groups when the females come into oestrus. It is therefore reasonable to suggest that individual housing is not unacceptable, provided that neither long term sensory or social deprivation is involved. The minimum space requirement, based on a liveweight of up to 300 kg and snout to tail length of up to 2 m, would be a shortest pen side of 2.6 m to allow the boar to comfortably turn around (Petchey and Hunt, 1990). The space required to allow adequate opportunity for exercise, and the consequences of inadequate space for boar welfare are yet to be defined. In Australia, the current Code of Practice specifies a minimum space allowance of 6 m^2 per animal, which would preclude housing of boars in stalls (Outdoor shelter space allowance of 2 m^2). Levis et al. (1995) examined the effect of breeding facility on plasma cortisol in boars; boar pens 2.6 x 3m compared to boar stalls 0.8 x 2.9 m. Mating occurred in the conventional boar pens, whilst boars were moved out of their stalls into a central arena for mating. There was no difference between the two treatments in daytime concentrations of free cortisol concentrations, and treatment did not result in a difference in cortisol response to ACTH. Based on these physiological measures of stress, Levis et al (1995) concluded no increased risk to welfare from housing boars in stalls relative to individual pens. However as is the case with sows in stalls, the use of a single-point stress measure results in the potential for a dysfunctional cortisol response.

It is normal commercial practice to keep mature boars individually. It has been demonstrated that boars which are reared from weaning without physical or visual contact with other pigs show reduced courting and copulatory behaviour when compared with those reared in all male or mixed sex groups (Hemsworth et al., 1977). A subsequent study found that a lack of physical and visual contact with other pigs during rearing accounted for 70% of the impairment in copulatory behavioural in boars (Hemsworth et al., 1978). Housing of individual post-pubertal boars near sexually receptive females resulted in enhanced courtship and copulatory behaviour in comparison with animals housed in visual and/or physical isolation to other boars (Hemsworth et al., 1977). A subsequent study found that housing boars adjacent to females which were not sexually receptive was also effective in maintaining male sexual behaviour (Hemsworth et al., 1981). (Hemsworth et al., 1983) concluded that isolating young post-pubertal boars from female pigs will reduce their subsequent copulatory performance. Furthermore, while the adverse effects of social isolation on sexual behaviour may be permanent if imposed on young post-pubertal boars (<1 year of age), they appear to be reversible in older animals (Hemsworth et al. 1983).

Housing of mature boars in a group reduced courtship behaviour but not copulatory performance in comparison with boars which were group reared but housed individually once mature (Hemsworth et al. 1978). Group housed boars were reported to be in better physical condition because of improved space for exercise. Cordoba-Dominguez et al. (1991) reported that the incidence of sodomy behaviour and aggression within established groups of mature boars is very low.

Conclusions, recommendations and further research on boars

There is no specific research on the housing requirements of mature boars, although it is reasonable to infer information on requirements such as space, flooring, temperature, lighting and social stimulation from guidelines for sows. Boars should not be reared in social isolation. While it is acceptable to house boars individually, they should not be housed in visual and olfactory isolation from other pigs. The dimensions of individual pens for mature boars should correspond to the weight and size of the pig, but the current Australian Code of Practice specification of a minimum space allowance of $6m^2$ per animal seems reasonable. The mixing of mature boars should be avoided and carried out only when essential, and under close supervision. Whilst it may not be viewed as a high priority, research on boar housing requirements and the implications for boar welfare is required.

3.5 Outdoor housing

Outdoor housing has gained considerable interest in the past decade as an alternative to conventional indoor housing, potentially due to lower upfront investment cost (i.e. infrastructure, facilities, equipment) as well as increased opportunity for animals to perform species-specific natural behaviour (Von-Borell et al., 2001, Millet et al., 2005). The Australian Model Code of Practice for the Welfare of Animals – Pigs requires all pigs housed outdoors to have access to shelter in cold weather and shade in hot weather, and feed and watering points to be provided such that all pigs have access. The Australian Model Code of Practice for the Welfare of Animals – Pigs prohibits outdoor housing of pigs on land that is contaminated with toxins, chemical residues, toxic plants or disease-causing organisms. It is recommended in the Australian Model Code of Practice that farrowing and rearing huts provide protection for pigs from the elements, and in locations with high summer temperatures the provision of shade, ventilation, wallows or water sprinklers is recommended. Recommendations also include the use of herd heath programs that includes vaccination, parasite control and regular pasture rotation and spelling. Consideration also should be given to using breeds like Large Black, Tamworth, Wessex Saddleback and Berkshire breeds or hybrids of such breeds that are more suited for outdoor conditions (Guidelines 4.6.8).

The New-Zealand Pigs – Animal Welfare Code of Welfare 2018 states that "Pigs must have access, at all times, to shelter that is adequately ventilated and provides protection from extremes of heat and cold". The code also requires that non-farrowing pigs have access to a dry area that is large enough to allow the pigs to stand up, turn around, and lie down in a natural position. Furthermore, according to the code faeces and urine must not be allowed to accumulate in any area in which the pig is kept to an extent that may pose a threat to the health or welfare of the pigs (Minimum Standard No. 5). It recommends that between batches of piglets, farrowing huts should be re-sited and bedding should be replaced in order to limit disease transmission. The Canadian Code of Practice for the Care and Handling of Pigs requires pigs to have access to shelter that minimises the effects of adverse weather and provides a dry resting area and shade. It also requires a protocol to be developed and implemented to protect pigs from parasites and predators.

The UK Codes of Recommendations for the Welfare of Livestock: Pigs requires pigs housed outdoors to, where necessary and possible, be provided with protection from adverse weather conditions, predators and risks to their health and be given access to a well- drained lying area. All pigs over two weeks of age must have permanent access to a sufficient quantity of fresh drinking water. Farrowing pens where sows are kept loose must have some means of protecting the piglets, such as farrowing rails.

Exposure to high heat loads is common for outdoor pig production in Australia. For a dry sow on straw, the upper critical temperature (UCT) of a sow depends on a range of factors, however, at optimal feed intake levels, UCT is likely to be 26–30°C (Bruce 1982). An early sign of heat stress is decreased feed intake, one of the only ways for a sow to reduce her heat burden, and this can result in loss of condition and reduced fertility. Reduced feed intake in lactating sows can also reduce their milk production and adversely affect their piglets. Although heat stress is also an issue for indoor-housed sows, it is generally ameliorated by the use of a cooling system. A further problem for the outdoor pig is sunburn, with white skinned animals particularly susceptible.

An Australian study by Barnett and colleagues (Agribiz, 1999); some data are reported in (Barnett et al., 1999) has shown that there may be some thermal problems for sows housed outdoors in Australia in the cooler months. Rectal temperature was similar in the indoor pigs across sampling periods, whereas in the outdoor pigs it was higher both overall and in February–April than in June–September. There was also a higher proportion of sows with a rectal temperature less than the lower 95% confidence limit in the outdoor pigs in September. The authors concluded that some pigs may have potential problems controlling their body temperature in the outdoor environment in winter. Other differences between the indoor and outdoor sows were that the outdoor sows had a greater variation in back-fat, a considerably longer claw length, and a lower farrowing rate. There were no differences in variation in body weight and scores for lameness and gait were generally similar. There were fewer lesions in outdoor sows, which concurs with the findings of Martin and Edwards (1994).

Whilst the literature is limited, and the reasons are not immediately clear, pigs housed in outdoor systems are generally believed to have a better health than pigs in indoor herds (Thornton, 1990). Sows housed in outdoor systems appear to have fewer respiratory problems than those housed indoors (Thorton, 1990). Tubbs et al. (1993) reported that outdoor pigs were healthier and had a lower incidence of enteric diseases than pigs in indoor systems. McGlone (1997) observed little or no E. coli-related scours among outdoor litters, whereas scour outbreaks were common in indoor litters. Kleinbeck (1995) found no differences in immunology in sows housed in indoor and outdoor systems. A controlled study by Lahrmann et al. (2004) comparing indoor and outdoor housing of pigs found outdoor pigs to have lower morbidity and mortality during all rearing periods. The outdoor housed pigs were also more active, had higher daily weight gain during the weaning and fattening phase and similar meat quality to their indoor counterparts.

Barnett et al. (1999) concluded that there were no large differences in risks to welfare, on the basis that variation in a number of selected variables was similar between sows in the two production systems, although they did identify potential areas for improvement. These were: nose-ringing, predator control, shelter, litter desertion, pre-weaning piglet mortality, selection and training of stockpeople, wallow design and management, overgrown claws, avoidance by pigs of others at feeding time, thermoregulation in winter, and any implications of lower backfat and mating management (the latter may be a welfare or production issue or a combination of both). The selection of appropriate breed of pigs also appears to be important to outdoor pig production, and breeding companies have developed genotypes for outdoor production systems. These genotypes are crosses that generally combine desired behavioural traits (e.g. mothering ability), hardiness, and economic efficiency (Steen, 1994). There has been no research published on the suitability of different genotypes and phenotypes for outdoor conditions in Australia.

3.5.1 Nose-ringing

The Australian Model Code of Practice for the Welfare of Animals – Pigs has no standards concerning nose-ringing. It recommends that nose-ringing should be avoided, however if performed, rings should be placed through the cartilage at the top of the snout. The Canadian Code of Practice for the Care and Handling of Pigs has no standards concerning nose-ringing but recommends that nose-rings should not be used. The UK's Codes of Recommendations for the Welfare of Livestock: Pigs does not permit nose-rings in pigs housed continuously in indoor systems. It also recommends that nose-ringing should be performed by a suitably trained and competent operator. The New Zealand Pigs – Animal Welfare Code of Welfare 2018 requires that if nose-rings, clips or wires are used, they must be placed through the cartilage at the top of the snout or in the tissue separating the nostrils.

Nose-ringing is performed on the outdoor housed sows in order to reduce soil digging with forepaw and thereby prevent damage to the pasture (Horrell et al., 2001, Studnitz et al., 2003, Eriksen et al., 2006). Some studies have explored alternatives to nose-ringing, for example by providing sows with a specialized rooting area with enrichment (e.g. root crops, spent mushroom compost) and/or feed concentrate buried inside (Bornett et al., 2003, Edge et al., 2005). These strategies were designed with the intention of restricting rooting to a designated area in order to reduce the amount of pasture destruction. Even though these studies found reduction in pasture damage by providing a designated rooting area, this reduction was not significant and hence further research is warranted in this area. Another alternative that could be explored is the use of virtual fencing in order to limit sow's movement to a designated area thereby reducing the pasture destruction. Research currently underway in Australia on a virtual fencing system in which automated animal collars that provide audio and electrical stimuli as the animal approaches the virtual fence line (Campbell et al., 2018). Use of virtual fencing is gaining significant interest in other pasture grazing animals (Bishop-Hurley et al., 2007, Butler et al., 2004) and has the potential to be a valuable resource in improving efficiency of outdoor housing without compromising animal welfare (i.e. using nose-rings). The Australian Pork Limited is a participant in this world-leading research project and thus in the future, there is the opportunity to examine the use of virtual fencing in outdoor housed pigs and evaluate its efficacy in an Australian outdoor system.

Conclusions, recommendations and further research on outdoor pigs

In their review of pig welfare, Barnett et al. (1999) concluded that there were no large differences in risks to sow welfare in indoor and outdoor systems based on the variation in a number of selected variables. However, they identified some potential areas for outdoor systems that require attention. These were nose-ringing, predator control, shelter, litter desertion, selection and training of stockpeople, wallow design and management, overgrown claws, avoidance by pigs of others at feeding time, thermoregulation in winter, and any implications of lower backfat.

4. Specific physiological and behavioural problems in pigs

4.1 Gastric ulceration

Gastric ulceration is a welfare problem in intensive pig production which can result in a failure to thrive and sudden death. The prevalence of gastric ulcers has been reported to be around 30% in slaughter pigs and even higher in culled breeding sows (Robertson et al., 2002, Swaby and Gregory, 2012). Common feeding practices, such as the feeding of finely grounded pelleted feed have been identified as a risk factor (Canibe et al., 2007, Mößeler et al., 2012). The provision of between 50 and 1000 g straw per pig per day compared to no access to straw reduced the prevalence of gastric ulceration (Nielsen and Ingvartsen, 2000, Bolhuis et al., 2007, Scott et al., 2007, Di Martino et al., 2013, Herskin et al., 2016b).

