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A review of factors affecting the welfare of weaned replacement heifers in pasture-based dairy production systems

Megan Verdon[A,*]

For full list of author affiliations and declarations see end of paper

*Correspondence to:
Megan Verdon
Tasmanian Institute of Agriculture, Faculty of Science, Engineering and Technology, University of Tasmania, Burnie, Tas. 7320, Australia
Email: megan.verdon@utas.edu.au

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ABSTRACT

The pasture-based replacement dairy heifer is typically housed and managed intensively from birth until weaning, but post-weaning is housed outdoors in paddocks under less intensive management. Little is published about the welfare of the weaned dairy heifer in pasture-based systems. The aim of this review is to consolidate the scientific literature and provide an overview of factors affecting the welfare of weaned heifers on pastoral dairies. Heifer welfare during transition to the milking herd can be optimised through calving support and by pre-exposing heifers to some of the stressful conditions associated with the milking herd. For the former, heifers should be well grown at calving (≥85% mature bodyweight) and could be mated to bulls that will produce a smaller calf (e.g. Jersey bulls, sexed semen to produce a female calf). Sires should be selected for high ease of calving predicted transmitting ability, and farms should develop and implement a calving intervention and assistance policy. Mixing heifers with milking cows prior to calving, exposing them to competitive grazing conditions and training them to the milking parlour may reduce overall stress burden and enhance adaptability, but research is needed to quantify the welfare and productive merit of this sort of program in seasonal pasture-based dairy systems. This review highlights a lack of recent data relating to the management of the replacement heifer between weaning and their first calving. Research needs to document and disseminate modern dairy heifer management practices in pasture-based systems, as these will affect heifer welfare. The following data need to be collected as a priority: (1) frequency that heifers are weighed or receive health assessments, (2) heifer grazing management, (3) frequency and age of surgical removal of supernumerary teats, (4) mortality rate from weaning until the first lactation, and (5) typical procedures to transition heifers to the milking herd, including management of the first calving. There is also a need to document the management and housing conditions of exported dairy heifers living in other countries.

Keywords: calf, cattle, dairy cow, grazing, health, pain, productivity, rearing.

Introduction

Dairy production is predominantly pasture-based in temperate climates such that occur in parts of Australia and New Zealand. In these dairy systems replacement heifers are often born within 2 months of each other and intensively housed and managed from birth until weaning (see review by Verdon 2022). Post-weaning, however, heifers are housed outdoors in paddocks that present fewer monitoring opportunities and less intensive management. Little is published about the welfare of the weaned dairy heifer in general (acknowledged by Mourits *et al.* 1997; Moran and McLean 2001; Rushen *et al.* 2008), and in pasture-based systems specifically. This has resulted in a paucity of scientific literature regarding factors that may affect the welfare of the dairy female from weaning until she joins the milking herd, and limits opportunities to develop solutions to current or emerging welfare issues.

The present review considers the available scientific literature relating to the welfare of the weaned replacement heifer on pasture-based dairy farms. By doing so, it aims to document the management of weaned replacement dairy heifers in pastoral settings, to highlight gaps in the scientific understanding of factors affecting their welfare under these conditions, and to identify directions for future research and development. The literature considered in this review relates to the period from weaning (excluding the weaning process) until entry into the milking herd (excluding the first lactation). This period corresponds to a time of reduced observation and less intensive management of the heifer. An assessment of the factors affecting the welfare of the pre-weaned calf in pasture-based dairy systems has been reviewed separately (Verdon 2022).

Animal welfare assessment requires a multidisciplinary approach that incorporates indicators of physical health and functioning, emotional experiences, and whether the environment enables species specific 'natural' development and behavioural expression. These approaches to animal welfare are typically referred to in the literature as 'biological functioning', 'affective states' and 'natural behaviours', and draw on a mix of veterinary sciences, ethology, neuroscience and psychology, among others. As reviewed by Taylor *et al.* (2022), the three areas can overlap (e.g. providing straw to farrowing sows allows nesting behaviour and reduces stress) or contradict (e.g. chickens are highly motivated to range outdoors, but this increases the risk of disease). The approaches used in assessing animal welfare, as well as their strengths, weaknesses and interactions, have been reviewed elsewhere (e.g. Hemsworth *et al.* 2015; Ede *et al.* 2019; Weary and Robbins 2019; Dawkins 2022).

The terms of this review are outlined below. Published research on heifers in pastoral dairy systems has focused on optimising farming efficiency, and minimising rearing costs through improved growth and reproduction. As described by Broom and Johnson (1993), production measures can be used as an indicator of physical health and functioning in animal welfare assessment. For example, delayed or failed reproduction and/or an interruption to growth (for growing animals) is observed in cases of undernutrition, disease or chronic stress (Broom and Johnson 1993). This paper includes measures of production as an indicator of animal welfare, particularly in discussions of pasture-based nutrition and mortality, but it is important to note that this is not intended as a review of factors affecting heifer productivity. Research from pastoral settings is prioritised in this review, but learnings from indoor systems are used when evidence from pasture-based systems is lacking (e.g. emotional experiences, social behaviour) or when the research is applicable across dairy systems (e.g. pain management). The live export of dairy heifers is also considered in this review. This decision may be controversial, because an exported heifer is no longer subject to a pasture-based dairy system, and because the trade also exists in countries with indoor housing systems (e.g. Canada). Live export is included because: (1) a proportion of heifers born into a pasture-based dairy system will be subject to the conditions of export, and (2) there is less awareness of the challenges faced by exported dairy cattle compared with cattle exported for slaughter. Some factors that are relevant to the welfare of the dairy heifer in pasture-based systems are not discussed in this review (e.g. thermal stressors, mastitis) on the basis that the scientific literature predominantly relates to the adult cow and will be reviewed separately. The reader is encouraged to refer to reviews by Ruegg (2017), Fisher (2020) and Polsky and von Keyserlingk (2017) for consideration of these factors.

Factors affecting the welfare of replacement heifers

Housing and management

Management and feeding of heifers at pasture

Heifers on pasture-based dairy farms are generally subjected to intensive feeding and management prior to being weaned at ~12 weeks of age (see Verdon 2022), but post-weaning are housed outdoors in paddocks where they receive less intensive management. There are some documented welfare benefits to growing heifers at pasture compared with indoors, such as reduced skin lesions and lower cortisol in the hair follicles, and increased positive behaviours (comfort and social) and immune responsiveness (Kerr and Wood-Gush 1987; De Rosa *et al.* 2007; Hultgren *et al.* 2008; Schubach *et al.* 2017). The pasture-based heifer herd, however, is often left grazing dry-land paddocks (i.e. 'run-off' blocks) that are located away from prime grazing areas which are reserved for the milking herd (Hough and Sawyer 1993; Moran 2002; Kristensen *et al.* 2006; Moran and Doyle 2015) or may be reared by an external party ('agistment'). The reduced visibility and remote locations of run-off or agistment blocks can limit opportunities for farmers to frequently monitor their animals and impose interventions to improve health and welfare. For example, albeit dated, an Australian study found that none of 55 surveyed dairy farmers weighed or body condition scored their replacement heifers, and less than one-third rotationally grazed their young stock (Hough and Sawyer 1993). In 2013, the Australian dairy industry developed and has since been operating an extension program that advises producers on measuring, setting and achieving growth targets for replacement heifers ('Heifers on Target'; Dairy Australia 2013). The impact of this program has not been documented specifically, but Spence and Woodhead (2000) demonstrated the success of a similar extension program. The authors found the program increased the number of farmers monitoring the weight and health of their heifers from 0 to 74% over a 5-year period. Although extension programs such as 'Heifers on Target' have likely improved management practices from those reported by Hough and Sawyer (1993), a lack of data relating to more modern heifer management in pasture-based systems prevents confirmation of this.

