Literature review of scientific research relating to animal health and welfare in livestock exports by air

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Acknowledgement of Country
Murdoch University acknowledges and pays respect to the Whadjuk people of the Noongar nation as the Traditional Custodians of the country and its waters that Murdoch University stands on in Noongar Country. We pay our respects to Noongar Elders past and present and acknowledge their wisdom and advice in our teaching and cultural knowledge activities.

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Executive summary

Air transport of livestock represents an opportunity to transport high value slaughter and breeding livestock between international ports in the shortest time possible. Often the final condition of the animal cargo is the criterion by which the customer judges the efficiency of air transport. However, the actual flight time that the animal is exposed to is not the only variable influencing its health and welfare. It is necessary to consider all aspects of the animals' journey, including transport from farm or a wild environment, to the destination airport, premises or farm where the animals are unloaded in the importing country.

A literature review was commissioned to provide a contemporary analysis of scientific literature pertaining to the health and welfare of Australian livestock exported by air, encompassing the process from sourcing to receival at the destination airport. This review was performed on all research that investigated the animal health and welfare impacts associated with air transport of Australian livestock. This included the sourcing, road transport and preparation of livestock (pre-export) and outcomes for livestock during export (in-flight and stop-overs) but did not include outcomes for animals after unloading from aircraft (in-country).

We identified relatively few peer-reviewed publications that presented empirical evidence related to animal health and welfare outcomes during live export by air. Several publicly available industry-funded research reports that were not peer-reviewed provided important insights into the management and risks of exported livestock during on-board stages. The majority of studies that presented empirical animal-based data were unpublished industry reports. Peer-reviewed articles were identified as those that presented findings indicative of stressors that livestock may face during air freight. There was very limited information on current practices within this industry, particularly for the stages of transport after arrival at an airport and during the on-board phase.

Our review concluded that there was a paucity of direct evidence for health and welfare outcomes for livestock transported by air and that several important knowledge gaps remain which could be the focus for future research. Some of these knowledge gaps identified were the total length of the voyage, how the livestock travel over the duration of the voyage, and contingency planning. Providing a holistic assessment of livestock welfare involving the physical and psychological aspects is challenging, especially given the tools for understanding the affective state of animals are not well advanced. However, closer monitoring and reporting of morbidity and behaviour of livestock during movement through commercial supply chains is suggested.

1. Introduction

1.1 Document background

This report was commissioned by the Department of Agriculture and Water Resources and describes considerations associated with animal health and welfare during the live export of livestock by air. A review was performed of literature related to animal health and welfare of Australian cattle, sheep, goats, camelids and buffalo. The scope of the review included sourcing, preparation and management of these animals whilst on-board the aircraft. A broad search strategy was devised whereby we included some literature that did not contain primary research to identify relevant journal articles, unpublished reports, and procedural documents. More literature was found relating to some topics (e.g. ventilation) but there were gaps in others (e.g. inspection and monitoring). Where a section has a small discussion, this means that no or few health and welfare-relevant literature items were found; it does not imply that the topic is an unimportant aspect of livestock health and welfare.

The live export industry, including both sea and air transport, is currently being guided by limited peer-reviewed literature in addition to other relevant procedural documents and anecdotal reports. Air freight from Australia is by nature an international phenomenon and is governed by both Australian and international regulations.

Two publications are defined as the main institutional guidance documents specifying inputs or procedures that should be used for exporters for livestock transport by air. They include standard operating procedures and codes of practice and while some standards overlap, they have a very different scope. The Australian Standards for the Export of Livestock (ASEL; Commonwealth of Australia 2011) are mandatory standards that represent basic animal health and welfare requirements for Australian stock. Within this review, version 2.3 of these standards will be referred to as ASEL. The International Air Transport Association (IATA) Live Animal Regulations (LAR) (International Air Transport Association 2017) stipulate a manual of industry regulation to be followed by all IATA Member airlines. IATA membership is extensive across the globe and currently consists of 290 airlines, but in addition some airlines may have their own specific requirements for the carriage of live animals. All persons who ship, accept or load animals must be familiar with the specific requirements for the individual species described in both these sets of regulations. ASEL only detail the transport of Australian livestock and are regularly reviewed (Farmer 2011; Department of Agriculture 2013). The IATA LAR cover all types of air freight and are reviewed annually by an international accredited body. Thus, it is important to note that any change made to a standard for livestock under ASEL, must not be in breach of an international standard stipulated by IATA LAR. In addition, livestock are further regulated once they arrive in the destination country according to the Exporter Supply Chain Assurance System (ESCAS), which is of limited relevance to this current review.

ASEL relate to the sourcing and on-farm preparation, land transport, pre-embarkation assembly of livestock, and the conditions on-board live export vessels, and have relevance to this review. ASEL are a set of resource-based animal health and welfare measures purported to maximise animal welfare outcomes during live export (Commonwealth of Australia 2011). ASEL set out the requirements that livestock exporters must demonstrate have been met to ensure animals presented for export are fit to export and will maintain their health and welfare status through the voyage. ASEL are given effect under the Australian Meat and Livestock Industry (Export Licensing) Regulations 1998 and Export Control (Animals) Order 2004, which makes compliance with ASEL a condition of an export licence Orders Part 43. In addition, exporters must submit several documents including details of the livestock to be sourced on a ‘Notice of Intention to Export’, a Consignment Risk Management Plan (CRMP), an approved export permit and a health certificate for the livestock. The Department of Agriculture is charged with being ‘the regulator’ for all exported livestock (Commonwealth of Australia 2011).

1.2 Background of livestock air transport from Australia

Air transport of livestock from Australia accounts for a relatively small proportion of all live export, accounting for 2% of Australian livestock exported in 2017, with the species commonly exported being sheep, cattle, goats, and camels (Norman 2018). Air freight is considerably more expensive than sea freight on a per head basis (Hogan and Willis 2009); however, most livestock that are airfreighted are high-value breeding or slaughter animals (Cronje 2007).

There are advantages to air transport compared to transport by sea that relate to the short shipment times, aiming to have the animal arriving in a ‘ready’ condition, restricted only by the importing country’s bio-security measures (Hogan and Willis 2009). However, animal health and welfare challenges are still present and can differ considerably from those associated with sea transport. The protection of flight crew and passengers from significant dangers while the aircraft is inflight is imperative. This therefore needs to be considered when establishing procedures to improve animal health and welfare during the flight.

1.2.1 Industry performance

Between 2016 to 2017, the number of sheep exported by air fell by 33% to 42,144 but remains the third highest figure recorded over the 2008 to 2016 period. During the same period, cattle exports by air rose by 53%, representing a return to average figures. Goat exports fell between 2016 and 2017 by 77% and the 2017 air export total was the lowest figure recorded over the 2008 to 2017 period (Norman 2018).

The majority of sheep were loaded out of Perth (48%) and Adelaide (43%) airports while cattle and goat exports were predominantly from Melbourne (cattle 67%; goats 24%) and Sydney (cattle 32%; goats 44%). The main importing countries for sheep by air were Malaysia (82%); followed by Singapore (9%) and China (7%). The main importing countries for cattle by air were Japan (31%), Taiwan (23%) and Malaysia (19%). Malaysia was also a major importer of goats by air (55%) followed by Nepal (26%) (Norman 2018).