4.2 Lameness

Lameness is common in the pig industry and is considered a major welfare concern that has the potential to induce pain and discomfort for extended periods of time (Barnett et al., 2001, Main et al., 2000). The primary cause of lameness is pain (Cockram and Hughes, 2011) and as a result lameness is associated with some level of suffering in the animal (Dawkins, 1980). Lameness, which is loosely defined as impaired movement or deviation from normal gait (Cockram and Hughes, 2011), is common in commercial sows (Chapinal et al., 2010). The causes of lameness range from inflammation and pain (Cockram and Hughes, 2011), and infected skin and claw lesions (Velarde, 2007), to broken bones (Marchant-Forde, 2009). The USDA has ranked lameness as the third most common reason for culling sows on farm (15% of sows; USDA, 2007), and Stalder et al. (2004) reported that leg soundness is one of the most commonly identified reasons for the involuntary culling of sows.

Quality of flooring is widely considered to be essential to pig welfare as it is likely to have a direct effect on foot health and the culling rate from lameness (Barnett et al., 2001). This aspect has been reviewed by Borell et al. (1997) and, for sows, focusses on the common use of partially slatted pens. Important factors include the space between the slats, the roughness of the surface and the edge design (Boon and Wray, 1989). Smooth surfaces and deep litter systems may cause excessive hoof growth, leading to lameness (Geyer, 1979), but some abrasion is necessary for foot health (Webb and Nilsson, 1983), while foraging substrates can reduce injury caused by slipping (Heinonen et al., 2013). In a study of 15 herds, Gjein and Larssen (1995) showed an overall lameness rate of 13.1% in sows with increased risks associated with concrete versus plastic slats and poor floor hygiene. The quality of flooring interacts with the thermal requirements and pen design on lameness in adult pigs. For outdoor sows, site and soil type are significant factors affecting lameness (Thornton, 1990).

4.3 Shoulder ulcers

Shoulder ulcers are seen in lactating sows in the week following farrowing, the underlying triggers for the development of such ulcers are not yet clear (Rioja-Lang et al., 2018). However, it is believed that constant pressure on the soft tissue restricts blood flow in the region causing necrosis which then leads to ulceration (Rolandsdotter et al., 2009, Rioja-Lang et al., 2018). Several sow related factors have been identified as underlying triggers for the development of shoulder ulcers such as; body condition post farrowing (Havn and Poulsen, 2004, Bonde et al., 2004), lameness (Anil et al., 2006b, Rosendal and Nielsen, 2004), health condition (Zurbrigg, 2006), duration of lactation (Pairis-Garcia et al., 2015), previous occurrence of shoulder ulcer (Thorup, 2006) and the duration of performing resting behaviour (Lundgren et al., 2012). The rate at which a shoulder lesion progresses to become an ulcer is unclear, however it believed that the ulceration begins from the outer layer of skin, reaches deep into the tissue and in severe cases it can penetrate the underlying bone (Jensen, 2009). Environmental risk factors for shoulder ulcers are related to the housing conditions such as floor type (slatted vs. non-slatted, (Rosendal and Nielsen, 2004), location of the pen (Zurbrigg, 2006), humidity and temperature (Kokate et al., 1995). Human literature suggests that friction forces rubbing against the skin in combination with high humidity leads to pressure related ulcers (Lahmann and Kottner, 2011). Similarly, friction along the floor surface as well as hardness and abrasiveness may all contribute to the development of shoulder ulcers in sows, however, further research needs to be done to validate these theories.

4.4 Stereotypic behaviours

As discussed earlier (Barren environments; 3.1.7, 3.2.3 and 3.3.2), indoor production systems are considered by some to provide captive animals with barren environments (Barnett et al., 2001) which have been implicated in the development of stereotypies. Stereotypies can occur in prolonged conflict or thwarting situations in which there is no chance to escape (Dawkins, 1980, Mason, 1991). Furthermore, stereotypies may originate from redirected behaviours (and other abnormal behaviours including displacement, redirected and vacuum behaviours) if the conflict or thwarting persists (Hemsworth, 2018b). Once developed, stereotypies can become ritualized to the extent that they become part of the behavioural repertoire and persist even in the absence of the original eliciting, stimuli/conditions (Mason, 1991).

In pigs, stereotypies are essentially oral activities and include vacuum chewing (sham chewing), head waving, chewing of bars, and licking, chewing or nosing of various available objects (Fraser, 1975, Stolba et al., 1983, Terlouw et al., 1991). Stereotypies have been reported in a range of housing systems including tethered, stall-housed and group-housed sows (Barnett et al., 2001, Schouten and Rushen, 1992). There has been, and still is, ongoing discussion and research on the welfare significance of stereotypies. But stereotypies in captive animals have been generally viewed either as an adaptive coping response to the captive environment or as the inappropriate output in a conflict or thwarting situation (Mason and Latham, 2004), there are some instances where there is a poor relationship between stereotypies and stress (Mason, 2006). For example, frustration-induced stress may be at least partly resolved if the behaviour itself reduces the underlying motivation. Therefore, within a group, individuals that perform stereotypies may thus be coping. Nevertheless, stereotypies indicate either a present problem for the animal or a past problem that has resolved.

Feed restriction and the inability to express manipulative and/or foraging behaviour have been proposed as a major cause of the development of oral stereotypies in sows (Lawrence and Terlouw, 1993). Indeed, increasing the amount of roughage and daily feed allocation generally reduces stereotypies and increases the time spent feeding (Appleby and Lawrence, 1987, Robert et al., 1993, Bergeron et al., 2000, Terlouw and Lawrence, 1993, Whittaker et al., 1998, Holt et al., 2006). While high-fibre diets increase the time sows spent feeding and reduce stereotypies as long as the animal's nutrient requirements are met (Robert et al., 1993, Brouns and Edwards, 1994, Ramonet et al., 1999), Feeding time per se appears to implicated in stereotypies since increased feeding time accounts for much of the reduction in stereotypy level associated with high-fibre diets (Robert et al., 1997). Thus, many authors have proposed that low fibre, high-concentrate diets for sows that require little food-searching behaviour and consummatory behaviours such as chewing, result in unfulfilled motivations to perform these natural foraging activities, and leads to increased oral stereotypies including oral stereotypic licking, bar-biting and sham-chewing or vacuum-chewing (Bergeron et al., 2006). Furthermore, stereotypies may develop from other lengthy conflict or thwarting situations and there is evidence that stereotypies can develop in response to barren or restricted environments (Mason, 1991, Würbel et al., 1998). Pigs are highly motivated to root and investigate their environment (Stolba and Wood-Gush, 1989). Modern systems of intensive pig production thwart the expression of key behaviours such as exploration and foraging. Enrichment suitable for pigs is therefore likely to be one that they can root, chew and preferably ingest with some nutritional benefits; effective enrichment should decrease the incidence of abnormal behaviour and increase the performance of behaviours such as exploration, foraging, play, and social interaction, which are within the range of the animal's, normal, species-specific behaviour (Chamove, 1989, Mench, 1994, Markowitz et al., 1995, Van de Weerd and Baumans, 1995). However, as discussed earlier, welfare implications of intensive, indoor and non-bedded systems in current pig production systems are poorly understood. The European Union Commission directive 2001/93/EC states 'pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, sawdust, mushroom compost or a mixture of such that does not compromise the health of animals.' The extent to which this provides effective enrichment has been questioned (Marchant-Forde et al., 2009, van de Weerd and Day, 2009), and as such indicates the need for continued investigation into effective environmental enrichment.

The utilisation of the enrichments has been studied, however the effects of enrichment on stress adaptability and indicators signifying poor welfare in pigs require further investigation (van de Weerd and Day, 2009). In a series of experiments, De Jong and colleagues (de Jong et al., 1998, de Jong et al., 2000, de Groot et al., 2000) have shown that rearing pigs in large farrowing pens and large growing-finishing pens with provision of straw can reduce manipulative behaviours directed towards pen-mates, such as massaging and nibbling, compared to rearing in farrowing crates and smaller growing-finishing pens with partially slatted solid floors. Furthermore, provision of straw that elicits foraging in terms of searching and chewing, has been shown to reduce oral stereotypies, such as bar biting and sham chewing, in gestating sows housed in stalls and groups (Spoolder et al., 1995, Bergeron et al., 2006). With the extensive use of fully- or partially-slatted, non-bedded and non-enriched environments in Australian pig production, further research is clearly required to investigate functional enrichment.

The imperative for this research is the anecdotal reports of high levels of stereotypic behaviours such as sham chewing in group-housed sows, indicate that research of this nature may be both pertinent from a sow welfare and productivity perspective and prudent in terms of addressing community and NGO criticisms of indoor group-housing of pigs on slatted or partially slatted concrete floors. However, it should be recognised that the immediate implications of stereotypies on welfare are not always clear. Although glucocorticoids can be affected by metabolic rate and thus may not be an appropriate physiological measure of stress associated with hunger (De Jong et al., 2002), there appears to be no consistent evidence of increased stress, based on plasma and urinary cortisol concentrations, in sows individually housed and restrictively fed (see review by Meunier-Salaün et al. (2001), and this is supported by more recent studies (de Leeuw and Ekkel, 2004; Toscano et al., 2007). In a review of several hundred papers on human and animal stereotypies and their links to welfare, Mason and Latham (2004) found that in most conditions (68% of studies) that increased stereotypies, welfare of the animals declined. However, in the remaining 32% of studies, welfare was either improved or no change occurred in conditions in which stereotypies increased.

4.5 Tail biting

Tail biting is a potentially serious welfare problem; light chewing on the tail can lead to a wound which can become attractive to other pigs in the group once the tail bleeds, leading to more severe consequences such as infection, spinal abscess, paralysis and, in extreme cases, death (Van Putten, 1969, Fraser, 1987, Schrøder-Petersen and Simonsen, 2001). As discussed previously, tail biting appears to occur in two stages, a pre-injury and an injury stage, with the second stage resulting in a wound and bleeding, and at times the more severe consequences. Tail biting is likely to cause both acute and chronic pain in the short-term in the recipient due to the actual tail biting and consequently weight loss and infection in the longer term (Sutherland and Tucker, 2011).

The aetiology of the behaviour remains poorly understood. Tail biting is believed to be a multi-factorial syndrome (Hemsworth et al., 2018). There is considerable research on the possible risk factors, but few experimental and epidemiological studies. Factors influencing tail-biting appear to include external factors such as manipulable objects or substrates that can be chewed and manipulated, and particularly straw, space, stocking density and group size; indoor and outdoor climate; crowding, flooring, and food and feeding system; and internal factors such as genetics, gender, age and weight, gastrointestinal discomfort and health status (see reviews of Schroder-Petersen and Simonsen, 2001; ESFA, 2007; Taylor et al., 2010; Valros, 2017).

Understanding the causation of tail biting is difficult because of its sporadic and unpredictable occurrence and the fact that many factors have been associated with the behaviour. In a review of the literature, Taylor et al. (2010) proposed that tail biting may not be a single homogenous behavioural category but rather comprise at least three different forms of behaviour, termed ‘two-stage’ (pre- and damaging stages), ‘sudden forceful’ and ‘obsessive’ tail biting, that each has differing underlying motivations. It is useful to consider this proposal by Taylor et al. (2010) here because it highlights the difficulty in understanding the aetiology of tail biting and appreciating both future research direction and possible solutions. The ‘pre-damage stage’, where the tail is lightly mouthed and manipulated causing no visible damage or distress to the recipient, is considered to be a normal extension of the pigs’ natural foraging and exploratory behaviour. However, at some point this manipulation may break the skin and once bleeding occurs, the problem can rapidly escalate as other pigs are attracted to the tail, leading to harmful injuries (the ‘damaging stage’). Therefore, preventing pigs from developing a manipulatory interest in tails by reducing the level of foraging/exploratory behaviour, or providing more appropriate substrates for foraging/exploratory behaviour, may be the key to preventing this form of tail biting.

Sudden forceful tail biting involves a pig’s tail being seized and forcefully pulled or bitten. This type of tail biting generally occurs without a prior period of gentle manipulation. Sudden forceful tail biting is most commonly observed in pigs that are unable to access a desired resource, such as feeders. Consequently, preventing this type of tail biting may require identification of situations which may result in competitive/frustrating interactions between pigs, such as competition for resources such as space, food, water and preferred lying areas.

