AVA Submission:

A short review of space allocation on live export ships and body temperature regulation in sheep

May 2018

Submission from the Australian Veterinary Association Ltd

www.ava.com.au

AUSTRALIAN VETERINARY ASSOCIATION

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About us

The Australian Veterinary Association is the national organisation representing veterinarians in Australia. Our 9,500 members come from all fields within the veterinary profession. Clinical practitioners work with companion animals, horses, farm animals including cattle and sheep, and wildlife. Government veterinarians work with our animal health, public health and quarantine systems while other members work in industry for pharmaceutical and other commercial enterprises. We have members who work in research and teaching in a range of scientific disciplines. Veterinary students are also members of the Association.

Executive summary

The primary guiding principle of the *Australian Standards for the Export of Livestock (Version 2.3) 2011 and Australian Position Statement on the Export of Livestock* (ASEL, 2011) states 'the health and welfare of animals is a primary consideration at all stages of the livestock export chain.' It is essential that the consideration of animal health and welfare and the associated requirements and regulations be science-based.

Animal welfare science has advanced significantly since the beginning of the live export trade. As part of the 2018-2019 ASEL review the AVA will provide comprehensive submissions to address the range of animal welfare issues associated with the export of livestock, with reference to current animal welfare science.

The following review presents an evaluation of the current science as it relates specifically to the export of live sheep to the Middle East in the northern hemisphere summer. The review details some relevant background information on the export of live sheep to the Middle East. It then addresses the relevant science as it relates to the core issues of space allocation and body temperature regulation and heat stress in sheep.

Importantly, animal welfare science relates to the physical and mental state of an animal and recognises the sentience of animals. Changes that are made should be based on ensuring the physical and mental welfare needs of exported animals throughout the entire journey, and not solely restricted to addressing mortalities.

Recommendations

The key recommendations from this short review are:

- Trucks delivering sheep for export must be weighed dockside at embarkation, so total sheep weight can be allocated to total deck area. No more sheep should be loaded onto the ship when total space has been allocated.
- Aggregated voyage data, including key animal welfare indicators, can and must be measured and collated using up-to-date technologies such as blockchain, with that data made available to scientists so future research topics are not only based on sheep mortalities, but also causes of morbidity during each voyage. Sheep must be individually identified with electronic ear tags to assist with data collection and for traceability.
- Space allocation per animal must be based on allometric principles and increased by at least 30% for sheep that weigh 40 to 60 kg (based on a k-value of 0.033). The typical sheep sent to the Middle East is an adult Merino wether in this weight range. This increase in space (k = 0.033) is the minimum amount needed to alleviate adverse welfare outcomes, and must be implemented across all body weights and all months of the year.
- Irrespective of stocking density, thermoregulatory physiology indicates that sheep on live export voyages to the Middle East during May to October will remain susceptible to heat stress and die due to the expected extreme climatic conditions during this time. Accordingly, voyages carrying live sheep to the Middle East during May to October cannot be recommended.

Table of Contents

List of abbreviations

AAV	Australian Government Accredited Veterinarian
AAWSG-Sheep	Australian Animal Welfare Standards and Guidelines for Sheep
AAWSGLTL	Australian Animal Welfare Standards and Guidelines for the Land Transport of Livestock
ASEL	Australian Standards for the Export of Livestock
AVA	Australian Veterinary Association
BCS	body condition score
DAWR	Department of Agriculture and Water Resources
DBT	dry bulb temperature
ESCAS	Exporter Supply Chain Assurance System
FAO	Food and Agriculture Organisation of the United Nations
HSRA	Heat Stress Risk Assessment (HotStuff)
HST	heat stress threshold
LEAP	Livestock Export Accreditation Program
MIR	Mortality Investigation Report
ML	mortality limit
OIE	World Organisation for Animal Health
PAT	pen air turnover
PS	Panting Score
RH	relative humidity
SEM	standard error of the mean
UAE	United Arab Emirates
WBT	wet bulb temperature

Introduction

The primary guiding principle of the *Australian Position Statement on the Export of Livestock* (ASEL, 2011) states 'the health and welfare of animals is a primary consideration at all stages of the livestock export chain.' It is essential that the consideration of animal health and welfare and the associated requirements and regulations be science-based and every opportunity is taken to improve the quality of animal health and welfare. In this regard, this review has considered evidence-based scientific literature and industry-funded reports, and takes no account of economic, regulatory or other factors associated with the live animal export industry.

Animal welfare science has advanced significantly since the beginning of the live export trade. The following review presents an evaluation of the current science as it relates specifically to the export of live sheep to the Middle East in the northern hemisphere summer. The review details some relevant background information on the export of live sheep to the Middle East. It then addresses the relevant science as it relates to the core issues of space allocation and body temperature regulation and heat stress in sheep. Importantly, animal welfare science relates to the physical and mental state of an animal, and changes that are made should be based on ensuring the physical and mental welfare of exported animals throughout the entire journey, and not solely restricted to addressing mortalities.

1.0 Background information on live sheep export to the Middle East

Export of live sheep to the Middle East from Australia first began in the 1960s, with mass-scale shipments of up to 125,000 sheep commencing by the mid-1970s. The first standards, which covered pen design and ventilation, were set by the Commonwealth Department of Shipping and Transport's Livestock Advisory Committee. In the 1960s these were expanded to cover stocking densities and feed and water allowances. In 1997, the livestock export industry developed its own standards which formed part of the industry's self-regulated Livestock Export Accreditation Program (LEAP).

However, following the MV Cormo Express disaster in 2003 where nearly 6000 sheep died, the Keniry Livestock Export Review[1] recommended that the Federal Government should regulate the live animal export industry through an "Australian Code for the Export of Livestock". In response, in 2004 the LEAP standards were modified to form version 1 of the Australian Standards for the Export of Livestock (ASEL).

Compliance with the ASEL is a condition of an export licence, administered by the Australian Government Department of Agriculture and Water Resources (DAWR). Prior to loading on to the vessel, the Australian Animal Welfare Standards and Guidelines for (a) sheep and (b) for land transport[2] also apply, *where these have been regulated under state animal welfare legislation* (this has not yet occurred in Western Australia).

Since 2004, the ASEL have been subject to minor modifications, most recently in 2011.[3] In 2013[4] a substantive review was undertaken and a new version of ASEL was drafted but was not progressed due to a lack of consensus on its contents and a change of government prior to its scheduled release for public consultation.

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[1] The Keniry Review is at http://www.agriculture.gov.au/SiteCollectionDocuments/animal-plant/animal-welfare/trade/export-transport-review/keniry_review_jan_04.pdf

[2] Australian Animal Welfare Standards and Guidelines for (a) Sheep are at http://www.animalwelfarestandards.net.au/files/2011/01/Sheep-Standards-and-Guidelines-for-Endorsed-Jan-2016-061017.pdf and (b) Land Transport of Livestock are at http://www.animalwelfarestandards.net.au/files/2015/12/Land-transport-of-livestock-Standards-and-Guidelines-Version-1.-1-21-September-2012.pdf

[3] The Farmer Review is at http://www.agriculture.gov.au/Style%20Library/Images/DAFF/__data/assets/pdffile/0007/2401693/indep-review-aust-livestock-export-trade.pdf

[4] A review of the Australian Standards for the Export of Livestock is at http://www.agriculture.gov.au/Style%20Library/Images/DAFF/__data/assets/pdffile/0010/2389186/review-of-asel-and-lesag-final-report.pdf

The current version of the ASEL (version 2.3 2011)[5] applies to sheep, cattle, goats, buffalo, camelids and deer and is currently under review by a five-member Technical Advisory Committee[6]. This Committee regularly liaises with a Reference Group consisting of industry[7] and animal welfare[8] bodies and will take submissions from any and all interested parties in three stages in 2018 and 2019. In light of recent footage aired by the television program 60 Minutes[9] on 8 April 2018, the interest has focused on the shipping of Australian sheep to the Middle East, particularly in the hotter months of the northern hemisphere, which is the focus of the current review.

There is a myriad of health and welfare issues that must be considered during the preparation and transport of livestock for live animal export by sea or air. The ASEL cover:

- sourcing and on-farm preparation of livestock
- land transport of livestock for export
- management of livestock in registered premises
- vessel preparation and loading
- on-board management of livestock, and
- air transport of livestock

in an attempt to reduce morbidity, and mortality of exported livestock.

There is cumulative stress over this extended period including transportation and loading stresses, high-stocking densities, exposure to loud noise, human handling, changes in day length and light intensity and a different climatic zone (**Figure 1**) (Phillips and Santurtun 2013). Sheep travelling from Portland and Adelaide face an extra five or six days on board ship.

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[5] Full Australian Standards for the Export of Livestock is at http://www.agriculture.gov.au/SiteCollectionDocuments/animal-plant/animal-welfare/standards/version2-3/australian-standards-v2.3.pdf

[6] The Technical Advisory Committee for the current review of ASEL consists of Dr Chris Back, Dr Theresa Collins, Dr Hugh Millar, Mr Keith Shiell and Mr Russell Phillips and their expertise is at http://www.agriculture.gov.au/animal/welfare/export-trade/review-asel/tac-review-asel.

[7] Australian Livestock Exporters' Council, LiveCorp, Australian Maritime Safety Authority, Australian Dairy Farmers, Cattle Council of Australia, Sheep Producers Australia, Australian Buffalo Industry Council, Australian Alpaca Association

[8] Australian Veterinary Association, Royal Society for the Prevention of Cruelty to Animals

[9] 60 Minutes footage: Part 1 https://www.9now.com.au/60-minutes/2018/clip-cjfqah0td003u0qs8g3pgsbl8 and Part 2 https://www.9now.com.au/60-minutes/2018/clip-cjfqb31p400410rqhq2vf9dmi

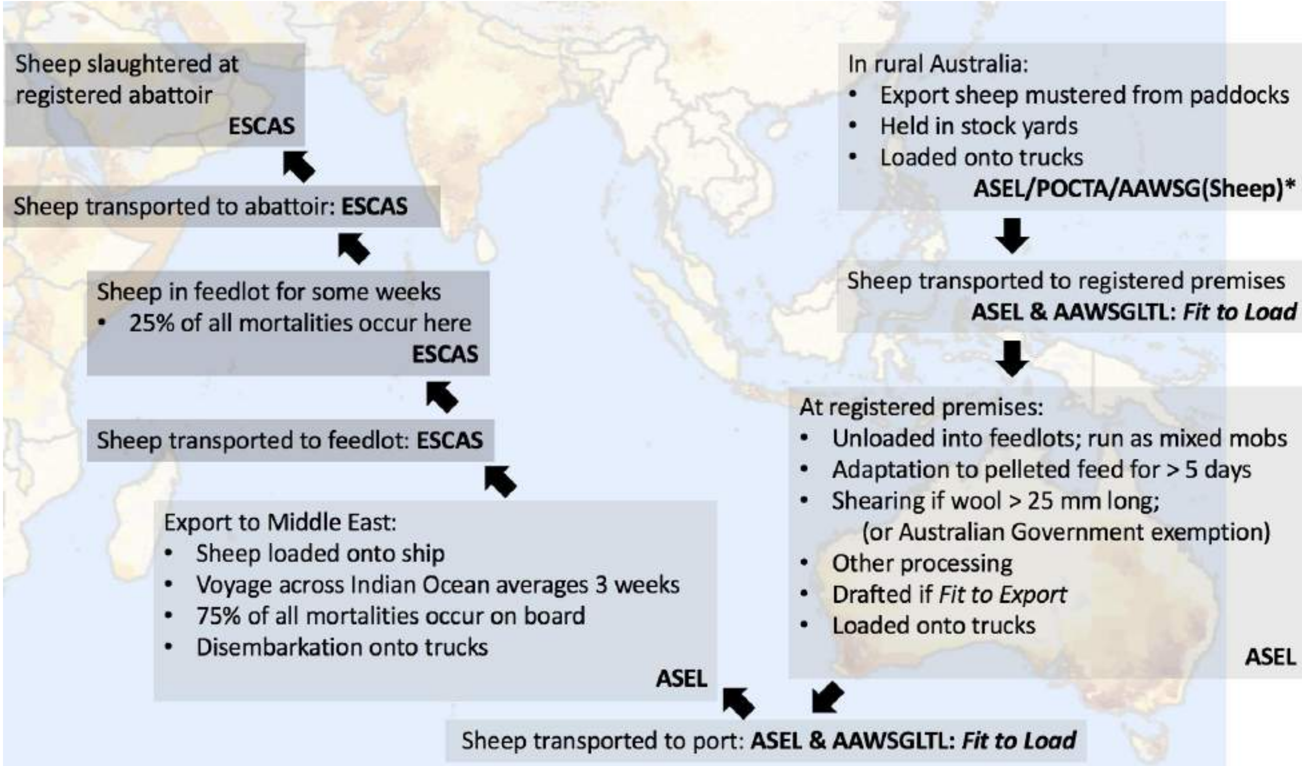


Figure 1. ***The transport process of live sheep from rural Australia to the Middle East. Different legislation covers sheep at different times of their journey, including State Government-dependent Prevention of Cruelty to Animals Acts (POCTA) which may or may not include the Australian Animal Welfare Standards and Guidelines for Sheep (AAWSG-Sheep)(*AAWSG-Sheep not included in Western Australian legislation); Australian Animal Welfare Standards and Guidelines for Land Transport of Livestock (AAWSGLTL); the Australian Standards for the Export of Livestock (ASEL); and the Exporter Supply Chain Assurance System (ESCAS). Note that sheep sourced from Adelaide and Portland can face an extra 5-6 days on board ship.***

Differences in mortality rates of sheep over time and location on any ship may be due to a variety of factors including, but not limited to, variations in age, weight, sex and breed of sheep, property of origin, port of loading, water access, nutritional status, space allocation, deck location, pen size, ventilation rates, air quality, depth and consistency of bedding quality/faecal pad consistency, day-to-day climate variation, exposure to solar radiation, sea water temperature, vessel movement during rough weather, pre-existing disease, exposure to pathogens and a multitude of other factors. The majority of these are not considered in this brief review.

The *Australian Position Statement on the Export of Livestock* (ASEL, 2011) and the ASEL standards take into account the relevant World Organisation for Animal Health (OIE) guidelines for transport of animals by sea; these require space for animals to comfortably rest, move and access food and water, and that animals should not be transported at all during conditions of extreme heat and cold.

1.1 Data collation and availability

Every six months, under the terms of the Australian Meat and Livestock Industry Act 1997, the Federal Minister for Agriculture tables a report before each House of Parliament that summarises all voyages that have carried livestock from Australia in the preceding 6 months.[10] Each report contains information on the date and duration of voyage, export licence holder, embarkation ports, disembarkation ports, numbers of different species on ship and mortalities.

Table 1 shows a summary of this information for 2010 to 2017.

Table 1. ***A summary of livestock numbers shipped annually from Australia, and associated deaths that occur during loading, shipping and disembarkation*** *(source: http://www.agriculture.gov.au/export/controlled-goods/live-animals/live-animal-export-statistics/reports-to-parliament).*

All Voyages	2010	2011	2012	2013	2014	2015	2016	2017
Number of Voyages	286	182	203	233	347	350	314	275
Cattle Exported	**848,265**	**718,025**	**626,504**	**776,583**	**1,307,579**	**1,325,527**	**1,109,513**	**889,525**
Cattle Mortalities	1,192	1,067	681	830	1,638	1,451	1,485	923
Total Mortality Rate	0.14%	0.15%	0.11%	0.11%	0.12%	0.11%	0.13%	0.10%
Sheep Exported	**3,001,976**	**2,592,028**	**2,199,999**	**1,897,270**	**2,249,643**	**2,007,549**	**1,759,340**	**1,741,314**
Sheep Mortalities	26,825	19,212	19,407	14,067	16,147	12,403	14,094	12,377
Total Mortality Rate	0.89%	0.74%	0.88%	0.74%	0.71%	0.62%	0.80%	0.71%
Buffalo Exported	**2,358**	**734**	**831**	**798**	**4,068**	**5,122**	**4,230**	**7,214**
Buffalo Mortalities	1	9	1	1	19	11	22	40
Total Mortality Rate	0.04%	1.22%	0.12%	0.13%	0.47%	0.22%	0.52%	0.55%
Goats Exported	**1,885**	**0**	**1,245**	**1,080**	**850**	**1,000**	**0**	**0**
Goats Mortalities	13	0	1	0	1	0	0	0
Total Mortality Rate	0.69%	0%	0.08%	0%	0.11%	0%	0%	0%

Whilst total annual sheep mortalities have declined in number over the period in question, the annual sheep mortality rate (%) has remained constant for the same period because fewer sheep are being exported each year.

[10] Six-monthly reports tabled in Parliament are at http://www.agriculture.gov.au/export/controlled-goods/live-animals/live-animal-export-statistics/reports-to-parliament

Every year, Meat and Livestock Australia publish a performance report for the national livestock export industry – sheep, cattle and goat transport, which summarises the industry performance for these species in terms of mortality levels of animals exported by sea and air from Australia in the year in question. Data is obtained from the ship Masters' Reports, as well as from loading, voyage and discharge reports. The latest version of the performance report (2016), indicates the sheep annual total mortality rate has not declined since 2002 (Norman 2017).

The ASEL require that when voyage mortality levels reach a certain threshold, DAWR must be advised within 12 hours and a report provided that includes details of the mortalities, factors that may have contributed to the deaths, the current location of the vessel, its destination and estimated time of arrival. The threshold varies depending on livestock species and duration of voyage but is set arbitrarily at 2% for all sheep voyages (**Figure 2**).

> The Australian standards for the export of livestock (ASEL) defines a reportable mortality level by species on a voyage or air journey as, the percentages listed below or 3 animals, whichever is the greater number of animals
>
> - Sheep and goats: 2%
> - Cattle and buffalo on a voyage less than 10 days: 0.5%
> - Cattle and buffalo on a voyage more than 10 days: 1%
> - Camelids: 2%
> - Deer: 2%
>
> The on-board stockman or Australian Government Accredited Veterinarian, if one accompanies the voyage, must immediately report a reportable mortality level to the Department of Agriculture and Water Resources.
>
> The department undertakes an investigation into livestock reportable mortality incidents to try to determine the cause of the mortalities and suggest future corrective action.