Mortality rates for 2017 were 0.04%, 0%, and 0.016% for sheep, cattle and goats respectively, with mortalities occurring in 2.9%, 1.2% and 2.7% of the flights for sheep, cattle and goats respectively over the 2008 to 2017 period. The majority of sheep and goat mortalities were in animals exported for slaughter. There is an effect of time of year on mortality rates of sheep and goats with mortalities being significantly higher in the second half of the calendar year (July-December) ($P < 0.05$) (Norman 2018).

1.2.2 The process of livestock transport by air

The transport of livestock by air needs to consider not only the flight but also the welfare of the animals during sourcing, preparation, road transport, total time confined in transport crates, and unloading. Although not considered in this review, being outside the jurisdiction of ASEL, there will also be continued exposure to transport stressors, and in some cases, slaughter, after unloading at the destination. The literature available on the handling of animals during each stage of transport by air is very limited, and the range in duration for these processes is uncertain and is likely to vary considerably.

1.2.3 Aircraft configuration

In this review, there will be reference to various locations on fixed wing aircraft typically used for air transport. Aircraft compartments are referred to as ‘holds’. Figure 1 illustrates the hold nomenclature used in this review. As described in Hogan and Binns (2010), in passenger aircraft, the main hold is fully utilised for passenger accommodation. In 'combi' configuration, the main hold is partly utilised for passenger accommodation, allowing 'cargo only' access to the remainder of the hold. Livestock might still be carried in the lower holds on passenger aircraft, or in the freight section of the main hold of combi aircraft, provided that adequate ventilation segregation is installed.

Not all lower holds or all parts of lower holds are configured to carry crates normally required for livestock transport. Similarly, not all lower holds on all aircraft are suitably ventilated for the transport of livestock – although this limitation generally applies more to older aircraft Hogan and Binns (2010).

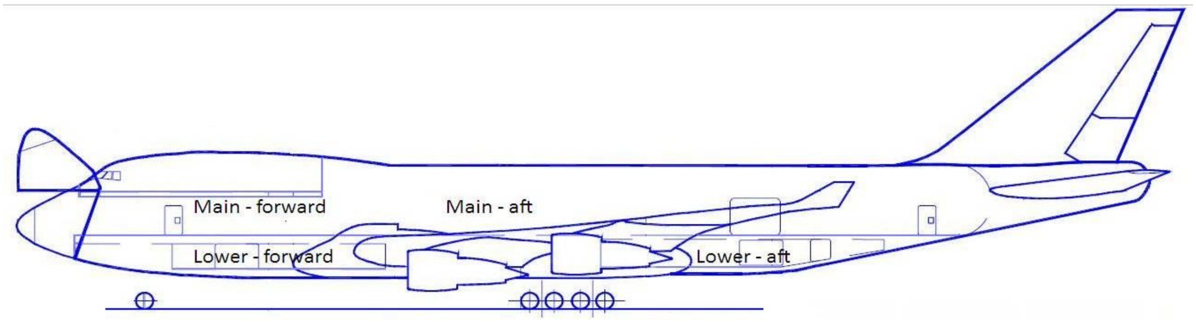

Figure 1: Hold nomenclature used in this review (B747-400 Freighter silhouette ©Boeing Commercial Airplane Company, 2002 in Hogan and Binns 2010).

2. Part A: Pre-export

2.1 Sourcing of livestock

Sourcing of farmed livestock (sheep and cattle) has been well described elsewhere and the animal welfare costs associated with paddock mustering and yarding will vary with the level of domestication of the selected livestock and are well-understood. When non-farmed animals (rangeland, free-ranging or 'feral' animals) such as goats and camels are exported via air transport, these animals may be considered compromised due to their relative lack of exposure to human infrastructure when compared to farmed animals (Petherick 2005). Current sourcing methods typically consist of trapping on water points (feral goats; Miller *et al.* 2018) and long-distance mustering using aircraft and motorbikes (feral camels; Hampton *et al.* 2016). Animal health and welfare risks associated with sourcing rangeland animals include injuries during trapping and mustering, duration spent in traps, unfamiliarity with yards and feed provided, and long-distance road transport to feedlots and airports. Methods currently employed to reduce these risks include mandatory acclimatisation periods and third-party inspections. These acclimatisation periods range with the species under ASEL specifications (Commonwealth of Australia 2011). No acclimatisation periods are set for domesticated sheep and cattle but stock are usually sourced in advance and are well habituated to yarding given the range of health testing requirements by the importing country.

Sourcing of the species, breed, class, weight, age and body condition score (BCS) of animals to be exported by air varies and is determined by the specific consignment requirements and ASEL (Commonwealth of Australia 2011). The number of animals sourced for any given consignment also varies from single individuals (e.g. a heavy *Bos taurus* bull) to several hundred of similar or mixed species.

2.2 Body condition score requirements prior to export

There is sparse literature relating to minimum body condition score (BCS) and animal welfare. The research is mainly focused on the relationship between BCS and productivity (Kenyon *et al.* 2014). Studies have suggested that BCS is a good indicator for animal welfare in terms of intra and inter-assessor agreement (Phythian *et al.* 2011) and a review conducted by Gaden *et al.* (2005) identified condition scoring systems which were suitable for scoring livestock for live export by sea. Within this review it was noted that very lean animals have little in reserve to handle additional export stressors. With animals that are already lean, there was particular concern if there was delayed adjustment to export conditions due to temperament or prior experience. It was also noted that very lean animals exposed to bad weather or unplanned delays in transit would be at higher risk than other groups. It was recognised in The Technical Advisory Committee's Issues Paper for the 2019 review of ASEL (Technical Advisory Committee 2019) that sheep under 24 kg and goats under 18 kg are a higher risk category that require a high level of care in an intensive management system, such as during the air transport journey. The report suggested that animal welfare may be enhanced if the minimum weight allowed for sheep exported by air was 24 kg for sheep and 18 kg for goats (Technical Advisory Committee 2019).

A review by (Kenyon *et al.* 2014) highlighted research indicating that low body condition score can have negative implications on both production and welfare. However, the relationship between BCS and production capacity, although generally positive, is not always linear. Therefore, simply suggesting that higher BCS means greater animal welfare (in terms of health, production and reproduction) may not be correct.

2.3 Preparation of livestock for air transport

2.3.1 Preparation for feed, water and handling

2.3.1.1 Sheep and cattle

Most of the recommendations for adaption of sheep to new feed and water provision are aimed at reducing the risk of persistent inappetence and subsequent death during live export shipping. However, exposing sheep to a pre-embarkation feedlot also allows animals to become accustomed to handling facilities and procedures while on-farm. Animals conditioned to well-designed handling facilities using trained stock people are less stressed by handling (Grandin 1997b). The majority of both exporters and scientific experts in the field of live export (100% and 55% respectively) believed that on-farm handling facilities and procedures have a moderate to high impact on performance of sheep during live export (Alliance Consulting and Management 2001). Encouraging exporters to preferentially select stock from Flockcare accredited properties should further minimise stress (Alliance Consulting and Management 2001).

Cattle which have had little experience with humans or handling will be more reactive and fearful and these responses will contribute substantially to their stress load. Selection of quiet, experienced, domesticated animals will minimise the impacts of the stresses of confinement. All exporters and 96% of experts agreed that on-farm handling experience has a major impact on live export performance of cattle and that pre-conditioning cattle to good handling will have a moderate to high impact on performance (83% of exporters and 80% of experts) (Alliance Consulting and Management 2001). All exporters and 77% of experts believed that handling facilities on-farm also have a significant impact on cattle performance (Alliance Consulting and Management 2001).