Obsessive tail biting is similar to forceful tail biting in that tails are forcefully pulled and bitten; however, it appears to be performed by one or a few individual animals in the group that seem to be focussed or fixated on biting tails. While either of the other two forms of tail biting may proceed it, obsessive tail biters may find the act of tail biting more rewarding than accessing the resource, thus resulting in tail biting itself becoming a consummatory, rather than appetitive, behaviour. It is also possible since this behaviour is extensively performed, and its occurrence is similar in frequency and intensity to that of stereotypies, that a degree of pathological change has taken place, for example with a dietary or health problem.

4.5.1 Enrichment and tail biting

Current research attention in EU is on the use of manipulable enrichment to reduce the welfare risks in pigs; including tail biting (D'Eath et al., 2014, Valros et al., 2016, Larsen et al., 2016b, Munsterhjelm et al., 2015b). As part of the shift away from tail docking, the EU's Council Directive 2008/120/EC has made it mandatory to provide 'pigs with permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, saw-dust, mushroom compost, peat or a mixture of such, which do not compromise the health of the animal. A study on 93 commercial pig farms in Finland showed that farms that provided thick straw bedding with less than 50% of solid barren space had a lower prevalence of tail biting, compared to the ones that provided thin bedding, or no bedding (Munsterhjelm et al., 2015b). A Danish study also found straw to be equally effective in reducing the prevalence of tail biting as tail docking (Larsen et al., 2016b). While tail-docked pigs with straw bedding had the lowest level of tail biting, straw bedding does not eliminate tail biting. Since highly valued resources when given as enrichment can increase competition and consequent frustration in pigs that fail to access them, it is important to provide sufficient quantity of the enrichment (Scott et al., 2007).

The European Food and Safety Association in their recent scientific review of pig welfare acknowledged that bedding material such as straw is more effective in reducing tail biting compared to other manipulable form of enrichment (EFSA, 2014). Extended studies on the use of straw as enrichment have shown that it is more effective when replenished daily, probably because clean and fresh straw is more appealing than old and moist (Hunter et al., 2001, Moinard et al., 2003). Comparative studies on enrichments have also shown that both compost rack (Beattie et al., 2001) and straw bedding (Courboulay et al., 2009) were more effective in reducing the percentage of tail injuries in pigs than hanging toys (Scott et al., 2006, Van de Weerd et al., 2006), rubber hose and chains (Zonderland et al., 2008).

In an epidemiological study, Moinard et al. (2003) found increased tail biting in farms that had not provided straw in the creep area during lactation than those providing straw at least once daily in the creep area. However, there is evidence that pigs that had access to enrichment during lactation, but not later in life are at higher risk of tail injuries due to tail biting (Munsterhjelm et al., 2009, Ruiterkamp, 1985). Clearly the long-term effects of enrichment in early life on subsequent tail biting require research.

4.4.2 Feeding and tail biting

While Hunter et al. (2001) found that pigs fed a pellet diet have increased risk of tail biting, Palander (2016) and Taylor et al. (2010) found that pigs fed a liquid diet are also at an increased risk of tail biting. However, due to the different composition of the diets in these studies, it is unclear whether the form of the feed or its composition is associated with the increases the risk of tail biting. Epidemiological studies have found restricted feeder space to be another risk factor for tail biting (Hunter et al., 2001, Moinard et al., 2003). In commercial setting, pigs that cannot feed simultaneously may show 'sudden-forceful' frustration driven tail biting (Taylor et al., 2010, Palander, 2016). The implication of competition at feeding is also shown by the fact that a high proportion of tail biting occurs around the feeder (Sutherland et al., 2009, Palander, 2016). Finnish producers that raise their pigs without tail docking highly rate the importance of long-trough feeding, whereby all pigs have enough space to eat at the same time (Valros et al., 2016). Furthermore, the producers also ranked feeder space allowance as one of the most important preventative factors for tail biting. Providing double or multi-space feeders has been shown to reduce the risk of tail biting (Hunter et al., 2001), while automated feeder system with more than five pigs per feeder space increased the risk of tail biting (Moinard et al., 2003). Most of the commercial pig farms in Australia deliver feed using automated feeder system and since group housing is the most common practice, it likely that each feeder space is utilized by more than five pigs, which might be a contributing factor in tail biting. Providing higher feeder space either by increasing number of automated feeders per pen or by providing longer feeder troughs may reduce the need for tail docking: In addition to reducing tail biting, other behavioural vices related feed-driven frustration may be reduced.

Housing condition and designs and tail biting

Controlling the temperatures during extreme weather conditions reduces the risk of tail biting (Schrøder-Petersen and Simonsen, 2001, D'Eath et al., 2014) and hence may eliminate the need to perform tail docking. Use of artificial ventilation has been shown to be associated with reduced risk of tail biting, as such both Finnish and Dutch farmers have ranked stable climatic condition as of the most important risk factor in tail biting (Bracke et al., 2013, Valros et al., 2016). Another target area to reduce the risk of tail biting is floor design. Fully or partly slatted floors are associated with increased risk of tail biting compared to solid floors (Schrøder-Petersen and Simonsen, 2001, Moinard et al., 2003, Palander, 2016). This could potentially be due to lack of or low levels of bedding used on slatted floor or higher level of noxious gases in slatted floor systems (Schrøder-Petersen and Simonsen, 2001). Hence providing bedding material in each pen might be beneficial to the pigs in more than one way.

4.5.3 Training and early detection

Early detection of tail biting is critical in isolating its incidences to fewer pigs and preventing an outbreak, and further reducing the need to perform tail docking (Valros, 2018). Four main behaviours have been recognized as potential predictors of tail biting: increased restlessness (Ursinus et al., 2014), changes in interaction with pen mate or rooting material (Zonderland et al., 2011, Ursinus et al., 2014), lowered tail position (Munsterhjelm et al., 2013, Larsen et al., 2016b, D'Eath et al., 2018) and reduction in daily feed intake (Wallenbeck and Keeling, 2013, Munsterhjelm et al., 2016). A study conducted by

(Munsterhjelm et al., 2015b) found that pigs consequently had bitten tails had reduced feed intake almost 2-3 weeks before the damaged tail was identified by farm stockpeople. Raising awareness amongst stockpeople regarding these behavioural changes may help manage tail biting more effectively and perhaps avoid the need for tail docking. In order to enable countries to phase out tail docking, future research needs to focus on potential methods of remotely detecting the predictors of tail biting automatically, such as the cameras used by D'Eath et al. (2018) to successfully detect tail posture in pigs. Researchers have proposed different avenues that could be explored in order to facilitate early detection of tail biting such as: automatic activity sensor at an animal or pen level (Larsen et al., 2016b), automatic feeder that can measure feeding changes at an individual pig level (Valros, 2018), measuring quantitative and temporal changes in the above-mentioned behaviours in relation to tail biting to help develop algorithm for automatic detection at commercial level (Valros, 2018). Further research is needed to be done on commercial farms assessing the practicality and cost effectiveness of using targeted intervention by identifying 'high risk' individuals within each group rather than making changes to each pig (D'Eath et al., 2014).

Conclusions, recommendations and future research on contentious behavioural and physiological conditions for all classes of pigs

Gastric ulceration, which can result in a failure to thrive and sudden death, is a common welfare problem in slaughter pigs and breeding sows. Finely grounded pelleted feed is a risk factor and provision of straw can reduce the prevalence of gastric ulceration.

Lameness is a major welfare concern because of the likely pain and discomfort for extended periods. Quality of flooring is widely considered to be essential to pig welfare as it is likely to have a direct effect on foot health. In slatted floor areas, the slat and gap widths should be appropriate to the claw size of the pigs to prevent injuries, while in solid floor areas, the surface should not be too smooth, but sufficiently rough to provide some abrasion to avoid excessive hoof growth.

Stereotypies may develop in long-term conflict or thwarting situations, and there is evidence that stereotypies can develop in response to barren or restricted environments as well as feed restriction and restricted foraging opportunities. The implication of stereotypies on pig welfare is contentious. A major review of the extensive literature on human and animal stereotypies and their links to welfare found evidence that increased stereotypies can be associated with reduced welfare, increased welfare or no change in welfare. Nevertheless, stereotypies generally indicate either a present problem for the animal or a past problem that has resolved. With the practice of restricted feeding of gestating sows, strategies to increase foraging and feeding times will reduce hunger and the likely development of oral stereotypies, such as oral stereotypic licking, bar-biting and sham chewing or vacuum chewing. With intensive, indoor and non-bedded systems in current pig production systems, providing opportunities to foraging in terms of searching and chewing for example with straw has been shown to reduce oral stereotypies. With the extensive use of fully- or partially-slatted, non-bedded and non-enriched environments in Australian pig production, further research is clearly required to investigate functional enrichment.

Tail biting is likely to cause both acute and chronic pain in the short-term in the recipient due to the actual tail biting and consequently weight loss and infection in the longer term is a potentially serious welfare problem for growing-finishing pigs. Tail biting is believed to be a multi-factorial syndrome factors influencing tail-biting appear to include external factors such as manipulable objects or substrates that can be chewed and manipulated, and particularly straw, space, stocking density and group size; indoor and outdoor climate; crowding, flooring, and food and feeding system; and internal factors such as genetics, gender, age and weight, gastrointestinal discomfort and health status. Tail-biting may not be a single homogenous behavioural category but rather comprise at least three different forms of behaviour, that each have differing underlying motivations. As concluded by Taylor et al. (2011) solutions to tail biting need to be tailored to tackle different types of tail-biting, and farmers and researchers should seek to identify more precisely the type of outbreak that is observed.

5. General management practices of pigs

5.1 Breeding for better welfare

In an intensive production system, there is a continuous need to achieve more sustainable economic and environmental gain without any negative impact on the welfare of animals. Selective breeding is one such means of obtaining a cumulative change, which can benefit one generation to the next (Turner et al., 2018). Despite the need to keep welfare of animals in mind, the main focus of pig breeding programs is productivity (Rauw et al., 1998). For example, successful breeding programs in pigs have achieved an annual improvement in growth rate of 5g/pig/day, which when accrued over decades of genetic selection is a dramatic change to productivity (Hermesch et al., 2015). However, selection for or against certain welfare traits in pigs is more challenging than perhaps selection for improved productivity, as pigs have large individual variations in their expression of negative welfare (Turner et al., 2018). This is potentially because traits that have major welfare implications are under both genetic and epigenetic control as a result of interactions between multiple genes (Balaban et al., 1996). One of the main advantages of improving animal welfare through genetic selection is that the traits can be improved without any major changes to the commercial farm itself, making it an economically viable option (Turner et al., 2018). Even though breeding programmes are not covered by the current code of practice in pig welfare, they play important role in addressing some of the main welfare shortfalls caused by the commercial production system. There are few studies that have looked at the heritability of certain welfare indicator traits such as; aggression, tail biting, neonatal mortality etc.

5.1.1 **Genetic selection against aggression**

The dynamic social environment of pigs housed in groups with conspecifics of similar competitive ability (i.e. similar in weight and size) without any means of escape is contradictory to their natural habitat, where living with an unfamiliar pig is uncommon and as such a gradual process (Mauget, 1981). Display of aggression to establish dominance is common amongst the wild boar, however, in commercial systems, aggression is displayed by pigs at all stages of production and its severity is more pronounced causing obvious skin lesions (Turner et al., 2006, Verdon and Rault, 2018). Even though there is variation in aggression within pig breeds, there is a positively skewed distribution amongst a small proportion of pigs that engage in high levels of aggression in every population (Turner et al., 2009, Desire et al., 2015). Certain aggression traits, such as the location and number of skin lesions have a heritability as high as growth rate, hence recording the location and number of skin lesions can be a fast way to predict genetic propensity of pigs to engage in aggressive behaviour (Turner et al., 2009). Current work on genetic programs against aggression focuses on selecting against skin lesions that will reduce the amount of active aggressiveness a pig might display, however this may reduce genetic predisposition of pigs to grow rapidly (Desire et al., 2015). Selection for reduced aggression in pigs is feasible and desirable, but as shown by d'Eath et al. (2009b), other behaviours such as general activity and ease of handling may have a positively correlated response to some degree, with possible implications for animal production and welfare. Although Løvendahl et al. (2005) found no genetic relationship between sow aggressiveness and maternal behaviour, research in this area is lacking.