Figure 2. ***Reportable mortality level by species on a sea voyage or air journey*** *(source http://www.agriculture.gov.au/export/controlled-goods/live-animals/livestock/regulatory-framework/compliance-investigations/investigations-mortalities).*

Following completion of the voyage, DAWR undertakes a desktop investigation into the incident based on the daily voyage reports and other information provided by the export company. These Mortality Investigation Reports (MIRs) are published on the DAWR website as they become available; this may be several months after the notifiable incident occurred.[11] Investigations are not conducted for voyages with above average mortality rates unless they include consignments that reach the reportable level.

Health of live sheep on any ship has not been considered for the purpose of this review as morbidity information is not recorded on the DAWR website alongside mortality figures, although this information is potentially recorded in the daily voyage report completed by the accompanying Australian Government Approved Veterinarian (known as an AAV) (Appendix 5.1, ASEL version 2.3, 2011.[12]) Nor is health information reported in the industry-generated national livestock export industry sheep, cattle and goat transport performance reports (Norman 2016, Norman 2017).

A recommendation of the Australian Veterinary Association is that aggregated voyage data, including key animal welfare indicators, can and must be measured and collated using up-to-date technologies such as blockchain, and that data made available to scientists so future research topics are not only based on sheep mortalities, but also causes of morbidity during each voyage.

[11] Mortality Investigation Reports are at http://www.agriculture.gov.au/export/controlled-goods/live-animals/livestock/regulatory-framework/compliance-investigations/investigations-mortalities

[12] Full Australian Standards for the Export of Livestock is at http://www.agriculture.gov.au/SiteCollectionDocuments/animal-plant/animal-welfare/standards/version2-3/australian-standards-v2.3.pdf

1.2 The Australian and Middle Eastern ports used in live sheep export

All sheep exported live by sea from Australia in 2016, using the most recent figures available, were loaded at Fremantle WA (89.5%), Adelaide SA (8.3%) or Portland Vic (2.2%)(Norman 2017). No shipments of sheep have been loaded at Portland since November 2017.

The five most frequented ports of arrival in the Middle East by Australian live sheep export ships historically have been in the countries of Kuwait, Bahrain, Qatar, UAE and Oman. The main importing countries in 2016 were Kuwait (36%), Qatar (30%) and UAE (9%), followed by Jordan, Israel and Oman (Norman 2017), whereas in 2015 they were Kuwait (36%), Qatar (24%) and Bahrain (16%) (Norman 2016). No sheep are currently being exported to Saudi Arabia or Bahrain.

The six-monthly voyage summaries indicate that ships tend to disembark sheep from west to east, namely Kuwait, Manama (Bahrain), Doha (Qatar), Jebel Ali (UAE) then Muscat (Oman). This order of port disembarkation increases the time that animals are on any ship, however, Kuwait has a lower relative humidity level compared with other ports in the region (Maunsell-Australia 2003) and this allows reduction of stocking rates on ships before they head to the more humid ports further east.

In the 2005 collation of census data of where sheep are farmed worldwide by the Food and Agriculture Organisation of the United Nations (the "FAO"), these ports all lie in regions designated "unsuitable for ruminants" (see **Figure 3**).

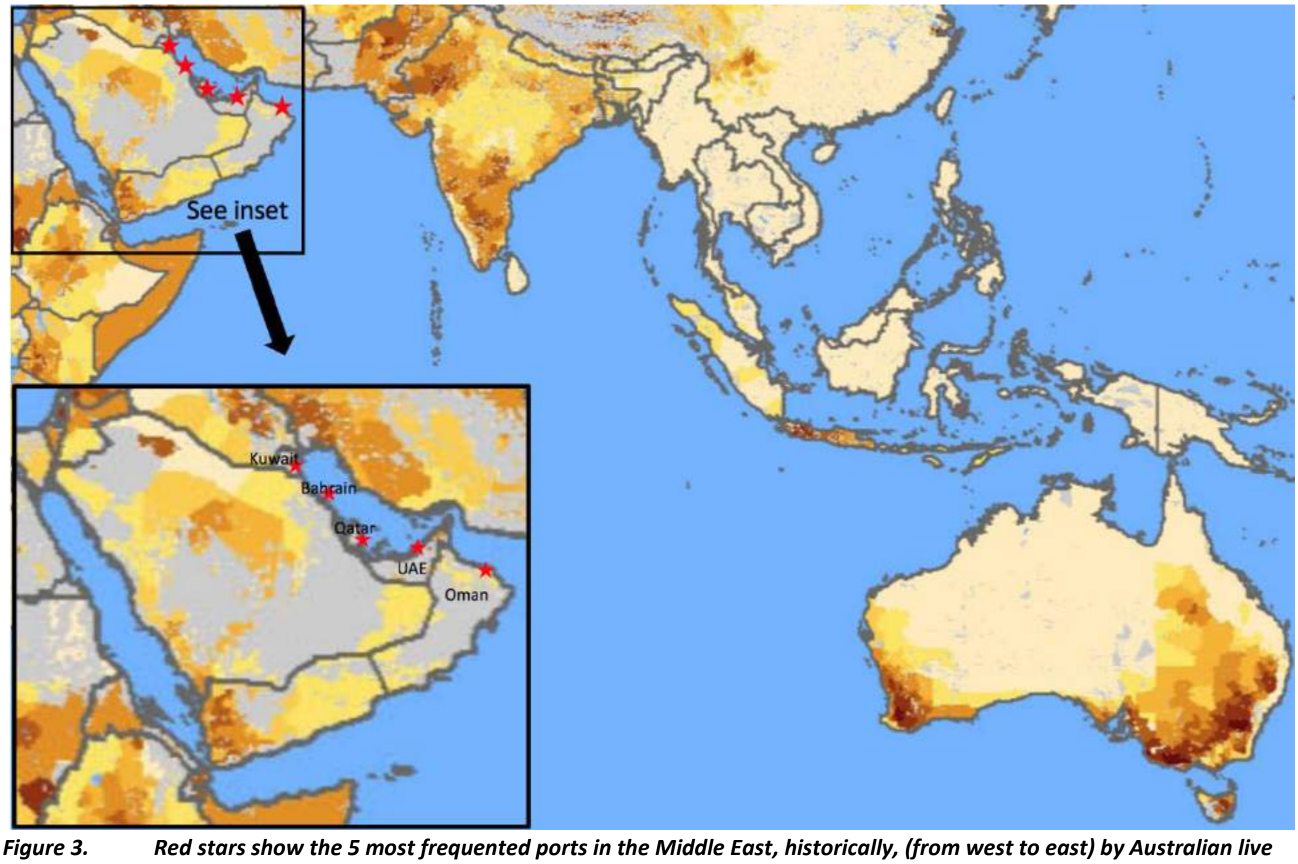


Figure 3. ***Red stars show the 5 most frequented ports in the Middle East, historically, (from west to east) by Australian live sheep export ships: Kuwait, Bahrain, Qatar, UAE; and Oman. Light yellow to dark brown areas indicate low to high sheep densities respectively, grey shading indicates land unsuitable for ruminants*** *(source: http://www.fao.org/ag/againfo/resources/en/glw/GLW_dens.html on 23/4/18).*

1.3 Live sheep voyages to the Middle East

Records[13] show live sheep are shipped from Australia to the Middle East in all months of the year (see **Figure 4** and **Appendix A**, **Table A.1** showing number of shipments each month, each year, between 2005 and 2017). Between 2005 and 2017, there were a total of 509 voyages that carried at least 15,000 sheep on any ship.

Of those, 51 (10%) shipments had ≥ 1.5% sheep mortality rate. Mortality investigations occurred on only 12 of these voyages. The average (± SEM) voyage duration of these voyages from Australia to the Middle East was 23.8 ± 0.7 days (range 15-36 days, n=51; see **Appendix B**).

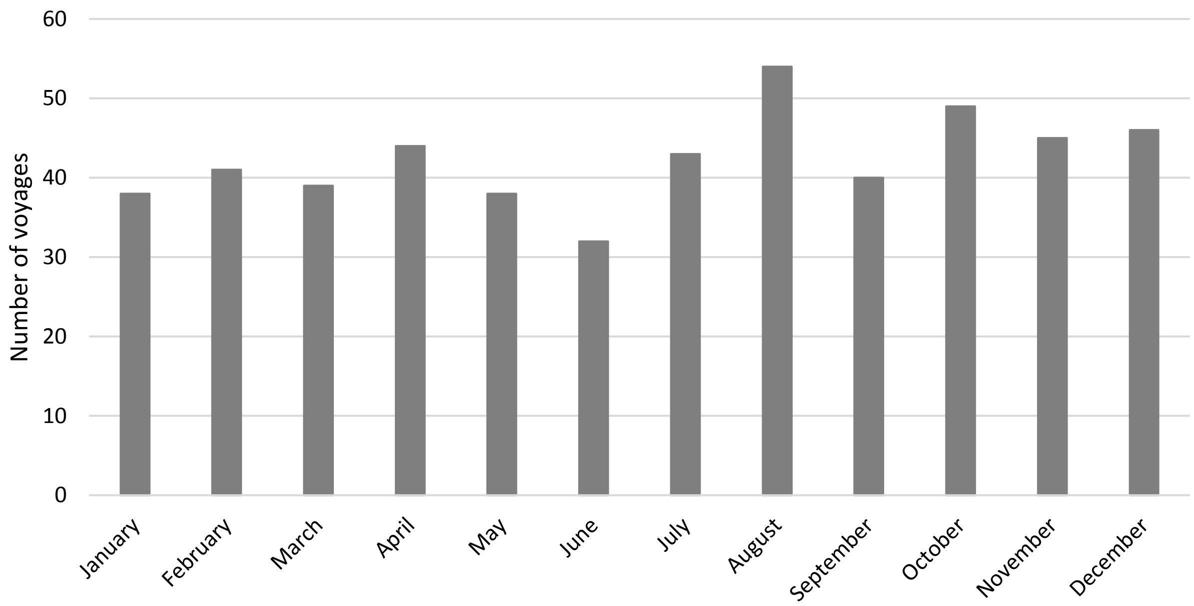


Figure 4. ***Total number of shipments (n=509) from Australia to the Middle East carrying > 15,000 live sheep between 2005 and 2017. Month indicates time voyage commenced.***

1.4 Seasonal mortality pattern

Mortalities in sheep being exported to the Middle East are more likely to occur when voyages commence in the months of May to October (see **Figure 5**) which corresponds to the hotter months in the region. The sharp rise in sheep deaths in voyages in August corresponds with extreme summer temperatures and increasing relative humidity in the region in August and September (see **Figure 6**). The DAWR Mortality Investigation Reports corroborate that heat stress is a major cause of mortality in sheep during these months (see **Appendix B**).

[13] Six-monthly reports tabled in Parliament are at http://www.agriculture.gov.au/export/controlled-goods/live-animals/live-animal-export-statistics/reports-to-parliament

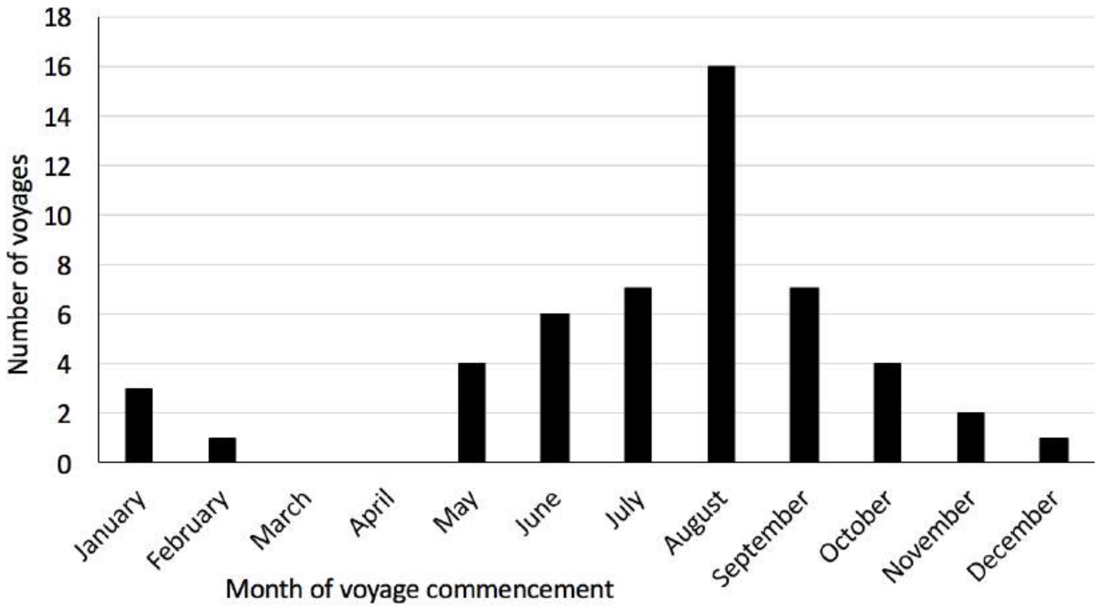


Figure 5. ***Number of voyages (n=51), by month of voyage commencement, when there were > 15,000 sheep on the ship from Australia to the Middle East between 2005 and 2017 and total sheep mortality rates were ≥ 1.5%.***

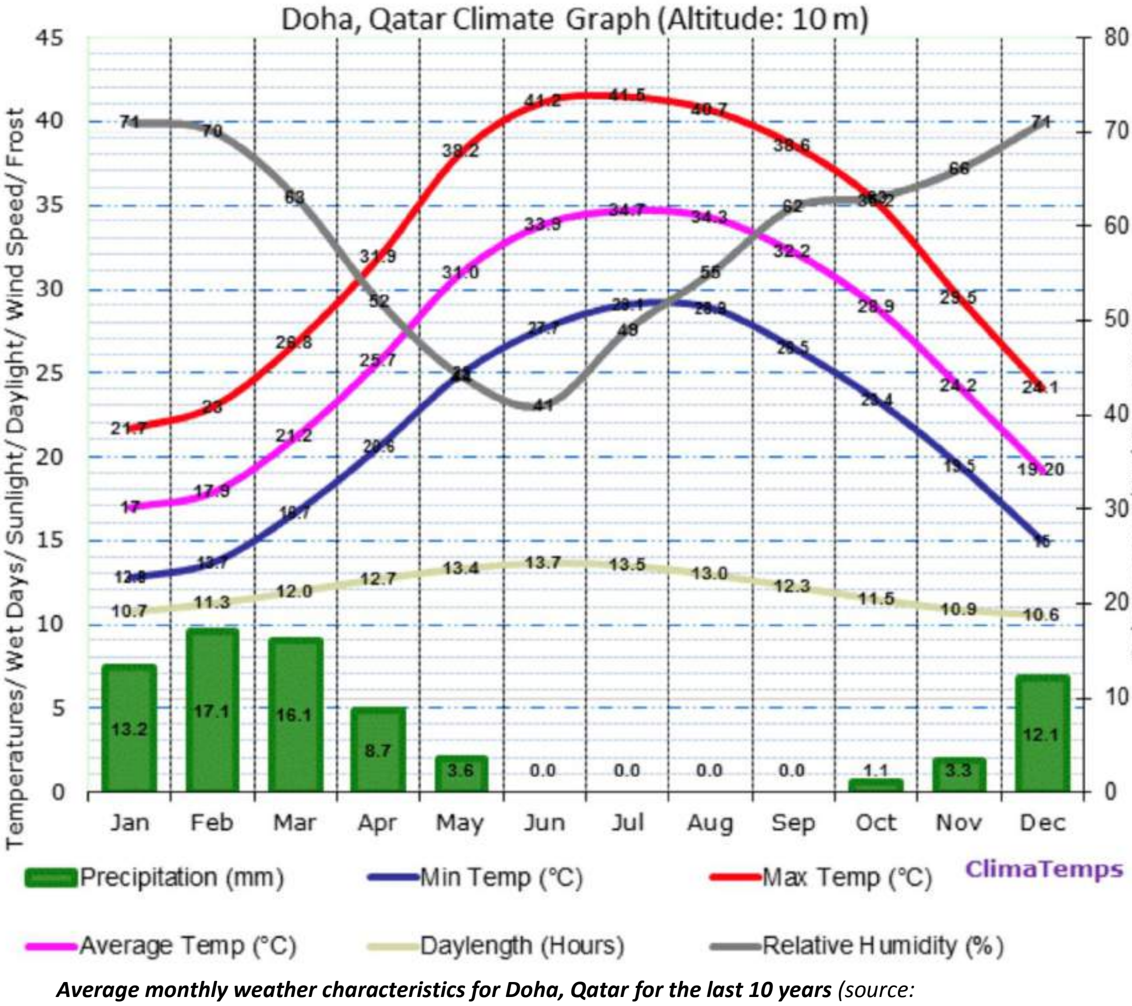


Figure 6. ***Average monthly weather characteristics for Doha, Qatar for the last 10 years*** *(source: http://www.qatar.climatemps.com/graph.php on 20/4/2018).*

The five-year average of total mortality rate of sheep shipped from Fremantle to the Middle East/North Africa shows mortality rates for sheep exported to the region are higher when sheep are loaded in May to October (see **Figure 7**) (Norman 2017). There is an "enduring stability of seasonal difference" of mortality rate in all classes of sheep over time (Norman 2017).

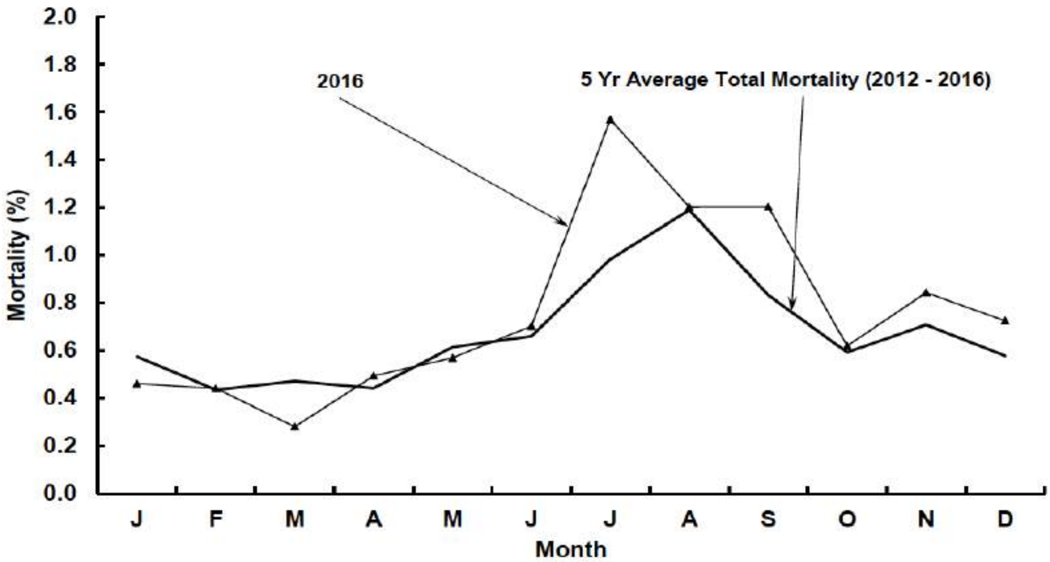


Figure 7. ***Monthly mortality rates in all classes of sheep shipped from Fremantle to the Middle East/North Africa in 2016 and the five year monthly averages (2012-2016). Taken from (Norman 2017).***

Figure 8 shows how ram mortality rates have been consistently higher than the average created by all classes (above) over many years (Norman 2017).