The decision to keep heifers off the milking platform (i.e. the paddocks grazed by the milking herd) is partly based on biosecurity advice that aims to reduce the transfer of the bacteria *Mycobacterium avium* subspecies *paratuberculosis* through the faeces of infected adult stock to younger animals (e.g. Aleri and Laurence 2020). Infection can lead to the development of Johne's disease, an incurable and untreatable inflammation of the digestive tract that results in chronic diarrhoea, and subsequently reduces growth, milk production and fertility (Barkema *et al.* 2018; McAloon *et al.* 2019*a*). If the infected animal is not culled, Johne's disease causes a continually declining condition and ultimately results in death. Risk of infection with *Mycobacterium avium* subspecies *paratuberculosis* is greatest in the first month of life, but it is generally accepted that heifers remain more susceptible to infection than adult cows until ~12 months of age (McAloon *et al.* 2019*b*; Garvey 2020). However, several scientific reviews suggest that segregation of cows and heifers aged >6 months has a negligible impact on the control of Johne's disease transmission in pasture-based dairy systems, with the targeted culling of cows that are clinically affected or are high- or super-shedding being the most effective means of reducing environmental contamination and thus transmission of *Mycobacterium avium* subspecies *paratuberculosis* (Windsor and Whittington 2010; Bates *et al.* 2019; Biemans *et al.* 2021).

There is an economic incentive for dairy farmers to monitor heifer growth. Heifers that achieve specific weight for age targets are more likely to become pregnant and have higher milk production in their first lactation (e.g. 30% mature weight at 6 months of age, 60% at 15 months of age and 90% at 22 months of age; Dairy NZ 2022*a*). These targets are based on achieving optimal production, and their relationship to heifer welfare is not clear. There is no doubt that providing good growth with good nutrition is essential to good welfare. An adequate diet helps avoid metabolic disorders and improves immune function to reduce disease susceptibility, with obvious implications for affective states, such as hunger, pain, malaise, and frustration (Bertoni *et al.* 2016). Hogan and Phillips (2016) defined malnourishment as '...a deficit, imbalance, or excess of nutrients with consequential adverse effects on the normal functioning of the animal, including behaviour, physiology, reproduction, health, and growth potential'. That heifer growth targets exist largely to improve reproductive success suggests that some females have traditionally been at risk of malnutrition, and consequently hunger, pain, malaise and frustration, but the extent and severity of this is not clear.

There is less control over nutrition in pastoral housing systems than in indoor systems, where heifers are fed a carefully formulated total mixed ration. In general, the quality of pasture on the run-off blocks is lower than on the milking platform. Pasture allocations also tend to be based on visual assessments which can lead to inconsistencies in the quantity of pasture provided. This, combined with seasonal variation of forage quality and availability, can expose grazing heifers to periods of energy and protein deficiencies. Supplementation of the grazed diet with a high-quality pasture or fodder crop silage can address the seasonal variability in nutrition such as those typically observed during winter, when pasture growth is slow, and summer, when quality declines. The strategic use of fertilisers can also improve the quality of pasture on run-off blocks and has been associated with higher heifer weights for age (Spence and Woodhead 2000), but this strategy may not align with the general push for reduced synthetic nitrogen fertiliser on dairy farms (e.g. Dairy NZ 2022*b*).

No data are available on how farmers are managing grazing in the weaned dairy heifer. Actively managing grazing heifers (e.g. rotationally grazing) and their feed-base provides opportunities for frequent surveillance, provides a more consistent supply of nutrients and encourages the development of more efficient grazing behaviour. Frequent provision of fresh pasture to dairy calves has been found to improve their growth (discussed by Roche *et al.* 2017), but not if the pasture is of low or variable quality (Mathews *et al.* 1994; Kristensen *et al.* 2006). Burggraaf *et al.* (2020) found that feed quality after weaning had a greater impact on the post-weaning performance of Hereford × Holstein-Friesian calves than the pre-weaning diet (i.e. quantity and duration of milk feeding). Calves weaned onto an irrigated, perennial ryegrass and white clover pasture grew twice as fast from 3 to 7 months of age, were 31 kg heavier at 7 months and were slaughtered 61 days earlier than those on low-quality pasture (non-irrigated).

In addition to the aforementioned challenges to pasture-based heifer nutrition, some soils are naturally deficient in trace elements. Animals grazing pasture grown on these soils could be at risk of deficiency in one or more element (Ellison 2002). Trace elements support hormone and immune function to help combat disease (Masters *et al.* 1999; Arthington and Ranches 2021). Supplementation of trace elements through topdressing or spraying of pasture, or direct animal supplementation (injectable and bolus) can help combat deficiencies (Ellison 2002), but there is no published research on how frequently they are needed or used for heifers on run-off blocks. The average daily gain of heifers grazing a perennial ryegrass, kale or fodder beet over winter was not affected by a trace mineral bolus (Atkins *et al.* 2020), but mineral supplementation improved the growth of Brangus-crossbred beef calves when injected three times from birth to 200 days of age (Arthington *et al.* 2014). The risk of deficiencies likely depends on the farm's location and factors such as soil characteristics, forage species, season and climate (Arthington and Ranches 2021). Routine monitoring of soil trace elements would allow for a targeted supplementation regime.

To summarise, there is a risk that rearing pasture-based heifers on the run-off block or through agistment limits the opportunities of farmers to monitor their growth, nutrition, welfare and health, and impose interventions when required. However, this assumes that heifers receive a low-intensive management on run-off blocks, a premise based on a 30-year-old West Australian survey of management practices for replacement heifers at pasture. Updated data relating to heifer management are required, particularly for standard farming practices, such as the frequency with which heifers are weighed, body condition scored and receive health checks, as well as management of the feed-base (e.g. irrigation, silage supplementation) and the animal-pasture interface (e.g. grazing management). Less intensive management may also affect welfare through interactions with the affective states of heifers. For example, reduced monitoring may increase fear or psychological stress when heifers do need to be handled (e.g. at weighing, vaccinations, artificial insemination), whereas less active pasture management may result in feelings of hunger or malaise due to energy shortages or nutrient deficiencies. Assessment of the affective experiences of heifers under less versus more intensive management would provide a comprehensive understanding of their welfare in pasture-based dairy systems.

Painful management practices

The following paragraphs use the framework proposed by Weary and Fraser (2004) to evaluate the painful management practices of branding and removal of supernumerary teats. The framework asks three questions to guide an assessment of a painful practice: (1) What are the aims of the procedure? (2) Does the procedure achieve its aims? and (3) Can the procedure be modified to reduce pain and distress, while still meeting the aims and practical constraints of the production system?

Branding is the first procedure considered. It provides a permanent means of easily identifying individual animals (in dairy systems, the brand is typically an individualised number on the rump). Identification can be important to assuring animal welfare, animal production and food safety. For example, individual identification enables dairy workers to record and communicate to colleagues about the needs of specific cows, such as those with a suspected health event that requires close monitoring (e.g. lameness, mastitis) or that are receiving a medication that has a milk withholding period. Traditionally, the brand is made by heating an iron to temperatures exceeding 500°C and applying it to the skin for 3–5 s (hot-iron branding). Hot-iron branding produces third-degree burns that, when healed, result in a hairless area of scar tissue (Adcock and Tucker 2018). An alternative to hot-iron branding involves using liquid nitrogen to cool the branding iron below −70°C and apply it to the skin for 15–30 s (freeze branding; Petherick 2010). Freeze branding kills the cells that pigment the hair so only white hair will grow from the area that has been branded (Rushen *et al.* 2008). Both hot-iron and freeze-branding procedures provide a permanent marking on the animal's body, thus achieving the aims of the procedure. It is important to note, however, that freeze branding will not provide suitable identification for white animals or those with little to no coloured markings on their rump.

The behavioural and physiological responses of cattle to hot-iron and freeze branding demonstrates both are psychologically and physically stressful as well as painful, but research consistently finds a more pronounced negative response during and after hot-iron compared with freeze branding (reviewed by Rushen *et al.* 2008 and Adcock and Tucker 2018). This key difference between practices is globally recognised, as indicated by increasing bans on hot-iron branding in parts of Europe and the UK and, more recently, in New Zealand (Spoolder *et al.* 2016; MPI 2020*a*). Although hot-iron branding is not banned in Australia, the Australian Veterinary Association (AVA 2009) does recommend freeze rather than hot-iron branding. The transition to freeze branding is an example of a procedural refinement that reduces pain and distress of the practice. In the interest of continual improvement in animal welfare, however, it is important to recognise that freeze branding remains a painful procedure that itself requires refinement to reduce its impacts on animal welfare.

