

The welfare implications of large litter size in the domestic pig II: management factors

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Abstract

Increasing litter size has long been a goal of pig (*Sus scrofa domesticus*) breeders and producers in many countries. Whilst this has economic and environmental benefits for the pig industry, there are also implications for pig welfare. Certain management interventions are used when litter size routinely exceeds the ability of individual sows to successfully rear all the piglets (ie viable piglets outnumber functional teats). Such interventions include: tooth reduction; split suckling; cross-fostering; use of nurse sow systems and early weaning, including split weaning; and use of artificial rearing systems. These practices raise welfare questions for both the piglets and sow and are described and discussed in this review. In addition, possible management approaches which might mitigate health and welfare issues associated with large litters are identified. These include early intervention to provide increased care for vulnerable neonates and improvements to farrowing accommodation to mitigate negative effects, particularly for nurse sows. An important concept is that management at all stages of the reproductive cycle, not simply in the farrowing accommodation, can impact on piglet outcomes. For example, poor stockhandling at earlier stages of the reproductive cycle can create fearful animals with increased likelihood of showing poor maternal behaviour. Benefits of good sow and litter management, including positive human-animal relationships, are discussed. Such practices apply to all production situations, not just those involving large litters. However, given that interventions for large litters involve increased handling of piglets and increased interaction with sows, there are likely to be even greater benefits for management of hyper-prolific herds.

Keywords: animal welfare, cross-fostering, human-animal interaction, litter size, nurse sow, split suckling

Introduction

Increasing litter size through genetic selection and management techniques, driven by a desire to improve production efficiency, has been, and is likely to continue to be, a goal of the pig industry (Webb 1998; Spötter & Distl 2006). However, concern has been expressed that there may be detrimental animal welfare consequences (Prunier *et al* 2010). Welfare issues related to litter size in the domestic pig (*Sus scrofa domesticus*) are complex, affecting sows and piglets. A companion review article (Rutherford *et al* 2013; this issue) examined the biological aspects of large litter size, identifying a number of important issues including increased piglet mortality, low birth weight, piglet pain and suffering, and detrimental longer term outcomes resulting from early life effects. The biological consequences for sow welfare are more uncertain but were discussed in relation to the process of carrying, delivering and raising a large litter. This review details the welfare consequences of certain management

interventions that are used when litter size routinely exceeds the ability of individual sows to successfully rear all the piglets (ie viable piglets outnumber functional teats). Such interventions include: split suckling; cross-fostering; the use of nurse sow systems and early weaning, including split weaning; and the use of artificial rearing systems. In addition, tooth reduction is used on some farms as a measure to limit the damage caused by fighting at the udder, often exacerbated in larger litters.

This welfare analysis takes an integrated approach, considering effects of large litter size management techniques on development, mortality, physiology, behaviour and health. Consideration is then given to the role of management in mitigating the welfare impact of large litter size. Key to this is the influence of human attitudes and behaviour towards pigs. Standards of stockhandling at all stages of the reproductive cycle play a critical role, with links between staff attitudes towards pigs, their subsequent behaviour and the

impact this has on pig fear levels, with consequences for production and reproduction. Subsequently, the role of staff training as a management tool to beneficially impact welfare is discussed, with emphasis on the view that skilled labour is a key factor in successfully coping with the demands of large litters. Attention is also given to the importance of the farrowing environment, including providing supervision at farrowing to improve piglet survival, as well as the potential for alternative systems to mitigate some of the negative effects on sow welfare. Finally, sow management to optimise her health and welfare is discussed in relation to coping with large litters and enhancing piglet welfare.

Litter size thresholds in the domestic pig

Litter sizes can be divided into notional categories based on particular thresholds that affect management and welfare outcomes. Firstly, litter sizes of six or fewer can be categorised as ‘abnormal’, as litter sizes in this region in modern genetic lines would generally be regarded as indicating reproductive pathology. These abnormally small litters may or may not represent a welfare concern depending on their cause. Litter sizes of between seven and thirteen piglets can be categorised as ‘small/medium’. The upper limit of this range is based on average number of functional teats seen in current commercial sows. Litter sizes between 14 and 20 can be classified as ‘large’, and litters of 21 or above as ‘very large’. For any given litter, if a sow produces fewer viable piglets than she has functional teats, then little or no intervention is necessary, as each piglet has a chance to locate and occupy a teat. Breed influences teat number; this typically varies between 8 and 18, with 12 to 14 being most common in Western breeds. Chinese breeds, such as the Meishan and Erhulian, can have more than 20 teats (although ~18 is average: Bazer *et al* 2001; Ding *et al* 2009), which fits very well with the larger litter sizes in these breeds. Dysfunction of individual teats will often reduce the litter-rearing capacity of a sow. Temporary inability to access all functional teats can also affect the effective teat number. This can be caused by: i) the anatomical position of teats under hind legs when the sow lies on her side; ii) the design and space available in farrowing accommodation, with the position of metal bars in crates used in many production systems obstructing teat access (Fraser & Thompson 1986; Pedersen *et al* 2011); and iii) sow posture during suckling resulting either in some teats not being exposed or being too high to be reached by small piglets (English *et al* 1977).

Management responses to large litter sizes

When the total litter size is known, generally after the placenta has been expelled, the stockperson decides which interventions may be necessary. If the total number of live piglets exceeds functional teat number (usually more than 14 piglets) some form of management intervention (eg split suckling or cross-fostering) will be required. Interventions, such as the use of nurse sows or artificial rearing systems, become necessary when large or very large litter sizes are consistently being produced across an entire farrowing batch. Tooth reduction is a measure that is sometimes used to reduce the immediate

pressure on the sow and piglets caused by increased fighting at the udder exacerbated by large litters and a limited resource (ie functional teats on the udder). It could be classified as a supplementary procedure as it does not reduce the number of piglets on the sow. The point at which the number of piglets produced is above teat capacity of the batch of course depends on the herd size, the numbers of sows farrowing at the same time, the variability in litter size, the number of piglets that an individual sow is expected to nurse, and the sows’ capability of nursing large litters. The welfare implications of these and other management techniques are described below.