Therefore, the correlated responses on other traits from the genetic selection against aggression needs to be fully understood, and the desirable behaviours possessed by sows of low aggressiveness need to be defined and the heritability estimated (Verdon et al., 2015). One of the main barriers in implementing such genetic selection is the ethical justification to breed against a behaviour that is natural and inherent to a species (Turner et al., 2018).

5.1.2 Genetic selection against tail biting

The propensity for tail biting seems to be lowly heritable and as such is observed more commonly in some breeds (e.g. Landrace pigs) (Breuer et al., 2005). Estimating heritability of sporadically occurring traits, such as tail biting is limited, as biters form only a fraction of the population and would require a large sample sizes to get substantial data. It means that, if a large sample size was obtained, the heritability of tail biting may in fact be higher than what is reported in the literature and that its potential of a genetic selection is underestimated (Turner et al., 2018). Another avenue of isolating genetic differences in tail biting population of pigs (including victims of tail biting) is using molecular genetic markers. Literature reports differences in single nucleotide polymorphism (SNP) of tail biters and their victims to the non-biting controls housed in the same pen (Wilson et al., 2012). Further research is needed to validate differences in these genetic markers on a larger population across different commercial farms. This may help select for pigs that have the genetic ability to avoid the delivery or receipt of tail biting (Turner et al., 2018).

5.1.3 Genetic selection to reduce neonatal mortality

Even after decades of intensifying pig production, the rates of piglet mortality, including still-births remain as high as 20% (Turner et al., 2018). To date, breeding programmes have focussed on increasing the litter size, which has simultaneously increased neonatal mortality (Rutherford et al., 2013). To address this issue, recent breeding programmes have expanded their selection criteria to include neonatal survival in addition to number of piglets born. So far, this inclusion hasn't reduced the piglet mortality rate, but it has increased the number of pigs weaned/litter (Roehe et al., 2009; 2010; Su et al., 2007). Another breeding benchmark that can be used to reduce piglet mortality is reducing intra-litter variations in birth weights (Damgaard et al., 2003; Rydhmer, 2000). Finally, one key determinant of piglet survival is maternal behaviour, especially with the shift towards farrowing pens in which piglet crushing by sows remain as one of the main cause of piglet mortality (Morrison et al., 2011, Turner et al., 2018). Therefore, breeding programmes to improve piglet survival should be in conjunction with selecting for sows with improved maternal behaviour (Baxter et al, 2011; Grandinson et al, 2005).

5.1.4 Genetic selection for better maternal behaviour

The current genetic selection to achieve higher productivity, as discussed earlier has increased the demands on sows during preweaning period (Grandinson, 2005). With the current shift towards farrowing pens, piglet crushing by sows remain one of the main cause of piglet mortality during preweaning period (Baxter and Edwards, 2018). Therefor breeding programmes to improve piglet mortality should be in conjunction with selecting for sows with improved maternal behaviour (Baxter et al., 2011; Grandinson et al., 2005). The main features of good maternal behaviour considered during genetic selection are: bonding behaviour between sow and offspring, nursing behaviour, responsiveness to piglets' distress call and attentiveness towards offspring (Grandinson, 2005).

A large-scale study of a Swedish Yorkshire breeding herd investigating genetic variations in sows' response to screaming piglets found very low heritability of this maternal behaviour (Grandinson et al., 2003). However, there was a high genetic correlation between piglet screams and high piglet survival rate. This indicates that selecting sows with a strong maternal response during a piglet scream test could improve early piglet survival rate (Grandinson et al., 2003). A study by Valros et al. (2002)

found nursing pattern was unique to each sow, indicating a genetic aspect to nursing behaviour. The study found that the frequency of successful nursing had positive correlation to piglet growth and survival rate (Valros et al., 2002). Improving maternal behaviour by genetic selection may be one of the key determinants of successful farrowing in large group pens as well as in outdoor housing. Further emphasis needs to be given to good record keeping of certain positive maternal behaviour as it may aid in selecting the right sows for specific needs or productive systems (Grandinson, 2005).

Conclusions, recommendations and future research on breeding for better welfare

Current focus of pig breeding programmes is mainly driven by market needs and economic benefit; however, future research needs to include welfare-relevant traits to help complement, and in some instances, resolve the effects of productivity based genetic selection. Future research should also focus on selecting sows with a better ability to regain body condition after lactation and reproductive function after weaning as this may have a flow on effect on piglet growth or survival.

5.2 On farm euthanasia of pigs

Pig farmers are required to have an efficient method of on-farm euthanasia for sick or injured pigs at all stages of production cycles (Turner and Doonan, 2010). The current Australian Model Code of Practice for the Welfare of Animals – Pigs states that the method of euthanasia must cause a sudden unconsciousness with death occurring when unconscious and it must be performed by a competent person who is suitably trained to perform the euthanasia practice. Acceptable methods are carbon dioxide gas inhalation, anaesthetic overdose, gunshot, penetrating captive bolt and blunt force trauma to the head (for piglets up to 3 weeks old). The New Zealand Pigs – Animal Welfare Code of Welfare 2010requires pigs to be killed by a person competent in the handling and killing of pigs and death must be confirmed by inspection of the animal. When a pig needs to be killed it must be handled, restrained and killed in such a manner as to minimise unnecessary pain and distress prior to death. The Canadian Code of Practice for the Care and Handling of Pigs requires consultation with a licensed veterinarian, and an on-farm written euthanasia plan to facilitate timely on-farm euthanasia to be developed and followed. Individuals who euthanize pigs must be trained in the appropriate euthanasia methods. The UK's Codes of Recommendations for the Welfare of Livestock: Pigs require stunning using a captive bolt pistol, concussion stunner or electrical stunner after which it must be followed by bleeding - or pithed - without delay (regulation 14 and Schedules 5 (Part II) and 6). If the animal is stunned and bled, the operation must be carried out by a slaughterman licensed for these operations (Schedule 1), unless the owner is slaughtering an animal for his own consumption; or killed by a free bullet (regulation 15 and Schedule 5 Part III); the animal should be killed with a single shot to the head.

This section of the review utilises and adds to the review by Gonyou et al. (2012b) on euthanasia. Euthanasia refers to a humane and painless death; rapid loss of consciousness should be followed by brain death, loss of breathing and cardiac arrest (AVMA, 2007). The assessment of animal welfare during euthanasia is focused primarily on the degree and duration of negative emotional states such as pain and distress, because aspects of the nature of the animal and its normal biological function are irrelevant at this time (Gonyou et al., 2012b). The effectiveness of methods for on-farm euthanasia of pigs is assessed with regard to the duration of time until loss of consciousness and subsequent death, the size of the animal, stockperson safety, ease of application and cost.

According to the AVMA (2007) death can be induced by either hypoxia, chemical depression of the central nervous system, or physical destruction of brain tissue. Euthanasia by hypoxia is a gradual decrease of oxygen levels in the blood and brain, leading to a state of unconsiousness which is followed by respiratory and cardiac failure (Velarde et al., 2007a, Velarde and Dalmau, 2017). An overdose of anaesthetic results in a depression of the central nervous system resulting in unconsciousness followed by death due to cardiac arrest and/or depression of the respiratory system. The physical destruction of brain tissue (or depolarization of neurons by electrocution) results in a rapid loss of consciousness and subsequent death when brain structures that control consciousness, as well as those controlling cardiac and respiratory function, are affected (Blackmore and Delany, 1988). Depending on the size of the animal, some euthanasia methods (e.g. the non-penetrating captive bolt gun) require a secondary step (such as exsanguination) to kill the animal after it is rendered unconscious (Gonyou et al., 2012b).

Euthanasia also involves two important considerations; determining when to euthanise an animal and assessing sensitivity (unconsciousness or insensibility). The decision to euthanize a pig is most commonly reliant on the degree of suffering a compromised pig is experiencing and the chances of recovery. This decision is important to consider in low-birth weight piglets (<1kg) that have a considerably higher chance of mortality before weaning than heavier piglets (Quiniou et al., 2002, Gondret et al., 2005). Low birth weight has been found to be associated with increased incidence of health problems and poor body condition, as well as decreased survival to weaning in piglets (Fix et al., 2010). Furthermore, weight at weaning and post-weaning has been shown to increase with increasing birth weight (Smith et al., 2007). Morrow et al. (2006) reported that high rates of mortality (if not euthanased) were found in piglets who experienced difficulty getting to feed and water, and those with swollen joints, lameness and hernias. These studies concluded that euthanasia of low birth weight piglets and of compromised piglets at weaning presenting the above condition is beneficial in terms of decreased suffering of the compromised piglets, improved overall herd welfare and increased economic viability (Smith et al., 2007, Morrow et al., 2006).

Insensibility is a temporary or permanent loss of brain function such that an animal is unable to perceive and respond to sensations, including pain, that is, a complete absence of awareness (Gonyou et al., 2012b). Following the application of a physical method of euthanasia, pigs will lose posture and may go into a tonic (rigid muscle extension) and/or a clonic (involuntary muscle contractions and spasms) phase of neuromuscular spasms. Whilst following euthanasia by gas inhalation, pigs will remain limp after losing posture (Grandin, 2010). Immediately after euthanasia, it is important to assess signs of sensibility to ensure that the animal is unconscious and dies without regaining sensibility (Gonyou et al., 2012b). For death to occur without pain or a return to consciousness, irreversible damage needs to be caused to the neural tissue in the brain stem, cerebral cortex and thalamus. The brain stem, cerebral cortex and thalamus are the regions of the brain involved with arousal and consciousness in mammals (Seth et al., 2005), and the brain stem is also involved in autonomic function such as control of respiration and heart rate.

Brain stem function can be verified by assessing the corneal reflex (eye blinking when the cornea is touched), the palpebral reflex (eye blinking when the edge of the eyelid is touched) and the pupillary light reflex (pupil constriction in response to shining light in the eye) (Erasmus et al., 2010, Grandin, 2010). The absence of these reflexes is indicative of loss of consciousness (Hall et al., 2001, Smith et al., 2008). Their presence does not however necessarily indicate that the pig is sensible, as is the case with head-only stunning when only the cerebral cortex is affected (Vogel et al., 2011, Smith et al., 2008). Therefore, other indicators such as the absence of spinal reflexes (e.g. response to nose-pricks, anal reflex, toe and claw reflex) and measures such as rhythmic breathing and regular heart rate are useful ways to determine whether euthanasia has been effective (Erasmus et al., 2010, Kaiser et al., 2006).

5.2.1 Piglets

Anaesthetic overdose is deemed a humane method of euthanasia for all pigs, because it depresses the central nervous system resulting in unconsciousness and subsequent death due to respiratory and cardiac arrest (AVMA, 2007). However, the type of anaesthetic and method of administration can influence the effectiveness (Gonyou et al., 2012b). For example, Whiting et al. (2011b) found that in an emergency mass killing of early weaning piglets, 5 of 240 piglets regained consciousness and 11 of 240 failed to die following an intraperitoneal injection of pentobarbital (Euthanyl), and therefore the authors did not recommend the use of anaesthetic overdose in this type of application. In addition, because it requires the use of a controlled substance, anaesthetic overdose must be performed by a veterinarian and is expensive, potentially delaying euthanasia when compared to other methods. There may also be problems with carcass disposal because of anaesthetic residue (Gonyou et al., 2012b).

Pre-weaning mortality is largely attributed to the first few days of a piglet's life (Johnson and Marchant-Forde 2009; Cronin et al. 2014). Euthanasia of neonatal piglets is most commonly performed by blunt force trauma delivered to the head; a manual blow to the head, using either a heavy instrument or a hard-flat surface, that causes severe concussion and brain damage leading to immediate unconsciousness and death within minutes in young piglets (Chevillon et al., 2004a, Widowski et al., 2008b, Kells et al., 2018). Blunt force trauma is considered a very effective means of euthanasia for neonates (if performed correctly), economically viable, convenient and safe for stock people given that the blow is applied accurately to the top of the head, with sufficient force and determination (Widowski et al., 2008). However, this method is aesthetically unappealing, emotionally difficult for the stockperson, and may not be well received by the public and consumers (Daniels, 2010)Morrow et al., 2010). The AVMA (2007) recommends only using blunt force trauma for young piglets, less than 3 weeks of age.