No practical method of reducing branding pain has been identified. An injection of local anaesthetic may reduce pain, but the size of the area requiring anaesthesia and the time taken for loss of sensation means it is unlikely to be implemented on large herds. Administration of local anaesthesia in the form of a cream, spray or gel could be more practical to apply at scale, but the effectiveness of these mediums at reducing branding pain has not been evaluated and many are not approved for this use (e.g. Tri-solfen). Systematic analgesia may not eliminate the acute pain response during and following branding. For example, a single injection of a non-steroidal anti-inflammatory drug (NSAID) did not reduce wound sensitivity, surface temperature or healing following hot-iron branding (Tucker *et al.* 2014). Scientific literature on strategies to mitigate branding pain has only studied the hot-iron procedure and needs to assess the efficacy of pain relief during and following freeze branding.

Development of alternative methods of identification that are suitable for pasture-based dairy systems could reduce the dairy industry's reliance on branding and eliminate any associated animal welfare issues. For example, Australian livestock must be tagged with a radio-frequency identification device allowing for lifetime traceability. These tags could potentially be scanned while a cow is being milked and, if the dairy facility is supported by the necessary electronic infrastructure, the cow's identification number displayed on a screen. Larger farms are leading the adoption of technology on pasture-based dairies (Beggs *et al.* 2015; Beggs *et al.* 2019), so may be better positioned than smaller farms to adopt this type of identification. A low-tech alternative is to use mirrors in the dairy to view the cow's identification ear tag. Numbered leg bands are used for identification in countries where hot-iron and freeze branding are banned (e.g. the Netherlands; NL 2011), but may require further engineering to overcome potential challenges associated with pasture-based dairy farms, such as faded or obscured identification from exposure to the sun and muddy conditions, and rubbing that could cause abrasions, especially for cows in large pastoral systems that can have long walking distances to and from the dairy.

Removal of a supernumerary teat is a lesser recognised painful husbandry procedure experienced by some replacement heifers. Supernumerary teats are an undesired, but common and heritable, abnormality of the bovine udder present in ~20% of heifers (range 10–44%, with considerable variation between breeds; Brka *et al*. 2002; Pausch *et al*. 2012; Butty *et al*. 2017; Wen *et al*. 2021). Surgical removal of supernumerary teats, typically using disinfected, sharp scissors, prevents them from disturbing milking procedures and accumulating bacteria resulting in mastitis (discussed by Brka *et al*. 2002; Butty *et al*. 2017; Hardwick *et al*. 2020).

There are no published data on the prevalence of supernumerary teats or their removal on the pasture-based dairies of Australia and New Zealand. A recent German survey found nearly half of studied dairy farms removed supernumerary teats (Hayer *et al*. 2021). American bovine, large animal, or mixed (≥50% large animal) veterinarians identified supernumerary teat removal as one of their most frequently performed procedures (Morin *et al*. 2002), but the survey by Hayer *et al*. (2021) found only 10% of German farms had a veterinarian present when conducting the procedure. Conditions of supernumerary teat removal are legislated for in New Zealand's Animal Welfare Regulations (MPI 2018), and include requirements for an experienced person to conduct the procedure, a clean cut and pain relief if the animal is >10 weeks of age, but the procedure is not outlined in the Australian Animal Welfare Standards and Guidelines for Cattle (AHA 2014).

Most supernumerary teats are rudimentary. For example, Joerg *et al*. (2014) found 19.2% of heifers of Simmental and Holstein breeds (and their crosses) had a supernumerary teat, but only 4.6% were associated with a mammary gland. Considering this, one potential refinement to the procedure includes only removing large supernumerary teats with complex anatomical structures, as these are a greater risk for mastitis infection (Hardwick *et al*. 2020). However, it isn't clear whether anatomically complex supernumerary teats can be differentiated from typical teats in young bovine. In ewes, anatomically complex supernumerary teats often look the same as normal teats (Hardwick *et al*. 2020). A second refinement is to perform the procedure when heifers are young and the teats are small, and to provide pain relief, especially when removing larger or more complex teats. It is assumed that post-procedural pain is more short-lived in the young heifer that has very small teats (Stull and Reynolds 2008); however, the limited data suggest extra teats are sometimes removed in the older heifer and often without pain control (Vasseur *et al*. 2010; Hayer *et al*. 2021). It would be logical to perform the removal of supernumerary teats during disbudding, provided best-practice disbudding procedures are followed (i.e. the animal is <8 weeks old, is sedated and the procedure is conducted by a veterinarian). Considering the medium-to-high heritability of supernumerary teats (Pausch *et al*. 2012; Joerg *et al*. 2014), breeding against their occurrence is an example of a longer term refinement that will reduce the need for their removal.

In conclusion, refinements to reduce the animal welfare impacts of branding include: (1) continued efforts to encourage the uptake of freeze rather than hot-iron branding methods, (2) research to identify strategies to mitigate pain associated with freeze-branding, and (3) development of opportunities to reduce reliance on branding for identification in the long term. Surgical removal of a supernumerary teat is also likely to be painful, but it is not clear how frequently this procedure is conducted, who conducts the procedure or the age of heifers when the procedure is conducted. These data are required to determine the size and severity of potential welfare issues associated with the removal of supernumerary teats, and to monitor the industry's progression towards a best practice management of the procedure (i.e. performed at a young age using pain relief and sedation, until selective breeding removes its need).

Live export

Australia exports live dairy heifers to increase breeding capacity in other nations. New Zealand banned the export of live cattle in 2021 (MPI 2021) but the number of heifers exported from Australia is experiencing substantial increases year on year (e.g. 70% increase from 2018 to 2019; Dairy Australia 2020). Industry data published by Dairy Australia (2019) show that the majority of the 92 456 heifers exported in the year from 2018 went to China (81%), followed by the Middle East (5.7%) and Malaysia (3.2%), with the remaining animals exported to other Asian countries (9.8%, e.g. Indonesia, Japan, Pakistan, Taiwan, Vietnam). All the 39 269 breeder cattle exported from New Zealand in 2019 went to China (MPI 2020*b*). Live export poses two general risks to heifer welfare – those associated with transportation, and those relating to management in the destination country. These are discussed below.

In 2019, 6.5% of breeder cattle exported from Australia were transported by plane (DAWE 2020*a*). There is little information on management practices and animal welfare before, during or after air transportation of livestock (reviewed by Collins *et al*. 2020). Livestock can reportedly react violently at take-off, resulting in injury or suffocation (Phillips 2019), although no cattle breeder mortalities have been reported on air journeys since 2015 (DAWE 2020*a*). As concluded by Collins *et al*. (2020), there is a critical need for greater transparency in air transport practices and for research assessing risks to animal welfare during air journeys.

Most Australian breeder cattle are transported by sea. An independent observer accompanies sea transportations and provides a report summarising the journey (DAWE 2020*b*). Fourteen reports detailing journeys during which breeder stock were transported from Australia to China in 2019 have been randomly selected and summarised in Table 1. It is important to note that some of these journeys included

Table 1. Summary of 14 randomly selected reports of sea journeys transporting breeding heifers from Australia to China taken in 2019 and attended by an independent observer.