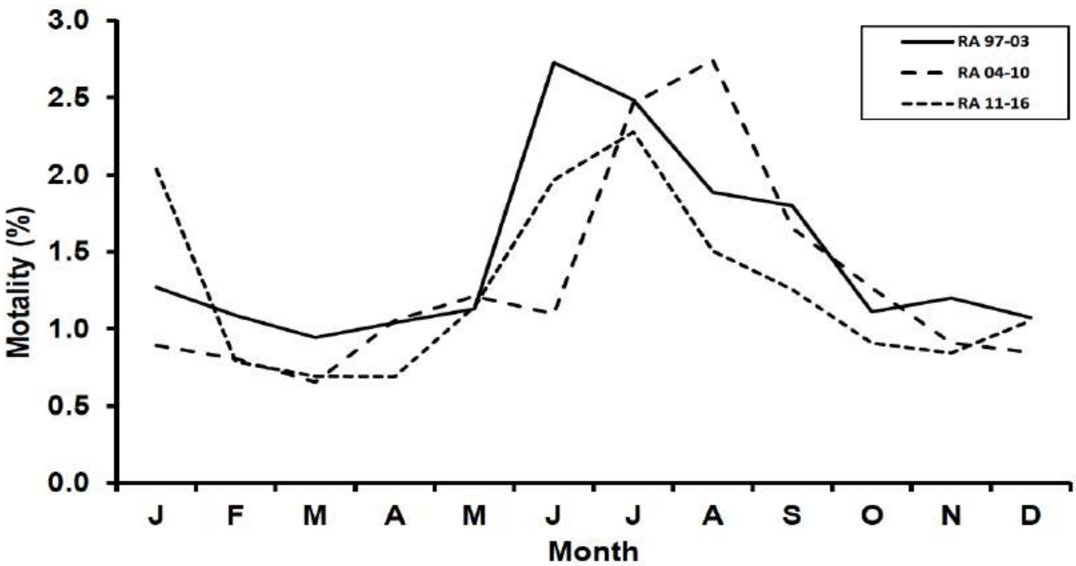


Figure 8. ***Average monthly mortality rate for adult rams over 3 time periods (see legend; RA = ram adults) shows the seasonal differences in mortalities is a long-term trend. Taken from (Norman 2017).***

Sheep die *en route* to the Middle East every summer. Industry annual reviews acknowledge that ongoing research to improve live exports should service "the trade in a way that compensates for the peak mortality of the year" (Norman 2016, Norman 2017). However, there is little evidence that industry research has had an impact on reducing average mortality rates or preventing high mortality incidents in the past decade (see **Table 1**).

2.0 Core Issues for sheep being shipped to the Middle East

The two core issues relevant to sheep during shipping to the Middle East in the months of May to October are (a) space allocation on ships and (b) body temperature regulation. Space allocation during transport is one of the most important aspects influencing animal welfare (Petherick and Phillips 2009) whilst body temperature regulation is an innate physiological requirement for normal organ function in mammals (Klein 2013).

2.1 Space allocation for sheep travelling on ships

Space allocation will vary for animals undertaking short-term (hours to days) and long-term (days to weeks) transport on land and sea and in intensive housing (weeks to months). Attempts have been made to calculate the area required under these different conditions by an animal while standing and recumbent using allometric equations (Petherick 2007). Space is important for livestock during transport as it allows them to perform normal behaviours, depending on the length of transport and the amount of space available. As duration of transport increases, space allocation must increase. For example, sheep transported for three hours on a truck can be loaded with a lower space allocation than sheep being shipped to the Middle East over a three-week period, as the latter must be able to eat, drink and rest, adjust their position and move around and interact with conspecifics to optimise health and welfare.

Space allocation can be estimated measuring the length and width of an animal and is described in terms of area (A, measured in square metres or m^2). However, it is difficult to perform these measurements under field conditions. Alternatively, the body weight of an animal can be used to calculate the volume of an animal: body weight raised to the power of 0.66 provides a measurement of the area an individual animal occupies, and when multiplied by a constant (*k*), provides a method of two-dimensional space allocation across different species for different postures (Petherick 2007, Petherick and Phillips 2009).

Accordingly, the appropriate formula for determining the space allocation for an animal is determined as:

$$A\ (m^2) = k \times W^{0.66}$$

(*Source: Petherick 2007 and Petherick and Phillips 2009*)

It is also possible to use body weight raised to the power of 0.33 to determine one-dimensional or linear requirements such as feed and water trough lengths (Petherick and Phillips 2009). However, the narrow scope of this review precludes further discussion of water and feed trough length allowance. The appropriate formula for such determinations being:

$$\text{Length (m)} = k \times W^{0.33}$$

(Source: Petherick and Phillips 2009)

In addition to the mathematical estimation of space allowance, other factors such as shape of animal, wool length and social hierarchy within the animal group, as well as environmental factors such as shape of the pen/yard, feed and water trough space, bedding, ceiling height, ventilation, temperature and humidity must also be considered.

In an attempt to quantify initial calculations of space allocation for transport, estimates have been made for animals in both standing and lying postures. Animals may lie with their legs tucked beneath the body (as camelids normally do), semi-laterally with their legs against the body (as sheep, cattle and goats normally do), or laterally with legs extended (e.g. livestock sun-baking to maximise vitamin D production).

In addition, animals also require some space to transition from lying to standing (and *vice versa*) as they extend their hind legs first, and tilt their head forward, before straightening their front legs. Animals in a moving vehicle, such as a truck or a ship will spread their legs to brace and maintain balance.

The *k*-value used as part of the space allocation equation above, can be used to compare space allocation for different postures, independent of animal body weight (see **Table 2**). For land transport journeys, where animals can remain standing and do not need to move around, eat or drink, the *k*-value is 0.020 (Petherick and Phillips 2009). In such a case, animals at this density would be tightly packed and have difficulty lying down and standing up.

A lower *k*-value than 0.020 results in poor welfare outcomes as the space allocation does not allow balanced standing, and would result in loss of balance, muscle damage, fatigue and stress over time (Petherick and Phillips 2009). However, higher space allocations for land transport journeys can exacerbate the impacts of vehicular motion, resulting in poor welfare of animals. For sea journeys, sheep travelling for three to four weeks need to be able to lie down to rest and to move around the pen to access feed and water troughs (Petherick and Phillips 2009). Furthermore, the motion of a ship at sea has a very different profile than vehicular motion and maintaining balance during rough weather is difficult to achieve when standing.

Space allowances for sheep undertaking longer term transportation such as sea voyages of three to four weeks duration require a minimum *k*-value ≥ 0.033 to reduce risks of adverse welfare outcomes (Petherick and Phillips 2009).

Table 2. ***Space allocation for different postures displayed by livestock during transport, where area, A (m^2) = k x $W^{0.66}$ and W is body weight in kg, and k is a constant in the equation that defines the space allowance for animals exhibiting various postures (Petherick 2007) (Petherick and Phillips 2009).***

Posture of animal	***k*-value**
Standing (short-term transport) or lying on sternum with legs folded beneath	0.020
Lying semi-laterally (legs folded against body)	0.025
All stock lying simultaneously (without necessarily allowing ability to rise or free movement to feed/water)	0.027
Threshold below which there are consistent adverse effects on welfare outcomes in intensive housing	***0.033***
Able to move between standing and lying and readily access feed and water (equivalent to lying laterally with legs extended away from body)	0.047

There is conjecture as to whether all sheep in a pen need to lie down simultaneously or whether animals are able to time-share space so that some individuals can lie down while others stand. Literature suggests that there is much variation in the amount of time sheep and beef cattle spend lying down depending on the situation and the time they are observed, but that both species spend a significant proportion of their time lying down (Arnold 1984, Cockram 1991, Kilgour, Uetake et al. 2012). This is likely to be increased in intensive housing conditions, such as on-board ship, where there is no opportunity to forage or graze.

The *k*-value for all animals in a pen to lie tightly packed simultaneously is 0.027 (Petherick and Phillips 2009). For an animal to move between standing and lying, the *k*-value is 0.047, but because not all animals lie down or stand up simultaneously, and can share space to manoeuver, the *k*-value is somewhere in between these 2 values when multiple animals share a pen (Petherick 2007, Petherick and Phillips 2009) . Nevertheless, on a three or four-week sea voyage, sheep also require space to move around the pen to access feed and water troughs. A *k*-value ≥ 0.033 will provide sufficient space to achieve both, assuming that some animals will be standing when access to feed and water is required (Petherick and Phillips 2009).

The space allowances in ASEL are not based on allometric principles or empirical evidence (Phillips and Petherick 2014). They are based on 1978 Marine Standards specifications which were incorporated into Requirements for the Carriage of Livestock by Sea in 1981 and have not changed significantly since (see **Figure 9**).

PART B - SHEEP

9. Number of Sheep to be Carried

9.1 The maximum number of sheep to be carried on a ship shall be arrived at from the following table.

Mass of Animal (Kilograms)	Minimum Floor Area per Animal (Square Metres)	Current ASEL minimum pen area (m^2/head)
20 or less	0.24	
35	0.278	0.278
40	0.29	0.290
45	0.304	0.303
50	0.316	0.315
55	0.328	0.338
60	0.34	0.360
65	0.356	0.394
80 or more	0.44	0.502

9.2 For a mass between the points in the table the minimum floor area is to be found by linear interpolation.

Figure 9. ***Extract from Commonwealth Department of Transport Marine Standards Division Specification No. 1/1978, June 1978, Chapter 3 – Livestock Fittings. Taken from Australian Bureau of Animals Health (1981) Sea Transport of Sheep, Commonwealth of Australia, Canberra. Figures in red indicate current ASEL (version 2.3, 2011) minimum pen areas for ease of comparison.***

The assignment of *k*-values in **Table 2**, allows a simpler interpretation across different body weights of the minimum pen area per head for sheep and goats exported by sea in the current ASEL (version 2.3, 2011; Table A4.1.5) as detailed below (see **Table 3**).

Table 3 *Minimum pen area per head for sheep and goats exported by sea according to ASEL (version 2.3, 2011; Table A4.1.5:) with k-values included. Values in red are considered to produce adverse welfare outcomes for intensively housed sheep (Petherick and Phillips 2009).*

	Nov-Apr		May-Oct			Nov-Apr		May-Oct	
Live weight (kg)	**Minimum pen area (m^2/head)**	***k*-value**	**Minimum pen area (m^2/head)**	***k*-value**	**Live weight (kg)**	**Minimum pen area (m^2/head)**	***k*-value**	**Minimum pen area (m^2/head)**	***k*-value**
28	0.261	**0.029**	0.261	**0.029**	**51**	0.320	**0.024**	0.322	**0.024**
29	0.263	**0.028**	0.263	**0.028**	**52**	0.324	**0.024**	0.329	**0.024**
30	0.265	**0.028**	0.265	**0.028**	**53**	0.329	**0.024**	0.337	**0.025**
31	0.268	**0.028**	0.268	**0.028**	**54**	0.333	**0.024**	0.344	**0.025**
32	0.270	**0.027**	0.270	**0.027**	**55**	0.338	**0.024**	0.351	**0.025**
33	0.273	**0.027**	0.273	**0.027**	**56**	0.342	**0.024**	0.357	**0.025**
34	0.275	**0.027**	0.275	**0.027**	**57**	0.347	**0.024**	0.363	**0.025**
35	0.278	**0.027**	0.278	**0.027**	**58**	0.351	**0.024**	0.369	**0.025**
36	0.280	**0.026**	0.280	**0.026**	**59**	0.356	**0.024**	0.375	**0.025**
37	0.283	**0.026**	0.283	**0.026**	**60**	0.360	**0.024**	0.381	**0.026**
38	0.285	**0.026**	0.285	**0.026**	**61**	0.367	**0.024**	0.389	**0.026**
39	0.288	**0.026**	0.288	**0.026**	**62**	0.374	**0.025**	0.398	**0.026**
40	0.290	**0.025**	0.290	**0.025**	**63**	0.380	**0.025**	0.406	**0.026**
41	0.293	**0.025**	0.293	**0.025**	**64**	0.387	**0.025**	0.415	**0.027**
42	0.295	**0.025**	0.295	**0.025**	**65**	0.394	**0.025**	0.423	**0.027**
43	0.298	**0.025**	0.298	**0.025**	**66**	0.401	**0.025**	0.432	**0.027**
44	0.300	**0.025**	0.300	**0.025**	**67**	0.408	**0.025**	0.441	**0.027**
45	0.303	**0.025**	0.303	**0.025**	**68**	0.415	**0.026**	0.450	**0.028**
46	0.305	**0.024**	0.305	**0.024**	**69**	0.422	**0.026**	0.459	**0.028**
47	0.308	**0.024**	0.308	**0.024**	**70**	0.429	**0.026**	0.468	**0.028**
48	0.310	**0.024**	0.310	**0.024**	**75**	0.465	**0.027**	0.515	**0.030**
49	0.313	**0.024**	0.313	**0.024**	**80**	0.502	**0.028**	0.563	**0.031**
50	0.315	**0.024**	0.315	**0.024**	**90**	0.575	**0.030**	0.658	**0.034**

In particular:

- Sheep between 28 and 61 kg have a stepwise reduction in *k*-value ranging from 0.029 to 0.024 which makes some allowance for weight gain in younger sheep during any voyage.
- Sheep weighing between 28 and 52 kg have the same space allocation for all months of the year.
- Sheep of more than 52 kg have a slightly greater space allowance (*k*-value 0.001-0.004 greater) in May to October, to coincide with the hot Middle Eastern months.
- Heavier sheep are allocated more space, with 62 to 90 kg sheep having *k*-values ranging from 0.025 to 0.030 in the cooler Middle Eastern months of November to April, and *k*-values ranging from 0.026 to 0.034 in the hot months of May to October. Rams have been associated with higher mortality rates over the last 10 years (**Figure 8**) (Norman 2017).
- The only category of polled sheep to receive a space allocation with *k*-value > 0.033, the minimum value considered to reduce adverse welfare outcomes, is 90 kg sheep that travel in May to October.

The *k*-values in the current ASEL (version 2.3, 2011) do not consider:

- sheep breed and shape
- access to trough space
- pen shape
- heavy faecal/urine contamination of faecal pad
- ventilation
- identification of shy feeders
- the need for clear visual inspection of all sheep.

Actual body weights may not be available on a voyage (McCarthy 2005). Any underestimation of body weight when calculating space allocation will reduce the *k*-value and therefore welfare of animals on board ship, so it is essential sheep are weighed accurately prior to embarkation. This could be achieved by, among other ways, trucks being put over a weighbridge *en route* to ship prior to loading.

Recommendation 8 of Farmer's Independent Review of Australia's Livestock Export Trade (2011)[14] states that *"the Australian Government should work with states and territories and industry to implement individual identification of all sheep and goats as soon as practicable"*. The technology is available to electronically identify sheep and would enhance accurate allocation of weighed sheep to pens during embarkation. The State of Victoria has implemented mandatory electronic identification of all sheep and goats born after 1 January 2017, but other states and territories are yet to follow. Individual identification is a requirement for cattle, but not sheep, under the Exporter Supply Chain Assurance System (ESCAS).

Following a reportable mortality incident on a voyage to the Middle East, the standard DAWR requirement of the export company in the next voyage (but not all future voyages) is to load sheep onto all decks of the ship with an extra 10% more space than the ASEL requirements (see **Appendix C** for *k*-values + 10%). Even with this increase, only sheep weighing 75 kg or more in May to October would receive a space allocation ≥ 0.033, the value considered to reduce adverse welfare outcomes (see **Appendix C**). It has also been demonstrated in an industry-funded trial undertaken on commercial voyages to the Middle East that a 10% increase in space allocation makes no difference to sheep welfare (Ferguson and Lea 2013). The likely reason no difference was found is because the space allowance was still too low to avoid adverse outcomes.

If a 17% increase in space allowance is applied to the current ASEL requirements, sheep ≤ 32 kg and sheep ≥ 75 kg all months of the year, and sheep ≥ 68 kg between May and October would receive a space allocation with a k value ≥ 0.033, the value considered to reduce adverse welfare outcomes (see **Appendix C** for *k*-values + 17%). However, most sheep that are exported are between 40 and 60 kg, and a 17% increase will be well below what is required to reduce adverse welfare outcomes.