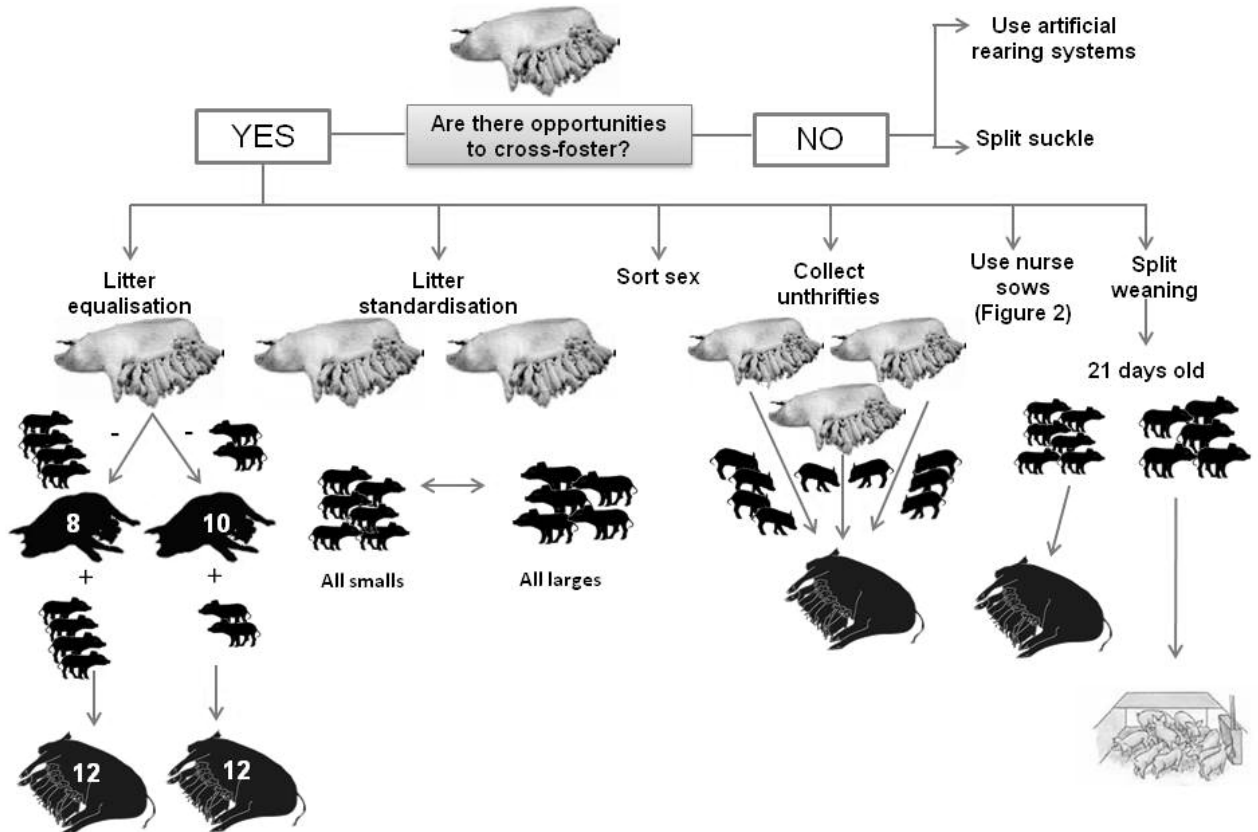
Tooth reduction

To reduce facial lesions on piglets and sow udder damage, full (down to the gum-line) or partial (removing the tip) clipping or grinding of ‘needle teeth’ (those used to defend teats: Fraser & Thompson 1991) of all or some piglets within a litter can be used as a management tool (Weary & Fraser 1999). Clipping to remove all or just the pointed tips of the teeth is not permitted in all countries (eg Denmark), thus grinding by abrading off the sharp tip using a rotating grindstone is an alternate method. With increasing litter size, and a finite number of functional teats, teat disputes are likely to intensify and this can lead to increased facial lesions (Fraser 1975; Drake *et al* 2008). Fraser (1975) and Hutter *et al* (1993) identified relationships between facial wounding and litter size. They noted that when teeth were left intact, piglets from what they classified as large litters (> 11 piglets) were more likely to be severely injured.

EU legislation (Directive 2008/120/EC) permits tooth reduction by either clipping or grinding, but discourages it and only allows the practice where “there is evidence that injuries to sows’ teats or to other pigs’ ears or tails have occurred”. This stance is taken because tooth reduction itself can lead to physical damage (Burger 1983; Bruckner 1986; Hutter *et al* 1993; FAWC 2011) and negative behavioural reactions. Opinion is divided in the literature on how grinding or clipping compare to each other (see Marchant-Forde *et al* 2009). In both practices the required restraint of the piglet is a known stressor and plasma cortisol concentration increases with restraint duration (Rosochacki *et al* 2000). Although physiological assessment of stress parameters suggest the impact of tooth reduction is not as great as for castration or tail-docking (Prunier *et al* 2005; Marchant-Forde *et al* 2009), the procedure is stressful (Marchant-Forde *et al* 2009) and painful (Hay *et al* 2004), with evidence of decreased weight gain in early lactation of piglets with clipped teeth (Robert *et al* 1995; Weary & Fraser 1999).

There are, to our knowledge, no published data on the extent to which tooth reduction is used specifically to manage large litter sizes. In countries where selection for litter size has advanced the most, the use of tooth reduction may actually be less prevalent, since more advanced management practices involving cross-fostering to reduce litter competition are routinely used. However, these practices can sometimes result in more competition with greater facial lesions as piglets are faithful to a particular teat and will fight to re-establish a teat order (Brown *et al* 1996; Robert & Martineau 2001).

Figure 1



Possible management interventions for large litters based on the opportunities to cross-foster. Image adapted and reproduced courtesy of Videncenter for Svineproduktion, Axelborg, Denmark.

Split suckling

Split suckling involves splitting the litter into two groups, often heaviest and lightest or strongest and weakest, removing the more advantaged of these groups for a set period of time to allow uncompetitive suckling for those remaining at the udder (Kyriazakis & Edwards 1986; Donovan & Dritz 2000). It is a technique used on the initial litters born in a farrowing batch when fostering opportunities are limited. The heavier piglets are marked for identification and then enclosed in a heated creep area or a designated box, whilst the group of lighter piglets have full access to the udder. The length of time away from the udder varies but current recommendations are 1 h before groups are switched (BPEX 2011a). This swapping continues throughout the working day before all piglets are reunited. Implementing split suckling should allow all piglets access to colostrum and therefore acquisition of passive immunity. Limited studies suggest these techniques are effective in promoting piglet performance of the lightest piglets in a large litter (Donovan & Dritz 2000), specifically reducing the variation in average daily gain in these piglets and reducing the proportion of underweight (< 3.6 kg) piglets at an 18-day weaning age. One other study showed that between days 1–3 light piglets in split-suckled litters tended

to gain greater weight than control litters (406 versus 301 g, respectively (Kyriazakis & Edwards 1986). Whilst the benefits in terms of weight gain and survival, particularly of lighter piglets, have been reported, there are no data on potential detriments of this intervention. For example, separation stress when isolated from the mother and the potential for increased fighting to re-establish a teat order when all piglets are reunited.

Cross-fostering

A common management practice to deal with large litter sizes and heterogeneous litters is to cross-foster. This involves removing some or all piglets from their birth sow to a foster sow or exchanging piglets between sows depending on their size, vigour and gender as well as physical characteristics of the sow's udder. If performed correctly, cross-fostering gives piglets enhanced survival prospects (English *et al* 1977; Cecchinato *et al* 2008) and can reduce the need for further management interventions for piglets that would otherwise suffer from remaining in a large litter, in particular for those low birth-weight piglets that fail to compete for a productive teat with their larger littermates. Cross-fostering can be performed with a number of aims, at different times after birth, or involving different strategies (Figure 1).

Litter equalisation

This management tool is used in most commercial production (Straw *et al* 1998). It comprises transfer of piglets between sows to achieve the same number of piglets on all sows, or to achieve a desired litter number on each individual sow. A key aim is to enable all piglets to have access to a functional teat.

Litter standardisation

This strategy is widely used in pig production, irrespective of litter size (Straw *et al* 1998) and involves transfer of piglets between sows in order to create more homogenous suckling litters for lactation; ie small piglets are grouped with small piglets and large piglets are grouped with large piglets. Normally, this includes transfer of more piglets than the previously mentioned 'litter equalisation'. Performing 'litter equalisation' will often involve transfer of the smallest or largest piglets born, and thus may partially be a form of standardisation.

Sorting piglets into same-sex litters

This is commonly practiced in some countries to improve efficiency of certain tasks, such as castration, and to save time at weaning when the sexes may be split to allow different feeding strategies for gilts and boars.

Transferring unthrifty piglets to other litters

As more piglets on the sow will increase the risk of some piglets falling behind, higher litter size may promote the use of this technique where one unthrifty piglet can be exchanged later in lactation with a more vigorous piglet in another litter. Occasionally, younger but larger piglets may even be weaned early and older but smaller piglets put in their place. However, fostering late in lactation can be disruptive and counter-productive (see *Fostering too late*).

Collecting surplus piglets onto nurse sows

When piglet numbers routinely exceed the capacity of farrowing sows, in terms of functional teats, surplus piglets may be grouped together (Figure 2) and transferred to a sow whose own piglets are weaned early (nurse sow) (the details and implications of this practice are discussed in a later section).

Keeping back surplus piglets at weaning (split weaning)

Piglets vary in size at birth and, as the largest piglets at birth tend to grow faster than their smaller litter mates, this difference increases during lactation. Under some management systems, if the focus is on size-segregated weaning procedures rather than age, then small piglets may be held back until they achieve a higher weight. This normally involves collecting small piglets and putting them on a sow whose litter has just been weaned.