Chevillon et al. (2004a) evaluated blunt force trauma to the head as a euthanasia method for piglets under 8kg (using a 0.5kg hammer) and piglets between 8-25kg (using a 1.5kg hammer). The authors reported that after the blow to the head, all piglets immediately lost consciousness; they collapsed instantly, did not vocalise and their pupils were dilated. While the piglets showed convulsions and spasms, they all became motionless within 1.5 minutes (<8kg piglets) and 4 minutes (8-25kg piglets), and cardiac arrest occurred within 10 minutes in all piglets with no return to sensibility (Chevillion et al., 2004a). Similar results were found in a study by Widowski et al. (2008b) in low viability newborn piglets (<24 hours of age). Manual blunt force trauma was delivered by holding the piglets' hind legs and firmly striking the top of their heads against a flat hard surface. All piglets were immediately unconscious, and no piglets showed a return to sensibility; they showed leg movements for 1.14±0.12 minutes and cardiac arrest occurred after 2.85±0.31 minutes (Widowski et al., 2008b). In the study by Widowski et al. (2008b), five stock people performed piglet euthanasia and it was reported that the piglets euthanised by one of the stock people had lower skull fracture scores than all other stock people. This result suggests that blunt force trauma may not be consistent and depends on the force the stock person applies to the piglet's skull. In addition, the authors suggested that given that this method is likely to be unpleasant for some stock people to perform, it may result in a delay in the euthanasia of compromised piglets (Widowski et al., 2008b). However, if performed with sufficient force and determination, blunt force trauma to the head is very effective in causing immediate unconsciousness followed by death without a return to sensibility in neonatal piglets (Gonyou et al., 2004).

Euthanasia with a captive bolt gun inflicts a concussion that causes irreversible damage to the brain stem leading to death (Blackmore & Delany, 1988). There are two types of captive bolt guns, penetrating and non-penetrating. There is considerable variation in the design of captive bolt guns that may affect the amount of force and damage they deliver (Woods et al., 2010a, Woods et al., 2010b). For penetrating captive bolt guns this includes the length of the penetrating bolt, the muzzle design and the size of cartridge or pressure settings. For non-penetrating captive bolt guns this involves the muzzle size, shape and stroke length of the bolt head and size of cartridge or pressure settings (Gonyou et al., 2012b). For both types of captive bolt gun, the pig is restrained as the shot is directed at the midline of the forehead, 4-5 cm above eye level with the gun directed perpendicular to the forehead (Chevillon, 2005, Gonyou et al., 2012b); however, Woods et al. (2010b) suggests that different gun designs may need adjustments to the placement on the skull.

Finnie et al. (2003) found that the impact to the brain of a non-penetrating captive bolt gun on the left temporal region in anesthetised 15-18kg piglets was not able to cause sufficient brain damage to kill the pigs; indicating the importance of correct placement of the gun to the front of the piglets' head. For non-penetrating captive bolt guns to be effective without a secondary step, the impact must provide enough force to result in sufficient damage to the brainstem to cause depression of the cardiac and respiratory systems (Gonyou et al., 2012b). A study by Widowski et al. (2008b) evaluated the use of a pneumatic non-penetrating captive bolt gun with a round-bolt head for euthanasia of neonatal piglets (<24 hours). The piglets received two shots, one on the frontal bone and the second one immediately afterwards on the back of the skull. All piglets were found to become immediately insensible, however some piglets showed signs of returning to consciousness (Widowski et al., 2008). In a similar study on neonatal piglets (<3 days) using the same gun modified to have a cone-shaped bolt head with a greater depth of depression, Casey-Trott et al. (2010) found that all piglets became insensible immediately and none showed signs of regaining consciousness. Thus, the shape of the bolt head, the depth of depression at the point of impact, and the force applied all appear to determine the effectiveness of the non-penetrating captive bolt gun euthanasia method (Gonyou et al., 2012b).

In another study where the age of piglets was not specified, a non-penetrating captive bolt gun was found to be the most effective method of euthanasia, when compared to manual blunt force trauma, a lethal dose of pentobarbital (intra-peritoneal injection) and shooting with a rifle (Whiting and Marion, 2011a). A number of large scale studies, both in experimental and commercial settings, by (Woods et al., 2010b, Woods et al., 2011a, Woods et al., 2011b) also found non-penetrating captive bolt guns to be an effective one-step euthanasia method for pigs weighing 2-10kg. Clonic movements occurred for an average of 1.7 minutes and heart beats stopped 3.9 minutes after firing of the captive bolt gun.

A penetrating captive bolt gun was also found to be an effective method for euthanasia of piglets (8-25kg) in a study by Chevillon et al. (2004a). All piglets lost consciousness immediately and no piglets regained sensibility whether or not exsanguination was performed. Local haemorrhaging occurred in all piglets as well as spasms, convulsions and leg movements. Piglets became motionless within 1.5 minutes and cardiac arrest occurred within 6 minutes (Chevillon et al., 2004a).

Non-penetrating and penetrating captive bolt guns have been found to be effective in euthanising piglets (immediate loss of consciousness with irreversible brain damage and death), commercially available, are safe for stock people and cost per pig is fairly inexpensive; however, training is necessary (Chevillon et al., 2004b). However, these methods can only be performed one animal at a time and often requires the human operator to hold or restrain the animal, which makes it highly dependent on the training and skills of the operator. It is critical that placement on the skull be appropriate for the type of device and that there is a proper match of equipment to the size and age of the animal (Gonyou et al., 2012b).

Electrical stunning by placing electrodes on the head and chest of the pig and allowing sufficient current to flow through the brain is commonly used in slaughterhouses (Faucitano, 2010). However, loss of consciousness is reversible unless a second step to kill the pig is performed within 15 seconds (McKinstry and Anil, 2004). Electrical stunning is inefficient in piglets because the resistance around the skin can be less than that across the body, which causes the electrical current to flow on the skin's surface rather than through the body (Rault et al., 2013).

Gas inhalation is another method of euthanasia for piglets. Carbon dioxide (CO_2) is the most commonly used gas for gas inhalation in euthanasia and slaughter of pigs and piglets. Prolonged exposure to a concentration of 80-90% CO_2 is regarded by the AVMA as an acceptable form of euthanasia for pigs (2013), although animal reactions to gas euthanasia appear to be closely tied to procedural details that vary widely within the industry and in published guidelines (Fielder et al., 2014). Carbon dioxide causes unconsciousness by reducing the pH of cerebrospinal fluid and subsequently death results from hypoxia (Raj, 1999). There are two methods of carbon dioxide inhalation; introducing the pigs into a pre-filled CO_2 chamber, and gradually filling the chamber with gas (Woods et al., 2010b).

Pigs of all ages appear to find inhalation of CO_2 highly aversive, and less humane than alternative euthanasia methods such as blunt force trauma. Carbon dioxide does not provide loss of consciousness, and following exposure to CO_2 pigs have been reported to display behavioural and/or physiological signs of distress (Raj and Gregory, 1996, Sutherland et al., 2017); escape and retreat attempts, gasping, head shaking and vocalizations observed frequently prior to loss of consciousness (Rodríguez et al., 2008, Chevillon et al., 2004a, Raj and Gregory, 1996, Sadler et al., 2011a, Sadler et al., 2014, Velarde et al., 2007a). Carbon dioxide causes two different aversive states; CO_2 sensitive receptors in the respiratory tract and the brain cause dyspnea (the feeling of breathlessness), and the irritation of mucus membranes by reaction of CO_2 with water to form carbonic acid causing a burning sensation (Rodríguez et al., 2008, Troeger and Woltersdorf, 1991).
Neonatal pigs reportedly find CO_2 less aversive and they succumb to it faster than weaned pigs, however fast flow rates are recommended (Sadler et al., 2014). The concentration of CO_2 and whether the pig is exposed to a prefilled chamber or with a gradual fill of the gas influence its effectiveness (Gonyou et al., 2012b). Growing-finishing pigs exposed to different concentrations of CO_2 (40% - 90%) showed less aversive reactions, including high locomotor activity, escape attempts, respiratory distress and vocalisations, for a shorter time after immersion as the gas concentrations increased (Raj and Gregory, 1996, Terlouw et al., 2006, Troeger and Woltersdorf, 1991). Sadler et al. (2011a) exposed weaned piglets using 100% CO_2 in either a pre-filled chamber (20%) or with flow rates of 20%, 35% or 50% chamber volume per minute. Piglets euthanised in the pre-filled chamber or with the fastest flow rate (50%) showed less aversive reactions and died sooner (last movement and loss of posture occurred sooner and there was less gasping) than if the flow rate was medium or low. These findings are supported by Sutherland (2010) who found that cessation of brain activity (as measured by electroencephalography [EEG]) and heart beat were significantly faster using a pre-fill method with a concentration of 90% CO_2 compared to gradual fill at a rate of 20% per minute.

Chevillon et al. (2004a) showed that exposure to 80% CO_2 for 6 minutes resulted in death of piglets, but it took at least 90 seconds for them to become unconscious. Sutherland (2010) found that loss of posture (used as a measure of loss of consciousness) occurred within 45 seconds (range 36 to 108 seconds) for piglets ranging from 1 to 6 weeks of age exposed to 90% CO_2 with no effect of piglet age. Similar results were found in a study by Sadler et al. (2011b) on piglet euthanasia using 100% CO_2 with neonatal piglets (0-3 days) and weaned piglets (16-24 days), although neonates lost consciousness faster than older piglets (99 versus 142 seconds, respectively). In addition, pigs gradually exposed to 90% CO_2 in a dip-lift system showed brain activity for up to 60 seconds after exposure (Rodriguez et al., 2008).

Gas euthanasia methods are commonly chosen when large groups of animals need to be humanely and efficiently put to death, for example during disease outbreaks (Fiedler et al., 2014). While the capacity to euthanise animals in groups is an advantage of gas inhalation (Atkinson et al., 2012), group euthanasia requires some consideration of both direct and conspecific effects (Fielder et al., 2014). Carbon dioxide exposure elevates stress hormones in pigs (Gregory et al., 1987, Forslid and Augustinsson, 1988, Kohler et al., 1998a) and increases vocalisation, agitation, and escape attempts (Raj 1999; Velarde et al 2007; Rodríguez et al 2008). Visual, auditory, and olfactory alarms have been shown to transmit fear and stress to conspecifics in proximity to an animal undergoing a distressing procedure (Vieuille-Thomas and Signoret, 1992, Talling et al., 1996, Amory and Pearce, 2000). The onset of insensibility following exposure to CO_2 varies between pigs in unpredictable patterns that can only be associated with individual variation (Holst, 2001). As such, during group CO_2 euthanasia there is the potential for conscious pigs to be exposed to violent convulsions, distress vocalisations, and alarm pheromones of conspecifics, to the possible detriment of welfare (Raj, 2006). A study by Fiedler et al. (2014) investigated the effects of chamber stocking rate (group sizes of one, two, four, or six pigs) on animal welfare and efficacy during CO_2 gas euthanasia of neonatal and weaned pigs (gradual fill 80% CO_2). Higher stocking rates were associated with higher CO_2 concentrations after gradual fill for both neonatal and weaned pigs. While there was no evidence of an effect of stocking rate on latencies to loss of posture or last movement in neonatal pigs, there was evidence of an effect on all measured efficacy variables in weaned pigs, with grouped pigs faster to succumb than solitary pigs. This study provided no evidence that isolation during gas euthanasia would benefit animal welfare.

Gas inhalation using alternative gases including argon (Ar), nitrogen (N_2) and nitrous oxide (N_2O), either administered alone or in combination with various concentrations of CO_2 or oxygen (O_2) have been studied. Chemically inert gases such as N_2, Ar, and N_2O possess anaesthetic properties without imparting any sense of breathlessness (Raj and Gregory, 1996). Oxygen deprivation rather than CO_2 inhalation has been proposed as a potentially more humane option for piglet euthanasia (Freed, 1983). A means of inducing oxygen deprivation is exposure to argon gas (Ar), as it known to displace oxygen causing hypoxia, loss of consciousness, and death of neurons (Leary et al., 2013). However, Ar is an inert gas that is only found in minute quantities in the atmosphere and hence more expensive than CO_2 gas (Raj and Gregory, 1995).