[14] Recommendation 8 of the Farmer Review (2011) can be found on Page XXV at http://www.agriculture.gov.au/Style%20Library/Images/DAFF/__data/assets/pdffile/0007/2401693/indep-review-aust-livestock-export-trade.pdf

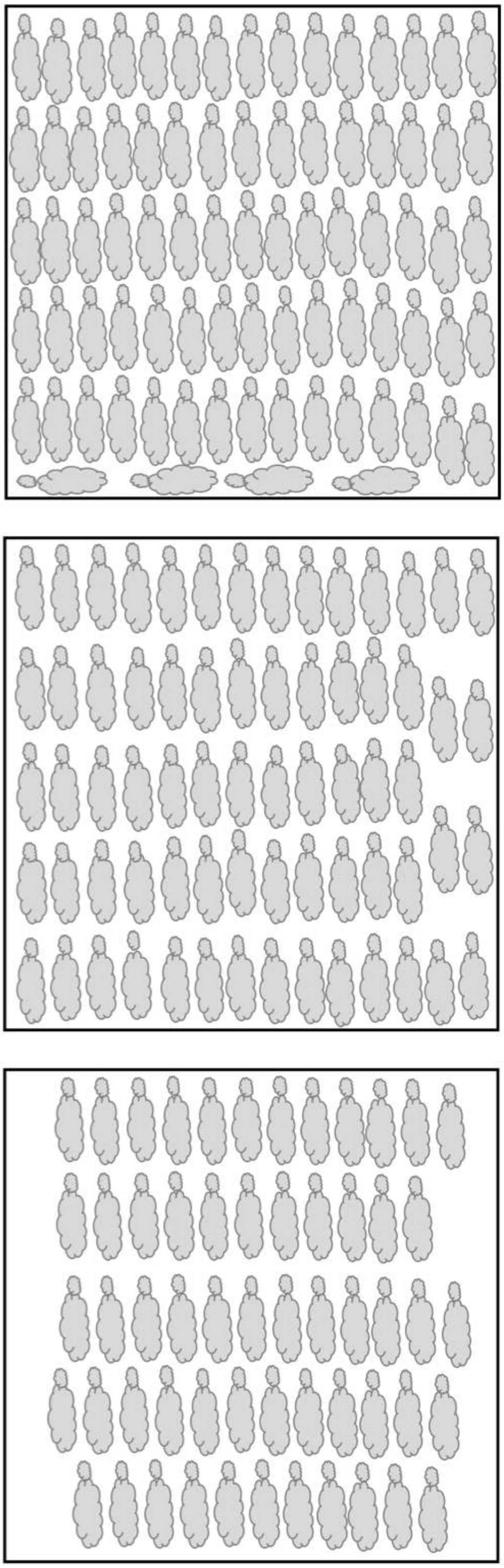
Table 4 shows the percentage increase in space allowance required from current ASEL minimum standards to provide a *k*-value of 0.033, the value considered to alleviate adverse welfare outcomes. A *k*-value ≥ 0.039 is required to provide basic access to feed and water, and allow most sheep to rest simultaneously.

"*Adult wethers are the mainstay of the live sheep export trade, and, by sheer weight of numbers, the largest component of mortalities*" (Norman 2017). In one industry-funded research into heat stress in sheep they used sheep that weighed approximately 53 kg, as they were typical of those being exported from Australia to the Middle East (Stockman, Barnes et al. 2011). In HotStuff 2003, a 50 kg sheep was measured during model development (Maunsell-Australia 2003). To match a *k*-value of 0.033, a sheep that weighs 50 kg requires a 39% increase in space allocation compared with current ASEL standards, at all times of the year, to alleviate adverse welfare outcomes. A 53kg sheep requires 38% increase in November to April, and a 35% increase in May to October. See **Figure 10** for pictorial comparison of *k*-values.

Table 4. ***The percentage increase in space allowance required for different sheep live weights from current ASEL (version 2.3, 2011) minimum standards to provide a k-value of 0.033. Sheep with an average weight of 50 and 53 kg were used in industry-funded research into heat stress in sheep as a typical sheep exported from Australia to the Middle East (Maunsell-Australia 2003).***

	Nov-Apr	**May-Oct**		**Nov-Apr**	**May-Oct**
Live weight (kg)	**% by which ASEL needs to increase so *k*=0.033**	**% by which ASEL needs to increase so *k*=0.033**	**Live weight (kg)**	**% by which ASEL needs to increase so *k*=0.033**	**% by which ASEL needs to increase so *k*=0.033**
28	14%	14%	**51**	38%	37%
29	16%	16%	**52**	38%	36%
30	18%	18%	53	38%	35%
31	19%	19%	**54**	38%	33%
32	20%	20%	**55**	37%	32%
33	21%	21%	**56**	37%	32%
34	23%	23%	**57**	37%	31%
35	24%	24%	**58**	37%	30%
36	25%	25%	**59**	37%	30%
37	26%	26%	**60**	37%	29%
38	28%	28%	**61**	36%	28%
39	29%	29%	**62**	34%	26%
40	30%	30%	**63**	34%	25%
41	31%	31%	**64**	33%	24%
42	32%	32%	**65**	32%	23%
43	33%	33%	**66**	31%	21%
44	34%	34%	**67**	30%	20%
45	34%	34%	**68**	29%	19%
46	35%	35%	**69**	28%	18%
47	36%	36%	**70**	27%	16%
48	37%	37%	**75**	23%	11%
49	38%	38%	**80**	19%	6%
50	39%	39%	**90**	12%	0%

At present, the current minimum standards for space allocation in ASEL (version 2.3, 2011) clearly put sheep at risk of adverse welfare outcomes during live export to the Middle East. Sheep weighing between 40 and 60 kg require at least a 30% increase in space allocation at all times of the year.



(a) 79 x 50 kg sheep
k = 0.024 (ASEL)
Space/head = 0.312 m^2

(b) 68 x 50 kg sheep
k = 0.028 (ASEL+17%)
Space/head = 0.368 m^2

(c) 58 x 50 kg sheep
k = 0.033
Space/head = 0.433 m^2

Figure 10 ***Comparison of sheep weighing 50 kg in a 5m x 5m pen, at k-values of (a) 0.024 (current ASEL minimum allowance), (b) 0.028 (ASEL + 17%), and (c) 0.033 (minimum to alleviate adverse welfare outcomes). Drawn to scale based on HotStuff (2003) (Maunsell-Australia 2003).***

2.2 Body temperature regulation and heat stress in sheep

This section of the review is broken up into 3 sub-categories, namely (2.2.1) Thermoregulation; (2.2.2) Heat stress; and (2.2.3) Effect of different climatic conditions on heat stress in sheep.

2.2.1 Thermoregulation in sheep

Sheep normally maintain an average body temperature of 39°C, despite living in a range of environmental temperatures (Radostits, Gay et al. 2007). They may exhibit a diurnal variation of approximately 1°C, being lower in the morning and higher in the afternoon. The critical upper limit of body temperature beyond which sheep are considered hyperthermic is 40°C (Radostits, Gay et al. 2007). The resting respiratory rate for sheep ranges between 16 and 34 breaths per minute (Fielder 2016).

Sheep use homeostatic mechanisms to maintain body temperature within a tight range in spite of changes in environmental temperature as *temperature is a major factor affecting tissue function*. Body temperature depends on the balance between heat inputs from environmental sources and all metabolic processes and heat outputs from convection, conduction, radiation and evaporation (see **Figure 11**) (Klein 2013).

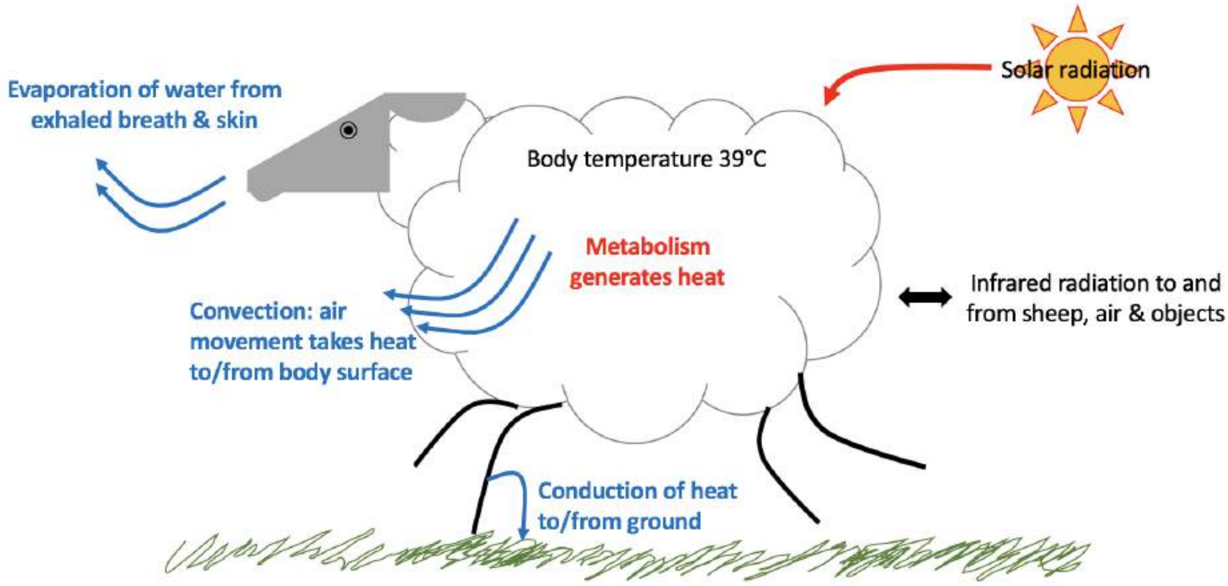


Figure 11. ***Heat inputs and outputs for a sheep in a thermoneutral zone where ambient temperature ranges from 5-25°C.***

Body tissues and organs have poor thermal conductivity. Therefore, heat transfer in the body occurs from tissues of high metabolism and heat production such as muscles and the liver, via blood by circulatory convection to the skin (peripheral vasodilation) and lungs in hot conditions or preferentially to certain organs in cold conditions to maintain core body temperature and brain function (Klein 2013).

The *thermoneutral zone* for any mammal is the range of environmental temperatures at which it can maintain body temperature in the normal range using vasomotor mechanisms to control blood flow to and from skin and other tissues. The thermoneutral zone varies with the metabolic rate and amount of insulation of any animal. Wool provides sheep with excellent insulation, so they have a relatively low thermoneutral zone which may be as wide as 5-25°C depending on breed, age, sex, fleece length, body condition, nutrition and behaviour (AMG 1989, Stockman 2006).

On a warm day when *ambient environmental temperatures are less than 25°C*, there is an adequate thermal gradient between the warmer sheep in a relatively cooler environment that allows dissipation of heat to maintain core body temperature in four ways (see **Figure 11** above) (Klein 2013). Such dissipation occurs through the following means:

- Heat loss by *convection* from the skin to warm the surrounding air.
    - Long wool insulates sheep and reduces efficiency of convection. The ASEL requires wool length in sheep exported to the Middle East in May-October to be < 25 mm unless approved by DAWR. At other times an additional 10% space must be allocated.
    - Forced convection through good ventilation continually removes the warmed air and replaces it with cooled air, but becomes limited to the space above the sheep if space allocation is low.
- Heat loss by *conduction* of heat from skin to cooler surfaces.
    - In hot climates, diurnal variation of body temperature allows sheep to increase their body temperature during the day by up to 1°C. In the early hours of the morning, they reduce body temperature through conduction to cooler ground surfaces. Desert-dwelling camels are excellent exponents of this method of cooling.
    - Sheep will absorb heat by conduction from hot steel on ships when housed in pens adjacent to the engine room bulkhead or other ship structures.
- Heat loss by infrared *radiation* from a warmer sheep to a cooler environment.
- Heat loss by *evaporation* of respiratory secretions, saliva and sweat.
    - The evaporation of 1 L water into water vapour requires 2400 kJ energy.
    - Sheep rely on panting to increase evaporative cooling as ambient temperature rises beyond their thermoneutral zone.
    - Sweating plays a lesser role in heat loss in sheep as they have fewer sweat glands compared with cattle and horses (Klein 2013) and reduce sweat output after a few hours of continuous exposure to high ambient temperature (Stockman 2006).

When ambient temperature rises above 25°C, the thermal gradient between sheep and environment declines and sheep are no longer in their thermoneutral zone. Above 25°C, the main form of heat dissipation in sheep is by evaporative cooling from respiratory and oral surfaces (see **Figure 12**). As a practical indicator of the onset of heat stress, respiratory rates in sheep will exceed 70 breaths per minute (Radostits, Gay et al. 2007). Sheep will also increase water intake (Stockman, Barnes et al. 2011) by up to 13% of body weight (Stockman 2006) and alter behaviour by eating less (Stockman 2006) and seeking shade.

Sheep also possess a counter-current heat exchange mechanism in the skull where the carotid artery forms a rete bathed in a sinus of cooled venous blood that has just drained from the nasal cavity. The cooled arterial blood then protects brain temperature (Klein 2013).

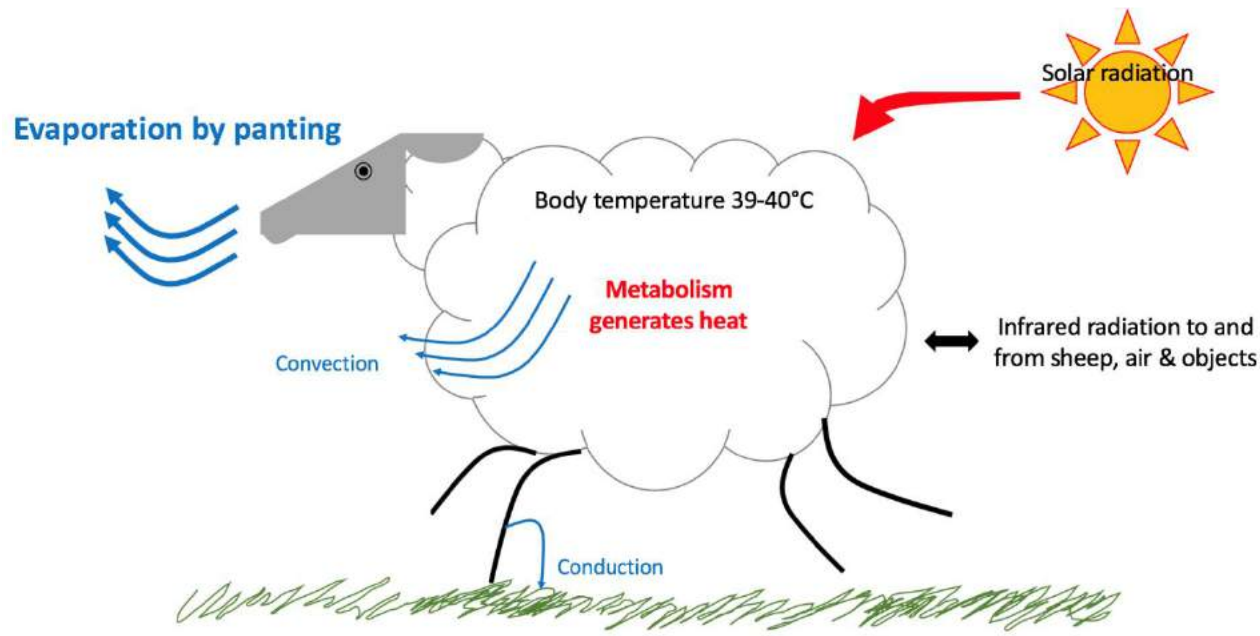


Figure 12. ***When ambient temperatures range from 25 to >29°C, heat regulation in sheep is mainly by evaporative cooling from panting. They will also increase water intake, eat less and seek shade.***

2.2.2 Heat stress in sheep

When ambient temperatures continue to rise, factors that increase the risks of heat stress include *increasing relative humidity* and *dehydration* (Klein 2013). The effectiveness of evaporative cooling decreases as relative humidity increases, typically due to climatic factors, poor ventilation and/or saturated bedding.

Phase one panting moves small tidal volumes at rapid frequency (between 120 and 300 breaths/minute) over engorged respiratory dead space (to avoid hyperventilation and respiratory alkalosis) and oral mucosa (saliva production also increases to elevate heat loss; see **Figure 13**) (Klein 2013). As a sheep's body temperature rises, its metabolic rate increases, more heat is produced and the sheep will begin open-mouthed, slower, deeper panting, known as second phase panting (Stockman 2006).

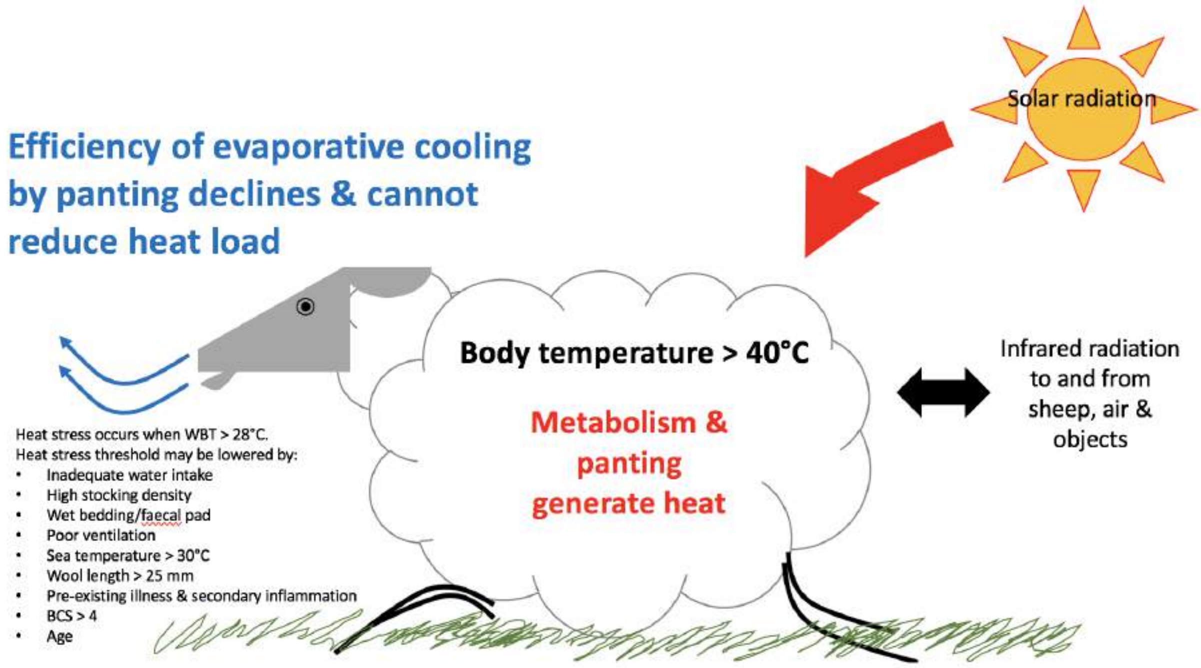


Figure 13. ***When the heat stress threshold is surpassed, sheep rely on evaporative cooling by open mouth panting. Hyperthermia, dehydration and electrolyte and acid-base imbalances will lead to vascular collapse, loss of consciousness and death if measures are not taken to reduce body temperature and rehydrate the animal.***

"Heat stroke" is the term used when environmental conditions are such that animals cannot shed enough heat to maintain their body temperature in the face of ongoing generation of metabolic heat (Maunsell-Australia 2003). On a ship, heat stroke is seen as deck-wide epidemics, with sheep weakened by pre-embarkation disease, salmonellosis, inanition or other voyage-based disorders, dying before the general population (Maunsell-Australia 2003).