The fear response to new and non-painful stimuli can be reduced by gradual exposure (Alam and Dobson 1986; Grandin 1997b) and Hutson (1985) has shown that stress during handling can be reduced by gradually conditioning the animals to the handling procedures. It is important that the design and construction of livestock handling facilities are such that cattle can be handled gently as this has been found to result in less agitation and bruising, improved weight gain and less live weight loss than cattle handled roughly (Grandin 1997a). Temperament is also associated with an animal's ability to cope with heat stress. More prominent alarm reactions displayed by flighty cattle will generate more heat, which could be damaging if the heat load is already high (Adams 2000).

Studies have found there is a significant effect on livestock performance resulting from the time taken from yarding on the farm of origin to delivery to the abattoir (Knowles *et al.* 1994; McNally and Warriss 1997). Minimising this time will limit the effects of all the behavioural, physical, nutritional and infectious stressors that are encountered during pre-delivery preparation for live export. There are advantages in conditioning of livestock to handling early in their life rather than just prior to export. The effects of proper handling early in life are long lasting and result in animals that are better able to adapt to the psychological stress caused by subsequent handling later in life (Dantzer and Mormede 1983; Grandin 1997b). Fordyce *et al.* (1985) found that adult *Bos indicus* cattle handled carefully and intensively in a crush at a young age were quieter, less stressed and easier to handle than cattle that were not. Weaning cattle in yards as opposed to weaning in paddocks is an early handling technique. Fell *et al.* (1998) found cattle weaned in yards had lower feedlot morbidity to bovine respiratory disease. All exporters and 62% of experts believed that yard weaning would have a moderate to high impact on performance of cattle during live export (Alliance Consulting and Management 2001). No mention of yard weaning is made in the ALES, the OFQAM or in any industry-specific research (Alliance Consulting and Management 2001).

2.3.1.2 Wild-caught camels and goats

There is little published information indicating required times or suitable methods for free-ranging animals to sufficiently adapt to being handled, eating processed feeds, and drinking from troughs. This knowledge gap results in no evidence-based basis for rejection of non-farmed livestock that have not conformed to any technical standard. The effect of longer times (e.g. beyond the mandatory 14 days required for camels) on improving animal health and welfare outcomes is unknown.

The methods employed to domesticate livestock during the preparation process are regarded as more important than the length of the process. Many different methods of domestication of livestock have been investigated (Gherardi and Johnson 1994; Le Neindre *et al.* 1996; Flint and Murray 2001). Indicators that can be used to determine readiness of rangeland goats to be exported have also been investigated (Miller *et al.* 2018). Goats exposed to high human interaction (HI) or low human interaction (LI) were tested for agnostic behaviour, avoidance of humans and flight response. In the HI group, a stockperson entered the goat yard twice daily and calmly walked amongst the goats for 20 minutes. In the LI group, a stockperson only briefly entered the pens to check feed and water daily. The HI group had significantly higher body mass, fewer agnostic events and a slower flight speed than the LI group after 3 weeks. Using Qualitative Behavioural Assessment, HI goats were scored as more 'calm'/'content' compared to LI goats that were scored more 'agitated'/'scared'.

2.3.2 Road transport

2.3.2.1 Journey time

Total transport time is generally considered to be the most significant factor in transport stress (Wythes *et al.* 1981; Holmes *et al.* 1982; Warriss 1990). In a live export industry survey, all exporters and 90% of experts believed that minimising total transport time will have a moderate to high impact on performance of stock during live export (Alliance Consulting and Management 2001). This issue is covered in the code of practice for the land transport of cattle. The current ASEL also specifically addresses this with a best practice recommendation for minimising transport time. According to ASEL, for journeys with an estimated journey time (from start to finish) scheduled in excess of 24 hours, the pen area must be increased by 10% during air transport (Commonwealth of Australia 2011). Unlike most land transport journeys, the animals to be exported by air are not provided access to food or water upon completion of the road journey. Hence, it is important to keep the road journey to the airport as short as possible.

A study by Fisher *et al.* (2010) found that loading and the initial phase of transport were the most stressful to livestock as indicated by the increase in blood cortisol concentration and body temperature. They also concluded that current maximum transport duration, which are based on the maximum period of water deprivation (48 hours), within the welfare codes for cattle and sheep are acceptable on animal welfare grounds for the class of stock examined and the experimental conditions that prevailed.

2.3.2.2 Recovery period

The time required for resting needs to be considered in terms of recovery from transport to airport from preparation facility. In the event of delays or cancellation of flights, animals may also have to return to the airport from the preparation facility. Most experts (72%) and half the exporters believed that rest between stressful episodes would have a moderate to high impact on performance of livestock during live export (Alliance Consulting and Management 2001).

The negative effects of stress adaptation can be recovered if animals are allowed to rest after a stressful episode (Adams 2000). However, the environment provided for livestock to rest in is important. Knowles *et al.* (1999) found that 42% of cattle did not consume water during the one-hour rest period following 14 hours of road transport. They concluded that a one-hour rest stop with access to water was of limited value in terms of rehydrating the cattle. Tarrant and Grandin (2000) noted that unless resting facilities are adequate and the animals are unloaded with care, rest stops may be counterproductive and only serve to prolong the overall journey time.

It appears that there are no facilities or ramps at Australian airports dedicated solely to livestock unloading or for the safe containment of livestock while unloading. Livestock being unloaded from multi-tiered vehicles are moved from the upper decks down into the crate using the internal ramp of the truck, and as driver access is difficult, this may slow the flow of animals into the crate. There is minimal opportunity to inspect animals both in the truck or in the crate apart from checking they are moving freely into the crate. While anecdotal evidence suggests that episodes of individual animals escaping from the truck or the crate are rare, they can occur.

The standards for loading and unloading facilities for livestock has been investigated and is an important factor for the welfare of livestock and the safety of personnel involved (Lapworth 1990). The Code of Practice for the Land Transport of Cattle (MCOP 1999) also has recommendations for loading/unloading facilities including, design of race, ramp and the need for artificial light at night.

3. Part B: Airport and in-flight management

3.1 The management and inspection of livestock

3.1.1 At airport prior to departure

There is little published information on the management and inspection of livestock undergoing air transport. According to ASEL (Commonwealth of Australia 2011) livestock must be checked to ensure they remain fit to travel immediately before departure. There are many variables that could limit the ability to view animals, including amount of light (if inspection occurs at night) and the restricted view of animals while in the crate, particularly with larger crates holding multiple animals. Livestock in the lower cargo area are of particular concern to some stakeholders in the air transport industry, who noted that they should be inspected as late as possible before animals are loaded onto aircraft and as soon as possible after they are unloaded (Technical Advisory Committee 2019). For livestock held on the main deck, stakeholders recommend that these animals are inspected from when they are loaded onto the aircraft until main door of aircraft is closed and then as soon as possible after aircraft lands (Technical Advisory Committee 2019).

At point of loading of livestock onto the aircraft, the responsibility of the livestock is transferred to the airline. The captain is advised of the species, location and quantity of all livestock and of any special requirements of the livestock on board the aircraft (Commonwealth of Australia 2011). It has been noted that management of environmental conditions on board can be considered prior to loading of the livestock. In report MIR 53 (2015) it was noted that prior to loading, all aircraft doors were opened for at least an hour with the Auxiliary Power Unit (APU) running to allow adequate ventilation (see Table 2, Appendix).