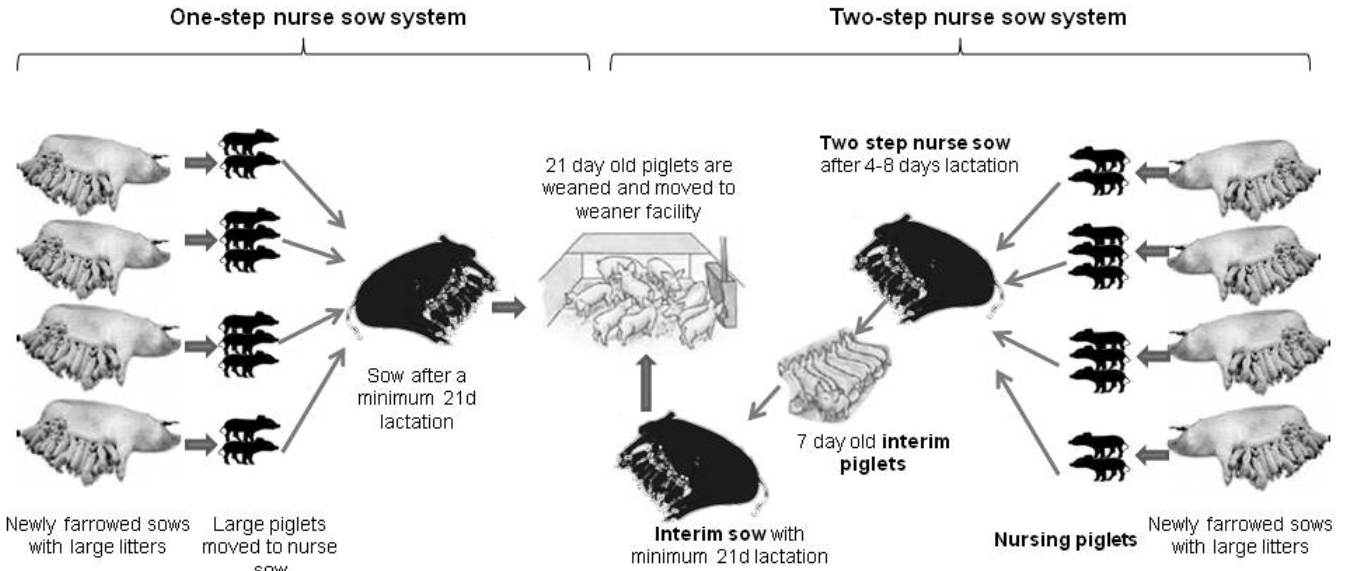
There are various welfare concerns surrounding these different fostering practices which relate to the time after birth when fostering occurs and the problems resulting from over-fostering.

Fostering too early

Very early moves to a new litter may deprive the piglet of access to colostrum, which is important to achieve maternally derived immunity (Bandrick *et al* 2011), assist ther-

moregulation and provide energy (Herpin *et al* 2002). A further complication of large litter size is that colostrum quantity does not increase with increasing litter size (Devillers *et al* 2007; Quesnel 2011), resulting in piglets in larger litters having, on average, less colostrum each. Moreover, free availability of colostrum only occurs for the first 12 h after the onset of farrowing when it is let down continuously; thereafter it is available for approximately 30 h during cyclical let-downs. Gut closure, the cessation of the ability for uptake of intact immunoglobulins (IgGs), takes place between 24–48 h after birth (Gaskin & Kelley 1995) but is dependent on the time of first colostrum ingestion (Lecce & Morgan 1962). Therefore, delayed intake results in the gut staying 'open' for longer, delaying gut maturity and increasing the risk of invasion by pathogens. If piglets are fostered without gaining sufficient colostrum they risk compromised immunity but, if they are fostered onto a sow of a similar stage that is still producing colostrum, these risks are significantly reduced and acceptance by that recipient sow is greater. The need to do this may be greater in large litters, where not all piglets will gain access to their own mother's colostrum and ingestion of any colostrum is critical. Timing is crucial however, as there is a rapid decline in the IgG content of colostrum as the time after farrowing increases (Klobasa *et al* 1987). There are further qualities of the biological mother's colostrum that would advocate the importance of piglets staying with their own mothers for a set minimum period of time before fostering if possible; colostrum and milk contain significant numbers of maternal cells of various types and other substances that may contribute to neonatal immunity (Wagstrom *et al* 2000). These include lymphocytes (B and T cells), cytokines, nucleotides, and various growth factors and there is evidence that certain cells are only absorbed when derived from the biological mother (Tubloy & Bernáth 2002; Bandrick *et al* 2011). There is also recent evidence of programming effects of maternal colostrum consumption on neonatal reproductive development, known as the lactocrine hypothesis (Bartol *et al* 2008; Chen *et al* 2011). In addition, although studies have not been specific to large litters, there is evidence that maternal colostrum protects against necrotising enterocolitis (NEC), an inflammatory condition common in pre-term or low birth-weight piglets (which are more common in large litters) (Bjornvad *et al* 2008). Therefore, in general, if intervention is necessary, the primary management focus should be to encourage maximum ingestion of colostrum within the first 12 h after farrowing starts. For these reasons the transfer window is generally recommended to be within the first 48 h post-partum and only after the piglet sucks from its own mother to ingest colostrum for 6 to 12 h (Thorup *et al* 2004). An advantage of fostering within this period is that piglet behaviours will be less risky in terms of acceptance by the recipient sow (Price *et al* 1994) because they are unlikely to have bonded strongly with their mother before separation. A recent study used three different cross-fostering techniques involving different compositions of piglets: i) 100% adopted; ii) 100% biolog-

Figure 2



Nurse sow systems. Image reproduced courtesy of Videncenter for Svineproduktion, Axelborg, Denmark.

ical; and iii) 50% adopted with 50% biological (Heim *et al* 2012). All were performed, on average, 20 h after birth and no adverse effects were found on survival and growth performance of adopted piglets. The only advantage observed for the non-fostered, 100% biological composition was less fighting for teats and less individuals involved in teat disputes after milk let-down. However, all litters were standardised to eleven piglets during fostering.

Fostering too late

In general, the later fostering takes place and the older the piglets are the greater the challenges to welfare; for example, if fostering takes place after two days of age there is greater fighting (Horrell 1982) and more disrupted suckling episodes, since the teat order is becoming established by then (De Passillé *et al* 1988; Pedersen *et al* 2011), and there is a greater chance of rejection by the recipient sow (Price *et al* 1994). Straw *et al* (1998) reported higher pre-weaning mortality in piglets fostered when over three-days old. Recognition of maternal odours can occur as early as 12 h old, with piglets showing a preference for their dam compared to other sows (Morrow-Tesch & McGlone 1990). Moreover, one-day old piglets can recognise their home pen, and by 36 h of age they can identify their dam's vocalisations (Horrell & Hodgson 1992a). As such, older fostered piglets are likely to experience stress when removed from their sow and pen. When foster piglets realise that they cannot reach their own dam, they go to the udder and seek out the teat in their previously preferred position (which may involve competing with the incumbent piglet) rather than identifying an unused, productive teat and establishing a new place in the teat order (Horrell 1982). This can lead to disruption of the teat order and aggression between piglets over teats, resulting in facial injuries and disrupted

suckling bouts as the sow is more likely to terminate a suckling bout (to the detriment of all piglets) in response to piglet screams (Horrell 1982; Appleby *et al* 1999; Pedersen *et al* 2011). Not only is there disturbance from these disputes, but piglets fostered after maternal bonds are established also show behaviours indicative of separation distress, performing high-pitched vocalisations, with younger piglets often 'quacking' (Weary *et al* 1999), failing to suckle initially and wandering the pen (Horrell & Bennett 1981; Price *et al* 1994) causing restlessness in the sow which can increase the risk of crushing.

Fostering as late as seven-days old results in a negative effect on growth rate of fostered as well as resident piglets (Horrell & Bennett 1981). Straw (1997), fostering piglets at 9–11 days, found that not only did 69% of cross-fostered piglets have lower growth rates following relocation, but 25% of non-moved residents in recipient litters had lower growth rates. Combining growth losses of both cross-fostered and resident piglets, there was a net loss of 0.23 kg per pig one week after cross-fostering. Piglets that are not growing well may be at greater risk of crushing by spending longer at the udder (Weary *et al* 1996). An additional disadvantage of fostering this late is that piglets are capable of recognising their littermates by around seven days of age (Horrell & Hodgson 1992a) and will fight, not just over teats, with non-littermates at this age (Jensen 1994; D'Eath 2005). Foster piglets also risk aggression from the sow, which is capable of discriminating between her own piglets and foreign ones by odour at about seven days of age (Horrell & Hodgson 1992b). Sows selectively show aggression towards fostered piglets, which may try to escape the new pen (Horrell 1982).