Report number	Journey taken	No. of cattle	Journey length (days)	Max temperature (°C)	Mortalities (%)	Mortality cause[A]	Inspection frequency/day	Pen clean frequency/journey
84	February	6386	25	32	0.06	NR	≥1	≥1
94	March	5012	20	NR	0.14	I, R	NR	≥1
109	April	5847	21	35	0.085	I, K, U	NR	2
111	April	4769	20	32	0.12	B, I	NR	2
119	May	5355	20	31	0.09	R, H, I	NR	3
144	June	5799	24	31	0.31	E, H, I, R, U	2	3–6
162	July	8050	20	29	0.16	E, I, R	2	≥1
166	August	3942	18	NR	0.02	I	NR	≥1
179	September	8316	17	28	0.02	FTT, R,	3	1–2
182	September	4593	23	33	0.04	I, R	3	3
195	October	5853	21	31	0.14	E, I, R	NR	NR
198	November	2618	18	33	0.11	I, R	NR	NR
201	November	4165	18	31	0		NR	2
210	December	4657	21	28	0.15	I, K, R	NR	2

Reports available at https://www.agriculture.gov.au/biosecurity-trade/export/controlled-goods/live-animals/livestock/regulatory-framework/independent-observer-reports.
[A]Mortalities reasons as listed in the report by an independent observer: B = bloat, E = enteritis, I = injury (fractures, infected wound, dislocation, lameness, head caught in gate railing), FTT = failure to thrive/ill-thrift, H = heart disease, K = ketosis, R = respiratory illness, U = undetermined.
NR = not reported.

breeder and slaughter cattle, but reporting does not differentiate between the two. The average consignment was 5383 cattle and had a mortality rate of 0.09% (range 0–0.31%) on a journey length of 20.4 days (range 17–25 days). This is comparable with the mortality rate of 0.07% reported in breeder cattle travelling from New Zealand to China on a 17-day journey (MPI 2020*b*). The reports commonly list injuries (fractures, dislocations, infection, lameness, head caught in gate railing) and respiratory illness as reasons for mortalities. Most reports specifically mention observing good animal handling and stockperson skills, and no reports considered mortalities to be linked to any systemic failure. Most animals were inspected at least once per day, and up to three times per day on some journeys (Table 1). Shy feeding, lameness, respiratory illness, leg injuries and pinkeye are among cattle ailments requiring treatment. Increased respiration indicated heat stress in an estimated 10% of cattle on some consignments, particularly when the ship approached the equator (Table 1). Underfeeding was reported on three journeys (report numbers 94, 201, 210, Table 1), and resulted in increased competition for feed, bullying behaviour and inequitable feed intakes. It is reasonable to presume that the injuries, illness and behaviours listed in the DAWE (2020*b*) reports also have implications for animal welfare through negative affective states, such as pain, fear and hunger. Despite the physiological and reproductive differences between breeder and slaughter cattle, the same factors as those listed in these reports are known to affect the welfare of feeder and slaughter livestock during long-haul sea journeys (see Phillips 2019).

There is no internationally regulated standard for the transport of livestock by sea (Phillips 2019). In Australia, the export agent is responsible for ensuring compliance with the Australian Standards for the Export of Livestock, and this applies to both breeding and feeder or slaughter cattle. Breeder livestock become subject to the importing country's laws upon disembarkation from the sea or air transportation vessel (Moran 2015). The Australian Exporter Supply Chain Assurance Scheme requires exporters to have commercial arrangements with supply chain partners to provide humane treatment and handling of livestock from arrival in the importing country up to the point of slaughter, but specifically excludes breeding cattle on the basis that it is practically difficult to trace them throughout the remainder of their lives (Moran, 2015). Ambiguity and anecdotal evidence frame discussions on the welfare of exported dairy heifers once leaving their country of origin. For example, there are reports of Australian dairy heifers exported to southeast Asia being permanently tied in a shed with a cement floor and no bedding, being fed a sub-maintenance diet, offered water only once or twice a day, and showing behavioural signs of psychological distress and heat stress (Moran 2015); however, a more comprehensive survey of the living conditions of exported dairy heifers is required to determine how representative such observations are.

Recent Australian studies have investigated strategies to improve the welfare of livestock exported to south and southeast Asia for slaughter. Comparable research does not exist for exported breeder dairy cattle, but some of the findings may be transferrable from slaughter to breeder cattle. For example, livestock industry workers are identified as the key stakeholders that should be engaged at the first stage of any strategic plan to improve animal welfare abroad (Sinclair and Phillips 2019). Strategies focusing on education, training and awareness of these stakeholders are the most likely to positively impact animal welfare (Descovich *et al.* 2019; Sinclair *et al.* 2019*a*; Sinclair and Phillips 2019). These are more likely to be successful if they communicate the financial benefits of good animal welfare (Sinclair *et al.* 2019*b*) and improve confidence in the stakeholder's ability to positively affect animal welfare (Sinclair *et al.* 2019*a*). It is promising that stakeholders involved with the dairy industry show the greatest knowledge improvement after participating in a training workshop, suggesting a high motivation for knowledge improvement (Erian *et al.* 2019). Knowledge and attitudes of industry stakeholders to animal welfare during transport and slaughter are influenced by their role in the industry (Sinclair *et al.* 2017), demographics (Descovich *et al.* 2019) and cultural background (Erian *et al.* 2019). Therefore, Sinclair and Phillips (2019) recommend that research and training programs designed to improve the welfare of exported cattle when in their destination country are locally led, and have the capacity to be modified according to region and the socioeconomic and political landscape.

In summary, welfare risks associated with the live export of dairy heifers can be categorised as: (1) those regarding transportation, and (2) those concerning housing and management in the country of destination. Exporting countries have responsibility for the welfare of animals while in transit, and the welfare risks during transportation of cattle by sea are documented. Exporting countries do not have authority over dairy cattle once they reach their destination, however, and there are no studies in the scientific literature of living conditions in the exported nation. These living conditions need to be documented and monitored over time.

Health

Parasitic infection

Grazing increases the risk of parasitic infections through ingestion of larvae that reside on fresh herbage. Immune resistance to parasitic infection develops over several months of exposure, making pastured youngstock more susceptible to infection than adult cattle (see review by Gasbarre *et al.* 2001). Data relating to the prevalence of parasitic infection of replacement heifers in the pasture-based dairy systems of Australia and New Zealand is lacking, but a Canadian study found that pasture access increased the prevalence of nematode eggs (65.6 vs 8.4%) and the average egg count (5.7 vs 0.3 eggs per gram) in the faeces of breeding-aged heifers (samples taken during late spring to mid summer; Scott *et al.* 2019). The pathology and epidemiology of the common parasites infecting dairy heifers are described by Stromberg and Averbeck (1999) and Stromberg and Moon (2008). To summarise, the helminths are the most significant parasites to heifers, particularly liver fluke and gastrointestinal nematodes (e.g. roundworm). The larvae of helminths grow from eggs that have been passed out in the faeces of an infected animal. Parasitism during development can impair normal growth and the development of the mammary parenchyma, while also delaying the onset of puberty (Perri *et al.* 2013). Helminth infections in livestock have also been associated with a reduction in growth, milk production and reproduction, and an increase in culling in the first lactation, whereas severe cases of lungworm can cause death (Mejía *et al.* 2009; Perri *et al.* 2011 and also reviewed by Charlier *et al.* 2014).

Resting pasture provides time for parasites to die off, making rotational grazing one of the most effective management practices in reducing the parasitic burden (Kristensen *et al.* 2006; Stromberg and Moon 2008; Bloemhoff *et al.* 2014). There are no recently published data on the grazing management of heifers in pasture-based dairy regions, such as Australia and New Zealand. The longer a pasture remains fallow, the lower the pasture larval burden at the subsequent grazing (Stromberg and Averbeck 1999). Reliance on anthelmintics for parasitic control is growing (Bloemhoff *et al.* 2014), despite increasing resistance over recent decades (Bullen *et al.* 2016). An Australian study found evidence of resistance on all 20 of the dairy farms studied and to all three of the available anthelmintic classes (Bullen *et al.* 2016). This research was conducted in an irrigated region of Australia that experiences cool summers, providing ideal environmental conditions for larval survival and transmission. Under these conditions, frequent drenching with anthelmintics is often the only means of parasitic control available to dairy farmers (discussed by Bullen *et al.* 2016). The same may be true for non-irrigated farming regions that experience high rainfall, but research is required to confirm this.