In Raj (1999) and Raj et al. (1997), growing pigs that were exposed to 90% Ar did not show any hyperventilation during inhalation, whereas pigs exposed to either 30% CO_2:60% Ar or 80-90% CO_2 did show hyperventilation. Ninety percent AR caused less aversion than N_2 with CO_2 (with greater CO_2 being associated with increased breathlessness), itself favoured over 90% CO_2 (Dalmau et al., 2010, Raj and Gregory, 1995). These studies suggest that pigs may find inhalation of Ar less noxious than CO_2, which is consistent to findings in rodents (Leach et al., 2002). Conversely, (Sadler et al., 2014b, Sadler et al., 2014c) reported that 100% CO_2 gas, rather than a 50:50 CO_2:Ar gas mixture, and fast, rather than slow, flow rates were advantageous for pig welfare and efficacy when euthanising both weaned and neonate pigs. Pigs exposed to Ar gas (50:50 CO_2:Ar gas mixture) showed increased vocalisation, increased righting and escape attempts compared to pigs that were exposed to CO_2 inhalation (Sadler et al., 2014, Sadler et al., 2014c, Sadler et al., 2014b). These contrasting findings indicate that further research is required before Ar can be used as means of piglet euthanasia in commercial farms.

Nitrous oxide (N_2O) has been shown to induce narcosis in piglets. Rault et al. (2013) concluded, based on behavioural observations, that a 2-step procedure in which pigs are anesthetized with a mixture of N_2O and O_2 before being euthanized by immersion in CO_2 was more humane than CO_2 alone. Whilst all studied gas mixtures were aversive compared with air (to various degrees), N_2O in O_2 appeared to be less aversive than N_2O, N_2, or Ar all combined with low (30%) concentrations of CO_2 or 90% CO_2 by itself (Rault et al., 2013). Rault et al. (2015) reported that N_2O is considerably less aversive than CO_2, and 90% N_2O can euthanize piglets. Latency to loss of awareness, based on isoelectric EEG, under 90% N_2O exposure was slightly longer than that when using 90% CO_2, but because piglets did not show an aversive response to N_2O gas, the authors concluded it to likely be more humane (Rault et al., 2015). More recently, Smith et al. (2018) investigated the on-farm use of a two-step euthanasia method, using nitrous oxide (N_2O) for six minutes and then carbon dioxide (CO_2) on compromised 0-7 day-old piglets. When compared to CO_2 alone, piglets in the N_2O treatment displayed more behavioural signs of stress and aversion; squeals, escape attempts, and righting responses in a group setting. The authors concluded that, based on the study's findings, euthanising piglets for 6 minutes with N_2O and then CO_2 was not more humane than euthanizing with CO_2 alone (Smith et al., 2018).

Gas inhalant euthanasia provides the advantage of euthanising multiple animals at once using a chamber, hence minimizing social distress, and is more aesthetic than other procedures. However, a lack of conclusive outcome-based evidence means that further research is required to determine the most effective and humane gas or gas mixture for gas inhalation euthanasia of piglets.

5.2.2 Growing-finishing and Adult pigs

Most Codes of Practice discussed in this review recommend the use of either a penetrating captive bolt gun or gunshot to head for on-farm euthanasia of adult pigs. The literature is limited regarding on-farm euthanasia of adult pigs, with most focussed on appropriate methods for euthanasia in piglets or young pigs.

Anaesthetic overdose is considered to be a humane method of euthanasia for all pigs, due to its depression of the central nervous system that results in unconsciousness and subsequent death due to respiratory and cardiac arrest (AVMA, 2007). However, the type of anaesthetic and method of administration can influence the effectiveness. Furthermore, it requires the use of controlled substance, and therefore anaesthetic overdose must be performed by a veterinarian and is expensive, potentially delaying euthanasia when compared to other euthanasia methods. Anaesthetic residue may also result in problems with carcass disposal (Gonyou et al., 2012).

As noted previously, euthanasia with a captive bolt gun inflicts a concussion that causes irreversible damage to the brain stem leading to death (Blackmore and Delany, 1988). In the study by Chevillon et al. (2004a) the use of a penetrating captive bolt gun for euthanasia was investigated in growing pigs (>25kg) and sows with or without subsequent exsanguination. The study found that all pigs lost consciousness immediately and no pigs regained sensibility, despite whether exsanguination was performed or not. All pigs showed signs of local haemorrhaging, as well as spasms, convulsions and leg movements. Growing pigs became motionless within 2.5 minutes and cardiac arrest occurred within 7 minutes without exsanguination and within 2 minutes with exsanguination. In sows, exsanguination reduced the spasms and convulsions, and cardiac arrest occurred after 2-8 minutes and within 5-7 minutes without exsanguination (Chevillon et al., 2004a).

Woods and colleagues evaluated the use of a penetrating captive bolt gun as one-step euthanasia procedure for pigs 15-300kg in a large-scale study both in experimental and commercial settings Woods et al. (2010), Woods et al. (2011b). These studies found that colonic movements occurred for an average of 1.7 minutes and heart beats stopped 3.9 minutes after firing of the captive bolt gun regardless of body weight. A single shot of the penetrating captive bolt gun was found to be effective in euthanising pigs under 120kg; above this weight a secondary step was necessary. This was shown both through assessment of traumatic brain injury of the thalamus (which was not observed in pigs over 120kg) and assessments of physiological responses to euthanasia. It was also reported that the placement of the captive bolt gun required a different angle than that commonly recommended for gunshot euthanasia. Furthermore, the authors suggested that inadequate restraint of the animal or bolt gun placement may result in ineffective euthanasia.

The penetrating captive bolt gun appears to be fairly inexpensive and effective method of causing immediate loss of consciousness with irreversible brain damage and death of pigs less than 120kg, when performed by an operator with appropriate training. For mature sows and boars (>120kgs), a penetrating captive bolt gun can be used for stunning but a secondary step (exsanguination) is required to ensure death (Woods et al., 2010, NationalPorkBoard, 2008).

Electrical stunning, performed by placing electrodes on the head and chest of the pig and allowing sufficient current to flow through the brain, is commonly used in slaughterhouses (Faucitano, 2010). However, whilst electrical stunning results in a loss of consciousness, it is reversible unless a second step to kill the pig is performed within 15 seconds (McKinstry and Anil, 2004). When using an electrical stun of 150-200V for 3 seconds on pigs weighing 60-80kg, the return to corneal reflex was reportedly on average 37 seconds with a minimum of 18 seconds (Anil and McKinstry, 1998, McKinstry and Anil, 2004). For on-farm euthanasia, the second step is generally another electrocution to the heart which causes cardiac arrest and death of the pigs, rather than bleeding which is commonly performed in slaughterhouses (Gonyou et al., 2012).

There are two methods to euthanise pigs with electrocution: the two-step system in which the pig is stunned then killed with electrocution through the heart; and the one-step system which requires greater current and simultaneously electrocutes the brain and heart (Gonyou et al., 2012). The two-step system, requires two electrodes to be placed on either side of the head (in the area between the corner of the eye and the base of the ear) to ensure proper electric current flow through the brain (Anil and McKinstry, 1998, Eike et al., 2005, Faucitano, 2010). If the placement of the electrodes is incorrect and do not span the brain (e.g. if placed on either side of the jaw or the neck) an effective stun may not occur (Anil and McKinstry, 1998). Once the first stun has been delivered, the electrodes are immediately moved from the pigs and placed on the chest (close to and spanning the heart) which will kill the pig through cardiac ventricular fibrillation (Woods et al., 2010).

The study by Chevillon et al. (2004b) investigated the use of a two-step electric euthanasia system on growing pigs (>25kg) and sows, which involved electrical stunning to the head (5 seconds) followed by electrocution to the heart (15 seconds). The first stun to the head resulted in immediate collapse and pupil dilation, and the second stun to the heart resulted in cardiac arrest within 1.5 minutes with the animals becoming immobile within 30 seconds. Vogel et al. (2011) studied the electrical stunning of market weight pigs using a commercially available stunning system (scissor-like clamp) with an application time of 3 seconds per electrocution at 313V and 2.3A. Approximately 30 seconds post-stun pigs were bled, at which time sensibility was assessed; no pigs showed rhythmic breathing, heartbeats, natural blinking, eye tracking to moving object or righting reflex. For two-step electrical stunning, the World Organization for Animal Health (OIE) recommends an electrode application of at least 3 seconds with a minimum of 125V for piglets younger than 6 weeks of age and 220V for pigs older than 6 weeks of age (OIE, 2010).

For one-step electrical stunning, simultaneous current flow through the head and the heart which results in immediate unconsciousness and death (Wotton et al., 1992), the OIE recommends using a minimum of 250V and applying the front electrode in front of the eyes and the rear electrode to the back, above or behind the heart for at least 3 seconds. Using a one-step head to back electrocution system with different placements of the rear electrodes, Wooton et al., (1992) euthanised finishing pigs with 300V at 50Hz for 3.5 seconds. The front most placement of the rear electrodes on the cervical vertebrae was the only placement that did not result in a 100% cardiac arrest; the other placements were further back on the thoracic vertebrae. Wotton et al. (1992) assessed cardiac fibrillation but did not measure signs of unconsciousness, because pigs were bled soon after euthanasia for carcass assessments. A study by Denicourt et al., (2009) examined the effectiveness of two methods of one-step electrocution in pigs ranging from 5-125kg using 110V for 5 seconds with electrodes placed at different contact points. The two methods tested both supplied current through the brain with a steel lasso attached to the upper jaw in conjunction with either an anal probe or a metal belt around the abdomen. Immediately after electrocution, all pigs showed dilated pupils, no corneal, nociceptive or respiratory reflexes and the electrocution induced cardiac fibrillation. However, it has been noted that this method of electrical stunning required considerable manipulation of the animal before euthanasia, and as such may not be humane (Denicourt et al., 2009).

Both one and two-step electrocution methods are efficient for an effective euthanasia of pigs without return to sensibility, with the one-step method requiring higher voltage (Gonyou and Brown, 2012a). However, the electrodes need to be kept clean, well designed and firmly applied to the skin before the current is started (Grandin, 2010, Sparrey and Wotton, 1997). This method of euthanasia is expensive and as such may not be practical for an on-farm use.

Gas inhalation using carbon dioxide is the method most commonly used to stun adult pigs before slaughter. For on-farm euthanasia of adult pigs, there has been some limited investigation into argon gas (Ar) as an alternative method for euthanasia as it is a non-irritant, odourless gas that is believed to cause loss of consciousness and death with little to no distress or aversion (Kells et al., 2018). A study by Raj and Gregory (1995) found that the pigs readily entered a chamber containing 90% Argon for food reward, but avoided the chamber that contained 90% CO_2. Even though, Ar is not aversive to pigs and a better option in terms of welfare compared to 100% CO_2, pigs when exposed to Ar take twice as long to lose consciousness and as such, Ar might not be the best choice for on-farm euthanasia (Raj and Gregory, 1995, Kells et al., 2018). At present, gas inhalation does not appear to be an effective or practical on-farm method of euthanasia in adult pigs. A gunshot to the head has a similar mode of action as a penetrating captive bolt gun in that it causes a concussion and destroys vital parts of the brain, however it uses a free projectile (Blackmore and Delany, 1988). The animal needs to be restrained to ensure the appropriate positioning of the gun with the muzzle placed close to the animal's head and aimed towards the brain (AVMA, 2007; Longair et al. (1991). It is recommended to aim the gun at the front of the head (as with the captive bolt gun) or behind the ear but without the gun touching the head (Gonyou et al., 2012). These positions have been reported to be effective for euthanasia of large pigs by (Blackmore et al., 1995). A gunshot to the heart is not an accepted method of euthanasia without prior stunning because the animal will not lose consciousness immediately (Woods et al., 2010). While some scientific studies have been performed on the use of a shotgun to euthanise adult pigs, it is likely that if the animal is restrained, the shot is powerful enough and well-aimed, it will cause immediate insensibility and death in adult pigs (Gonyou and Brown, 2012a). There are however concerns for human safety (risk of ricochet), the person performing the euthanasia must be well trained, have a gun license and perform the euthanasia outdoors (AVMA, 2007). In the case of a compromised animal, it may be difficult to move it outdoors, and thus this method may not be the most appropriate for adult pig euthanasia.