Stockman and co-workers (2011) showed that Merino wethers exposed to increasing heat and humidity without diurnal variation for 5 days could not compensate fully for the increased heat load, but recovered following return to thermoneutral conditions (Stockman, Barnes et al. 2011). Sheep breeds adapted to hot, humid conditions, such as Awassi sheep, are able to regulate body temperature better under the same conditions (Stockman 2006).

Panting and inadequate water intake, such as inability to access water troughs on ships because of high stocking rates/inadequate water delivery mechanisms, may also lead to dehydration. Dehydration impairs the sheep's ability to regulate its body temperature as reduced blood flow makes it more difficult to transfer heat from its core to the respiratory system and skin, and the respiratory and oral surfaces dry out. There may be associated electrolyte imbalances and acid-base disturbances in this situation (Stockman, Barnes et al. 2011).

When body temperature reaches 41.5-42.5°C, cellular function is impaired, and this results in vascular collapse and circulatory failure, depression of the nervous system including the respiratory centre, loss of consciousness and death (Radostits, Gay et al. 2007, Klein 2013). Nevertheless, sheep may recover from exposure to heat and humidity if measures are taken to reduce body temperature through environmental modification and cooling of the animal, and rehydration with balanced electrolytes.

It is difficult to measure the rectal temperature and respiratory rate of sheep in highly stocked pens on a ship, and respiratory rate may decrease in cases of severe heat stress during second phase panting (Stockman 2006). Therefore, McCarthy (2005) has recommended that a sheep's Panting Score be used as the primary indicator of heat stress during live sheep export as "*it has proved to be a reliable and repeatable measure despite its subjectivity*". Observations made during collection of the data noted that there was a lag between onset of "*hotter*" environmental conditions and increase in respiratory rate as sheep acquired heat load over three to four days of hot weather (McCarthy 2005).

Table 5 is an attempt to equate subjective and objective measurements that can be obtained during visual and physical examination of any sheep, from observations made during live sheep export (McCarthy 2005) and under controlled experimental conditions (Stockman 2006, Stockman, Barnes et al. 2011).

Table 5. ***Panting Score and Heat Stress Score approximated with respiratory rate and breathing condition of adult sheep housed under different wet bulb temperatures (WBT), and on voyages to the Middle East* [after. (McCarthy 2005, Stockman 2006, Radostits, Gay et al. 2007, Stockman, Barnes et al. 2011)].***

Clinical signs	Approx. Heat Stress Score	WBT (°C)	Rectal temp. (°C)	Respiratory rate (breaths/min)	Panting Score (PS)	Breathing condition
At rest	0	≤ 20	39	16-45	0	Normal respiration, no panting
Normal activity	0	20-22		45-80	0	Increased respiratory rate
Mild heat stress	0	≈25	39.5+	80-100	0.5	Slight panting, mouth closed; no drool or foam
Mild heat stress	0	≈26		100-140	1	Increased breaths/minute; drooling
Moderate heat stress	1	≈28	40+	140-180	2	Fast panting; drool or foam present
Moderate heat stress	1			140-180	2.5	As for PS 2 but with occasional open mouth
Severe heat stress	2	≈29	40.5+	> 180#	3	Open mouth, head extended and usually held up; some drooling
Severe heat stress	2			> 180#	3.5	As for PS 3 but with tongue slightly out
Severe heat stress	2			> 180#	4	Open mouth, tongue out, neck extended and head up; drooling
Severe heat stress	2			> 180#	4.5	As for PS 4 but head held down
Gasping	3	>30	41.5+	Near death	Near death	Near death

*Data was collected on 9 voyages between April and October 2004, and significant heat stress was observed on three of those voyages.
#Respiratory rate may decrease with second phase panting.

The use of a sheep's Panting Score has not apparently been implemented on ships, despite its inclusion in the mobile application *VetHandbook®* (version 1.0; Meat and Livestock Australia). In particular, the Mortality Investigation Report 69[15], for sheep exported by sea to Qatar, Kuwait and United Arab Emirates in August 2017, used the Heat Stress Score method to assess sheep.

[15] Mortality Investigation Reports are at http://www.agriculture.gov.au/export/controlled-goods/live-animals/livestock/regulatory-framework/compliance-investigations/investigations-mortalities

2.2.3 Effect of different climatic conditions on heat stress in sheep

Understanding some meteorological terms and other definitions allows interpretation of research undertaken relating to heat stress in livestock.

- *Dry bulb temperature* (DBT) is a measure of air temperature using a mercury-in-glass thermometer (Crowder 1995).
- *Wet bulb temperature* (WBT) is measured using a mercury-in-glass thermometer covered with a muslin bag that is kept moist. Evaporation of water from the muslin cools the temperature below DBT and degree of cooling is determined by the amount of water vapour in the air (Crowder 1995).
- *Relative humidity* (RH) compares the actual amount of water vapour in the air with the amount of water vapour required to saturate the air at that temperature, thus indicating the amount of moisture in the air (Crowder 1995).
- *Heat stress threshold* (HST) is defined as the maximum ambient wet bulb temperature (WBT) at which heat balance of the deep body temperature can be controlled using available mechanisms of heat loss (Maunsell-Australia 2003). That is, when the local WBT reaches an animal's HST, the animal is on the verge of becoming heat stressed. However HST has also been defined as the ambient WBT at which core body temperature (CBT) significantly increased 0.5°C above normal (Stockman 2006).
- *Mortality limit* (ML) is defined as the ambient wet bulb temperature at which the uncontrollable rise in deep body temperature leads to death (Maunsell-Australia 2003). That is, ML is the WBT above which the animal is dead.

The difference between DBT and WBT decreases as relative humidity increases. With increasing humidity, evaporative cooling created by the wet cloth on thermometer bulb decreases (see **Figure 14**) (Stull 2011).

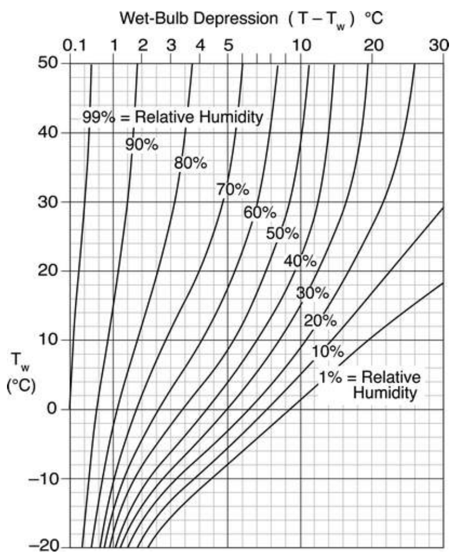


Figure 14. ***Psychrometric graph for standard sea level pressure of 101.325 kPa demonstrating how wet bulb depression, the difference between dry bulb temperature (T) and wet bulb temperature (T_w), decreases as relative humidity increases [taken from (Stull 2011)].***

In terms of DBT *vs* WBT in Australia, the southern ports of departure like Portland and Adelaide rarely reach WBT values of 20°C and average 16-17°C, while Fremantle reaches a mean WBT of 20°C in summer (Maunsell-Australia 2003). Values fall significantly as winter approaches.

As an example of a Middle Eastern Port, WBT distribution for Doha, Qatar (see **Appendix D**) shows WBTs reach mid-20s in May, and high 20s and low 30s in June to October (Maunsell-Australia 2003).

The Indian Ocean generally exhibits lower WBTs than the Persian Gulf, but equatorially and north of the equator, WBTs can rise to 26-28°C in April and May, and 30°C in June (Maunsell-Australia 2003).

2.2.3.a What is the heat stress threshold (HST) in sheep?

The ability and speed of a sheep to respond to heat stress can depend on:

- breed, weight, age, sex and wool length (see **Figures 15** and **16**) (Maunsell-Australia 2003)
- whether the sheep has been sourced from winter- or summer-acclimatised district [see **Appendix E**; (Stockman 2006, Nienabar and Hahn 2007)]; and/or
- where the sheep is located on a ship, e.g. near ventilation inlet or outlet, adjacent to engine bulkhead, directly beneath steel roof on top deck [**Figure 17**; (Maunsell-Australia 2003)].

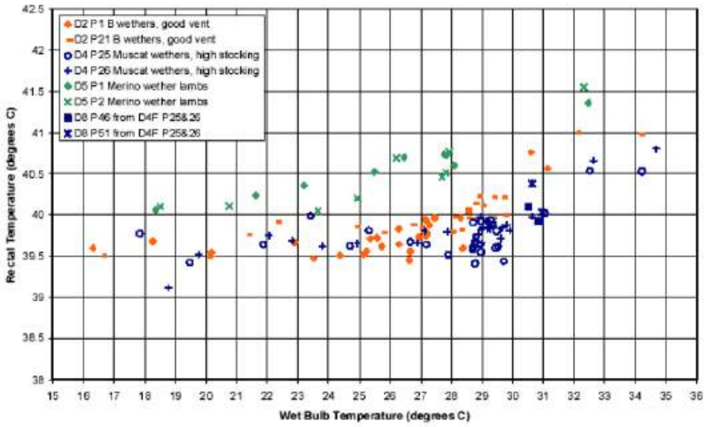


Figure 15. Comparison of deck wet bulb temperature (WBT) with rectal temperature of Merino lambs (green symbols) and wethers (orange), and Muscat wethers (blue) on a ship [taken from (Maunsell-Australia 2003)].

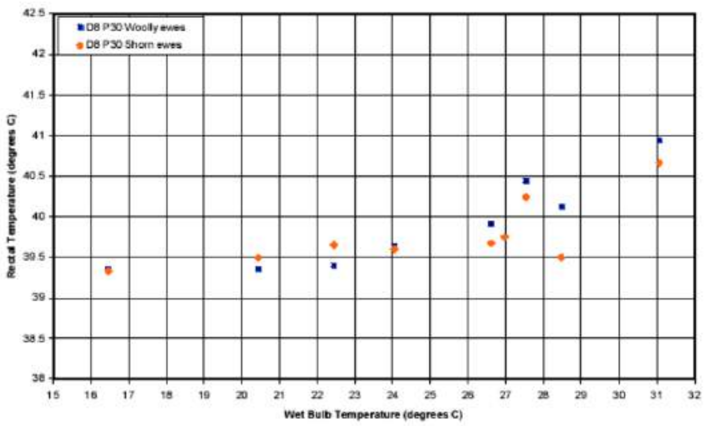


Figure 16. Comparison of deck wet bulb temperature (WBT) with rectal temperature of shorn (orange) and woolly ewes (blue) on a ship [taken from (Maunsell-Australia 2003)].

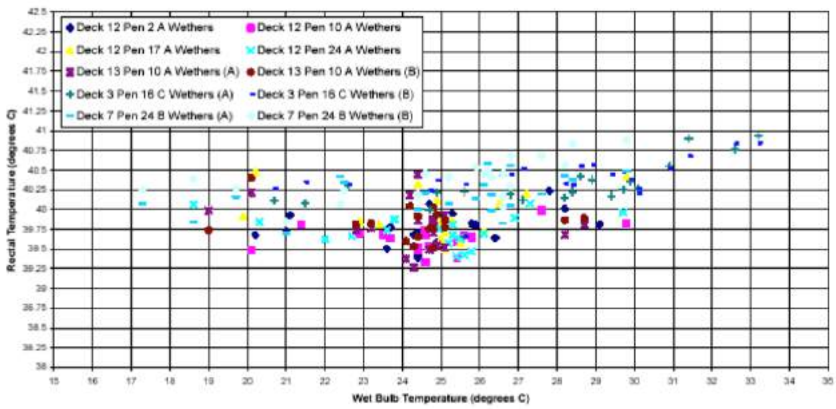


Figure 17. Comparison of deck wet bulb temperature (WBT) and rectal temperature of sheep housed in different locations on a ship [taken from (Maunsell-Australia 2003)].

The heat stress threshold (HST) for Merino ram lambs (approx. 8 months old, 58 kg), adult rams (approx. 5 years old, 71 kg) and adult wethers (approx. 4 years old, 56 kg) has been measured at wet bulb temperature (WBT) of 25°C (see **Table 6**) (Stockman 2006). The sheep used to determine these temperatures were housed in individual pens with individual feed and water buckets, good ventilation, on land rather than a ship. Sheep had room to turn around and lie down (e.g. 60 kg sheep, 0.88 m^2 pen size gives *k* value of 0.059, more than twice the space allocation for sheep on ships), < 25 mm wool length and were *winter* acclimatised. After an initial period of 4 days of acclimatisation, temperature and humidity were increased by 2°C every 48 hours until 32°C was reached (Stockman 2006).

Table 6. The mean wet bulb temperature (WBT) for (a) heat stress threshold (HST), (b) when core body temperature (CBT) significantly increases at least 0.5°C and (c) when CBT significantly increases at least 1°C, for 3 different classes of Merino sheep (Stockman 2006).

Class of Merino sheep	Mean WBT (°C) HST	Mean WBT (°C) when CBT 0.5°C above normal*	Mean WBT (°C) when CBT 1°C above normal
Lamb rams	25	26	27
Adult rams	25	28	29
Adult wethers	25	28	28

*The ambient WBT at which core body temperature significantly increases 0.5°C above normal has also been used to define HST within the live export industry (Stockman 2006).

In another study, using *summer* acclimatised adult Merino wethers (approx. 3 years old, 53 kg) with a fleece length of 15 mm, HST was 27°C (Stockman, Barnes et al. 2011).

Sheep on a ship are not individually penned, have approximately half the space allocation of the studies described above, the decks are variably ventilated and the ship is moving. Australian sheep being shipped to the Middle East in May-October are *winter*-acclimatised.

2.2.3.b Heat Stress Risk Assessment (HotStuff)

When voyages are being planned from Australia to the Middle East, a Heat Stress Risk Assessment (HSRA) is undertaken as part of the export application process. Inputs include predicted weather conditions, animal physiology and ship design, ventilation and proposed route. Output from the model is used to manipulate space allocation on ships to provide a less than 2% probability of a 5% mortality on the voyage.

The model, known as HotStuff, was developed by the Australian livestock export industry in 2003 and uses a WBT HST of 30.6°C applied to a 40 kg, body condition score 3, shorn adult Merino that is acclimatised to WBT of 15°C; the ML is set at 35.5°C (Maunsell-Australia 2003). Merino lambs in the model have a WBT HST of 26.7°C and ML of 35.2°C. Awassi sheep are dealt with separately in the model (Maunsell-Australia 2003). The Wet Bulb Distribution for Doha, Qatar used in the modelling are listed in Appendix D. Statistics were gathered from the airport nearest the sea port and it was noted that coastal wet bulb values are probably equal to or higher than indicated by the probability distributions presented in the report (Maunsell-Australia 2003).

In the original HotStuff document, that pre-dated the research of Stockman (2006), the authors stated "*while the animal HST and ML are uncertain, the trends of there (sic) parameters with the risk influences of weight, breed, coat, acclimatisation and fat score are less clear*" (Maunsell-Australia 2003). The Stockman studies were funded by industry, based on the uncertainty of HST in the original model. The parameters of the HSRA model should be reassessed as results set out in Stockman (2006) strongly suggest the HST should be lowered, and is supported by comments by Shiell and co-workers (Shiell, Perkins et al. 2013).

2.2.3.c Wet bulb temperatures during voyages in May to October

Lack of diurnal temperature variation prevents sheep from dissipating heat at night, thus resulting in an accumulated heat load (Stockman, Barnes et al. 2011, Norman 2017). **Figure 18** overlays data collected during 2 different prolonged heat exposure events, separated by 36 hours, when the climate controlled room reverted to ambient temperature (Stockman, Barnes et al. 2011, Caulfield, Cambridge et al. 2014). As WBT approaches 30°C the core body temperature increases to around 39.7°C and there is a marked increase in respiratory rate. This thermoregulatory response is unable to maintain constant body temperature and core body temperature rises beyond 40.5°C when WBT stays over 30°C for 2 more days (Caulfield, Cambridge et al. 2014). The second prolonged heat exposure event in **Figure 18** increased sheep core temperature at a lower ambient temperature and faster rate than the first event due to accumulated heat load.

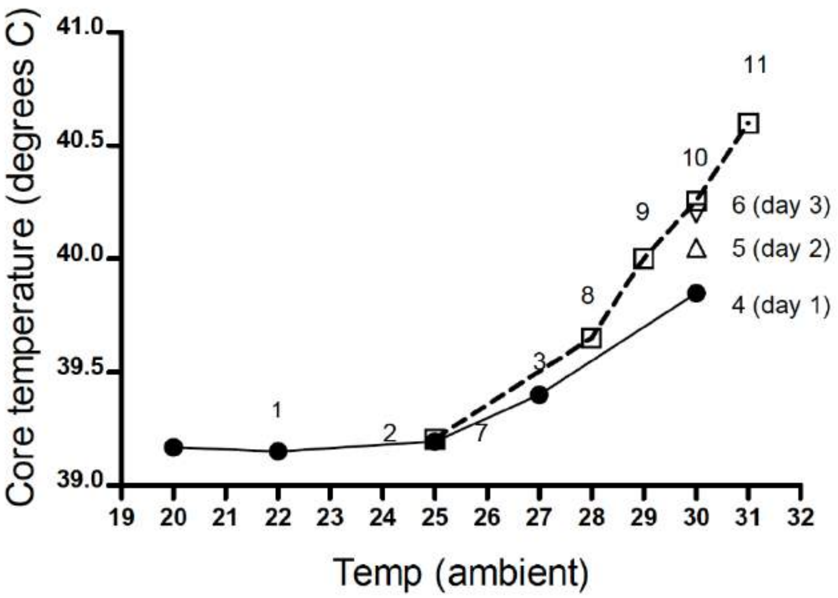


Figure 18. Progressive daily environmental temperature increase and core temperature of Merino sheep exposed to two heat events (WBT 30°C for 3 days and WBT 30-31°C for 4 days), 36 hours apart (solid circles represent data collected during first heat exposure, open squares represent data collected during second heat event; (Caulfield, Cambridge et al. 2014).

Appendices E, F, G, H, I and J contain graphic data extracted from Mortality Incident Reports that have been investigated and published[16] when total sheep mortality, or a consignment within a shipment, has exceeded 2%, where heat stress is the main contributing factor to sheep mortality. Figures in **Appendix G** illustrate the extended periods of days to weeks during voyages where WBT is greater than the HST. A sudden increase in WBT exceeds the ML and sheep die in very high numbers following accumulation of heat load in the preceding days and the inability to thermoregulate adequately during the peak WBT.