Fostering too much

Some farm managers will repeatedly cross-foster piglets and move them from sow-to-sow in order to manage growth rates for weaning. However, such practices are very disruptive for both the sow and piglets. They have been reported as injurious and counter-productive, with continuously cross-fostered piglets failing to suckle regularly, acquiring facial lacerations and showing no improvement in weaning weights (Robert & Martineau 2001). Moreover, repeated handling is both acutely stressful (Stanton *et al* 1972; Wootton *et al* 1982) and may also have longer term effects; Weaver *et al* (2000) found neonatally handled boars showed higher plasma adrenocorticotrophic hormone (ACTH) levels, higher locomotor scores in an open field test and a lower body weight until seven months of age. The rodent literature has more thoroughly documented long-term effects of neonatal handling including differences in hypothalamic-pituitary-adrenal (HPA) axis activity and behavioural stress responses, differences in body fat distribution and reduced sexual behaviour (Young 2000; Pryce & Felden 2003). Such effects cannot be ruled out in pigs experiencing repeated handling.

With litter standardisation, producers expect the more homogeneous piglets to thrive better, as small piglets are inferior to larger litter mates (English *et al* 1977). However, animals matched for body size/weight are effectively matched for fighting ability, which may lead to more escalated aggression and difficulties establishing a stable social hierarchy (Arnott & Elwood 2009). Indeed, Milligan *et al* (2001) found that piglets fought more when cross-fostered into new groups with piglets closer to their own size than they did when moved to groups with much larger piglets. However, Deen and Bilkei (2004) found that, in litters of 12 piglets, low birth-weight piglets spent more time in teat disputes when littermates were larger, and as a consequence missed more nursing opportunities. This was not the case in litters of eight piglets.

There are various reports of long-term impacts on survival, growth, behaviour, reproductive success and immunity as a result of cross-fostering. Cross-fostered piglets may have lower survival during the post-weaning period or nursery stage than resident piglets originally in the litters (Neal & Irvin 1991), although other studies have found no such effects (Stewart & Diekman 1989). However, Stewart and Diekman (1989) did find that gilts reared by foster dams had lower reproductive success in their first parity (poorer conception and farrowing rates and fewer live-born piglets). They also found that cross-fostered pigs reached a market weight of 105 kg four days later than piglets that were not cross-fostered, suggestive of a long-term effect on growth rate. Moinard *et al* (2003) found that farms where cross-fostering was practiced had a higher incidence of tail biting. However, since this was an epidemiological study, whether fostering contributed directly to later likelihood of tail-biting occurrence or whether this association was related to a common causal factor (for instance herd size increasing the likelihood of fostering) is unclear. There are also effects on the development of active immunity and therefore negative effects on long-term health for cross-fostered piglets (Rooke *et al* 2003).

Nurse sow systems

The use of nurse sows, as a solution to the challenges of large litters, is now close to ubiquitous in countries such as Denmark and The Netherlands where hyper-prolific breeding programmes have resulted in the consistent production of surplus piglets. However, such systems have yet to be widely used in other countries. There are two main types of management procedure that involve using nurse sows: one-step and two-step (Figure 2). One-step management involves weaning piglets which are at least 21 days old from a chosen nurse sow and then fostering on surplus piglets from newly farrowed sows when the piglets are at least 12 h old. The nurse sow then rears this second litter to at least 21 days of age, when they are weaned and she returns to a dry sow facility for service. Two-step management, sometimes called 'cascade fostering', involves the use of two lactating sows. A so-called interim sow is identified and her litter is weaned at 28 days old (or at least 21 days old) and then a second-step nurse sow is identified whose piglets are 4–7 days old. These piglets are all fostered onto the interim sow. The second-step sow is then given surplus, large, newly farrowed piglets.

The welfare implications for the sow are described in a later section. The welfare implications for the piglets are likely to be similar to those experienced by cross-fostered piglets. The separation distress and aggression involved in re-establishing teat order may be less in one-step or two-step nurse sow management than in cross-fostering if the whole litter is fostered on and off, or because the young piglets have yet to form a teat order or bond to their mother. However, for the 4–7 day old piglets in the two-step management scenario, the process is likely to be more difficult because mother-offspring bonds have been formed and a teat order has been developed. One possible major welfare detriment experienced by piglets during nurse sow management is the risk that the fostered piglets suffer hunger and chilling during the process of acceptance. Successful sucklings can take up to 6 h after piglets are given to the nurse sow (Thorup & Sørensen 2006). It should be stressed, however, that piglets born into large litters are at equal risk of starvation and chilling if no managerial intervention is employed.

Although the larger and more vigorous neonatal piglets are transferred to the nurse sow, there is a mis-match between the growth and development needs of these piglets with the milk supply of the nurse sow; at 21 days the sow reaches the peak of her lactational output (Elsley 1971), thereafter the milk supply plateaus whilst the energy demands of the piglets increase. In addition, there are issues relating to disease transmission between different farrowing batches if nurse sows are kept back and disrupt an 'all in all out' system.

Nurse sow systems involve a form of early weaning and therefore welfare issues relating to weaning age are relevant to discuss here. Arguably, the normal artificial weaning which is practiced universally by the pig industry is 'early' since, under natural, free-ranging conditions, the age by which piglets are fully weaned is around 60–137 days (Newberry & Wood-Gush 1985; Jensen & Recén 1989).

According to EU legislation, piglets cannot be weaned until 28 days after birth, unless there is a risk of health problems for sow or piglets (Council Directive 2008/120/EC). Piglets can, however, be weaned as young as 21 days if they are weaned into cleaned housing sections where they are not mixed with older animals. Weaning involves the withdrawal of maternal care and of the milk supply. Weaning is stressful for piglets as it involves changes in diet and in the social and physical environment (Fraser *et al* 1997). Recently attention has also been drawn to the possible psychological and long-term consequences of early weaning (Newberry & Swanson 2008; Weary *et al* 2008). Moreover, studies suggest that stress associated with weaning increases with decreasing weaning age (Metz & Gonyou 1990; Weary & Fraser 1997). Colson *et al* (2006) compared the effects of weaning at 21 or 28 days, finding that piglets weaned at the earlier age had a greater extent and duration of reduced daily weight gain. Furthermore, distress vocalisations persisted for longer in the group weaned at 21 days old, consistent with other studies (Weary & Fraser 1997; Weary *et al* 1999; Mason *et al* 2003) that found vocalisations increase in length and intensity as weaning age decreases. Post-weaning aggressive behaviour and belly nosing have also been shown to be increased in piglets weaned at 21 days, compared to older ages (Fraser 1978; O'Connell *et al* 2005; Jarvis *et al* 2008). Belly nosing is regarded as an indicator of poor welfare in newly weaned pigs (Dybkaer 1992; Fraser *et al* 1997), thought to reflect redirected suckling motivation (Weary *et al* 1999) and hunger (Worobec *et al* 1999), and may represent a stress coping mechanism (O'Connell *et al* 2005). Interestingly, O'Connell *et al* (2005) found that a barren maternal lactation environment led to greater levels of belly-nosing behaviour in response to weaning at 21 days old compared to an enriched lactation environment. It was suggested that this may have reflected increased responsiveness to weaning stress as a result of greater stress during a lactation period spent in a barren environment. This raises the possibility that lactational enrichment may provide a means to ameliorate some of the negative effects of early weaning. Regarding physiological measures of stress, weaning at 21 days of age increases cortisol levels in the immediate post-weaning period compared to weaning at older ages (Worsaae & Schmidt 1980; Dantzer & Mormede 1981; Mason *et al* 2003). However, studies examining the long-term impact on the HPA axis of different weaning ages have failed to detect differences (O'Connell *et al* 2005; comparing weaning at 21 or 35 days; Jarvis *et al* 2008; comparing weaning at 12, 21 or 42 days). There are also likely to be important individual differences in responses of piglets to weaning at different ages (Mason *et al* 2003) that require further investigation.