The strategic use of anthelmintics in the case of an outbreak in combination with grazing management may be an effective parasite control strategy in regions that can achieve 30-day (or greater) grazing rotations. Examination of parasitic control strategies over a range of pastoral dairy farming regions will provide a more complete understanding of the anthelmintic use and the risk of developing resistance. Individual susceptibility to parasitic infection is strongly influenced by genetics with 15–25% of the herd being responsible for most of the transmission (see review by Gasbarre *et al.* 2001). Thus, targeted genetic management may reduce the overall parasite transmission without relying on anthelmintics (Gasbarre *et al.* 2001).

Infectious bovine keratoconjunctivitis (pinkeye) also warrants discussion when considering the replacement heifer. This highly contagious and painful bacterial infection of the eye affects young animals that have not yet developed protective antibodies. It causes inflammation, ulceration and, in severe cases, blindness, while the associated pain can reduce feed intake (Ali *et al.* 2012; Dewell *et al.* 2014; Seid 2019). There are few reports on the incidence of pinkeye in dairy heifers. Older American research reported pinkeye in 5.2% of weaned replacement heifers and in 53% of the studied herds (Gardner *et al.* 1990). There are many strains of the causative *Moraxella bovis* bacterium meaning that existing vaccines cannot be relied upon to prevent pinkeye (Seid 2019). Early detection, segregation and treatment of the infected heifer is essential to reducing the duration and severity of the infection. Prevention may be achieved by reducing risk factors (e.g. grazing heifers away from manure deposits to limit fly infestation, topping pastures to reduce seed heads, providing shade on high UV days), providing good nutrition and supporting the immune system (vaccination, low-stress management; Ali *et al.* 2012; Seid 2019).

Thus, faeces present a common path of transmission of parasites within groups of grazing animals. Rotational grazing of replacement heifers reduces environmental contamination with faeces making it an effective way of reducing the risk of an infectious disease outbreak. Parasitic transmission can be further reduced with a long-term breeding program that selects against susceptibility to infection.

Mortality and culling

There is a clear lack of data on the mortality of the weaned replacement heifer in pasture-based dairy systems, and disparity between research from indoor systems in terms of the period of development studied, ages at weaning, breeding and first calving, the type of study (prospective vs retrospective), and housing (Table 2). Recent years has seen an increase in data from retrospective studies (Table 2). These benefit from a large data set but may underestimate the true number of mortalities. A recent prospective study from New Zealand describes the only peer-reviewed data on heifer mortality in pasture-based systems (Mason *et al.* 2020). The authors report 2.7% (range 0–7.9%) of heifers die or are culled between weaning at approximately 3 months of age and the second mating at 27 months, and the hazard of death did not change throughout the study period. This is much lower than the mortalities (including culling) reported from 1 month until the first calving for heifers reared in barns (7.4 to 16.1% mortalities, including culls, Brickell *et al.* 2009; Brickell and Wathes 2011; Raboisson *et al.* 2013; Zhang *et al.* 2019). These data from barn systems include part of the early rearing period in the calculation of heifer mortality, a time during which the heifer is at increased risk of illness and death (see review by Verdon 2022).

Published research from indoor dairy systems find disease, accident and reproductive failure the most common causes of mortality and culling in the replacement heifer (Gardner *et al.* 1990; Svensson *et al.* 2006; Hultgren *et al.* 2008; Gulliksen *et al.* 2009; Zhang *et al.* 2019). Respiratory disease is implicated in up to 20% of the mortalities of barn-reared heifers below breeding age (Svensson *et al.* 2006; Brickell *et al.* 2009; Gulliksen *et al.* 2009; Zhang *et al.* 2019), but may not be as prevalent in heifers reared at pasture due to improved ventilation and reduced stocking density. Culling for reproductive problems is the main reason for heifer deaths above breeding age (Brickell *et al.* 2009; Zhang *et al.* 2019), followed by calving-related disease and trauma (i.e. fractures, dislocation, entrapment in fittings, drowning; Svensson *et al.* 2006). Infertility accounts for 47–58% of total culls, with a total of 2.3–3.5% of heifers being culled for failed reproduction (Gardner *et al.* 1990; Hultgren *et al.* 2008; Wathes *et al.* 2008; Brickell *et al.* 2009). Whether or not research includes the number of heifers culled in their mortality calculations does not appear to affect the prevalence of mortalities from 1 to 6 months of age (2–3.5%), but mortalities from 6 months of age until first calving are noticeably lower when culls are not included in the calculation (2.2–2.9% Svensson *et al.* (2006) and Fuerst-Waltl and Sørensen (2010) vs 4.3–7.7% Brickell *et al.* (2009) and Raboisson *et al.* (2013)). Improving heifer reproduction through better nutrition and monitoring of growth rates is an obvious way of reducing mortalities due to culling. This task starts at birth (see reviews of Roche *et al.* 2015 and Verdon 2022). In addition to having a reduced risk of culling due to reproductive failure, heifers that are well grown at calving are less likely to experience a difficult calving, produce more milk in their first lactation and have a longer lifespan in the herd (reviewed by Roche *et al.* 2015). The challenges of achieving a consistent high plane of nutrition for heifers in a pastoral setting was discussed earlier in this review (see section titled ‘Management and feeding of heifers at pasture’), while the reviews of Roche *et al.* (2015) and D’Occhio *et al.* (2019) can provide the reader a more comprehensive analysis of the interaction between nutrition, growth and reproduction in growing heifers (dairy and beef).

Culling an otherwise healthy heifer for failed reproduction can raise ethical concerns based on the premise that a life has a good of its own; that is, killing a healthy animal is seen as a waste of a life (see review by Bruijnis *et al.* 2013). Such discussions are beyond the scope of this review. Killing a healthy animal is not itself a welfare issue if it is done humanely; however, the conditions around the cull can affect animal welfare. For example, a high culling rate for poor reproduction could indicate high levels of malnutrition, disease or stress. The welfare implications of transportation and lairage are also well known, as are the welfare implications of the handling and method of slaughter itself. These can be manipulated to reduce impacts on the animal. These risk factors are discussed by Cockram (2021), albeit in relation to the cull cow. The present review has

Table 2. Summary of 13 studies from 12 articles reporting on post-weaning mortality rates in the replacement dairy heifer, sorted by year of publication.