The maximum WBT on any voyage investigated for heat stress is around 33°C but it reached 37°C on a voyage in August 2017 (MIR 69; **Figure F.6**). There are, however, uncertainties about the accuracy of WBT data. The WBT chart in **Figure F.5** shows that WBT was collected at 11 am (**Appendix Figure F.5**). WBT is likely to keep rising after this time so reported temperatures may not reflect the true maximum WBT. For example, a heat stress event during a voyage in 2004 occurred between 1400-1800 hours (McCarthy 2005). Mortality Investigation Reports do not state where the thermometers on each deck are located with respect to proximity to ventilation outlets and height above deck (sheep height vs human eye level for ease of

[16] Mortality Investigation Reports are at http://www.agriculture.gov.au/export/controlled-goods/live-animals/livestock/regulatory-framework/compliance-investigations/investigations-mortalities

recording vs near ceiling to protect thermometer from damage). Wet bulb temperature may vary 3-4°C within a hold (**Appendix F**) (McCarthy 2005).

Different classes and weights of sheep may show different tolerances to heat stress (**Appendix H**). Basal metabolic rate/kg body weight is greater in smaller animals due to higher surface area to volume ratio (Klein 2013) and may explain why lambs may have a lower HST thus making them more susceptible to heat stress. Nevertheless, in extreme weather conditions mortality rates in all classes of sheep will be high (MIR 69).

From July to September, minimum and maximum sea temperatures in the region of Doha, Qatar are > 30°C and lack diurnal variation (see **Figure 19**) and may contribute to accumulated heat load in sheep during voyages.

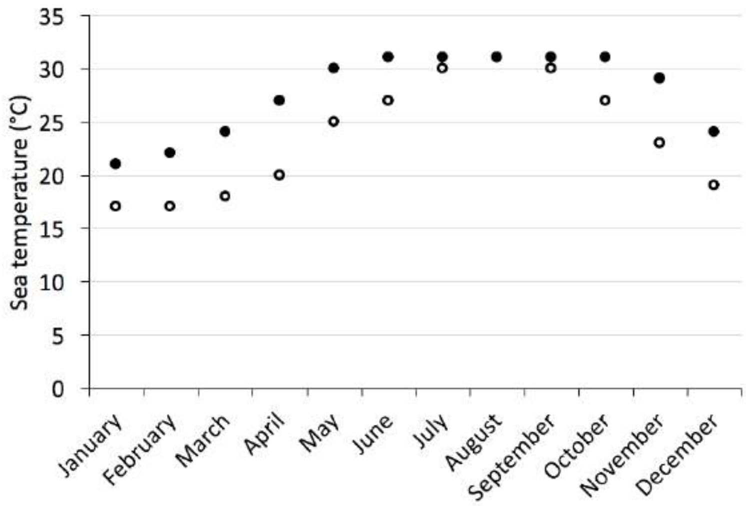


Figure 19. ***Average minimum (open circles) and maximum (closed circles) sea temperature in Doha, Qatar (source: https://seatemperature.info/doha-water-temperature.html).***

It is possible that decreased welfare during high mortality voyages could be the result of atypical conditions. However, the few available reports of voyages where ASEL mortality limit was not exceeded indicate that *animals experience heat stress even during typical voyages* (Caulfield, Cambridge et al. 2014) . During development of the heat stress model, it was noted that "*there is clear indication that the animal could be in trouble even when alone in the ambient conditions*" (Maunsell-Australia 2003). McCarthy (2005) collected temperature and relative humidity data on 9 voyages between April and October, and significant heat stress was observed on 3 voyages and mild heat stress occurred on an unspecified number of the other six voyages. In MIR 69, the AAV recorded "*moderate heat stress … in some areas from day 5 till day 13*" (see **Appendix G, Figure G.5**).

2.2.3.d Other factors contributing to mortality rates during heat stress events

A contributing factor that exacerbates sheep mortality rates when the WBT exceeds HST and initiates a heat stress event, is the occurrence of "bogging" on sheep decks on a ship. This phenomenon was observed on the 60 Minutes footage televised on 8 April 2018[17] and reported in MIR 65 (**Appendix J, Figures J.1 and J.2**) and in MIR 69 (**Figure J.3**).[18] As ships approach the Middle East, sheep have been travelling with low space allocation for more two to three weeks and floors are covered with a deep pad of faeces. As WBT rises, sheep expel water vapour from their nose and mouth while panting, which contributes air saturation and increases the relative humidity in the hold. In addition, sheep increase water intake due to the high WBT and

[17] 60 Minutes footage: Part 1 https://www.9now.com.au/60-minutes/2018/clip-cjfqah0td003u0qs8g3pgsbl8 and Part 2 https://www.9now.com.au/60-minutes/2018/clip-cjfqb31p400410rqhq2vf9dmi

[18] Mortality Investigation Reports are at http://www.agriculture.gov.au/export/controlled-goods/live-animals/livestock/regulatory-framework/compliance-investigations/investigations-mortalities

in response to water loss from panting. Sheep may drink 13% of their body weight as water when suffering heat stress (Stockman 2006) so urine output will increase also. Therefore, the faecal pad becomes boggy during heat stress events and sheep expend more energy trying to extricate themselves from the faecal bog, thus generating more metabolic heat in a vicious cycle.

Appendix J contains information regarding deck condition on two voyages where heat stress occurred. **Figure J.1** and **Figure J.2** illustrate the boggy conditions during periods of high relative humidity and how quickly the faeces dried out when humidity decreased suddenly.

An excerpt from MIR 69 gives an insight into bogging during heat stress events:
"The AAV recorded moderate heat stress was evident in some areas from day 5 till day 13 of the voyage. Daily reports record maximum wet bulb temperature ranged from 29.1 degrees Celsius to 31.9 degrees Celsius during this period. In McCarthy and Banhazi (2016) the report refers to findings of an unpublished report McCarthy (2008 unpublished) that describes the negative impacts of extended periods of relatively high temperature and humidity with associated increase water intake and urination in sheep. This situation overwhelms the capacity for the ships ventilation to 'lift' moisture from the deck. When extreme temperature and humidity is experienced with these deck conditions already a problem, high mortalities will occur. The AAV also believes this is a factor in this reportable mortality."

Space allocation and heat stress are inextricably linked with air quality. The original model used to predict heat stress and space allocation for sheep indicates that an increase in space allocation of 40-60% is warranted between May and October as "many sheep decks have a pen air turnover (PAT) < 100 m/hr" (see **Figure 20**) (Maunsell-Australia 2003) . Airflow is measured as Pen Air Turnover ("PAT") measured in cubic metres per square metre of pen space per hour, abbreviated as "m/hr" (McCarthy 2005). HotStuff 2003, as well as subsequent reviews, recognise the importance of ships maximising flow rate and distribution of supply air on ships (Ferguson, Fisher et al. 2008, Shiell, Perkins et al. 2013).

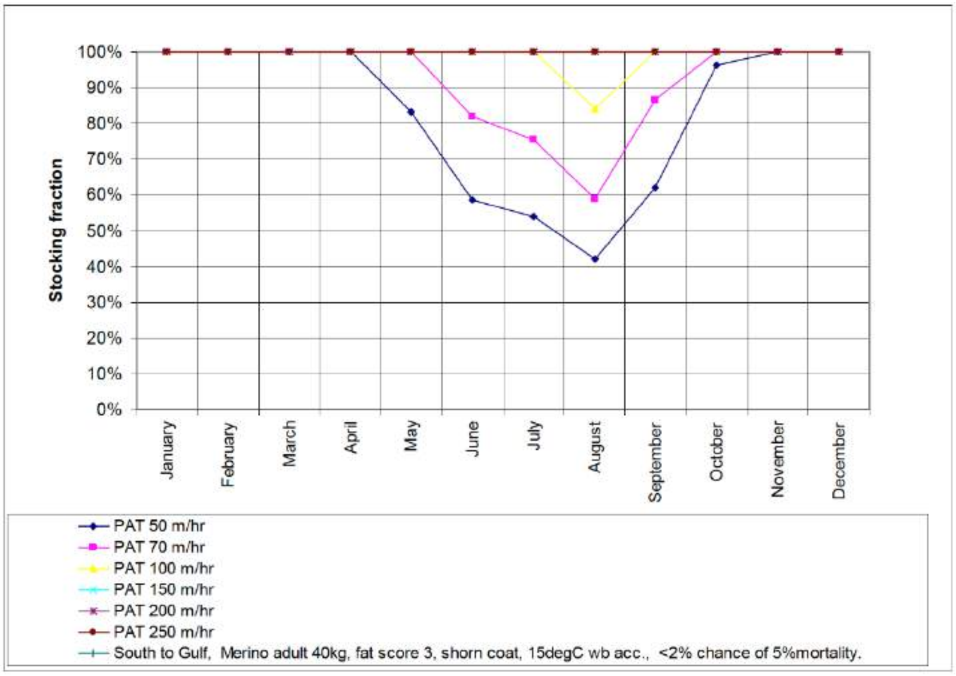


Figure 20. ***Predicted stocking fraction for 40 kg adult Merinos, fat score 3, acclimatised to wet bulb temperature 15°C, shorn. When Pen Air Turnover (PAT) is ≤ 100 m/hr, space allocation per sheep needs to increase during the hotter months of the year [taken from (Maunsell-Australia 2003)].***

Previous reviews

In 1985, the Senate Select Committee on Animal Welfare into Export of Live Sheep from Australia wrote "*it is not in the interests of the animal to be transported to the Middle East for slaughter*" (see **Appendix K**).[19] It is essential that science underpins review of standards to continually improve the health and welfare of sheep undergoing export. The AVA Code of Professional Conduct states that "*changes in society, science and the law constantly raise new ethical issues regarding animals, and may challenge existing ethical perspectives*".[20] Historically, little change has occurred in space allocation on live export ships in response to reviews following adverse animal welfare events. Two comprehensive reports have attempted to address these issues: the *Report by the Senate Select Committee on Animal Welfare into Export of Live Sheep from Australia (1985)*, *Keniry Livestock Export Review (2003)*[21] and the *Farmer's Independent Review of Australia's Livestock Export Trade (2011).*[22]

Conclusions

Animal welfare science has advanced significantly since the beginning of the live export trade. However, the current standards do not reflect these advances. Importantly, animal welfare science relates to the physical and mental state of an animal, and recognises that animals are sentient. Changes that are made should be based on ensuring both the physical and mental welfare needs of exported animals throughout the entire journey, and not solely restricted to addressing mortalities.

The Five Freedoms model of animal welfare, which encompasses nutrition, environment, health, behaviour and mental state, has served for many years as a useful, outcomes-based framework to help identify and evaluate actions necessary to promote good animal welfare:

- freedom from hunger and thirst
- freedom from discomfort
- freedom from pain, injury and disease
- freedom to express normal behaviour, and
- freedom from fear and distress

It is vital to ensure that these survival-related factors are optimised at all times. In addition, in 2018, we know that ensuring good animal welfare means providing animals with all the elements required to ensure their health, physiological fitness and a sense of positive individual wellbeing in what is now known as the Five Domains model of animal welfare (Green and Mellor 2011) (Mellor and Beausoleil 2015).

Based on the available science on space allocation, sheep body temperature regulation, heat stress in sheep and the effect of climatic conditions on heat stress in sheep, space allocation for sheep being shipped to the Middle East must be increased by significantly more than 17% at all times of the year. Specifically, 40-60 kg sheep require an increase in space allocation of at least 30% to improve animal welfare outcomes and meet the World Organisation for Animal Health (OIE) Standards on Animal Welfare.[23]

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[19] Report by the Senate Select Committee on Animal Welfare into Export of Live Sheep from Australia (1985) is at www.aph.gov.au/Parliamentary_Business/Committees/Senate/Significant_Reports/animalwelfarectte/exportlivesheep/index

[20] The Australian Veterinary Association Code of Professional Conduct is at http://www.ava.com.au/conduct

[21] The Keniry Review is at http://www.agriculture.gov.au/SiteCollectionDocuments/animal-plant/animal-welfare/trade/export-transport-review/keniry_review_jan_04.pdf

[22] The Farmer Review is at http://www.agriculture.gov.au/Style%20Library/Images/DAFF/__data/assets/pdffile/0007/2401693/indep-review-aust-livestock-export-trade.pdf

[23] http://www.oie.int/en/animal-welfare/animal-welfare-at-a-glance/

Recommendations

The key recommendations from this short review are:

- Trucks delivering sheep for export must be weighed dockside at embarkation, so total sheep weight can be allocated to total deck area. No more sheep should be loaded onto the ship when total space has been allocated.
- Aggregated voyage data, including key animal welfare indicators, can and must be measured and collated using up-to-date technologies such as blockchain, with that data made available to scientists so future research topics are not only based on sheep mortalities, but also causes of morbidity during each voyage. Sheep must be individually identified with electronic ear tags to assist with data collection and for traceability.
- Space allocation per animal must be based on allometric principles and increased by at least 30% for sheep that weigh 40 to 60 kg (based on a *k*-value of 0.033). The typical sheep sent to the Middle East is an adult Merino wether in this weight range. This increase in space ($k = 0.033$) is the minimum amount needed to alleviate adverse welfare outcomes, and must be implemented across all body weights and all months of the year.
- Irrespective of stocking density, thermoregulatory physiology indicates that sheep on live export voyages to the Middle East during May to October will remain susceptible to heat stress and die due to the expected extreme climatic conditions during this time. Accordingly, voyages carrying live sheep to the Middle East during May to October cannot be recommended.

Appendix A

Table A.1. Number of shipments per month from Australia to the Middle East carrying > 15,000 live sheep between 2005 and 2017[24].

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Monthly total
January	5	4	5	5	2	3	2	3	4	3	0	1	1	**38**
February	4	3	3	3	5	4	3	3	1	3	3	2	4	**41**
March	3	5	5	4	4	3	4	1	2	1	2	3	2	**39**
April	4	4	2	6	4	3	2	4	2	4	3	3	3	**44**
May	3	2	4	3	6	2	2	3	4	3	3	1	2	**38**
June	1	4	3	3	2	2	3	3	2	3	2	2	2	**32**
July	3	4	3	5	6	4	4	3	1	3	2	3	2	**43**
August	6	6	5	5	3	7	3	3	3	3	2	4	4	**54**
September	5	4	3	4	3	1	4	3	3	2	4	2	2	**40**
October	6	5	6	4	4	6	4	2	2	3	2	2	3	**49**
November	6	7	6	6	4	2	2	3	1	2	1	2	3	**45**
December	6	6	5	5	5	4	2	3	3	2	3	1	1	**46**
Annual Total	**52**	**54**	**50**	**53**	**48**	**41**	**35**	**34**	**28**	**32**	**27**	**26**	**29**	**Total = 509**

[24] Data sourced from http://www.agriculture.gov.au/export/controlled-goods/live-animals/live-animal-export-statistics/reports-to-parliament

Appendix B

Table B.1. ***List of voyages from Australia to the Middle East where total sheep mortalities were ≥ 1.5% (n=51) by month of voyage commencement, when there were > 15,000 sheep on the ship. All voyages were ≥ 15 days in duration (mean 23.8 ± SEM 0.7 days; range 15-36 days) and occurred between 2005 and 2017*** *(source: http://www.agriculture.gov.au/export/controlled-goods/live-animals/live-animal-export-statistics/reports-to-parliament).*

Date voyage started	**Export licence holder**	**Loading ports**	**Destination/s in order of disembarkation**	**Voyage duration (days)**	**Sheep number**	**Deaths**	**Mortality (%)**	**Mortality Investigation Report number: Comments**
Aug-05	**Emanuel Exports**	**Fremantle**	**Port Sultan, Qaboos, Kuwait, Bahrain**	**19**	**59094**	**1569**	**2.66**	
Sep-05	Livestock Shipping Services	Fremantle	Aqaba, Eilat	22	71163	1204	1.69	
Sep-05	Emanuel Exports	Fremantle	Port Sultan, Qaboos, Kuwait, Doha, Jebel Ali	21	75094	1373	1.83	
Sep-05	Samex Aust Meat Co	Portland, Fremantle	Bahrain, Kuwait, Jebel Ali	24	70992	1151	1.62	
Oct-05	Emanuel Exports	Fremantle	Jeddah	16	86567	1727	1.99	
Oct-05	Emanuel Exports	Fremantle	Port Sultan, Bahrain, Kuwait, Jebel Ali	23	104680	1791	1.71	
Dec-05	Livestock Shipping Services	Fremantle	Jeddah	19	106730	1804	1.69	
Feb-06	**Roberts**	**Portland, Devonport**	**Jebel Ali, Bahrain, Kuwait, Doha**	**27**	**71309**	**1683**	**2.36**	**MIR 2: inanition**
Jun-06	**EMS Rural Exports**	**Portland, Fremantle**	**Kuwait, Bahrain, Doha, Jebel Ali**	**26**	**72210**	**1425**	**1.97**	**MIR 7: heat stress; 449 died in group of 20,701 (2.17%)**
May-07	**Wellard Rural Exports**	**Portland, Fremantle**	**Muscat, Jebel Ali, Bahrain, Kuwait, Muscat**	**31**	**109035**	**2051**	**1.88**	**MIR 15: heat stress, especially on open decks**
May-07	EMS Rural Exports	Adelaide, Fremantle	Bahrain, Kuwait, Doha, Jebel Ali	26	77353	1423	1.84	
Jun-07	**Emanuel Exports**	**Adelaide, Fremantle**	**Jebel Ali, Muscat, Bahrain, Kuwait, Doha**	**32**	**105242**	**1659**	**1.58**	**MIR 16/19: heat stress**
Jul-07	**Samex Aust Meat Co**	**Portland, Fremantle**	**Kuwait, Bahrain, Doha, Jebel Ali**	**27**	**77464**	**1330**	**1.72**	**MIR 17: heat stress on open decks, enteritis**
Aug-07	International Livestock Export	Fremantle	Kuwait, Bahrain, Doha, Jebel Ali	22	74499	1142	1.53	
Aug-07	EMS Rural Exports	Portland, Adelaide	Kuwait, Bahrain, Jebel Ali, Muscat	30	92398	1493	1.62	
Aug-07	**International Livestock Export**	**Fremantle**	**Kuwait, Bahrain, Doha, Jebel Ali**	**21**	**76149**	**1923**	**2.53**	
Sep-07	International Livestock Export	Fremantle	Jeddah	16	50243	859	1.71	
Oct-07	**International Livestock Export**	**Fremantle**	**Jeddah**	**16**	**55520**	**1142**	**2.06**	
Nov-07	Wellard Rural Exports	Fremantle	Jeddah, Muscat	22	116162	1766	1.52	
Nov-07	Livestock Shipping Services	Fremantle	Jeddah	23	114631	1980	1.73	
Jul-08	Emanuel Exports	Portland, Fremantle	Kuwait, Bahrain, Muscat	28	72492	1125	1.55	
Jul-08	EMS Rural Exports	Portland, Fremantle	Kuwait, Bahrain, Muscat	30	86280	1391	1.61	
Aug-08	Wellard Rural Exports	Fremantle	Jeddah, Muscat	24	73740	1240	1.68	
Aug-08	International Livestock Export	Fremantle	Jeddah	16	54505	878	1.61	
Aug-08	Emanuel Exports	Adelaide, Fremantle	Bahrain, Kuwait, Jebel Ali	26	75063	1187	1.58	
Sep-08	Emanuel Exports	Fremantle	Bahrain, Kuwait, Jebel Ali, Muscat	21	72448	1130	1.56	
May-09	International Livestock Export	Fremantle	Jeddah	17	59705	950	1.59	