3.1.2 During flight

According to ASEL (Commonwealth of Australia 2011) livestock must be checked to ensure they remain fit to travel, within 30 to 60 minutes of commencement of journey, at least every 2–3 hours during the journey as conditions warrant, and then immediately prior to departure after any transit stops. Stakeholders within the industry have expressed concern over the ability to inspect livestock during flights (Technical Advisory Committee 2019). The inspection would be difficult if not impossible depending on the crate location in the aircraft hold and the tier level. The inspection process may also have negative welfare effects in some situations (Technical Advisory Committee 2019). Industry stakeholders recommended that following closure of main door prior to take off, livestock should be visually checked again once the aircraft lands. The presence of a stockman on board allows monitoring of animals in the main hold; however, access to the lower hold is not possible during the flight

(MIR 47, 2014). The role of a stockman on board is limited in terms of access not only to the lower hold but also to the inside of the crate.

The temperature in the cargo hold containing livestock must be monitored throughout the flight (Commonwealth of Australia 2011); however, remote monitoring to allow real time assessment would be preferable, rather than retrospective retrieval of data. Software has been developed to assess the ventilation capacity of aircraft and their ability to safely dissipate generated heat, moisture and carbon dioxide (Hogan and Binns 2010; Flynn *et al.* 2014). The program presents the heat, moisture and carbon dioxide outputs for any single consignment of cattle, sheep and goats and any combination of these livestock. It then uses psychrometric calculations together with publicly available aircraft ventilation data to determine if the aircraft has the basic capability to transport the consignment without incident. The Live Air Transport Safety Assessment (LATSA) software was trialled on eights flights (Flynn *et al.* 2014). However, it is unknown if the software is currently being used by exporters.

3.1.2.1 Contingency planning

There appears to be some discrepancy between ASEL requirements and those of IATA in terms of euthanasia requirements. According to ASEL (Commonwealth of Australia 2011) livestock should be euthanased without delay as necessary. However, International Air Transport Association (2017) states that the use of humane killers or anaesthetic darts within the confines of the aircraft must be avoided due to possible damage to aircraft or injury to crew or other animals.

It is also unclear to what degree some ASEL standards can be met given the lack of access to crates during the flight and during any stop overs. This includes standards relating to removal of sick or dead livestock and the offering of feed and water (Commonwealth of Australia 2011). To the authors knowledge there is a paucity of direct evidence on suitability of contingency planning for livestock transported by air.

In the event of a change in flight plan the International Air Transport Association (2017) states that it is important that health and custom requirements are met not only in the importing country but also in-transit stops or alternates.

3.2 Environmental conditions

3.2.1 On tarmac prior to loading

According to ASEL (Commonwealth of Australia 2011), when the aircraft carrying livestock is on the ground, the ventilation and temperature in the livestock hold must be adequate to maintain animal health and welfare. It is important to also consider the time between when livestock are loaded into the crate and loaded onto the aircraft. Loaded crates may remain on the tarmac prior to loading onto aircraft usually for a minimum of three to four hours, due to aircraft trimming. International Air Transport Association (2017) states that livestock must not be exposed to direct sunlight and be protected from wind, rain and snow.

The conditions animals experience within the crates while on the tarmac may be similar to that of being in a stationary livestock transport vehicle. Conditions in stationary sheep transport vehicles were monitored by Fisher *et al.* (2004). Some increases in the THI occurred in stationary vehicles despite ambient conditions being mild, suggesting that the lack of airflow was a critical factor. During stationary periods, 34% of THI readings exceeded 75, and, on average, the THI increased by 0.16 for every minute of a stationary period. The longer the stop, the greater the temperature increase inside the vehicle and the greater the risk of losing animals.

In addition to the effect of limited airflow, the animals' heat production will impact on environmental conditions inside the crate. Total heat production of animals during loading and handling may increase up to four to five times more than that produced during rest (SAE Aerospace 2003). Therefore, it is likely that following loading into the crate the heat production of the animals will be higher, adding to the heat load in the crate.

Road transport studies have recommended that for sheep, stops should be as brief as possible and that drivers should park vehicles where there is airflow (Fisher *et al.* 2004). For livestock in crates awaiting loading onto aircraft, fan assisted ventilation may alleviate some heat load within the crates. The location of the crates during this period should also be considered to maximise airflow into the crates and to ensure they are in the shade. This is particularly important during summer. Loading at night is recommended to avoid high temperatures and solar exposure (Le 2012). Maintaining dry conditions from loading to unloading should also be a priority to ensure good animal welfare (MLA report W.LIV.0289, 2019).

3.2.2 On-board

There is a paucity of information about the behaviour of livestock in stock crates or in-flight. Animals must be stocked and managed at a density that allows them to maintain balance during take-off, landing and during periods of turbulence, similar to that experienced during road transport. How the temperament of animals may affect the manner in which they endure the long crating period or in-flight conditions is also not documented. Studies of the behaviour of livestock using video captured during the flight would be useful to describe the effects of flight conditions on the physical and affective state of animals.

Using temperature and humidity loggers, real time data was collected during eight shipments of livestock by air (Flynn et al. 2014). Analysis of the flights showed there were issues with temperature consistency within and between holds, temperature uniformity inside and outside the crates, and air quality. Analysis of carbon dioxide (CO_2) revealed an overall increase of concentrations during transport, indicating an underperformance in the ventilation of CO_2, and most probably, other noxious gases (Flynn et al. 2014). Based on these risk assessments, adjustments can be made to stocking densities and/or the total number of animals to minimise the risk, refine carrying efficiencies and better improve animal welfare conditions during transport.

The compartment temperature, CO_2 concentration, and humidity depend on the ambient temperature, animal type, the number of animals transported, air-conditioning pack capability and environmental control system (ECS) setting (Le 2012).

The humidity and CO_2 levels inside the compartment are not controllable by ECS settings and an animal's heat load can result in higher compartment temperatures than that set from the flight deck (Le 2012). According to Le (2012) the conditioned supply air from the air distribution nozzles contains some moisture and CO_2, prior to mixing with the air inside the compartment. The air distribution nozzles are located in the ceiling or sidewall of the aircraft. The supply air combined with the animal heat load, CO_2 and moisture generation determine the overall compartment air properties. A preliminary animal carriage calculation should be performed to predict the compartment temperature, relative humidity and CO_2 levels prior to animal shipment. If these are beyond recommended levels, stocking rate should be reduced (Le 2012).

Adequate ventilation helps prevent unhealthy levels of CO_2 and humidity accumulating in the closed cargo compartment. Therefore, it is recommended to close cargo doors last before departure and open cargo doors first upon arrival (Le 2012). Boeing recommends night loading of crates to minimize heat load and excessive CO_2 (Le 2012).

When ventilation systems are functioning 'without defect' it has been reported that aircraft internal temperatures ranged from 23–27°C (MIR 48, 2014). Presumably this was a measure of dry bulb temperature. In that mortality report, the three air conditioning packs were used at high-flow throughout the flight. It was noted in MLA report W.LIV.0289 (2019) that functional aircraft environmental control systems can effectively maintain temperature and humidity within the desired range.