Conclusions, recommendations and future research on on-farm euthanasia

Anaesthetic overdose is effective for a painless death in all classes of pigs, but euthanasia may be delayed because veterinary supervision and administration is required, and it is expensive. When applied with sufficient force, blunt trauma and non-penetrating captive bolt are effective methods of euthanasia for piglets and result in immediate unconsciousness and death. Penetrating captive bolt is effective as a single step method for euthanasia of pigs under 120kg. For mature sows and boars, penetrating captive bolt causes loss of consciousness, but a secondary step (e.g. exsanguination) is necessary to ensure death. All three methods of euthanasia are safe for the stockperson and cost effective, however highly dependent on the training and skills of the operator. Furthermore, blunt force trauma is likely to be unpleasant for some stock people to perform, and as such it may result in a delay in the euthanasia of compromised piglets.

Electrocution for pigs less than 2.3kg causes immediate death; an electric current flows through the brain resulting in unconsciousness and through the heart leading to cardiac arrest. This can be performed with a simultaneous electrocution of brain and heart, or in two-steps by electrocuting first the brain then the heart. Cost and maintenance of equipment may limit this euthanasia method.

Carbon dioxide (CO_2) is the most commonly used gas for gas inhalation euthanasia in piglets. Exposure to carbon dioxide (>80% CO_2), to a mixture of CO_2:argon, argon gas (90%) or nitrous oxide in either pre-filled chamber or with a high flow rate have all been found to be effective methods to kill pigs. However, CO_2 inhalation is highly noxious and causes signs of distress until loss of consciousness which may occur as long as 2 minutes following exposure to the gas. Piglets exposed to alternative gases or gas mixtures also show some signs of distress. A lack of conclusive outcome-based evidence means that further research is required to determine the most effective and humane gas or gas mixture for gas inhalation euthanasia of piglets. At present, gas inhalation does not appear to be an effective or practical on-farm method of euthanasia in adult pigs. When properly executed, gunshot to the head is effective for euthanasia in adult pigs, however human safety may be a concern.

6. Human resource management

The principle that management, including supervising and managing animals, affects farm animal welfare is widely recognised within the livestock industries. However, the manner in which management affects farm animal welfare, both directly and indirectly, and the impact of this influence are probably not fully appreciated. At the level of farm management, human resource management practices, including employee selection and training, and animal management practices, such as best practice in housing and husbandry, and implementation of welfare protocols and audits, all impact on farm animal welfare. At the stockperson level, together with the opportunity to perform their tasks well, stockpeople require a range of well-developed husbandry skills and knowledge to effectively care for and manage farm animals.

Technical skills and knowledge are important attributes of the work performance of stockpeople. Knowing and being skilled at the techniques that must be used to accomplish a task are clearly prerequisites to being able to perform that task and thus these job-related characteristics will be limiting factors on job performance in situations where specific technical skills and knowledge are required to perform the tasks. Furthermore, there is a considerable body of evidence of the effects of human interactions on farm animal fear and stress responses. There has been a number of recent reviews on the impact of stockperson attitudes and behaviour on animal fear, stress, productivity and welfare (Hemsworth and Boivin 2011; Hemsworth and Coleman 2011; Coleman and Hemsworth 2014; Hemsworth et al., 2018), and this section of the present review briefly reviews the research on the welfare implications of an improved human-animal relationship on pig welfare and the opportunities to improve this relationship and thus pig welfare.

6.1 Relationships between stockperson characteristics and pig welfare and pig productivity

There are three main lines of evidence that demonstrate that negative or aversive handling by affecting fear responses to humans can affect the welfare of farm animals: handling studies under controlled conditions; observed relationships in the field; and intervention studies in the field targeting stockperson behaviour. The concerns for the welfare of fearful farm animals arise since fear is a negative emotional experience (Mellor, 2012) and is widely considered an undesirable state of suffering (Jones and Waddington, 1992). These effects of stockperson behaviour on the welfare and productivity of farm animals, particularly pigs, will be briefly reviewed here.

6.1.1 Evidence from handling studies

Handling studies, predominantly on dairy cattle, pigs and poultry, show that negative or aversive handling, imposed briefly but regularly, will increase fear of humans and reduce the growth, feed conversion efficiency, reproduction and health of farm animals (see reviews by Hemsworth and Coleman 2011; Hemsworth et al. 2009; Waiblinger et al. 2006). Studies with pigs clearly demonstrate that a chronic stress response is implicated in these adverse effects on productivity since handling treatments which resulted in high fear levels, often produced either a sustained elevation in the basal free cortisol concentrations or an enlargement of the adrenal glands in pigs (see Hemsworth and Coleman 2011; Hemsworth et al., 2018).

6.1.2 Evidence from field observations

Field studies examining inter-farm correlations indicate sequential relationships between stockperson attitudes, stockperson behaviour, animal fear of humans and animal productivity. These studies have been reviewed in detail by Hemsworth and Coleman (2011) and Hemsworth et al. (2018) and the main findings are briefly described below.

First, negative inter-farm correlations have been consistently found between fear of humans, as assessed on the basis of the animal's behavioural response to an unfamiliar human in a standardized test, and the productivity of dairy cattle, pigs and poultry. In pigs, high fear responses were associated with reduced productivity in terms of reproductive performance of commercial sows.

Second, inter-farm correlations have been found between the behaviour of stockpeople and the fear of humans in farm animals. The frequent use of handling behaviours, which can be considered as negative in nature, was associated with high fear levels in farm animals. In the pig industry, these negative stockperson behaviours included slapping, hitting and pushing pigs. Conversely, the frequent use of handling behaviours, which can be considered as positive in nature, was associated with reduced fear levels in farm animals. In the pork industry, these positive stockperson behaviours included patting and stroking pigs as well as resting the hand on the pig's back when the opportunity arises.

Third, correlations have been found between stockperson attitudes and behaviour in the field. Questionnaires were used to assess the attitudes of the stockpeople on the basis of their beliefs about their behaviour and the behaviour of their animals. In general, positive attitudes to the use of petting, such as talking and stroking, and the use of verbal and physical effort to handle pigs were associated with reduced use of negative stockperson behaviour to pigs.

In addition to these human-animal relationships on farm, similar relationships have been observed at pig abattoirs as well as cattle and sheep abattoirs (Coleman et al. 2003, 2012; Hemsworth et al. 2011, 2016).

6.1.3 Evidence from intervention studies in the field

Studies in the dairy and pork industries have demonstrated that cognitive-behavioural training of stockpeople, in which the key attitudes and behaviour of stockpeople are targeted, can be successfully used to improve animal welfare and productivity. These intervention studies resulted in improvements in the attitudes and behaviour of stockpeople and, in turn, reductions in fear of humans and improvements in the milk yield of commercial dairy cows and the reproductive performance of commercial sows (Coleman et al. 2000; Hemsworth et al. 1994, 2002).

Cognitive-behavioural techniques basically involve retraining people in terms of their behaviour by firstly targeting both the beliefs that underlie the behaviour (attitude) and the behaviour in question and secondly, maintaining these changed beliefs and behaviours (Hemsworth and Coleman 2011). This process of inducing behavioural change is a comprehensive procedure in which all of the personal and external factors that are relevant to the behavioural situation are explicitly targeted.

6.2 A model of human-animal interactions in the livestock industries

As indicated above, there is a substantial body of evidence that the interactions between stockpeople and their animals can have a substantial effect on the behaviour, welfare and productivity of farm animals. Essentially, stockperson attitudes towards their animals and working with them, their beliefs about other people's expectations of them, and their beliefs about the extent to which they have control over their ability to appropriately interact with the animals determine the nature and extent of their interactions with these animals (Hemsworth and Coleman 2011; Coleman and Hemsworth 2014; Hemsworth et al. 2018). Furthermore, it is this history of stockperson interactions with the animal that leads to the development of a stimulus-specific response of farm animals to humans: through conditioning, farm animals may learn to associate humans with rewarding and punishing events that occur at the time of human-animal interactions and thus conditioned responses to humans develop. In situations in which stockperson interactions are poor, through animal fear and stress, both animal welfare and productivity are at risk.

Since attitudes are learned and because they are the main dispositional factor affecting volitional human behaviour, there are likely to be opportunities to manipulate human-animal interactions in the livestock industries in order to influence farm animal welfare and productivity, by improving the attitudes and behaviour of stockpeople towards farm animals.

6.3 Interactions between stockperson attitudes and behaviour and other job-related characteristics

Stockpeople clearly require a basic knowledge of both the requirements and behaviour of farm animals, and also must possess a range of well-developed husbandry and management skills to care for and manage their animals effectively. Therefore, while cognitive-behavioural training addressing the key attitudes and behaviour of stockpeople that affect animal fear is important in improving animal welfare, it is obvious that knowledge and skills training are also fundamental to improving the welfare of commercial livestock.

In addition to the direct effects of the stockperson's behaviour on animal welfare and productivity, stockperson attitudes and behaviour may also have indirect effects on animal welfare and productivity by affecting other important job-related characteristics, such as job satisfaction, work motivation and motivation to learn. In many industries outside agriculture, the effects of motivating factors on job satisfaction and, thus in turn, work motivation are well recognized. Hemsworth and Coleman (2011) have proposed that the attitude of the stockperson towards the animal may affect job-related characteristics, such as job satisfaction, work motivation, motivation to learn new skills and knowledge about the animal, which in turn may affect work performance of the stockperson. In fact, Coleman et al. (1998) in a study of pig stockpeople found that the willingness of stockpeople to attend training sessions in their own time was correlated with attitudes towards characteristics of pigs and towards most aspects of working with pigs. Job enjoyment and opinions about working conditions showed similar relationships with attitudes. Thus, the stockperson's attitudes may indeed be related to aspects of work apart from handling of animals and consequently improvements in stockperson attitudes towards animals may influence other important job-related characteristics such as job satisfaction, work motivation and motivation to learn.

6.4 Opportunities to improve human-animal relationships and farm animal welfare

The results of the intervention studies in the field, taken in conjunction with handling studies and field observations on the relationships between stockperson attitudes, stockperson behaviour, animal fear and animal productivity (see earlier), not only provide evidence of causal relationships between these stockperson and animal variables, but also provide a strong case for introducing stockperson training courses in the livestock industries that target the attitudes and behaviour of the stockperson.

Therefore, this research on human-animal relationships in animal production demonstrates the important role and responsibility of the stockperson in the development of human–animal relationships in the animal industries and thus underlines the need to understand not only these relationships but also the opportunities to improve them in order to safeguard animal welfare. The attitudes of stockpeople are amenable to change, so stockperson training can improve human-animal relationships in the livestock industries. Technical skills and knowledge are important attributes of the work performance of stockpeople and clearly training targeting these attributes is important in improving animal welfare and performance via the technical skills and knowledge competencies of stockpeople. Indeed, the results presented here suggest that both technical and cognitive-behaviour training are necessary to not only reduce the stress associated with handling and husbandry procedures involving humans, but also to improve the motivation in stockpeople to learn new technical skills and knowledge and to apply these competencies to the management of the animals under their care. The relationships between stockperson attitudes and behaviour on work performance, both direct via handling of animals and indirectly via important job-related characteristics such as job satisfaction, work motivation and motivation to learn, together with the obvious importance of technical skills and knowledge, highlight the need to include training targeting the attitudes and behaviours of stockpeople towards farm animals in conjunction with the technical skills and knowledge of stockpeople.

Conclusions, recommendations and future research on contentious behavioural and physiological conditions for human resource management

Irrespective of the housing system, the skills, knowledge and motivation of stock people to effectively care for and manage their animals are integral to the standard of welfare experienced by their animals. Attitudes influence not only the manner in which stock people handle pigs, but also their motivation to care for animals. Thus, training targeting technical skills and knowledge as well as the attitudes and behaviours of stock people should be a primary component of the human resource management practices at a farm.

7. Mitigation of risk in emergency situations

The Model Code of Practice should have provisions to minimize risk to pigs during emergency situations such as fire, extreme weather conditions, flooding and power or supply failure. In case of natural emergencies, the Australian Code of Practice states that:

i) Action must be taken to detect, and cool heat distressed pigs
ii) All buildings must have fire prevention measure in place in accordance with requirements of controlling authorities.
iii) Approved firefighting equipment must be available for use in all pig accommodation. Large shelters that are difficult to service with fire equipment, pigs must have access to gates that can allow them to escape.