Appendix B (cont'd)

Table B.1. ***List of voyages from Australia to the Middle East where total sheep mortalities were ≥ 1.5% (n=51) by month of voyage commencement, when there were > 15,000 sheep on the ship. All voyages were ≥ 15 days in duration (mean 23.8 ± SEM 0.7 days; range 15-36 days) and occurred between 2005 and 2017*** *(source: http://www.agriculture.gov.au/export/controlled-goods/live-animals/live-animal-export-statistics/reports-to-parliament).*

Date voyage started	Export licence holder	Loading ports	Destination/s in order of disembarkation	Voyage duration (days)	Sheep number	Deaths	Mortality (%)	Mortality Investigation Report number: Comments
Jul-09	Wellard Rural Exports	Fremantle	Muscat, Bahrain, Doha	16	60171	960	1.60	
Aug-09	Samex Aust Meat Co	Portland, Fremantle	Kuwait, Bahrain, Jebel Ali	28	78421	1516	1.93	
Aug-09	EMS Rural Exports	Portland, Adelaide	Kuwait, Bahrain, Jebel Ali	24	75823	1272	1.68	
Aug-10	**Emanuel Exports**	**Fremantle**	**Bahrain, Kuwait, Jebel Ali**	**22**	**69024**	**1407**	**2.04**	**MIR 38: heat stress**
Aug-10	**EMS Rural Exports**	**Adelaide, Portland**	**Kuwait, Bahrain**	**26**	**77523**	**2572**	**3.32**	**MIR 37: heat stress**
Aug-10	EMS Rural Exports	Adelaide, Portland	Bahrain, Kuwait, Muscat	26	69952	1242	1.78	
Jan-11	Samex Aust Meat Co	Portland, Fremantle	Doha, Kuwait, Karachi	29	77176	1381	1.79	
Jun-11	**Emanuel Exports**	**Portland, Fremantle**	**Doha, Kuwait, Bahrain**	**27**	**65203**	**1006**	**1.54**	**MIR 40: enteritis, inanition, heat stress**
Jul-11	EMS Rural Exports	Fremantle, Portland	Doha, Bahrain, Kuwait	26	69722	1353	1.94	
Jan-12	Wellard Rural Exports	Adelaide, Fremantle	Bahrain, Doha, Jebel Ali	29	104528	1592	1.52	
May-12	Wellard Rural Exports	Fremantle	Bahrain, Doha	15	66204	1117	1.69	
Jun-12	Emanuel Exports	Fremantle	Manama, Kuwait	23	96864	1728	1.78	
Jun-12	EMS Rural Exports	Adelaide	Bahrain, Jebel Ali, Kuwait, Muscat	27	65499	1101	1.68	
Jul-12	Livestock Shipping Services	Broome, Fremantle	Adabiya, Aqaba	28	15640	301	1.92	
Aug-12	Wellard Rural Exports	Fremantle	Muscat, Doha, Port Qasim	32	75364	1357	1.80	
Sep-12	Wellard Rural Exports	Fremantle	Doha	16	64291	966	1.50	
Aug-13	**Livestock Shipping Services**	**Adelaide, Fremantle**	**Doha, Jebel Ali**	**33**	**75508**	**4179**	**5.53**	**MIR 46: heat stress accounted for 97% of mortalities**
Oct-13	Emanuel Exports	Fremantle	Jebel Ali, Kuwait	23	69593	1155	1.66	
Jan-14	**Wellard Rural Exports**	**Fremantle**	**Aqaba (Jordan), Eilat (Israel)**	**36**	**42550**	**1654**	**3.89**	**MIR 51: ruminal acidosis secondary to new feed**
Aug-15	Emanuel Exports	Fremantle	Bahrain, Jebel Ali, Kuwait, Muscat	21	71677	1253	1.75	
Jul-16	**Emanuel Exports**	**Fremantle**	**Hamad, Jebel Ali, Muscat, Kuwait**	**25**	**69322**	**1741**	**2.51**	**MIR 65: heat stress**
Sep-16	Otway /Wellard	Fremantle	Eilat	18	26479	525	1.98	
Jul-17	Emanuel Exports	Fremantle	Kuwait	18	23617	393	1.66	
Aug-17	**Emanuel Exports**	**Fremantle**	**Kuwait, Jebel Ali, Port Hamad**	**23**	**63804**	**2400**	**3.76**	**MIR 69: heat stress**

Appendix C

Table C.1. Minimum pen area per head for sheep and goats exported by sea according to ASEL (version 2.3, 2011; Table A4.1.5:) with (k-values +10%) and (k-values +17%) included. Values in red are considered to produce adverse welfare outcomes for intensively housed sheep (Petherick and Phillips 2009) .

	Nov-Apr			May-Oct				Nov-Apr			May-Oct		
Live weight (kg)	**Minimum pen area (m2/head)**	***k*-value +10%**	***k*-value +17%**	**Minimum pen area (m2/head)**	***k*-value +10%**	***k*-value +17%**	**Live weight (kg)**	**Minimum pen area (m2/head)**	***k*-value +10%**	***k*-value +17%**	**Minimum pen area (m2/head)**	***k*-value +10%**	***k*-value +17%**
28	0.261	**0.032**	**0.034**	0.261	**0.032**	**0.034**	**51**	0.320	**0.026**	**0.028**	0.322	**0.026**	**0.028**
29	0.263	**0.031**	**0.033**	0.263	**0.031**	**0.033**	**52**	0.324	**0.026**	**0.028**	0.329	**0.027**	**0.028**
30	0.265	**0.031**	**0.033**	0.265	**0.031**	**0.033**	**53**	0.329	**0.026**	**0.028**	0.337	**0.027**	**0.029**
31	0.268	**0.031**	**0.033**	0.268	**0.031**	**0.033**	**54**	0.333	**0.026**	**0.028**	0.344	**0.027**	**0.029**
32	0.270	**0.030**	**0.032**	0.270	**0.030**	**0.032**	**55**	0.338	**0.026**	**0.028**	0.351	**0.027**	**0.029**
33	0.273	**0.030**	**0.032**	0.273	**0.030**	**0.032**	**56**	0.342	**0.026**	**0.028**	0.357	**0.028**	**0.029**
34	0.275	**0.030**	**0.031**	0.275	**0.030**	**0.031**	**57**	0.347	**0.026**	**0.028**	0.363	**0.028**	**0.029**
35	0.278	**0.029**	**0.031**	0.278	**0.029**	**0.031**	**58**	0.351	**0.026**	**0.028**	0.369	**0.028**	**0.030**
36	0.280	**0.029**	**0.031**	0.280	**0.029**	**0.031**	**59**	0.356	**0.027**	**0.028**	0.375	**0.028**	**0.030**
37	0.283	**0.029**	**0.031**	0.283	**0.029**	**0.031**	**60**	0.360	**0.027**	**0.028**	0.381	**0.028**	**0.030**
38	0.285	**0.028**	**0.030**	0.285	**0.028**	**0.030**	**61**	0.367	**0.027**	**0.028**	0.389	**0.028**	**0.030**
39	0.288	**0.028**	**0.030**	0.288	**0.028**	**0.030**	**62**	0.374	**0.027**	**0.029**	0.398	**0.029**	**0.031**
40	0.290	**0.028**	**0.030**	0.290	**0.028**	**0.030**	**63**	0.380	**0.027**	**0.029**	0.406	**0.029**	**0.031**
41	0.293	**0.028**	**0.030**	0.293	**0.028**	**0.030**	**64**	0.387	**0.027**	**0.029**	0.415	**0.029**	**0.031**
42	0.295	**0.028**	**0.029**	0.295	**0.028**	**0.029**	**65**	0.394	**0.028**	**0.029**	0.423	**0.030**	**0.031**
43	0.298	**0.027**	**0.029**	0.298	**0.027**	**0.029**	**66**	0.401	**0.028**	**0.030**	0.432	**0.030**	**0.032**
44	0.300	**0.027**	**0.029**	0.300	**0.027**	**0.029**	**67**	0.408	**0.028**	**0.030**	0.441	**0.030**	**0.032**
45	0.303	**0.027**	**0.029**	0.303	**0.027**	**0.029**	**68**	0.415	**0.028**	**0.030**	0.450	**0.031**	**0.033**
46	0.305	**0.027**	**0.029**	0.305	**0.027**	**0.029**	**69**	0.422	**0.028**	**0.030**	0.459	**0.031**	**0.033**
47	0.308	**0.027**	**0.028**	0.308	**0.027**	**0.028**	**70**	0.429	**0.029**	**0.030**	0.468	**0.031**	**0.033**
48	0.310	**0.026**	**0.028**	0.310	**0.026**	**0.028**	**75**	0.465	**0.030**	**0.031**	0.515	**0.033**	**0.035**
49	0.313	**0.026**	**0.028**	0.313	**0.026**	**0.028**	**80**	0.502	**0.031**	**0.033**	0.563	**0.034**	**0.037**
50	0.315	**0.026**	**0.028**	0.315	**0.026**	**0.028**	**90**	0.575	**0.032**	**0.035**	0.658	**0.037**	**0.040**

Appendix D

Table D.1. ***The wet bulb distribution for Doha, Qatar (°C) for May to October. Statistics were gathered over 6 years (1997-2002) from the airport nearest the sea port (Maunsell-Australia 2003). During modelling of HotStuff (2003), it was noted that coastal wet bulb values are probably equal to or higher than indicated by the probability distributions presented in the report (Maunsell-Australia 2003).***

Doha	May	Jun	Jul	Aug	Sep	Oct
Minimum	17.0	19.2	20.6	21.5	21.4	19.4
1st percentile	17.3	19.3	20.9	22.1	22.3	20.4
2nd percentile	17.6	19.6	21.1	22.5	22.7	20.8
5th percentile	18.3	20.8	21.5	23.3	23.2	21.7
10th percentile	18.8	21.1	22.1	24.7	24.2	22.5
20th percentile	19.6	21.6	22.8	25.9	24.9	23.1
30th percentile	20.4	22.5	23.8	26.9	25.5	23.4
40th percentile	20.9	23.3	25.1	28.1	26.0	23.7
50th percentile	21.5	23.8	26.1	28.8	26.8	24.3
60th percentile	22.0	24.4	26.9	29.2	27.1	24.7
70th percentile	22.7	24.9	28.0	29.6	27.5	25.5
80th percentile	23.4	25.8	28.8	29.9	28.1	26.0
90th percentile	24.4	27.1	29.6	30.4	29.1	26.6
95th percentile	25.0	27.6	30.4	30.7	29.6	27.4
98th percentile	25.8	28.0	31.0	30.9	30.1	27.9
99th percentile	26.8	28.6	31.5	31.3	30.2	28.5
maximum	31.6	28.9	31.6	31.3	30.2	28.6

Appendix E

Examples of winter-acclimatised sheep being more susceptible to heat stress than those sourced from a relatively warmer zone.

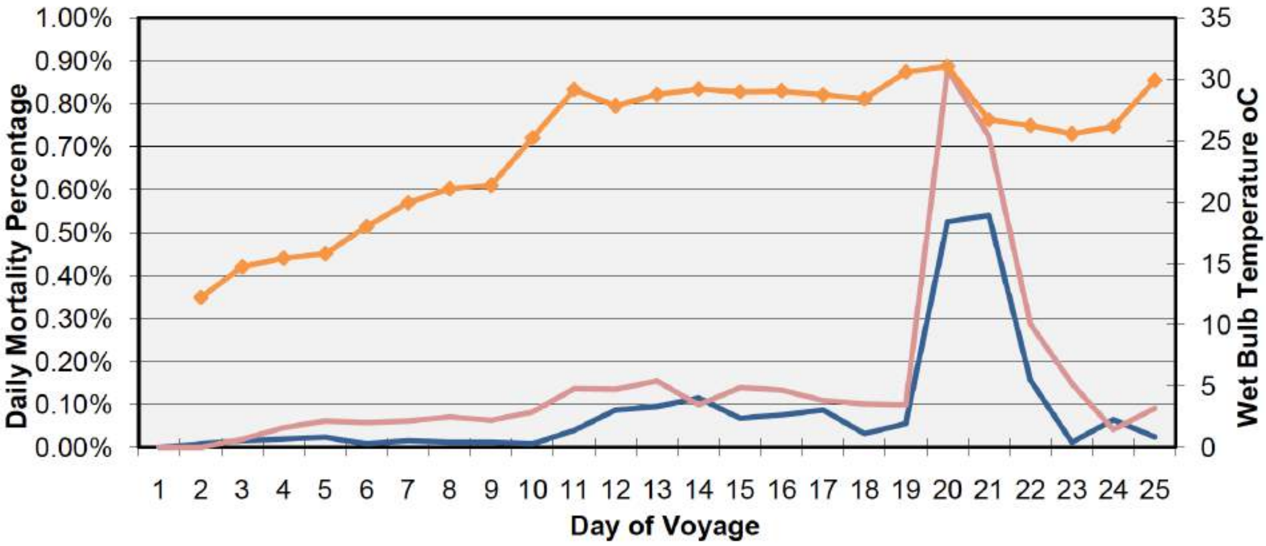

Figure E.1. ***Comparison of daily average wet bulb temperature and sheep mortality percentage across all decks, by day of voyage (blue/dark lines for sheep loaded in Adelaide SA, pink/light lines for sheep loaded in Portland Vic) (source: Mortality Investigation Report 37, Adelaide and Portland to Kuwait and Bahrain, July 2010).***

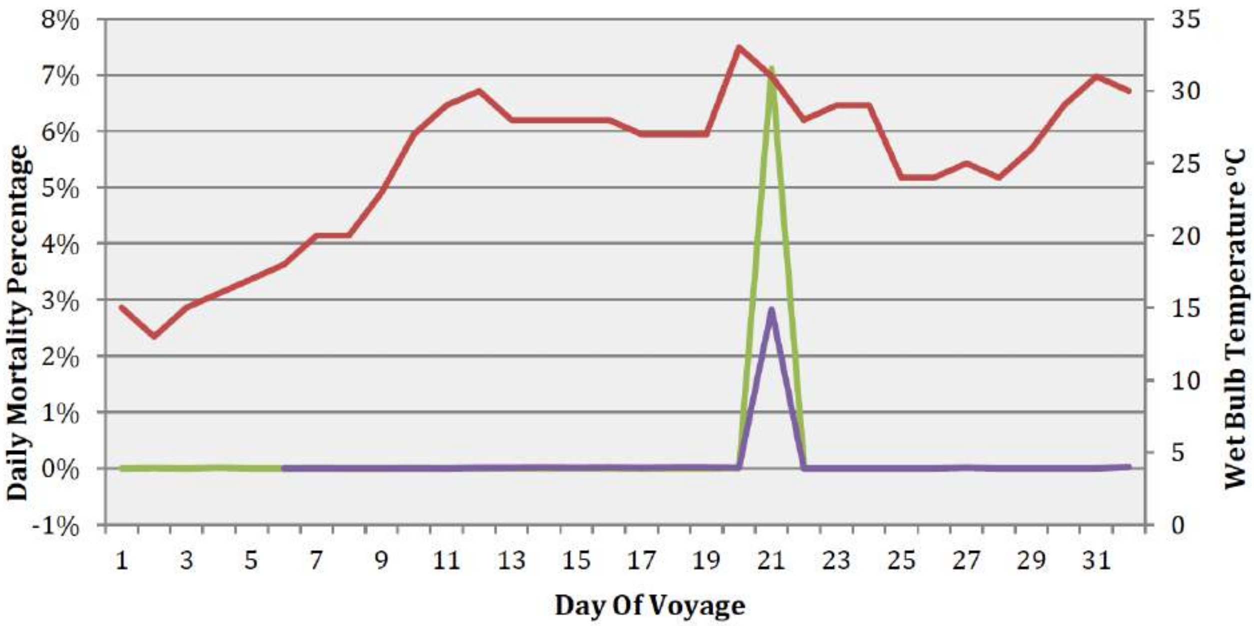

Figure E.2. ***Comparison of daily average wet bulb temperature and sheep mortality percentage across all decks, by day of voyage (green/light lines for sheep loaded in Adelaide SA, purple/dark lines for sheep loaded in Fremantle WA) (source: Mortality Investigation Report 46, Adelaide and Fremantle to Qatar and the United Arab Emirates, September 2013).***

Appendix F

Daily wet bulb temperatures during voyages in which there was > 2% sheep mortality rate due to heat stress.

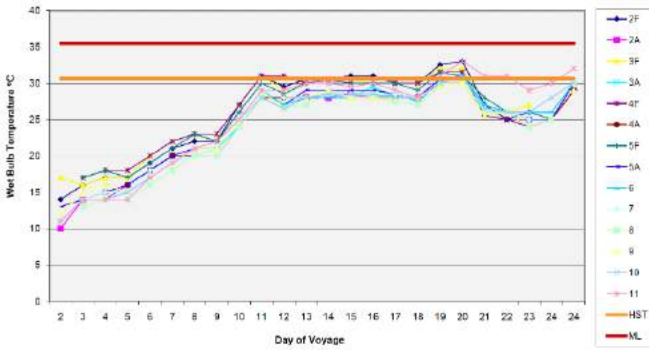

Figure F.1. Comparison of wet bulb temperature by deck (see legend) and day of voyage, and heat stress threshold (HST; —) and mortality limit (ML; —) (source: Mortality Investigation Report 37, Adelaide and Portland to Kuwait and Bahrain, July 2010).