Reference	Type of study[A]	Country	Housing	No. of herds	No. of animals	Age period	Mortality (%)
Gardner *et al.* (1990)	Prospective	USA	Dry lot with some pasture access (mostly)	24	Not reported	Weaning (1–6 months) to first calving (age not specified)	1.2[B]
Svensson *et al.* (2006)	Prospective	Sweden	Indoor group pens[C]	122	8964	3–6 months	0.9[D]
Svensson *et al.* (2006)	Prospective	Sweden	Indoor group pens[C]	122	8964	6 months – first calving (27 months)	2.2[D]
Hultgren *et al.* (2008)	Prospective	Sweden	Indoor group pens[C]	122	3081	Birth – first calving (27.6 months)	14.2
Brickell *et al.* (2009)	Prospective	UK	Not reported[C]	19	1097	Birth – first calving (26.5 months)	14.5
Brickell *et al.* (2009)	Prospective	UK	Not reported[C]	19	506	1–6 months	3.4
Brickell *et al.* (2009)	Prospective	UK	Not reported[C]	19	489	6 months – breeding (16.4 months)	3.5
Brickell *et al.* (2009)	Prospective	UK	Not reported[C]	19	450	Breeding – first calving	4.2
Gulliksen *et al.* (2009)	Retrospective	Norway	Indoor group pens[C]	14 399	235 584	1–6 months	2.2[D]
Gulliksen *et al.* (2009)	Retrospective	Norway	Indoor group pens[C]	14 102	195 363	6 months – 1 year	0.6[D]
Gulliksen *et al.* (2009)	Retrospective	Norway	Indoor group pens[C]	14 102	195 363	Birth – 1 year	7.8[D]
Gulliksen *et al.* (2009)	Prospective	Norway	Indoor group pens[C]	125	5382	Birth – 1 year	9.5[D]
Fuerst-Waltl and Sørensen (2010)	Retrospective	Denmark	Not reported[C]	Not reported	513 868	Birth – first calving (age not specified)	9.4[D]
Fuerst-Waltl and Sørensen (2010)	Retrospective	Denmark	Not reported[C]	Not reported	794 472	1 month – 6 months	2.7[D]
Fuerst-Waltl and Sørensen (2010)	Retrospective	Denmark	Not reported[C]	Not reported	729 198	6 months – 1 year	0.97[D]
Fuerst-Waltl and Sørensen (2010)	Retrospective	Denmark	Not reported[C]	Not reported	474 904	1 year – first calving (age not specified)	1.9[D]
Brickell and Wathes (2011)	Prospective	UK	Straw or cubicle yard[C]	18	468	1 month – first calving (26.5 months)	11
Raboisson *et al.* (2013)	Retrospective	France	Not reported[C]	70 912[E]	1.1M	1–6 months	3.1
Raboisson *et al.* (2013)	Retrospective	France	Not reported[C]	65 149[E]	898 507	6 months – 1st calving (age not specified)	4.3
Gates (2016)	Retrospective	UK	Not reported[C]	17 122	1.3M	Birth – 6 months	5.8
Winder *et al.* (2018)	Retrospective	Canada	Not reported[C]	1076	Not reported	Weaning – 1st calving (age not specified)	2.4[D]
Zhang *et al.* (2019)	Retrospective	China	Free-stall barn	31	142 833	2 months – 1 year	7.4
Zhang *et al.* (2019)	Retrospective	China	Free-stall barn	31	124 407	1 year – first calving (age not specified)	8.7
Mason *et al.* (2020)	Prospective	New Zealand	Pasture	24	3770	Weaning (90 days) to second mating (27 months)	2.7

[A]Prospective study – farmers are recruited, and data collection in real time according to research guidelines. Retrospective – utilised existing data, typically from a national database.
[B]Reported as mortalities per 100 animal years.
[C]Indoor housing typical for dairy heifers in Europe, the UK and Canada include group pens with slatted floors or deep litter and less often tie stalls from breeding to first calving. Heifers may graze pasture in the warmer months (2–4 months), e.g. Brickell and Wathes (2011).
[D]Not including culls.
[E]Average numbers from two separate study periods.

considered culling as a factor affecting heifer welfare because even in the best-case scenario, a healthy cull heifer will likely experience some physical and psychological stress, fear, hunger, and thirst during transportation and prior to slaughter.

To summarise, New Zealand data indicates that the mortality of weaned heifers is lower in pasture-based compared with indoor dairy systems, but data relating to the rate and reason of mortality for weaned heifers under Australian conditions are required. Improving the reproductive success of heifers will likely reduce mortalities due to culling. This requires heifers to be well grown, a task that starts at birth. Research needs to document the proportion of heifers achieving pre-breeding target weights, and to assess the relationships between the frequency of monitoring of heifer weight and body condition, heifer growth trajectory at different developmental stages, and the incidence of culling for poor reproduction.

Transition to the milking herd

The first calving

Parturition is an intrinsically risky event for both dam and offspring across species. It can result in maternal health problems and mortality, in addition to decreased food intake and milk production (reviewed by Mainau and Manteca 2011 and Nagel *et al.* 2019). In cattle, dystocia (the term used to describe a difficult parturition) increases the risk of retained fetal membranes, lacerations and fistula, as well as inflammatory disease, such metritis and endometritis (Mainau and Manteca 2011; Laven *et al.* 2012). These inflammatory diseases are painful (Stojkov *et al.* 2015), and reduce subsequent cow fertility and longevity (e.g. Tenhagen *et al.* 2007; Eaglen *et al.* 2011). A heifer that experiences dystocia has increased risk of sustaining rectovaginal injuries (Mainau and Manteca 2011) and is up to four times more likely to have retained placenta, metritis or to be culled involuntarily (Erb *et al.* 1985) compared with heifers that calve normally (termed eutocia). Dystocia also increases the risk of nerve damage causing calving paralysis, of downer cow syndrome (i.e. cows that are down in sternal recumbency for >24 h with no evidence of systemic illness, Poulton *et al.* 2016) and of calving via caesarean section, especially for first parity cows (Barkema *et al.* 1992; Poulton *et al.* 2016). There is evidence that cows requiring assistance at parturition experience psychological stress, pain and inappetence in the peripartum period (Mainau and Manteca 2011) resulting in reduced milk production (Eaglen *et al.* 2011; Shock *et al.* 2018).

The present literature review has chosen to discuss dystocia in the context of the heifer but acknowledges that it is relevant to both the primiparous and the multiparous cow. This decision was made on the basis that dystocia is more prevalent in the heifer. A survey of Australian dairy farmers reported one in six heifers had difficulty calving, with the prevalence of dystocia in heifers ranging from 0 to 77% between farms (Hough and Sawyer 1993). In a study of 152 641 calving records from pasture-based dairy systems in Ireland, Mee *et al.* (2011) reported the incidence of calving assistance (assistance managed by one person and no mechanical pull) and dystocia (assistance requiring mechanical pull or ≥2 people or veterinary intervention) was 40.2 and 9.3% for the primiparous cow compared with 28.2 and 5.8% for the multiparous cow. More recent Irish data using the same scale found 19.9% of calvings require assistance, with 5.9% classified as dystocia (Fenlon *et al.* 2017). The latter data are comparable with reports on the incidence of dystocia on Australia's pasture-based dairy farms (defined as any calving that required assistance, 8% Chuck *et al.* 2018; 5% Beggs *et al.* 2019). Neither Mee *et al.* (2011) nor Beggs *et al.* (2019) found a relationship between the incidence of dystocia and herd size in pasture-based systems, whereas an Irish survey of 98 dairy farmers found that larger farms were more likely to view calving difficulty as a problem (Martin-Collado *et al.* 2017).

Evidence from animals and humans suggest that parturition is an intensely painful experience, the degree of which is affected by parity and dystocia (reviewed by Mainau and Manteca 2011). Behavioural (restless behaviour, lateral lying, hunching back) and physiological (heart rate, respiratory rate, serum cortisol) indicators of pain are increased in dystocial dairy cows and buffalo compared with their eutocial counterparts (Barrier *et al.* 2012; Mohammad and Abdel-Rahman 2013). The recognition and control of pain is an essential component to good welfare (Mainau and Manteca 2011). Administering the muscle relaxant denaverine hydrochloride to cows during parturition reduces pulling force if assistance is required (Lange *et al.* 2019), and may increase dilation, thereby decreasing the need for episiotomy, birth canal lesions and clinical endometritis, and improving subsequent reproduction (Zobel and Taponen 2014). The unblinded research by Zobel and Taponen (2014) studied 200 cows and heifers and found that denaverine hydrochloride halved the need for assistance during calving, whereas the blinded study of 83 heifers by Lange *et al.* (2019) found no effect on assisted calving. Further research is required to confirm the positive early indications that denaverine hydrochloride can reduce dystocia. Post-parturition inflammation and pain is ameliorated through the administration of an NSAID in the hours after birth (e.g. meloxicam or carprofen), resulting in increased feed intake, milk production and subsequent reproduction, while reducing mastitis, metritis and voluntary culling in barn-housed cows and heifers (Stilwell *et al.* 2014; Antanaitis *et al.* 2018; Shock *et al.* 2018). There are few data on the prevalence of pain mitigation strategies for dystocia in dairy cattle. Huxley and Whay (2006) report that 66% of veterinary practitioners in the UK have administered NSAIDs to dystocic cows, but did not distinguish between beef and dairy cattle, whereas a recent survey of Canadian beef producers reports 46% of cows received an NSAID after experiencing dystocia (Moggy *et al.* 2017). As described by Laven *et al.* (2012), most dystocia cases are dealt with by farm staff, so the relatively high use of pain relief by veterinarians may have little bearing on the actual numbers of animals treated.