Other mortality reports (MIR 49, 2014; MIR 53, 2015; MIR 59, 2016) indicate problems with the ventilation system (Table 2, Appendix). MIR 49 (2014) noted that, during the flight, a malfunction message was generated in the ventilation system; however, action could not be taken to fix the problem. There was no access to the lower cargo hold and no monitoring could be done of environmental conditions. Inadequate ventilation was reported as the most likely cause of mortalities. Action was taken in subsequent flights to ensure that the lower cargo area had a suitable ECS and not to deploy any aircraft with air conditioning defect when live animal shipment was booked.

In report MIR 53 (2015) it was noted that, following arrival at the destination, maintenance checks found that one of the air conditioning packs was underperforming. All air conditioning packs were operated at high flow and low temperature setting. Aircraft data provided by the airline show that, two hours into the flight, temperature readings reached 35°C on the main forward monitor and 25°C on the main aft monitor and remained at these temperatures for the remainder of the flight. It was considered likely that temperatures inside the crates were much higher. This was despite aircraft doors being open with the APU running for at least an hour prior to loading to allow adequate ventilation (outside ambient temperature was 22.9°C at loading). Following inspection by the pilot, the ECS was set to its lowest setting (4°C), and lights were turned off to reduce heat production. At inspection on arrival, it was noted that ammonia levels in some crates were particularly high.

In report MIR 59 (2016) it was reported that the flight ventilation system was set at 16–18°C while livestock were on-board. It was reported that the ventilation was fully functional. Once arriving at the stop-over airport, the lower deck livestock crates were unloaded immediately, and remaining livestock were reported in good health. However, during the stopover the APU required to run the ventilation system could not be started until two hours after landing. During this time the cargo doors were opened and a ground air conditioning trolley was directed at the main deck (outside air temperature was 31°C and 75% humidity). During the stop-over, the livestock cargo also needed to be rebalanced taking approximately five hours to be resolved (total stop over time: 5 hours 22 minutes). On the final leg of the flight the ventilation system was reported to be fully functioning.

Norman (2018) reported another flight carrying sheep during 2009 that recorded a 7.4% mortality rate when one of the air conditioning packs deactivated resulting in inadequate ventilation in the main cargo area.

3.2.3 Stop-over

The environmental conditions at any stop over must also be considered, because of the effect of the ambient air temperature on the overall conditions within the hold. Livestock are particularly at risk of excessive heat load during journeys which have time on the tarmac in hot, humid regions.

Studies examining air transport of mice (Syversen *et al.* 2008) and horses (Thornton 2000) found that conditions experienced in-flight were often markedly different to those during stop overs. During hot weather, it took some time for temperature to stabilise, if it did at all, after take-off. Thornton (2000) suggested that on-ground conditions at intermediate or refuelling stops are possibly more important than in-flight conditions in respect to heat stress.

International Air Transport Association (2017) recommended that during prolonged transit stops where ramp temperature exceeds 20°C, the aircraft doors must be opened, and in extreme temperatures ground equipment must be used to control the condition of air within the compartments.

In flight report MIR 48 (2014) the ambient temperature at the stop-over (Singapore) was 29°C. During the stop, the cargo doors were closed and all three air conditioning packs were operated by the APU. In addition, a supplementary air conditioning cart was connected and in operation while on the ground. The stockman's report indicated there was a noticeable amount of vapour in the hold during the stop that was inconsistent with other consignments (this consignment was the fifth in a series of nine). The excessive condensation and moisture on the main deck was also noted after departure from Singapore. The aircraft internal temperature recorded up to 32°C in the main deck after departure from Singapore and it was noted that this temperature may have been higher inside the crates. There was no identified or known defect in the aircraft's environmental control system (ECS).

Flights that were environmentally monitored by Flynn *et al.* (2014) also had problems with stopovers during transit, with critical dry and wet bulb temperatures reaching 32.5°C and 31.6°C respectively, conditions that fall within the critical limits for animal discomfort.

3.3 Aircraft transport crates

3.3.1 Crate design

The transport crates must provide strong, secure holding for the livestock, but also need to meet aircraft specific features as well, such as consideration of weight, capacity for airflow through the crate, and holding of effluent.

In mortality investigation reports it was noted that livestock crates met the best practice standards for design of crates for livestock by air (Hogan and Willis, 2009). In one mortality investigation report (MIR 48, 2014), two industry consultants provided conflicting opinions about whether the design of these crates allowed sufficient airflow into the crate. The report also noted the aircraft manufacturers' concerns about the crate design. Anecdotal reports from exporters indicate that crate dimension and composition are frequently custom designed and are determined by both the intended class and species of animal to be carried and the aircraft type sourced for the voyage.

3.3.1.1 Allowance for ventilation

The ventilation of the animals is critical, in ensuring favourable environmental conditions without excessive heat or moisture, and in removing noxious gases such as CO_2 and ammonia. Ventilation of the animals will depend on both ventilation of the hold area, and airflow around the animals; there is concern that crate design and stowage may limit this airflow. Ventilation may be of particular concern during periods of delay, or during transit, when crated animals may be stored either in stationary aircraft or in large enclosures at foreign airports with high environmental temperatures and humidity.

IATA standards state that the ventilation rates in aircraft are expressed in terms of the number of times the entire volume of air in the passenger cabin (or cargo hold) is being notionally replaced each hour. The ventilation rates vary considerably between aircraft, as detailed by Flynn *et al.* (2014). Optimal conditions for the transport of animals via aircraft can vary, and final hold conditions will be dependent on such variables as ground conditions pre-flight and temperature settings (controlled from the cockpit by the pilots). The total number and type of consignment (cattle, sheep alpaca and goats) will also impact on airline hold conditions.

Conditions viewed by the primary and export industries as the 'optimal' ranges of dry bulb temperature are 10 - 20°C and 40 - 80% relative humidity (Flynn et al. 2014). Dry bulb temperatures recorded internally in the crates were between 10°C and 13°C warmer than externally, and wet bulb temperatures were 12°C to 16°C warmer than externally. The warmer conditions were assumed to be due to decreased ventilation reaching the inside of the crates due to low crate permeability (Flynn *et al.* 2014). Between rows of crates it was found that dry and wet bulb temperatures were 4.5°C and 3°C higher respectively, than other areas of the hold (Flynn *et al.* 2014).

From environmental monitoring of eight consignments of livestock transported by air, it was found that carbon dioxide concentrations were on average around 1500 parts per million (ppm) (Flynn *et al.* 2014). At no time did they reach concentrations above the upper limits for animal stress at 5000 ppm (Flynn *et al.* 2014). It was observed that CO_2 gradually increased in concentration during the flight periods indicating that the ECS was under performing in the ventilation of CO_2 and most probably, other noxious gases (Flynn et al. 2014). High concentrations of carbon dioxide and ammonia were measured at times during some flights examined in a Meat and Livestock Australia study (W.LIV.0289, 2019). Ammonia concentration rose as the flight progressed on three of the six flights - including to concentrations above health guidelines. The elevated ammonia concentrations were suddenly resolved (via the environmental control system) suggesting manual operation of the hold environmental control system. The report indicated this leads to underperformance on some aircraft and flights. Air turnover volumes must operate to a level that controls concentrations of these compounds at all times.