Split weaning

This management technique involves weaning the heavier piglets in a litter at approximately 21 days of age and leaving their lighter siblings with the sow for a further week (Figure 1). The potential welfare issues regarding early weaning have already been discussed. There are reported

benefits (Edwards *et al* 1985), particularly for the lighter piglets that remain; Pluske and Williams (1996) reported that 'light' piglets in split-weaned litters grew 61% faster than their counterparts in control, non split-weaned litters between 22–29 days of age and were 15% heavier at weaning. They studied the mechanisms of this increased growth and identified a 49% increase in milk intake (64 versus 43 g per sucking) as a result of multiple teat swapping and an associated longer duration of sucking during let-down. However, there may be some disadvantages for the early weaned 'heavy' piglets, with Pluske and Williams (1996) finding they were lighter at 29 days than their counterparts in control litters.

The use of artificial rearing systems

An alternative management strategy to the use of nurse sows for rearing surplus piglets is an artificial system. One such system, widely used in The Netherlands, the USA and increasingly in Germany, is the Rescue Deck system (Rescue Deck® System, S&R Resources LLC, USA). This is a specially designed unit, recommended by manufacturers to sit above the farrowing crates and house either surplus or low viability piglets. The decks are fully slatted, heated and lit and have artificial milk, water and, when piglets are older, a creep-feeding system. Piglets are typically housed there from 3–20 days old and often this system does indeed 'rescue' piglets that would otherwise die (BPEX 2011b; van Dijk 2012). Although, to our knowledge, there is no scientific evidence regarding the advantages and disadvantages of Rescue Decks, an industry report suggests they do save piglet lives (BPEX 2011b). However, Tölle and Meyer (2008) found that artificially reared piglets were 2 kg lighter at 22 days compared with piglets reared by sows. Moreover, reports suggest that piglets reared in Rescue Decks have poorer growth rates, take longer to reach slaughter weight and have poorer lifetime average daily gain (Futterkamp 2011). The effects on long-term health and behaviour are still to be investigated (Müller 2011). Piglets removed from their mother as early as three days old, when maternal bonds will be in place (eg Morrow-Tesch & McGlone 1990; Horrell & Hodgson 1992a), will be subjected to the stress associated with separation from the dam and change to artificial milk feeding, and this may have important welfare consequences. Although not directly comparable, studies examining the effects of extreme early weaning strategies (eg between 7–14 days) suggest there may be important consequences of using Rescue Decks. Findings of relevance include: increases in aberrant behaviours such as belly and flank biting (Metz & Gonyou 1990; Bøe 1993; Gonyou *et al* 1998; Weary *et al* 1999; Jarvis *et al* 2008); an increase in aggression at later mixing (Yuan *et al* 2004); behavioural inhibition in an open field test, coupled with changes in brain neurobiology (Summer *et al* 2008); and altered HPA axis activity (Hohenshell *et al* 2000; Hay *et al* 2001). It is unclear whether there are welfare detriments for the sow(s) whose piglets are removed. As the decks are recommended to sit above the farrowing crates there could be disturbance and distress if removed piglets behave in a similar way to fostered piglets,

showing behaviours indicative of separation distress, performing high-pitched vocalisations (Weary *et al* 1999). However, these comments are speculative as no data are available on the potential welfare detriments to sows in this situation and further investigations are warranted. Rescue Deck systems are likely to require very careful management and industry reports warn that Rescue Decks are not a substitute for good sow management and that first-rate stockpersonship to ensure hygiene and maintenance of such systems are imperative to success (BPEX 2011b).

Welfare impact on foster or nurse sows

For a lactating sow, the move to being a foster or nurse sow can be a significant transition. There are a number of potential welfare implications, with the impact depending on the time in lactation when the transition is performed, how many piglets are involved and how well management supports the sow's nutritional needs. During the first days of lactation, milk production is not dependent on whether the sow is being nursed (Theil *et al* 2006), nor is the sow bonded to specific piglets (De Passillé *et al* 1988). However, later in lactation the sow may experience a build-up of milk when not nursed at normal intervals. Moreover, if sows are not well fed, extended lactation may deplete body lipid and protein reserves (Kim & Easter 2001; Prunier *et al* 2010), and a large literature has shown that an energetically expensive lactation is associated with subsequent fertility problems (Quesnel & Prunier 1995; Close & Mullan 1996; Prunier & Quesnel 2000; Thaker & Bilkei 2005; Quesnel 2009; Prunier *et al* 2010), although the extent to which this affects the welfare of nurse sows is unclear. In addition, poor body condition increases the risk of developing shoulder sores (Zubrigg 2006; Knauer *et al* 2007). Shoulder sores develop as a result of ischaemic tissue damage caused by pressure between a surface and tuber of the scapular spine, typically the result of long, or repeated lying periods (Jensen 2009). These sores are thought to cause varying levels of pain dependent on developmental stage, and also offer an entrance for infectious pathogens (Herskin *et al* 2011). However, Pedersen *et al* (2010) found no increase in shoulder sores in nurse sows, possibly because such sows are chosen for their better body condition.

An immediately obvious welfare consequence (in current systems) for the nurse sow is that her confinement within the crate environment will be extended beyond the normal weaning time. For example, one-step and interim sows are early weaned at the height of lactational output (approximately 21 days: Elsley 1971) and are then expected to rear another litter for at least 21 or 14 days, respectively, meaning such sows may spend 42 to 49 days in a farrowing crate, not including the pre-farrowing period. This raises issues for welfare relating to both the behavioural restriction associated with the crate and also to potential physical damage, such as shoulder sores, already described. Jarvis *et al* (2006) found that by 29 days in a crate, sows begin to show a higher cortisol/adrenocorticotropin ratio following corticotrophin-releasing hormone injection, suggesting changes in the HPA axis indicative of chronic stress. Similar results were

reported by Cronin *et al* (1991). In addition, there is likely to be an issue of parent-offspring conflict where, during the latter stages of lactation, the needs of the sow and her litter become increasingly dichotomised because of conflicting evolutionary strategies (Trivers 1974): the (interim or one-step) sow wants to spend more time away from her piglets (Bøe 1991), reducing her lactational output in order to maintain body condition and safeguard future reproductive success (Weary *et al* 2008). The neonatal or 4–7 day old piglets, on the other hand, require much more constant udder access to satisfy their increasing growth and energy demands and safeguard survival.

When a sow is transitioning to become a nurse sow, the limited literature available reports that she does not lactate for an extended period of time (3–12 h), which is likely to cause significant discomfort in the udder and could initiate lactational oestrus (Thorup 2007). Studies have shown that removal of piglets for 2 h, and thus reduction in nursing frequency, causes an increase in plasma cortisol levels (Rushen *et al* 1995) and leads to reduced prolactin levels and altered patterns of somatotropin secretion (Rushen *et al* 1993). When suckling frequency is reduced during the last part of lactation, follicle growth and ovulation can be induced during lactation (Soede *et al* 2012). For nurse sows there may also be detrimental effects on mammary tissue because of the interruption in let-down pattern when they are early weaned and in transition, as well as resulting from an extended lactation (Farmer *et al* 2007).

There are also welfare concerns associated with the early separation of the sow from her natural litter, exacerbated by the distress shown by her foster litter, which is often not nursed for the first 6 h (Thorup & Sørensen 2006). As such, piglets may become frantic for milk, vocalising frequently when hungry (Weary & Fraser 1995) and adding to the nurse sow's distress. Furthermore, since piglets can distinguish their own sow from an alien sow by 12 h old (Horrell & Hodgson 1992a), they will be expressing behaviour associated with maternal separation, causing further problems for litter acceptance. In the one-step nurse sow management routine this stress may manifest itself in poor maternal behaviour, with 18–20% piglet mortality rates reported post-fostering (Thorup & Sørensen 2006). It is likely that some of the negative effects described are transient as once foster piglets are accepted and sucklings are settled the remaining lactation is reported as 'normal' (VA Moustsen & F Thorup, personal communication 2012). However, strategies to mitigate any negative effects of these systems are merited.

Management factors involved in mitigating the impact of large litter size

There are numerous studies relating to nutritional management of the sow during gestation and lactation that impact upon piglet mortality and vitality, thus potentially mitigating some of the biological welfare detriments for piglets born into large litters. These are discussed in a companion review (Rutherford *et al* 2013) and thus will not be addressed here. Instead, the following section concentrates on the benefits of good sow and litter

management, including positive human-animal relationships, that could apply to all production situations and not just those involving large litters. However, given that the interventions discussed above for large litters involve increased handling of the piglets and increased interaction with the sow, there are likely to be even greater benefits for management of hyper-prolific herds.