Fetal–maternal size mismatch is one general cause of dystocia (Arnott *et al.* 2012) and the most common cause of dystocia in the heifer (Mainau and Manteca 2011). Psychological stress at parturition due to heifer inexperience (Mainau and Manteca 2011) has implications for vulva constriction and prolonged delivery (Mee *et al.* 2011; Nagel *et al.* 2019), and may exacerbate difficulties associated with fetal-size mismatch. Commonly listed factors implicated in fetal–maternal disproportion include calf sex, cow parity, twinning, sire and dam breed, and calving difficulty predicted transmitting ability (PTA), age at first calving and body condition score at calving (Mourits *et al.* 1997; Mainau and Manteca 2011; Mee *et al.* 2011). Thus, the incidence of dystocia is partly affected by management decisions regarding, for example, bull selection and age at first breeding (Toaff-Rosenstein 2018; Ritter *et al.* 2019). Although a heifer weight target of at least 80% mature live weight at first calving is commonly recommended, good nutritional management can ensure heifers achieve a live wight closer to 90%, which is desirable in terms of first lactation production (reviewed by Roche *et al.* 2015), and perhaps also from a welfare perspective by reducing the risk of fetal–maternal disproportion.

Mee *et al.* (2014) recommends that dairy producers focus on factors that are within their control to reduce the incidence of dystocia. These include the quality and quantity of calving supervision, implementing a calving intervention and assistance policy, ensuring high maternal health status, and reducing maternal–calf mismatch through sire selection and sexed semen. Irish research, however, shows considerable variability in the importance dairy farmers placed on the sires heritability of calving difficulty (Martin-Collado *et al.* 2017). Most dairy farmers were willing to accept a small increase in dystocia to increase calf value (e.g. Martin-Collado *et al.* 2017; Berry *et al.* 2020), and 12% of farmers were prepared to accept a significant increase in sire calving difficulty PTA (Martin-Collado *et al.* 2017). Comparable data do not exist for pastoral systems in the southern hemisphere. Other, less documented decisions related to sire selection that may reduce maternal–calf mismatch and thus dystocia include using the smaller Jersey breed bulls over heifers or mating with bulls with short gestation length PTAs. Caution is required when relying on short gestation genetics to reduce dystocia, however, as the impacts on calf mortality and morbidity are not clear (discussed in review by Verdon 2022).

There may be an opportunity to repurpose precision dairy technologies designed to provide information on cow health and reproductive status to detect the onset of calving or maybe even dystocia, allowing for increased surveillance and more timely interventions. Observing changes in activity, rumination time and lying behaviour have been successful at predicting the day of calving, and at times up to 8 h prior to delivery, but continued refinement is required to improve detection sensitivity (Borchers *et al.* 2017; Kovács *et al.* 2017; Barraclough *et al.* 2020). To date, behaviour monitoring has not been successful in detecting calving difficulty (Saint-Dizier and Chastant-Maillard 2015; Kovács *et al.* 2017).

In consideration of the first calving, it is worth mentioning that dairy cows are commonly bred via artificial insemination (AI) which may affect welfare through physical discomfort and fear (i.e. yarding, handling, restraint, hormonal synching, invasive practices associated with artificial insemination and pregnancy testing), particularly for the primiparous heifer who is experiencing these procedures for the first time. To the best of my knowledge, there are no published data on the welfare of heifers when impregnated via AI compared with a natural mating. As reviewed by Ritter *et al.* (2019) 'Due to a lack of sufficient information regarding the incidence of injuries to cows as a consequence of natural mating versus using AI (e.g. damage or perforation of the uterine wall), no definite conclusions on each practice's risk for the cow can be drawn'. Presumably, the level of expertise and care taken by the AI practitioner would be integral to reducing possible welfare implications, but this requires assessment.

In conclusion, parturition is a painful and physically risky process, particularly for the heifer. Difficult parturitions (dystocia) exacerbate both pain and health risks. Reducing fetal–maternal size mismatch is key to reducing the risk of dystocia. This can be achieved by ensuring heifers are well grown at calving, using sexed semen on heifers and through sire selection for high ease of calving PTA. Research needs to assess the uptake of these management tools, as well as explore the factors affecting farmer decision making around sire selection.

Training to the milking parlour

The milking parlour and its procedures are novel to heifers. Behaviours indicative of fear are observed when heifers are exposed to the visual cliff formed by a herringbone milking pit and milking facility noises, even without close human contact and imposition of milking procedures (Arnold *et al.* 2007*a*, 2007*b*). Cortisol concentrations are higher during the first milking of barn-housed primiparous cows in a tandem milking parlour compared with milking on Days 4 and 130 of lactation (Van Reenen *et al.* 2002), and <40% of pasture-based heifers eat in their first milking in an automatic milking system (AMS; Jago and Kerrisk 2011). There is considerable variation in the response of heifers to milking, however, with those characterised as being more fearful showing a more pronounced negative response (Van Reenen *et al.* 2002; Sutherland and Huddart 2012).

A recent New Zealand survey found that 52% of dairy farmers introduced heifers to the milking parlour prior to calving, with 79% of these saying they do the training to reduce psychological stress (Sutherland *et al.* 2018). Experimental research shows that introducing heifers to the milking parlour and its associated noises and increased human contact (but without attaching the milking units) in the 2 weeks prior to calving reduces cortisol, residual milk volumes and behavioural signs of discomfort or fear early in lactation, but do not affect milk production or avoidance of humans (Sutherland and Huddart 2012; Kutzer *et al.* 2015). Brief periods of handing may not be sufficient to reduce fear of humans in the milking environment. An experiment by Bertenshaw *et al.* (2008) found 5 min of brushing per week for 6 weeks prior to calving (total of 30 min) was enough to reduce the fear response of heifers during milking and improve behaviour in the milking parlour, but four sessions of gentle touching/stroking over 2 days within 11 days of calving had no effect on agitation in the milking parlour or human avoidance (Ivemeyer *et al.* 2015). Increases in dry matter intake and milk production, and a decrease in somatic cell count, are recorded if the habituation period includes attachment of the milking units (Daniels *et al.* 2007). Moving heifers through an AMS improves ease of entry at their first milking, but doesn't affect the number of days to the first voluntary milking (Jago and Kerrisk 2011). There are not additional benefits to exposing heifers to the noises and sounds of the AMS or teat spraying during training (Donohue *et al.* 2010; Jago and Kerrisk 2011). Considering the natural herding instincts and social facilitation of learning in cattle (Veissier *et al.* 1998; Russell *et al.* 2017), experienced dairy cows could strategically be used when training heifers to move through the milking parlour or traffic to the AMS (e.g. Donohue *et al.* 2010). Indeed, over half of dairy farmers in New Zealand that do not train their heifers to the milking parlour prior to calving say they rely on the cow to 'teach the heifers' how the system works (Sutherland *et al.* 2018).

To summarise, introducing heifers to the milking environment prior to their first calving allows them to habituate to the milking yards, proximity to handlers, novel sounds, attachment of the cups and other milking procedures. This reduces psychological stress and hastens the adjustment of heifers to being milked for the first lactation.

Social integration to the milking herd

The cumulative experience of the first parturition followed by an abrupt separation from the calf, interacting with older cows for the first time in an intensive and competitive grazing system, and being milked (with the corresponding proximity to humans) make transitioning from the heifer herd to the milking environment a particularly stressful time in the life of a dairy cow. The fact that these physical and social stressors are experienced simultaneously may exacerbate their detrimental effects on welfare and productivity. For example, barn-housed cows that experience abrupt environmental as well as social change exhibit reduced feed intake and increased agonistic behaviour compared with cows that are regrouped without relocation (Schirmann *et al.* 2012). There is a paucity of peer-reviewed scientific literature regarding the social integration of dairy heifers into the milking herd in pasture-based dairy systems. Consequently, the following paragraphs provide a more housed perspective on this transition.