Airline hold conditions are also influenced by placement and positioning of crates within the hold. From information provided in the mortality investigation reports (MIR 47, 2014; MIR 48, 2014) there is an indication that the location of cargo is an important consideration to providing optimum ventilation. In MIR 47 (2014) it was suggested that the location of additional containers in the cargo hold may have resulted in obstruction of airflow and reduced air movement in the aircraft hold. However, previous flights with this load plan did not result in any mortalities. In MIR 48 (2014), it was suggested that the placement of double livestock crates loaded side by side in one block may have impacted airflow on the main deck to the point where it influenced the compartments' environmental conditions. However, previous flights with this load plan did not result in any mortality. The inadequate ventilation may have been further compounded in this flight by a stop-over in Singapore with its hot and humid climate (MIR 48, 2014).

Crate design may be restricting air circulation according to MLA report W.LIV.0289 (2019). Multi-tiered animal crates were suspected to restrict air flow within holds and this may be contributing to high concentrations of noxious gases - especially gaseous ammonia. Further research comparing the ventilation of upper versus lower hold, the gaseous concentrations inside versus outside the crates and comparing short versus long haul flight is recommended.

The physiological state of the animals may also affect the requirement for ventilation, and therefore, may influence stocking density. Respiratory gaseous exchange and heat production differs between sexes and between animals in different physiological states (e.g., lactating vs non-lactating, young versus mature). Heat production at maintenance is higher for intact males than females or castrated males in studies on both sheep and goats (Lou *et al.* 2004b; Sahlu *et al.* 2004). Stress, such as that experienced by animals during air transport, may cause the heart rate to be elevated. An elevation in heart rate in goats has been associated with increased energy respiratory gaseous exchange and heat production (Puchala *et al.* 2007).

3.3.1.2 Structural integrity of crates

The report of Hogan and Willis (2009) outlines the best practice design of crate for air transport of livestock and describes risk factors for crate failure. This report provides the standard for livestock crates in Australia (MIR 2014). MLA report W.LIV.0289 (2019) suggested that stock crates for live export by air may need to be certified as fit for purpose. This would require a crate standard to be defined.

3.3.1.3 Effluent containment

Voided faeces and urine from the animals (collectively termed 'manure' here) must be retained in the animal crates; there is no capacity for cleaning manure from the aircraft holds. The recommendation by the OIE is an upturn of 20 cm with impermeable material so that manure cannot escape from the crate; however, the material must not block ventilation openings (Office International des Epizooties 2018).

Evaporation from the manure can make a significant contribution to atmospheric moisture levels in a confined environment (Scientific Committee on Animal Health and Animal Welfare 1999). The evaporative flux rate will depend in part on the manure temperature and moisture content, as well as the ambient temperature, air speed and humidity or vapour pressure (Liberati and Zappavigna 2005).

3.3.1.4 Ability to achieve normal posture

The total journey time within the crate may be in excess of 12 hours and therefore it is important that animals can achieve normal posture. Anecdotal reports from stakeholders inform that the animals spend much of the time standing, and therefore height is an important factor.

According to ASEL (Commonwealth of Australia 2011), camels must be sourced that meet shipping height requirements (i.e. camels standing in their natural position do not touch any overhead structure). Similarly, other transported livestock must be penned in crates that allow no part of the animals' body or horns to touch the overhead part of the crate. Recommendations by the OIE (Office International des Epizooties 2018) are for at least 10 cm clearance above the animals' head when standing in a normal position.

There is no published information about the effect of crate design on posture or behaviour and so it is not known what percentage of animals will lie down, if any, and if a recumbent position can be sustained to allow animals to rest.

3.3.2 Stocking density

Stocking density is a critical factor in all aspects of air transport. It influences animal comfort, behaviour and welfare from a space perspective; the production of heat, moisture and expired gases such as CO_2 will affect ventilation effectiveness; and it will affect weight and load plan of the aircraft.

For air transport of livestock, animals must be loaded according to the species-specific stocking density requirements written in IATA and ASEL. According to ASEL (Commonwealth of Australia 2011), livestock must be able to stand normally and once lying down should be able to regain their feet unaided and without undue interference from other stock. However, the rounding up of stocking density to the nearest whole number is permitted (Technical Advisory Committee 2019) and is routine practice under IATA LAR. This means that where a permitted density of 5.5 head per crate is estimated, the actual head loaded is six head per crate. There is no scientific evidence to determine what the impact of the recommended density or the rounding up is on livestock behaviour during the crated journey, either in-flight or when waiting in transit. At high stocking densities, it is known that animals may not be able to lie down simultaneously or may be prevented from lying down (Cockram *et al.* 1996; Knowles 1998), and this may cause fatigue and muscle damage, particularly during long journeys (Knowles 1998).

ASEL specifies a requirement for additional space for horned animals and rams, heavy cattle, buffalo and pregnant cattle (Technical Advisory Committee 2019)**.** Currently, there is a requirement for lower stocking density in the lower cargo area without specific evidence to support this, and a lower stocking density for goats has been proposed. When livestock are loaded with mixed cargo in aircraft lower holds, the pen area must be increased by 10%. The committee based this conclusion on findings by Hogan and Binns (2010) that although the ventilation system in the lower hold is generally better than the main hold, the LATSA software (developed by Flynn *et al.* (2014)) underestimated dry bulb temperature in the lower hold by 7°C. Furthermore, the findings by Hogan and Willis (2010) seemed to only apply when there was no other cargo restricting airflow.

The way load plans are communicated to relevant airport personnel may need to be examined. It was noted in MIR 47 (2014) that the exporter load plan approved by the department is not always provided as a hard copy to the airline. In this flight, the additional 10% of stock space required by livestock was communicated by the exporter verbally to the airline but these instructions were not carried out.

The high stocking rates typical of intensive animal industries such as feedlotting and live export can have a negative effect on the social behaviour of animals. Dominant animals have their social status and are free to move at will, with minimum interference. They are less likely to be crowded in any situation. For subordinates, their individual distances are constantly being traversed. They must avoid entering the personal space of more dominant neighbours (McBride et al. 1963). Under high stocking rate avoidance is physically impossible, causing subordinates to undergo repeated alerting or alarm reactions; with increased inter animal aggression (Syme and Syme 1979; Metz and Mekking 1984; Tennessen *et al.* 1985; Kondo *et al.* 1989). Repeated triggering of these reactions becomes stressful to an animal under strain (Squires 1975). Furthermore, increased threats and fighting can potentially cause injury and dark firm and dry meat (Grandin 1980). Studies on sheep and cattle have found an increase in space allowance per head was associated with a decrease in occurrence of all interactions between animals and potentially injurious events (Kondo *et al.* 1989; Jarvis and Cockram 1995).

At a high stocking density, the risk of heat stress also increases, because the increased contact between animals will limit their ability to dissipate heat and at the same time will increase heat exchange between individuals (Schrama *et al.* 1996; Knowles *et al.* 1998). Stocking density on the aircraft has been found to impact on overall temperature and humidity within the aircraft holds (Flynn *et al.* 2014). Stocking density will also impact on other aspects of ventilation, with more animals resulting in more expired CO_2, and potentially limiting the airflow to remove it.