Staff attitudes and behaviours towards pigs

The level of animal welfare within any given farm system is highly dependent on the people who operate the system. Standards of care at all stages of the reproductive cycle, from gilt rearing onwards, can impact on piglet outcomes, including survival and welfare in both the short and long term. The importance of such effects may be overlooked because cause and effect are separated in time; in large units, staff may specialise in specific parts of the production cycle and therefore have limited awareness of the long-term consequences of the way they manage the pigs. Hemsworth and colleagues, over a number of studies, have clearly demonstrated the sequential links between the attitudes that stockhandlers have towards pigs, their subsequent behaviour towards pigs, the impact this has on pig fear levels and finally the consequences of increased fear for production and reproduction (Hemsworth *et al* 1981, 1989, 1994, 1995; Coleman *et al* 2000). For example, Hemsworth *et al* (1981) found a strong negative relationship between sow fear towards humans and the number of piglets born per sow per year, while a later study (Hemsworth *et al* 1989) showed that the proportion of physical interactions with pigs that were negative was significantly related to both total litter size and number born alive. Furthermore, the attitude of stockhandlers on verbal effort required to move pigs was significantly correlated with numbers born alive. In another study, 18% of the variation, between farrowing units, in the proportion of stillborn piglets was accounted for by variation in how sows responded to approach from an unfamiliar human (Hemsworth *et al* 1999). Thus, farms using the same genetic stock, the same nutritional strategy, with the same housing and husbandry conditions can still vary widely in piglet outcomes as a consequence of how gilts/sows are handled before they ever reach farrowing accommodation. Poor management of pregnant sows which increases stress levels, particularly at the stage in gestation when the HPA axis is developing in foetal piglets, can have long-term effects on stress-reactivity in those offspring (eg Haussmann *et al* 2000; Jarvis *et al* 2006). Given that piglets from large litters are likely to experience management interventions shown to be stressful (as discussed above) an increased stress reactivity as a result of pre-natal programming will be a further detriment (Rutherford *et al* 2012).

Training to improve stockhandler attitudes and behaviours towards pigs on Australian farms was shown to improve the number of piglets weaned per sow per year by 5% during a period when control farms showed a 2% decrease in that measure (Hemsworth *et al* 1994). This training programme involved providing information on how pig productivity and welfare are impaired by the action of stockhandlers and

information on how to behave towards pigs to minimise fear. A study by English *et al* (1999) showed that ‘befriending’ sows and gilts for seven days before they enter the farrowing accommodation and two days post-farrowing resulted in reduced fear of humans, improved ease of handling, reduced birth intervals and reduced savaging behaviour. Stockhandler behaviour during lactation can also influence outcomes; Somnavilla *et al* (2011) found that piglets coped better at weaning when stockhandlers behaved in a calm and friendly (neutral) manner during lactation.

Human behaviour and pig fear levels interact to influence piglet mortality. For example, when sow fear levels are high, human presence may be a risk factor for crushing- and savaging-related deaths (Hemsworth *et al* 1995). Furthermore, Marchant-Forde (2002) classified gilts on a behavioural ‘shy-bold’ continuum on the basis of their response in a human-approach test conducted during pregnancy, finding that gilts at the shy end of the spectrum were more likely to savage their offspring. Increased fearfulness may be a significant risk factor for piglet-directed aggression and piglet-directed aggression has been proposed as a fear reaction towards the newborn piglets (English *et al* 1977). More general detriments to sow maternal behaviour as a consequence of maternal anxiety were reported by Janczak *et al* (2003), who found associations between behavioural measures of fear and anxiety at around two months of age and later quality of maternal care as reflected by piglet mortality. Neophobia and nervousness towards humans has also been found to be associated with piglet crushing (Lensink *et al* 2009). This nervousness, coupled with increased restlessness as a result of large litters increasing the frequency of piglet behaviours disturbing to the sow (eg teat disputes), is likely to further increase the risk of crushing.

Although there is no direct evidence that increasing litter size is related to maternal fear, a study in rodents suggests such an effect can occur; D’Amato *et al* (2006) showed that the larger the litter, the more aggressive and more anxious the female was towards a male’s cues. However, irrespective of whether litter size or other factors are causally related to fear, efforts to optimise maternal emotionality — using genetic selection or rearing conditions that promote the development of calm temperament — may go some way to ameliorate the outcomes of large litter size. Just as large litters require the highest possible standards of stockhandling, they also require that sows are produced which provide the highest possible quality of maternal care. Reducing general fear levels in reproducing females may go some way towards mitigating the negative effects of being born in a large litter on mortality risk but could also influence how successful an animal is in accepting foster piglets or becoming a nurse sow.

The development and implementation of suitable training programmes would be highly beneficial in helping address piglet mortality and welfare consequences of large litter size. Large litters place greater emphasis on skilled labour, not just more labour *per se*. Providing effective training and education to farmers and stockhandlers in order to cause change is not a simple task and requires insights from social science and psychology (Edwards-Jones 2006; Leach *et al* 2010a,b).

Farrowing induction, supervision and piglet treatments

In order to facilitate targeted supervision with day-time farrowings, and enable greater cross-fostering opportunities, sows can be induced to farrow. A single intramuscular injection of prostaglandin F_{2α} (PGF) or PGF analogue is usually administered up to two days before due date. This protocol usually results in approximately 50 to 60% of sows farrowing in the next working day (Cassar *et al* 2005). Induction is only recommended if gestation dates are well known and, for that reason, is not recommended in gilts. Early induction (pre-113 days of gestation) can result in a larger number of vulnerable piglets being born with immature lungs and lower birth weights. Gundvaldsen *et al* (2007) followed piglets for 16 days of lactation and showed that piglets from non-induced sows had a better growth rate, calculating that for every extra day of gestation (average 117 days) piglets grew an extra 26 g. In piglets from induced sows, bodyweights at 16 days of age were 576 g lower and the relative risk of morbidity was twice as high, with a tendency towards higher mortality during lactation. Given that piglets from large litters can already suffer from detriments associated with low birth weight or growth retardation (see Rutherford *et al* 2013 for more detail) any intervention that exacerbates this creates further negative consequences and potentially greater need for management interventions for these piglets.

Farrowing supervision does not necessarily involve induction and one obvious welfare benefit of attending farrowings is the quick treatment or euthanasia for injured piglets. However, there is no clear consensus of opinion in the literature on whether farrowing surveillance is of benefit or not for those not requiring these specific interventions. Whilst Friendship *et al* (1986) observed no relationship between time spent in the farrowing house and piglet mortality, Hoshino *et al* (2009) recommended farrowing assistance for gilts and high parity sows to improve piglet survival. Moreover, researchers (Holyoake *et al* 1995; White *et al* 1996) found that supervision for 3 h after the start of farrowing, increased numbers weaned due to both decreased numbers of stillbirths and decreased neonatal mortality (attributed to fewer crushings and better survival specifically of low birth-weight piglets). However, Vanderhaeghe *et al* (2010) found when supervision of farrowing was performed only occasionally, there were significantly more stillbirths compared to no or frequent farrowing supervision, thus indicating a complex relationship, likely involving interactions between levels of staff training and fear responses of sows to humans as already discussed (Hemsworth *et al* 1995).