Cattle are a gregarious species that abide by a hierarchical social structure within which exist strong affinities (Reinhardt and Reinhardt 1981; Bouissou *et al.* 2001; Boyland *et al.* 2016). Introducing new members to an established herd requires a reorganisation of social relationships. This inevitably involves agonistic behaviour and social stress (Grant and Albright 2001; Bøe and Færevik 2003; Lobeck-Luchterhand *et al.* 2014), resulting in a temporary reduction in milk production (Von Keyserlingk *et al.* 2008; Smid *et al.* 2019). Torres-Cardona *et al.* (2014) observed a reduction in milk yield after regrouping multiparous cows with primiparous cows, but this was largely attributed to the primiparous females. Other research reports that the primiparous cow has higher concentrations of faecal cortisol metabolite than the multiparous cow when introduced to an established group (Mazer *et al.* 2020). Introduced primiparous cows spend less time lying and have desynchronised behaviour patterns compared with resident primiparous cows, but the same difference is not seen between introduced and resident multiparous cows (Gutmann *et al.* 2020). A lack of experience interacting with older and larger animals may make integration into the lactating herd challenging for heifers. Heifers that are reared with dam contact, as well as contact with unrelated cows in the herd, show more appropriate social behaviour (submissive behaviour) during their first lactation compared with those that had no contact with the herd (Wagner *et al.* 2012). Knowledge of social behaviour of cattle at mixing stems from research in indoor dairy systems and needs to be validated for pasture based systems; however, similar findings have been reported in other species (horses Bourjade *et al.* 2008; rats McCarty 2017; pigs Verdon *et al.* 2019).

The presence of a preferred social partner at mixing is one strategy that may ease social integration into the milking herd (see reviews by Veissier *et al.* 1998; Rault 2012, 2019; Neave *et al.* 2018). Cattle form strong and lasting preferential relationships with the peers they are reared with under both semi-natural (Reinhardt and Reinhardt 1981) and commercial conditions (Raussi *et al.* 2010; Gutmann *et al.* 2015; Boyland *et al.* 2016; Lecorps *et al.* 2019; Gutmann *et al.* 2020). Pairs of familiar heifers continue their close association for at least one month after being introduced to the milking herd (O'Connell *et al.* 2008; Gutmann *et al.* 2020), and have a lower concentration of faecal cortisol metabolite following introduction compared with heifers that are individually introduced (Mazer *et al.* 2020).

Following social integration into the milking herd, the primiparous cow is likely to assume a low social ranking. High social rank in cattle is associated with age, weight and feed intake (Phillips and Rind 2002; Crossley *et al.* 2018; Neave *et al.* 2018; Verdon *et al.* 2018). In both indoor and pasture-based dairies, the more competitive the system, the more pronounced the effects of social rank on feed intake are (Peyraud *et al.* 1996; DeVries and von Keyserlingk 2009; Jensen 2018; Verdon *et al.* 2018). Barn-housed heifers of low social rank are displaced from the feed bunk more often, and produce less milk than higher ranking heifers (Hasegawa *et al.* 1997) and multiparous cows (González *et al.* 2003; Neave *et al.* 2018). Modern grazing regimes (e.g. strip-grazing) restrict the availability of fresh pasture and can therefore be considered a competitive feeding environment. The intensively grazed heifer monitors her spatial relationships relevant to the more dominant cow, and will reduce her bite rate, stop feeding or move away as the proximity between herself and the dominant cow reduces (Sowell *et al.* 1999; Neave *et al.* 2018). Research from pasture-based dairy systems report substantially higher milk yields and pasture intakes in the multiparous than the primiparous cow, and the discrepancy between intakes increases as the amount of pasture offered decreases (Peyraud *et al.* 1996).

Grazing is a socially learnt behaviour (reviewed by Neave *et al.* 2018). Intensively grazing heifers with an experienced social model during rearing may help them adapt to the competitive grazing environment when in the milking herd. Lopes *et al.* (2013) found that grazing experience in either the first or second year of life, or both, increased the time heifers spend grazing and milk yield when introduced to pasture as a lactating cow, compared with those that received no prior grazing experience. Further, heifers that are introduced to pasture with an older experienced cow learn how to graze more quickly (Costa *et al.* 2016) and become more efficient grazers (Arrazola *et al.* 2020) than heifers with inexperienced companions. One strategy may be to introduce heifers to the milking herd during the dry period so that they are experienced with adult cows and competitive grazing conditions prior to their first lactation. The practical feasibility of this sort of management needs to be considered (in terms of nutritional needs, for example) and its implications for heifer welfare during the transition to the milking herd studied.

In conclusion, scientific understanding of the effects of heifer social integration into the milking herd on heifer welfare and productivity is derived from research in indoor settings. This research suggests introduced heifers assume more submissive social ranks and are thus less successful when competing for access to desired or restricted resources (e.g. food, resting space), experience more psychological stress and show reduced productivity compared to their multiparous counterparts. Experience of social interactions with older cows and of intensive grazing conditions may attenuate these negative effects for the heifer. This needs to be explored under seasonal, pasture-based management conditions.

Conclusions and recommendations

The life of a pasture-based dairy cow starts and ends with periods of daily management – first as a pre-weaned calf and later as a lactating cow – but there is a distinct lack of data on how animals are managed between these two life phases. Management decisions relating to the weaned dairy heifer affect both welfare and lifetime productivity. For example, frequent management of grazing heifers (i.e. weights, health checks) and the pasture they are fed (i.e. irrigation, rotational grazing) can improve welfare by reducing variation in the quality and quantity of feed offered, reducing the risk of parasitic infection, increasing opportunities for famers to monitor their animals and impose interventions to improve health and welfare if required, and allowing for better control of the growth trajectory. Reducing malnutrition will improve heifer welfare in the immediate future and long-term by reducing feelings of hunger, pain, malaise and frustration as well as the risk of culling for reproductive failure or poor milk production later in life.

Although the absence of records on management does not equate an absence of management, collecting these data is an essential first step to making visible areas of improvement and identifying changes in management over time. Specifically, for pasture-based systems it is not clear: (1) how often replacement heifers are weighed or receive health checks, (2) whether heifers are rotationally grazed, and the quality of pasture they are provided, (3) the frequency and age of surgical removal of supernumerary teats, (4) what the mortality rate from weaning until the first lactation is, and (5) what training procedures to introduce heifers to the milking parlour are used. These data need to be collected and broadly disseminated so that researchers and industry specialists can remain current with modern management practices and respond accordingly.

There is also a pressing need to document the management and housing conditions of exported dairy heifers living in other countries. The relatively long lives of breeding animals such as dairy cattle compared with those destined for slaughter means that mismanagement or inappropriate conditions can result in an extended suffering, but also provides opportunity to intervene for improved welfare outcomes. Although some countries, such as Australia, do not have authority over cattle once they reach their destination, exporting nations are able develop training programs aimed at improving dairy cattle welfare, as has been done for cattle exported for slaughter.

This review highlights opportunities to maximise heifer welfare during their transition to a milking cow. The following management can improve heifer recovery post-calving: (1) the risk of dystocia can be reduced by ensuring heifers are as close as possible to 90% adult weight at calving, are inseminated with sexed semen and/or mated to bulls with high ease of calving estimated breeding values, (2) farms should develop a calving intervention and assistance policy in collaboration with an advising veterinarian, and ensure it is circulated and visibly displayed for easy reference by farming staff, and (3) pain relief should be provided following a long or difficult calving. Separating stressors relating to the first parturition from those involved with transition to the milking environment (mixing with older and larger animals, competitive grazing conditions, and the novel milking parlour) may reduce overall stress burden and enhance heifer adaptability. For example, grazing heifers and cows together for some weeks of the dry period could provide heifers with the valuable experience of interacting with adult animals under competitive grazing conditions. The full biosecurity and nutritional management requirements of this approach need to be considered. Research needs to quantify the productive merit of implementing a program of heifer management as outlined above, in terms of physical recovery post-calving, first lactation milk production, and health and longevity.

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Author affiliation
[A]Tasmanian Institute of Agriculture, Faculty of Science, Engineering and Technology, University of Tasmania, Burnie, Tas. 7320, Australia.