At very high stocking densities an animal may also be prevented from lying down (Cockram *et al.* 1996; Knowles *et al.* 1998). Studies have found that during periods of minimal stress and low stocking rates, adult cattle will stand for about 4 hours and then 15% will become recumbent. In general, calves and sheep will normally stand for 2–3 hours and most will be lying after 6 hours (Watts 1982). It is important to allow for this natural behaviour pattern to reduce fatigue and muscle damage, particularly during long journeys (Knowles *et al.* 1998). Jarvis and Cockram (1995) found that lying behaviour in sheep increased as space allowance per animal increased (0.22 to 0.98 m^2). A previous study concluded that lying behaviour in a slaughterhouse lairage was affected by space allowance and that an area greater than $1m^2$ per sheep was required before most sheep within a group lay down (Kim *et al.* 1994). However, other studies have found that sheep do lie down at stocking rates less than this (Jarvis and Cockram 1995). Sheep have clear preferences in the way they position themselves in enclosed areas, tending to lie next to, and parallel to, open pen walls (Hutson 1984). Standing sheep tend to face the nearest adjacent pen of sheep and distribute themselves regularly in the pen; each sheep thus maximising the distance to its nearest neighbour (Hutson 1984).

Le (2002) recommends that the longer the time on the ground and the duration of flight, the lower the recommended density of animals in the cargo compartment, while according to ASEL (Commonwealth of Australia 2011) for total journey time (from start to finish) scheduled in excess of 24 hours, the pen area must be increased by 10%.

3.3.3 Penning arrangements

Penning arrangement in crates is dependent on body weight and height and is carefully managed by the exporter load plan before the loading of the truck. The livestock are usually prepared in crate lines, according to both weight and height prior to loading at the facility. The livestock are unloaded directly from the truck into the crate as it is important to keep animals of similar size and weight together (see Appendix 3.1). The penning arrangement is important as initially when animals from different groups are mixed, a hierarchy is developed (Mech et al. 1990). In terms of the rank of an animal, it has been found that horned animals will be dominant over polled animals (Bouissou 1972; Beilharz and Zeeb 1982), heavier animals will dominate lighter ones (Bouissou 1972; Syme and Syme 1979), older animals (up to 9 years) will dominate younger ones (Syme and Syme 1979), males will be more aggressive and will be dominant over females (Soffie *et al.* 1976) and animals that have spent more time within a group will be dominant over newly introduced animals (Schein and Fohrman 1955).

The development of a social hierarchy is extremely stressful for the animals involved (Mounier *et al.* 2005). In dominance tests the number of fights was significantly higher in single sex, single age groups (Stolba *et al.* 1990). Due to this aggressive behaviour, International Air Transport Association (2017) state that non-castrated male livestock should not be grouped together in the same container. In addition to physical injury, cattle and sheep have been found to suffer from lack of rest and time lying down during the period of establishing a hierarchy (Jarvis and Cockram 1995). The normal pattern of standing and lying down as a group does not emerge for at least 48 hours after the new hierarchy is formed (Wieckert 1971).

The point of social stabilisation is the time when non-physical agnostic interactions among group members predominate and the ratio of physical to non-physical interactions remains comparatively stable (Kondo and Hurnick 1990). The time taken for hierarchy to be established can be anywhere from 1 day (Kondo *et al.* 1984) to 2 weeks (Landaeta-Hernàndez *et al.* 2005) depending on the grouping.

Through segregation of animals into groups with similar characteristics there is inevitable division of familiar social groups. Stolba *et al.* (1990) found that a family group of cattle had less fighting, frequency of movement and attention behaviour compared to similar non-family groups. Similarly, the time sheep spent lying down decreased as the number of unfamiliar groups it was mixed with increased (Lynch *et al.* 1992).

Energy expenditure associated with increased animal activity such as agnostic behaviours will affect heat production and moisture losses, impacting on environmental conditions on-board (Flynn *et al.* 2014). In a modelling program, LATSA, this has been incorporated as a 'behaviour factor' (Flynn *et al.* 2014).

The sourcing of animals from a number of properties has been reported in MIR but it is unknown whether the groups remained together. It is preferable for animals to stay in familiar social groups not only to minimise the stress and injury associated with the development of a new hierarchy but also to minimise drafting into segregated types of animal. The drafting process has been found to be more stressful than dipping and drenching, represented by a greater increase in plasma cortisol (Hargreaves *et al.* 1990).

There is also concern in terms of disease spread when mixing groups sourced from various locations.

3.4 Provision of feed

Limiting of feed is a major stressor in livestock production systems (Kelley 1980). Depletion of energy reserves is a common outcome in transported cattle (Cole and Hutcheson 1985). Therefore, appropriate nutrition in the week prior to transport to increase body reserves of energy can enable cattle to better adapt to feed deprivation during transport and improve subsequent performance. *Ad libitum* feeding and increasing the concentrate percentage of the pre-transport diet results in a greater feed intake subsequent to transport, improving post-transport performance (Hutcheson *et al.* 1984; Cole and Hutcheson 1985; Hutcheson and Cole 1986; Pritchard and Mendez 1990). However, most of these studies were conducted on younger feeder calves as opposed to adult cattle and hence the effect of pre-transport feeding management on live export performance is not known.

In the context of air transport of livestock, it is important to note that the interval between an animal's last meal and the type of meal consumed will affect the consumption of O_2, heat generation and the production of CO_2 and water in expired breath, and therefore the ventilation requirements for the livestock. If animals are fed immediately before a flight, heat production will increase by 21% or 38% for concentrate or forage diets, respectively, within two hours of the meal and decrease gradually over the next six hours to a level in excess of that before the meal (Puchala *et al.* 2007). Corresponding changes in respiratory gaseous exchange would be expected.

3.5 Provision of water

It is common that animals will be curfewed from water before trucking to the airport, and there is limited capacity to provide water to crated animals at any point during the journey until unloading at their destination. Therefore, livestock may be off water for at least 12 hours and possibly much longer; there are anecdotal reports of dairy heifers being off water for 30 hours from farm departure to arrival at destination. The OIE (Office International des Epizooties 2018) recommendation is allowance for the provision of water and possibly food during transportation that is longer than 6 hours. ASEL (Commonwealth of Australia 2011) states that feed and water must be offered to all livestock for export by air while in transit if climatic conditions, species and class of livestock and total journey time warrant. International Air Transport Association (2017) state that food and water containers must be provided either fixed inside the container or attached to it with a means of access provided.

The practical implications for the provision of water to crated livestock experiencing flight delays is challenging given the relative inaccessibility to livestock once crated.

Under the Australian Model Code of Practice for the Land Transportation of Cattle (Primary Industries Standing Committee 2004), the maximum allowable transport duration is primarily determined by the maximum time that stock can be deprived of water. For mature dry cattle, the maximum duration is 36 h and for cattle known to be more than six months pregnant is 24 hours. However, this can be extended to 48 hours if the animals are not displaying obvious signs of fatigue, thirst or distress and if the extension allows the journey to be completed within 48 hours. For mature healthy sheep, the maximum proposed time is 32 hours, but this can be extended to 38 hours. These maximum durations also include any period of pre-transport curfew where access to water is restricted. Importantly, this would not apply to pre-transport curfews that allow access to water but not food.

3.5.1 Welfare effects of water deprivation

The effects of an extended time off water on livestock during air transport are not reported. The effect of water deprivation during land transport has been extensively reviewed by Fisher *et al.* (2006) and researched by Ferguson and Fisher (2008). In those studies it was noted that food, or food and water deprivation over varying periods up to 72 hours did not affect blood cortisol concentration in cattle (Gaylean *et al.* 1981; Parker *et al.* 2003a), sheep (Warriss *et al.* 1995; Horton *et al.* 1996) and goats (Kannan *et al.* 2000) indicating it was not stressful to ruminants. In contrast, Fitzpatrick and Parker (2004) found that following 60 hours of water deprivation, *Bos indicus* steers had a significant increase in the concentration of plasma cortisol.