With regards to natural emergencies, the Code of Practice recommends that:

i) During very hot weather (35 ^{0}C or more) and steps should be taken to alleviate distress and avoid deaths.
ii) At temperatures above 38 ^{0}C, lactating and gestating sows should be checked regularly for signs of heat stroke and cool any animals that are affected.
iii) Firebreak should be established around pasture for open-range systems and pig sheds when the risk of fire is high.
iv) In regions with high summer temperatures risk mitigation measures should be put in place to reduce the risk of heat stress. This may include provision of shade, ventilation, wallows and water sprinkler.

With regards to delivery failure, the Model Code of Practice recommends that there should be contingencies to provide an alternate means of feed, in case of supply failure or delays in delivery. The Canadian and New Zealand Code of Practice requires farmers to have an emergency plans for alternate source of water and feeding available in case of equipment or power supply failure. Both the countries also require for the farmers to have emergency plan ready in case of natural emergencies such as fire (New Zealand) or freezing conditions (Canada).

The Australian Model Code of Practice for the Welfare of Animals – Pigs does not have any provision for emergency situations such as a disease outbreak or extreme natural disasters (e.g. bush fire, flooding) that requires large-scale evaluation or depopulation of the farm animals. Historical data on outbreaks shows that the best strategy to prevent them from becoming epidemic is rapid diagnosis, isolation and depopulation of infected herds and finally pre-emptive slaughter of herds that have been in contact with or located near infected herds (Stegeman et al., 2000). For example, until the 1980s, pigs in the Netherlands were frequently infected with classical swine flu. At first, they tried to control the outbreak by vaccinating pigs against swine flu, however it was found to be an ineffective strategy, which led them to employ tools for rapid diagnosis and eradication of infected herds. However, these strategies were proven to be ineffective yet again and the country was hit by swine flu epidemic in 1997, which ultimately led to a large-scale depopulation of millions of pigs. The only means by which they were able to control the epidemic was pre-emptive slaughter of herds that were either nearby or directly in contact with the infected herds.

Conclusions, recommendations and future research on contentious behavioural and physiological conditions for mitigation of risk

It is important to have contingency plans incorporated in the code of practice for large-scale depopulation of herds in case of an outbreak. The Code should also have a standard that requires farmers to prepare and practice an emergency plan in case of natural disasters such as bush fires or flooding, relevant to their geographical location. Farmers should also be required to have a contingency plan in case of a power failure as that would impact the ventilation, heating and cooling of the sheds as well as automated drink and feed dispensers.

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APPENDIX I

Minimum space allowance for gilts, sows and boars

Class	Australia	Canada	Denmark
Gilts in group housing	1m^2	1.4 – 1.7m^2 (partly slatted) 1.5 – 1.9m^2 (solid bedded)	1.64m^2
Sows in group housing	1.4m^2	1.8 – 2.2m^2 (partly slatted) 2.0 – 2.4m^2 (solid bedded)	2.25m^2
Sows in stall	0.6m x 2.2m	0.6m – 0.8m (width) (<150kg to >340)	
Farrowing crate	0.5m x 2.m		
Farrowing pen	5.6m^2 per sow		
Boars in stall	0.7m x 2.4m	0.7m x 2.13m (upto 135kg) 0.82m x 2.29m (upto 180kg) 0.91m x 2.44m (>225kg)	
Boars in individual pens	6.0m^2	5.6m^2 (partly or fully slatted) 7.4m^2 (solid bedded)	6m^2 (housing) 10m^2 (service)
Weaners, growers and finishers (10kg to 120kg)	0.14 - 0.74m^2	0.16 – 0.82m^2	0.15 – 1.0 m^2
OUTDOOR HOUSING			
Dry sows (paddock)	20-25 sows/ha		
Lactating sows with piglets (paddock)	9-14 sows/ha		

Dry sows (shelter)	1.2 - 1.5m²/sow		
Lactating sows with piglets (shelter)	4 – 6m²		
Boars	2m²/ boar		

APPENDIX II

Comparison of Code of Practice for provision of enrichment

Australia	New Zealand	Canada	Denmark	UK
N/A	Does not specifically state to provide enrichment but requires pigs to be managed in a manner that provides them sufficient opportunities to express and satisfy their normal behaviour	Pigs must be provided with multiple form of enrichment to improve the welfare of animals through the enhancement of their physical and social environments	All pigs must have permanent access to a sufficient quantity of enrichment materials that does not compromise their health and enables them to carry out proper investigation and manipulation activities and fulfil their behavioural needs	To enable proper investigation and manipulation activities, all pigs must have permanent access to a sufficient quantity of material such as straw, hay, wood, sawdust, mushroom compost, peat or mixture of such which does not adversely affect the health of the animals.

APPENDIX III

Comparison of elective husbandry procedure

Procedure	Australia	New Zealand	Canada	Denmark	UK
Castration	Recommends surgical castration of pigs older than 21 days must be carried under anaesthesia and by veterinary practitioner	Surgical castration of pigs at any age must be carried out by a veterinarian	Castration performed at any age must be done with analgesics to help control post-operative pain	Surgical castration of pigs should be abandoned	Male pigs may be castrated provided it is not done by tearing tissues. Castration carried out after 7 days of life must be done by veterinary surgeon
Tail docking	If performed, tail docking should be carried out before 7 days of age	Tail docking performed over 7 days of age should be done by a veterinarian	Tail docking performed at any age must be done with analgesics to help control post-operative pain	If necessary, no more than half the tail may be docked, and may be carried out between 2nd and 4th day of life	Must not be performed routinely. Only part of tail can be docked. If performed after 7 days must be done under anaesthetic and prolonged analgesia
Teeth clipping	Recommends that teeth clipping should not be a routine procedure. Where necessary, should be done within 3 days of life, by removing no more than quarter of the tip.	Teeth clipping, or grinding must be carried out before 5 days.	Need for teeth clipping should be evaluated and performed only when deemed necessary	Needle teeth may be removed by grinding within first 3 days of life	Can be done by uniform reduction of needle teeth by grinding or clipping no later than 7th day of life. Other measures to improve environmental conditions or management systems should be considered first

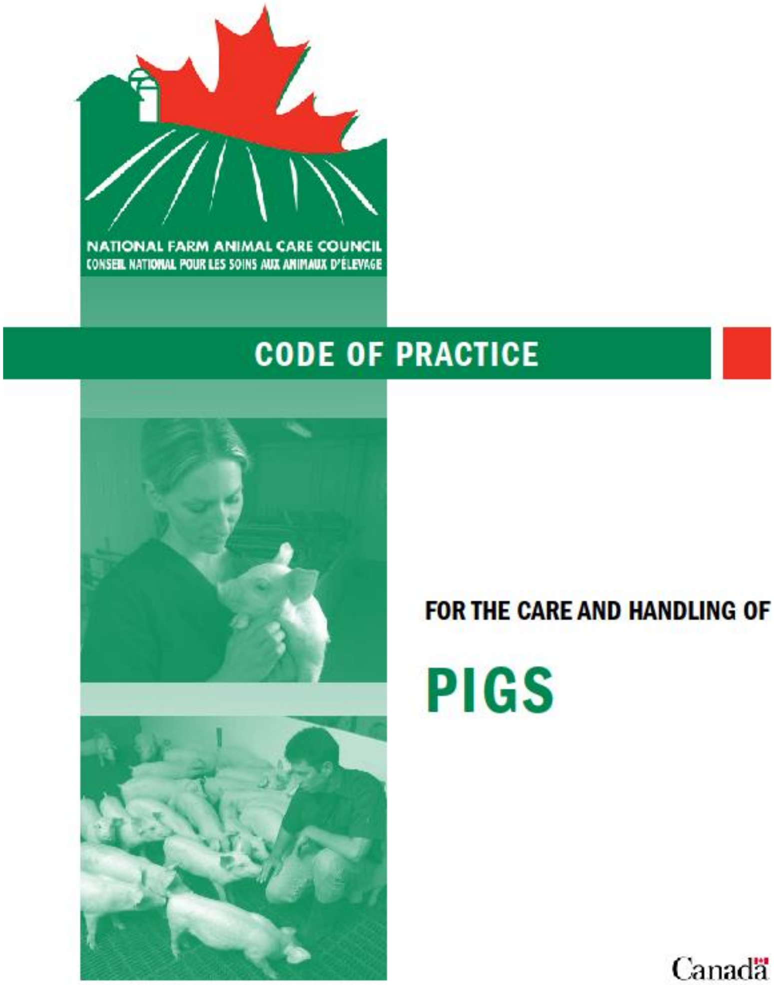
Model Code of Practice for the Welfare of Animals – Pigs (revised)

This revised Model Code of Practise for the Welfare of Animals - Pigs is the final draft as approved by the Primary Industries Ministerial Council on Friday, 20 April 2007.

This Code is yet to be edited and formatted for final public release. This will be done in the coming weeks and the final version will be available through CSIRO. Editing and formatting will be to style only. There will be no further amendments made to the content of the revised Code.

APPENDIX V

Code of Practice for the Care and Handling of Pigs, 2014 (Canada)



APPENDIX VI

Codes of Recommendations for the Welfare of Livestock: Pigs (The United Kingdom)

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APPENDIX VII
Council Directive 2008/120/EC (The European Union)

18.2.2009 EN Official Journal of the European Union L 47/5

DIRECTIVES

COUNCIL DIRECTIVE 2008/120/EC

of 18 December 2008

laying down minimum standards for the protection of pigs

(Codified version)

THE COUNCIL OF THE EUROPEAN UNION,

Having regard to the Treaty establishing the European Community, and in particular Article 37 thereof,

Having regard to the proposal from the Commission,

Having regard to the opinion of the European Parliament (1),

Whereas:

(1) Council Directive 91/630/EEC of 19 November 1991 laying down minimum standards for the protection of pigs (2) has been substantially amended several times (3). In the interests of clarity and rationality the said Directive should be codified.

(2) Most Member States have ratified the European Convention for the protection of animals kept for farming purposes. The Community has also approved this Convention by Council Decision 78/923/EEC (4).

(3) Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes (5) establishes Community provisions applying to all farmed animals in relation to construction requirements for animal housing, insulation, heating and ventilation conditions, equipment inspection and inspection of livestock. It is therefore necessary to deal with these matters in this Directive when more detailed requirements have to be established.

(4) Pigs, being live animals, are included in the list of products set out in Annex I to the Treaty.

(5) The keeping of pigs is an integral part of agriculture. It constitutes a source of revenue for part of the agricultural population.

(6) Differences which may distort conditions of competition interfere with the smooth running of the organisation of the common market in pigs and pig products.

(7) There is therefore a need to establish common minimum standards for the protection of pigs kept for rearing and fattening in order to ensure rational development of production.

(8) Pigs should benefit from an environment corresponding to their needs for exercise and investigatory behaviour. The welfare of pigs appears to be compromised by severe restrictions of space.

(9) When pigs are kept in groups, appropriate management measures for their protection should be taken to improve their welfare.

(10) Sows prefer to have social interactions with other pigs when provided with freedom of movement and environmental complexity. Keeping sows in continuous close confinement should therefore be prohibited.

(11) Tail-docking, tooth-clipping and tooth-grinding are likely to cause immediate pain and some prolonged pain to pigs. Castration is likely to cause prolonged pain which is worse if there is tearing of the tissues. Those practices are therefore detrimental to the welfare of pigs, especially when carried out by incompetent and inexperienced persons. As consequence, rules should be laid down to ensure better practices.

(12) A balance should be kept between the various aspects to be taken into consideration, as regarding welfare including health, economic and social considerations, and also environmental impact.

(13) It is necessary for official services, producers, consumers and others to be kept informed of developments in this field. The Commission should therefore, on the basis of an opinion from the European Food Safety Authority, actively pursue scientific research into the best pig-rearing system(s) from the point of view of pig welfare. Provision should accordingly be made for an interim period to enable the Commission to complete this task successfully.

(1) OJ C 146 E, 12.6.2008, p. 78.
(2) OJ L 340, 11.12.1991, p. 33.
(3) See Annex II, Part A.
(4) OJ L 323, 17.11.1978, p. 12.
(5) OJ L 221, 8.8.1998, p. 23.

APPENDIX VIII

Pigs – Animal Welfare Code of Welfare 2010 (New Zealand)

Code of Welfare

Pigs

Code of Welfare

1 October 2018

Issued under the Animal Welfare Act 1999

New Zealand Government

Pigs

Animal Welfare (Pigs)
Code of Welfare 2010

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