All newborn piglets are at risk of chilling, starvation and crushing (Edwards 2002), however low birth-weight (LBW) piglets have been shown to be at greater risk (discussed further in a companion review; Rutherford *et al* 2013). Since there are a greater proportion of LBW piglets in large litters, early intervention to assist these piglets could be beneficial. White *et al* (1996) developed an extensive protocol where all piglets were dried, had their airways cleared of mucus, and received an oral dose of

bovine colostrum. In addition, all low birth-weight piglets received oxygen through a face mask for 30 to 45 s (see also Herpin *et al* 2001). This protocol lowered pre-weaning mortality from 18.2 to 10.1% and increased piglet weaning weight. Other piglet treatments could potentially be applied if farrowings are supervised. For example, 2-IminoBiotin, an inhibitor of nitric oxide synthase (which is believed to play a critical role in brain damage associated with hypoxia), has been investigated as a treatment for neonatal piglets (Peeters-Scholte *et al* 2002a,b; Van Dijk *et al* 2008). In an observational study of 39 Norwegian farms (Andersen *et al* 2007), piglet mortality was reduced when piglets were helped to find a teat shortly after birth, and a later study found a benefit of drying or placing piglets under a heat lamp for reducing subsequent mortality (Andersen *et al* 2009). In these studies, the control group was not observed at farrowing and the piglets thus not helped in any way. In a further small-scale study, no benefit of piglet drying or warming was seen on behavioural landmarks such as latency to contact the udder or suckle, but piglet mortality was reduced by both treatments (Christison *et al* 1997). Musse (2007), in contrast, found an opposite effect with the frequency of piglets dying after birth being significantly higher when piglets were dried after farrowing than if the piglets were transferred to the udder or left untouched behind the sow. It was speculated that the vigorous drying of the piglets, which was intended to remove placental fluids and activate bloodflow and respiration, may also have removed a germ-protecting layer from the skin (F Thorup, personal communication 2012), similar to the *vernix caseosa* present in human neonates. In humans, the *vernix caseosa* is a white cream-like substance that covers the skin of the newborn baby and has antibacterial peptides/proteins thought to offer host immune properties for the neonate (Tollin *et al* 2005). However, no bacteriology was performed in the Musse (2007) study and further work would be required to validate this theory. Furniss *et al* (1988) tried two treatments: placing piglets in a bedded and heated creep at birth for 45 min followed by free access to the sow (treatment 1) and; allowed to suckle naturally for 15 min after first successful suckling before placed in the creep for 45 min then free udder access was restored (treatment 2). Treatment 1 showed the best results for maintaining adequate body temperature but treatment 2 showed a trend for better survival. These conflicting results suggest early colostrum intake may be more imperative for survival than immediate warmth, perhaps because early colostrum intake serves a triple purpose; providing maternally derived immunity (Bandrick *et al* 2011) and energy, whilst assisting thermoregulation (Herpin *et al* 2002). Intervention that provides an appropriate microclimate for the piglets whilst still enabling full udder access may be the best option to achieve adequate thermoregulation and early intake of colostrum.

The positive studies certainly suggest that, if performed well, supervision can improve litter mortality figures; however, if poorly performed, supervision can produce a

worse outcome than doing nothing at all (which probably explains the lack of consensus in the literature regarding advice on best practice). There is a danger of over-interference if stockhandlers are paid to attend farrowings, and increased disturbance caused by human presence may actually delay farrowing and potentially stockperson intervention actually disturbs the sow and could be counter-productive if disrupting positive maternal behaviours (ie prolonged lateral lying allowing safe udder access). However, if assistance was targeted and focused on clear protocols there could be consistently positive outcomes. Several groups have investigated the use of technology to allow stockhandlers to predict farrowing time more precisely in order to deliver better care to the sow and her litter (eg Bate *et al* 1991; Oliviero *et al* 2007; Wang *et al* 2007). This could be preferable to induction of parturition to synchronise farrowings and target labour, given the potential detriments of induction as discussed earlier.

There are several energy and colostrum supplements marketed to increase a piglet's chances of survival when there is a risk of poor supply or availability of the mother's colostrum. Some farmers will provide bovine or porcine colostrum by tube feeding low viability piglets. Given the importance of colostrum, already discussed, it is likely that this is good practice, however scientific evidence of the efficacy of these supplements is sparse. Müller *et al* (2012), administered 25 ml of sow colostrum to every second newborn piglet in 27 litters and a further 25 ml 9 h after birth. They found increases in blood plasma IgG levels but no improvement in survival. Given the multifactorial nature of piglet mortality, the limited intervention in this study without continued aftercare, particularly of low viability piglets, is unlikely to have a significant impact on survival. If supplements are administered it appears that natural colostrum is superior to enriched formulae, particularly regarding improvement of intestinal function and development of stable and beneficial microbiota in the gastrointestinal tract (Edwards & Parrett 2002) and resistance to NEC in low birth-weight or pre-term piglets (Møller *et al* 2011). Supplementing the mother's milk supply during lactation with milk replacers is also a strategy advertised. Studies are not specific to large litters, but certain high protein formulae have been developed to promote catch-up growth and brain development in low birth-weight piglets (Morise *et al* 2011). The benefits of these high-protein formulae and other milk supplements seem to be positive effects on growth rates and weaning weights (see King & Pluske 2003).

Farrowing environment

The majority of sows will farrow in conventional farrowing crates (approximately 60% of sows farrow indoors in the UK with 96% of these in crates: Guy *et al* [2012]; 95% in EU and 83% in USA: Johnson & Marchant-Forde [2009]). However, there could be specific benefits mitigating the effects of large litters by allowing sows to be loose-housed during farrowing and lactation. As discussed in the companion review (Rutherford *et al* 2013), giving birth to large litters results in prolonged farrowing duration (Herpin

et al 1996) and all litters will benefit from high-quality maternal care to mitigate negative piglet outcomes. Loose farrowing with appropriate nesting material allows the performance of species-specific nest-building behaviours known to reduce farrowing duration and promote good maternal behaviour, with several authors proposing a link between high nest-building activity and reduced risk of crushing (Andersen *et al* 2005; Pedersen *et al* 2006). Sow comfort may be improved in less-restrictive environments and allow for less disrupted suckling bouts with longer milk let-downs during bouts (Pedersen *et al* 2011). In addition, access to teats may be improved in loose-housed systems where there are no crate bars obstructing access (Fraser & Thompson 1986; Pedersen *et al* 2011). This could reduce teat disputes and disturbance. As discussed previously, sow restlessness and irritation is a significant concern for the welfare of both piglets and sow and may be exacerbated by confinement farrowing systems: De Passillé and Robert (1989) suggested that, since sows use posture changes to stop piglets annoying them, they may experience fewer proper rest periods when litters are large or the farrowing environment is restricted in size and barren. With a large litter the frequency of piglet behaviours (nosing, nibbling, exploration) orientated towards the sow may be greater and could interfere with rest or cause irritation (De Passillé & Robert 1989; Arey & Sancha 1996). Alternative housing, where the sow can be loose for lactation, could reduce irritation by allowing the sow the ability to move away from the litter. For example, in a loose lactating system where sows had access to a 'get-away' area from the piglets, suckling bouts decreased from 22.9 to 4.3 bouts per day over a ten-week period, suggesting that, if given the choice, sows would spend some period of their day away from their piglets (Bøe 1991). Use of a loose lactation system may particularly improve the welfare of nurse sows given their increased period of confinement to raise a second litter. However, if a system was chosen which would allow the sows to reduce contact with the piglets (ie a get-away pen) this improvement for the sow may come at the expense of her younger, adopted litter. In addition, Watson and Bertram (1982) suggested that the level of irritation for the sow could be decreased by providing enrichment for the piglets. A more complex environment for the piglets may reduce aggression, particularly that displayed between fostered and resident piglets, and therefore reduce disturbance and increase acceptance by the sow.

However, the potential benefits of supervision (in terms of ability to intervene to help individual piglets) may be reduced in non-crate farrowing systems where safe access to piglets by stockhandlers can be greatly reduced (although Andersen *et al's* (2009) study showing supervision benefits was conducted in loose-housed sows). Post-farrowing managerial interventions for large litters involving cross-fostering and nurse sows may also be more challenging in a loose-housing system. Optimum design of such systems that considers management of large litters is of critical importance when developing alternative farrowing systems (Baxter *et al* 2011, 2012) and the efficacy of such interventions in these systems requires investigation.