The hypothalamic-pituitary-adrenal axis may not necessarily reflect that animals will experience hunger and thirst during periods of food and water deprivation. The psychological impacts of hunger and thirst in livestock cannot be reliably quantified at present. Consequently, we are reliant on quantifying the biological costs via physiological measurements. Physiologically, restricted food and water intake leads to altered metabolism, increased tissue catabolism and dehydration (Galyean *et al.* 1981; Phillips *et al.* 1991; Parker *et al.* 2003; Fisher *et al.* 2010). Of these, dehydration is undoubtedly the most significant welfare concern.

Road transport or fasting studies where cattle were deprived of food and water up to 48 hours clearly show haemoconcentration indicating some level of dehydration (Schaefer *et al.* 1990; Phillips *et al.* 1991; Parker *et al.* 2003a). However, in these studies the level of dehydration was not classed as being of clinical concern. These results could be partly attributed to the ruminal reservoir of fluid which acts as a useful buffer during periods of water restriction (Knowles and Warriss 2000; Parket *et al.* 2003b). A study by Parker *et al.* (2003b) found sheep are also tolerant of considerable periods of water deprivation with reduction in urinary output only evident after 72 hours of deprivation. However, other studies have found evidence of dehydration and tissue catabolism, indicated by carcass weight loss, within 12 hours of food and water deprivation of sheep and lambs (Kirton *et al.* 1972; Thompson *et al.* 1987), and by 24 hours in cattle (Wythes and Shorthose 1984).

There will be an interaction between water deprivation and the environment to which the animals are exposed. Animals subject to hot and humid conditions will be more affected by water deprivation and dehydration that may limit their capacity for evaporative heat loss. Given the extended period that livestock have restricted access to water, it may be that the need for pre-transport curfews should be predicated on consideration of key factors such as the nutritional background and condition of the cattle and sheep, and the duration of the total transport process. A study by Ferguson and Fisher (2008) found that subjecting healthy, grass-fed cattle or lambs to pre-transport periods of food and water deprivation (12 and 24 hours compared with 0 hours) prior to transport for 12 or 24 hours did not adversely affect animal welfare. On the other hand, in that study, pre-transport feed and water withdrawal did not enhance the capacity of the animals to cope with transport but simply added to the overall feed and water deprivation period and its associated effects.

4. Conclusions

The review has collated information from a variety of sources including published studies, industry reports and procedural documents. There have been few independent studies performed in the context of air transport with most of the research provided by industry reports. The health and welfare risks of livestock exported by air transport are nonetheless well understood and include land transport journeys, high density confinement in crates on-board, lengthy waiting times, extended periods of water and feed deprivation, a variation in thermal conditions and potential exposure to noxious gases, all imposed for various durations up to 12–48 hours. The impact of these conditions on the welfare of livestock increase with total journey duration.

The frequency of mortality and /or adverse events is very low, with most cases resulting from ventilation failure or breakdowns. Potentially the main concerns identified by stakeholders in the industry are; food and water deprivation times for livestock particularly when aircraft are delayed, the access to and management of crated animals in transit especially in hot and humid climates, and the adequacy of ventilation. However, as there is a paucity of direct evidence regarding livestock transport by air, how these factors influence livestock behaviour, health and welfare remain unclear. Further studies to investigate the behaviour and affective state of livestock are required to better understand the impacts of export practices on livestock well-being.

Other potential concerns identified were the suitability of crate design, the lack of suitable facilities to adequately inspect animals prior to and during flights and the provision of contingency plans. It is suggested that further research is undertaken to address these areas to ensure the continual improvement of animal welfare for livestock undergoing air transport.

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6. Appendices

Images of crates used for transport of livestock by air
All photographs sourced from Flynn *et al.* (2014)

Layout of single and double tiered crates. Note the space between crates down the centre of the hold. This area was identified as "Hot Spots", where air flow and therefore heat flux would be lower.

Distance between crates and fuselage wall of the main hold. Exhaust vents run down the hold near the floor.

Positioning of triple tiered crates into the main hold.

Available head space for cattle in the bottom tier of a double tier crate.

Available head space for goats in the bottom tier of a triple tier crate. Air flow through these bottom tiers will be reduced due to the enclosed area.

Internal area of a single tiered crate.

Animals being loaded into a double tiered crate.

Single tier crate

Double tier crate

Triple tier crate

Summary table of mortality investigation reports (MIR)

Report # and time of year	Species and mortality	Stocking rate	Route	Length of journey	Stop over	Stopover time	Location of mortality	Reasons	Stockman onboard
MIR 47(2014) September	Wagyu heifers (218 – 301kg) 6.45% (18/279)	6 – 9 animals/ crate. Load plan stipulated an extra 10% space above min ASEL requirements, but this was not carried out	Melbourne to China	15 hours 11 minutes	Darwin	Not recorded	All cattle died in the 2 single tier crates positioned on lower deck	-Dehydration and suffocation due to inadequate ventilation -Possible obstruction of airflow due to additional containers placed in lower hold	Yes
MIR 48(2014) October	Angus, red angus and hereford heifers (248 to 318 kg) 15.3% (49/321)	Animals loaded on lower deck had an extra 10% space above minimum ASEL requirements	Melbourne to Kazakhstan	17 hours 13 minutes	Singapore	1 hour 17 minutes	In top tiers of double crates on upper deck	-Gas intoxication due to inadequate ventilation. -Concerns on placement of double crates side by side in one block and the impact on air flow -Concerns about humid environment during stop over	Yes
MIR 49(2014) November	Dorper crossbred and merino wethers and rams (15mm wool) 39.3% (44/112)	As per ASEL requirements	Perth to Kuala Lumpur	5 hours 40 minutes	none	NA	Top tiers of 3 double crates in forward cargo hold of lower deck	-No cause of death from post mortem due to decomposition Inadequate ventilation due to malfunction with ventilation system	Not specified
MIR 53(2015) October	Merino wethers (shorn) 7.91% (174/2200)	As per ASEL requirements	Perth to Singapore	5 hours 30 minutes	none	NA	Primarily in the upper tiers (88% in 3rd and 12% in 2nd tier of triple crates) Crates located in the forward main deck	-Fatal heat prostration (heat stroke) and air circulation failure due to inadequate ventilation. Most likely resulting from an underperforming air conditioning pack -Live sheep were showing signs of heat stress and dehydration	Yes but not present in cargo area
MIR 59(2016) August	Merino rams and wethers 18.66% (125/670) Slaughter goats 4.8% (48/1000) Breeding goats	As per ASEL requirements Animals sorted into separate lines that were penned separately	Sydney to Malaysia (Kuala Lumpur)	7 hours 27 minutes to stop over 2 hours 7 minutes to Kota Kinabalu	East Malaysia (Kota Kinabalu)	5 hours 22 minutes	Primarily in top and middle tiers of triple tier crates on main deck	-Pulmonary failure with congested lung tissue. Bodies had rigor mortis indicating death a number of hours before. Cause of death inadequate ventilation during flight and problems with starting ventilation system during stop over with humid environment. -Live animals were showing signs of dehydration	No