Sow treatments

Pain and discomfort of the sow during farrowing and in the period following completion of farrowing may contribute to negative piglet outcomes (Haussmann *et al* 1999; White 2008; Mainau & Manteca 2011). Moreover, it seems likely that large litter sizes could contribute to more pain in the peri-parturient period, particularly by prolonging farrowing duration (Van Dijk *et al* 2005; Mainau *et al* 2010). Irrespective of whether litter size is a causal factor or not, addressing the pain experiences of pigs after farrowing could improve neonatal piglet outcomes. Haussmann *et al* (1999) found that treating sows with analgesia following farrowing reduced posture changes, which could lower the risk of crushing. Furthermore, improvements in maternal behaviour as a consequence of better pain management would have both direct (reduced crushing and savaging deaths or injuries) and indirect (improved suckling and colostrum intake) impacts on neonatal mortality and also longer term health and performance of piglets. Treating sows with Meloxicam (a non-steroidal anti-inflammatory drug [NSAID]; Boehringer Ingelheim Vetmedica GmbH, Ingelheim, Rhein, Germany) following farrowing has been shown to improve maternal behaviour and had a particularly beneficial effect on low-weight piglets, which showed better growth (Manteca 2009). In contrast, Cassar *et al* (2010) recently suggested there was no benefit of providing analgesia around farrowing. However, this study involved both a pre- and post-farrowing treatment of Ketoprofen (an NSAID; Anafen, Merial Canada Inc, QC, Canada), so that negative impacts on farrowing itself cannot be discounted. In any event, further work in this area is merited. Along similar lines, although not addressing pain experience, it has recently been claimed that a single injection of Azaperone (Stresnil, Janssen Animal Health, Buenos Aires, Argentina) after farrowing promotes piglet survival and is particularly beneficial for promoting the survival of low birth-weight piglets (Miquet & Viana 2010) which are more prevalent in large litters. However, as yet, little information is available to verify this claim and, regardless of the effects on piglet survival, an ethical appraisal of practices using drugs with sedative properties is clearly merited.

Large litters which prolong the farrowing process can result in sow fatigue, both maternal and uterine (discussed further in a companion review; Rutherford *et al* 2013). To counter uterine fatigue and speed up farrowing progression, exogenous oxytocin is used. However, this can be counter-productive when mis-used, causing a surge in uterine pressure and an increase in the risk of stillbirth, and can cause additional stress for the sow (Mota-Rojas *et al* 2002, 2005, 2006).

Sow feed intake is often monitored during lactation and the importance of a high feed intake to promote piglet growth and development, maintain sow body condition and reduce the risk of shoulder sores is well known and particularly pertinent to a sow rearing a large litter, under increased metabolic stress (Quesnel & Prunier 1995; Eissen *et al* 2003). However, sow water intake is rarely assessed but, if monitored, could be beneficial; water intake has been

shown to be highly correlated with piglet growth over the first three days post-farrowing (Fraser & Philips 1989) and weaning weights (Kruse *et al* 2011). The correlation between high water intake and heavier weaning weights reflects greater milk production and is likely to be a result of increased water intake stimulating increased feed intake (Kruse *et al* 2011). In addition, monitoring water intake may serve as an early warning system for potential problems, as various issues could negatively impact upon water intake; including physical condition (lameness causing a reluctance to stand), feelings of pain and sickness post-farrowing, or poor nipple drinker design or function. Maintaining a high water intake may be particularly beneficial around the farrowing period as sow feed intake has to be carefully managed and is often restricted around this time to reduce the risk of metritis, mastitis and/or agalactia (Martineau *et al* 1993). The restriction comes at a time when sows have experienced a highly fatiguing farrowing process and might benefit from increased energy intake. Providing energy supplementation to sows before farrowing has been shown to reduce dystocia levels (eg isotonic supplements: van Kempen 2007), a problem which is increased in large litters. Such energy supplements could also relieve sow fatigue and increase water intake with the subsequent benefits of increased milk production.

Discussion

Animal welfare implications

Management interventions designed to promote piglet survival and welfare, such as tooth reduction, cross-fostering, the use of nurse sows and associated early weaning, and the use of artificial rearing systems, clearly can also have negative implications for piglet and sow welfare, particularly when they are poorly implemented. The different possible ways that these management interventions for large litter size could affect animal welfare in pig production, particularly for cross-fostered piglets and nurse sows, are summarised in Table 1. Based on the available literature, the evidence for relationships between litter size and different welfare outcomes has been classified as speculative, uncertain, sound or strong. Based on the possible level of welfare impact and the associated level of certainty, each possible issue has been assigned a level of priority for action. Although these assessments are inevitably subjective, they allow for attention to be focused on the most immediately important issues in this area. In some cases the necessary action is further research to clarify uncertainties in how litter size and that outcome are related, whereas for other factors the onus is on the pig industry to act to mitigate such outcomes.

A selection of possible mitigation strategies to reduce the welfare impact of large litter size and its knock-on consequences, over the short, medium and long term, have been discussed here and also in a companion paper (Rutherford *et al* 2013). These strategies include genetic, nutritional, and management approaches to deal with large litter sizes and their welfare consequences. None of these are the

Table 1 Summary of welfare impacts of management strategies for large litter size on animal welfare outcomes for piglets and nurse sows.

Welfare problem (Proximate cause)	Relationship to litter size	Welfare impacts [†]	Individual severity [‡]	Welfare impact certainty	Priority for action [§]
<i>Issues for piglets</i>					
Cross-fostering and use of Rescue Decks (Transient hunger)	Sound	Low	1	Low	Low
Cross-fostering/Nurse sow system (Distress from maternal separation)	Strong	Medium	1	Low	Low/Medium
Cross-fostering/Nurse sow system (Rejection by sow)	Sound	Medium	2	Low	Low/Medium
Cross-fostering (Later tail-biting incidences)	Uncertain	High	3	Low	Medium
Tooth reduction (Pain and distress)	Sound	High	2	Medium	Medium
<i>Issues for nurse sows</i>					
Early removal of native piglets	Uncertain	Medium	2	Low	Low/Medium
Acceptance of new litter (Udder discomfort, disturbance)	Sound	Medium	2	Medium	Medium
Prolonged lactation	Sound	High	2	High	High
Prolonged environmental restriction (Risk of shoulder sores, depleted body condition)	Sound	High	3	High	High
Longevity (Return to oestrus length)	Uncertain	Medium	1	Medium	Medium

[†] Welfare impact is an estimate of the overall effect on the individual (severity × duration) combined with the proportion of individuals affected.

[‡] Individual severity scores, based on Smulders (2009; Table 5). Score 0 (negligible): No pain, malaise, frustration, fear or anxiety; Score 1 (limited): Minor pain, malaise, frustration, fear or anxiety; Score 2 (moderate): Some pain, malaise, frustration, fear or anxiety. Stress reaction, some change in motor behaviour, occasional vocalisation may occur; Score 3 (severe): Involving explicit pain, malaise, frustration, fear or anxiety. Strong stress reaction, dramatic change in motor behaviour, vocalisation may occur; Score 4 (critical): Fatal, death occurs either immediately or after some time. Physiological effects may be recorded as well as moderate behavioural change.

[§] See Rutherford *et al* (2011) for how combinations of welfare impact and uncertainty dictate suggested priority for action.

sole solution, but there is good reason to believe that a combination of different strategies could be highly effective in remedying at least some of the potential negatives. Many of these strategies relate to the central issue of piglet mortality. However, the other consequences of litter size for welfare should be kept in mind and strategies to address these also considered.

Genetic approaches provide potential longer term benefits to mitigate the effects of large litter size (Rutherford *et al* 2013). However, for most survival-type traits, 0–15% of the variation is genetic, whereas 85–100% is environmental. For example, despite having similar genetic stock, the bottom 25% of Danish herds have overall pre-weaning mortality levels around six percentage points higher than the best 25% (Rutherford *et al* 2011). Therefore, the investigation of non-genetic strategies to mitigate the possible problems associated with increasing litter size is of continued value. Management strategies to promote good temperament (low fearfulness in particular) in sows could also greatly contribute to welfare outcomes for the piglet. Critical to this process, under any system of management, will be standards of stockhandling at all stages of the reproductive cycle. Farrowing supervision has substantial potential, if defined and practiced well, to improve piglet survival. Finally, improvements to farrowing and lactation environments has the possibility to ameliorate welfare outcomes for both piglets and sows.

Perhaps the largest issue might be whether the continued goal of increasing litter size should be reconsidered. At some point it will become uneconomical to continue to produce additional piglets, with associated costs including: increased labour inputs; sow nutrition; and rearing piglets that are of poorer quality. Moreover, there are important ethical concerns surrounding the issues of large litters and these are the focus of a companion paper (Jensen *et al* in prep).

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