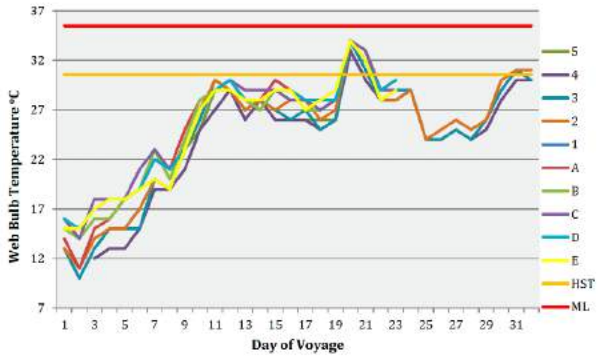

Figure F.4. Comparison of mid-morning wet bulb temperatures by deck (see legend) and day of voyage, and heat stress threshold (HST; —) and mortality limit (ML; —) (source: Mortality Investigation Report 46, Qatar and the United Arab Emirates, September 2013.)

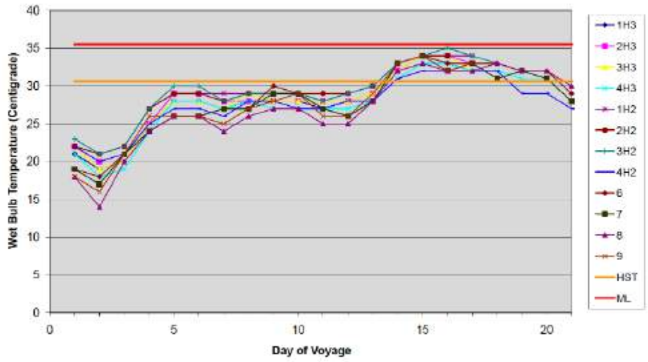

Figure F.2. Comparison of wet bulb temperature by deck (see legend) and day of voyage, and heat stress threshold (HST; —) and mortality limit (ML; —) (source: Mortality Investigation Report 38, Fremantle to Bahrain, Kuwait and UAE, August 2010).

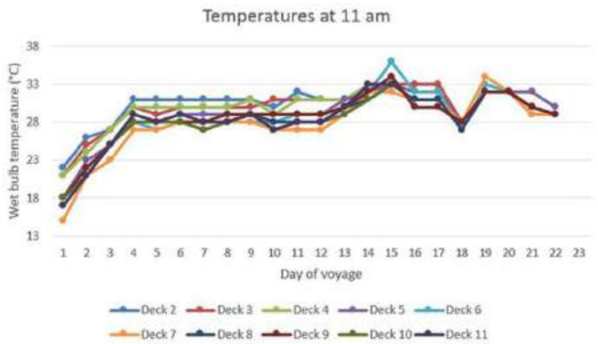

Figure F.5. Comparison of mid-morning wet bulb temperature by deck (see legend) and day of voyage (source: Mortality Investigation Report 65, Fremantle to Qatar, Kuwait, the United Arab Emirates and Oman, July 2016; amended January 2018).

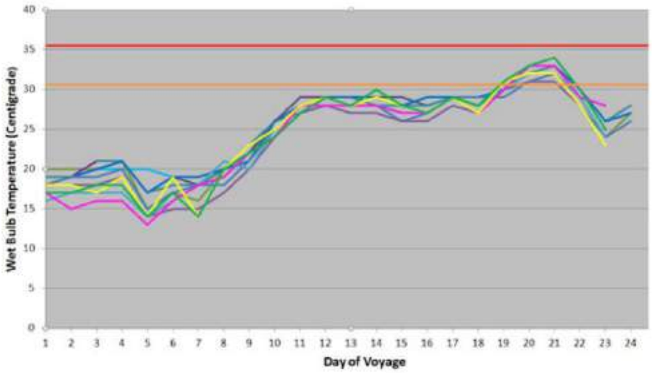

Figure F.3. Comparison of wet bulb temperature by deck and day of voyage, and heat stress threshold (HST; —) and mortality limit (ML; —) (source: Mortality Investigation Report 40, Portland to Qatar, Kuwait and Bahrain in June and July 2011).

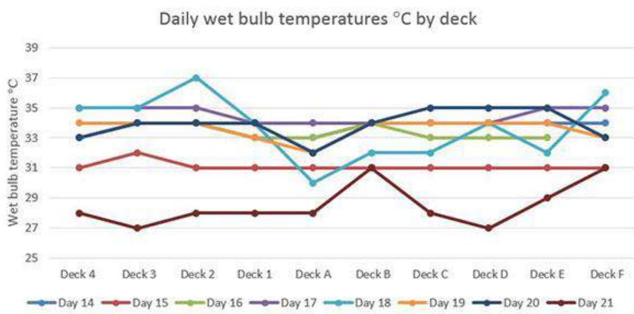

Figure F.6. Comparison of wet bulb temperature by day of voyage (see legend) and deck (source: Mortality Investigation Report 69, Fremantle to Qatar, Kuwait and United Arab Emirates, August 2017).

Appendix G

Comparison of daily sheep mortality and wet bulb temperature, by day, during voyages in which there was > 2% sheep mortality rate due to heat stress.

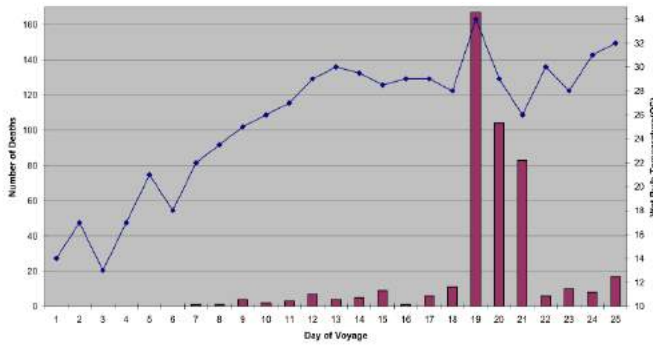

Figure G.1. Comparison of daily sheep mortality and wet bulb temperature, by day of voyage (source: Mortality Investigation Report 7, Fremantle to Kuwait, Bahrain, Doha and Jebel Ali, July 2006).

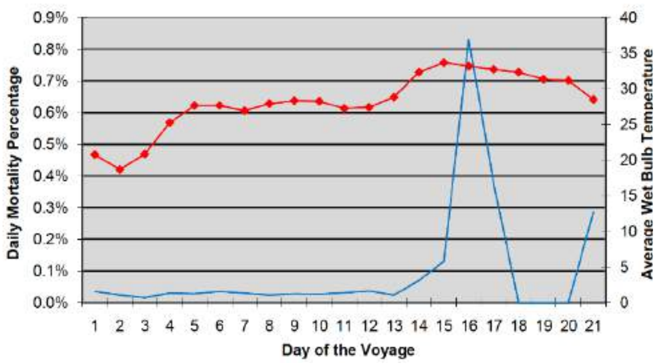

Figure G.2. Comparison of daily sheep mortality percentage and wet bulb temperature, by day of voyage, across all decks (source: Mortality Investigation Report 38, Fremantle to Bahrain, Kuwait and UAE, August 2010).

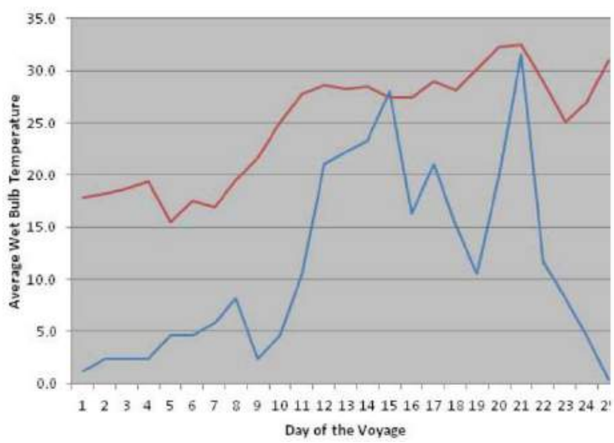

Figure G.3. Comparison of daily sheep mortality (lower/blue line) and wet bulb temperature (upper/red line), by day of voyage (source: Mortality Investigation Report 40, Portland to Qatar, Kuwait and Bahrain in June and July 2011).

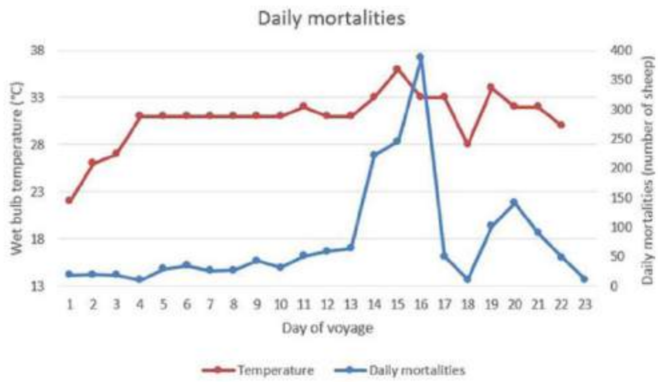

Figure G.4. Comparison of daily sheep mortality and wet bulb temperature, by day of voyage (source: Mortality Investigation Report 65, Fremantle to Qatar, Kuwait, the UAE and Oman, July 2016; amended January 2018).

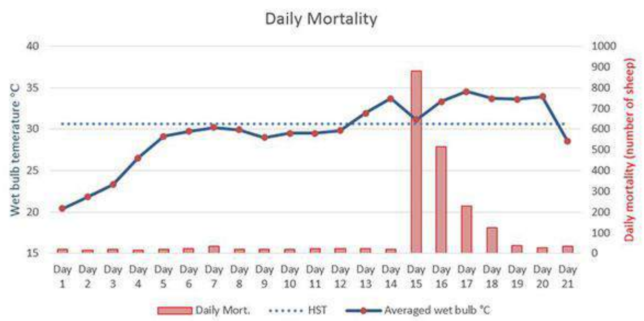

Figure G.5. Comparison of daily sheep mortality and wet bulb temperature, by day of voyage (source: Mortality Investigation Report 69, Sheep exported by sea from Fremantle to Qatar, Kuwait and United Arab Emirates, August 2017).

Appendix H

Different classes of sheep possess different physiological capabilities to respond to heat stress during voyages in which there was > 2% sheep mortality rate due to heat stress.

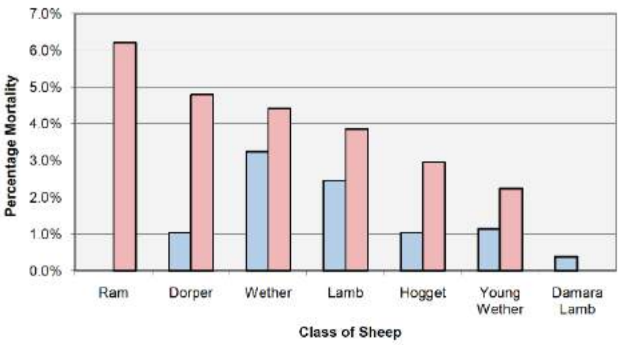

Figure H.1. Comparison of mortality percentages for different classes of sheep loaded in Adelaide (blue/left bars) and Portland (pink/right bars) (source: Mortality Investigation Report 37, Adelaide and Portland to Kuwait and Bahrain, July 2010).

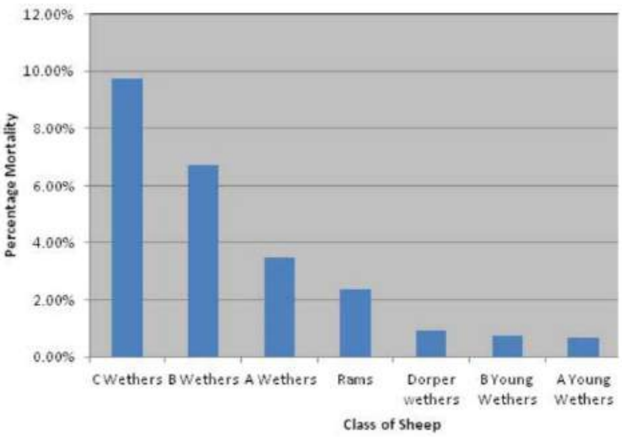

Figure H.2. Comparison of mortality percentages for different classes of sheep (Source: Mortality Investigation Report 40, Portland to Qatar, Kuwait and Bahrain in June and July 2011).

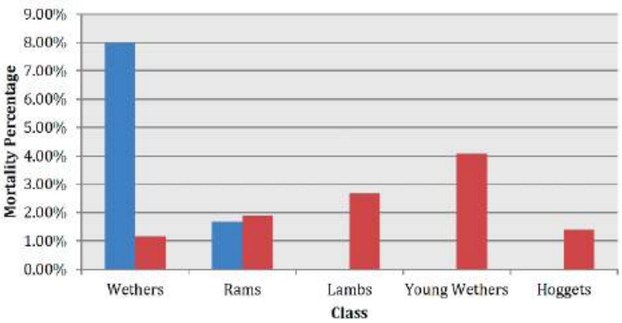

Figure H.3. Comparison of mortality percentages for different classes of sheep loaded in Adelaide (blue/left bars) and Fremantle (red/right bars) (source: Mortality Investigation Report 46, Qatar and the United Arab Emirates, September 2013).

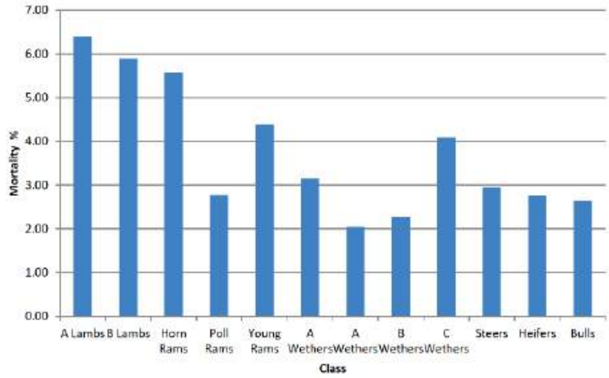

Figure H.4. Comparison of mortality percentages for different classes of stock (source: Mortality Investigation Report 51, Israel and Jordan, January 2014).

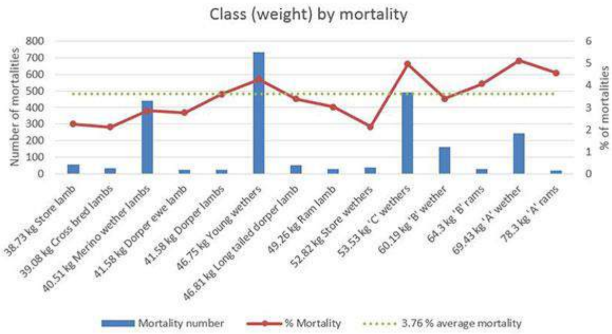

Figure H.5. Comparison of mortality percentages for different classes of sheep (source: Mortality Investigation Report 69, Fremantle to Qatar, Kuwait and United Arab Emirates, August 2017).

Appendix I

Sheep mortality percentages vary within the same deck of a ship and among different decks during voyages in which there was > 2% sheep mortality rate due to heat stress.

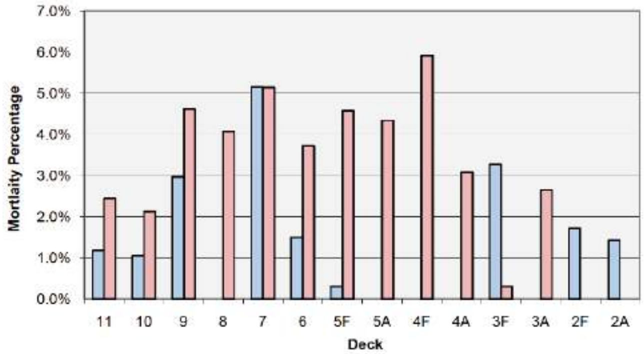

Figure I.1. Comparison of mortality percentages by deck for sheep loaded in Adelaide (blue/left bars) and Portland (pink/right bars; F=forward, A=aft) (source: Mortality Investigation Report, Adelaide and Portland to Kuwait and Bahrain, July 2010).

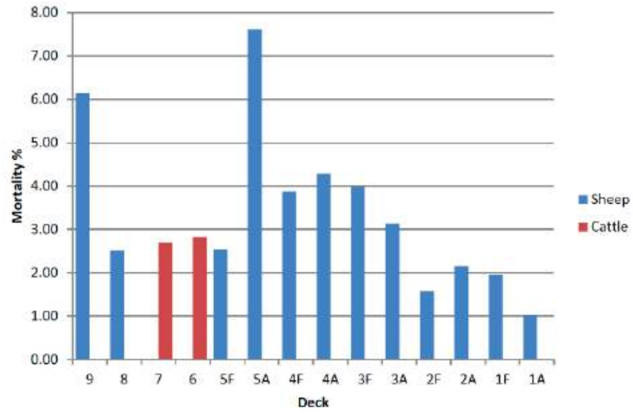

Figure I.3. Comparison of mortality percentages by deck for sheep and cattle (source: Mortality Investigation Report 51, Israel and Jordan, January 2014).

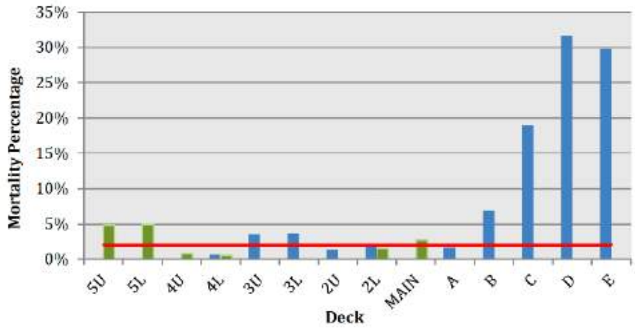

Figure I.2. Comparison of mortality percentages by deck for sheep loaded in Adelaide (blue/left bars) and Fremantle (green/right bars; Red horizontal line indicates reportable level) (source: Mortality Investigation Report 46, Qatar and the United Arab Emirates, September 2013).

Figure I.4. Comparison of mortality percentages by deck for sheep (source: Mortality Investigation Report 69, Fremantle to Qatar, Kuwait and United Arab Emirates, August 2017.)

Appendix J

Decks become very wet in high relative humidity conditions during voyages in which there was > 2% sheep mortality rate due to heat stress.

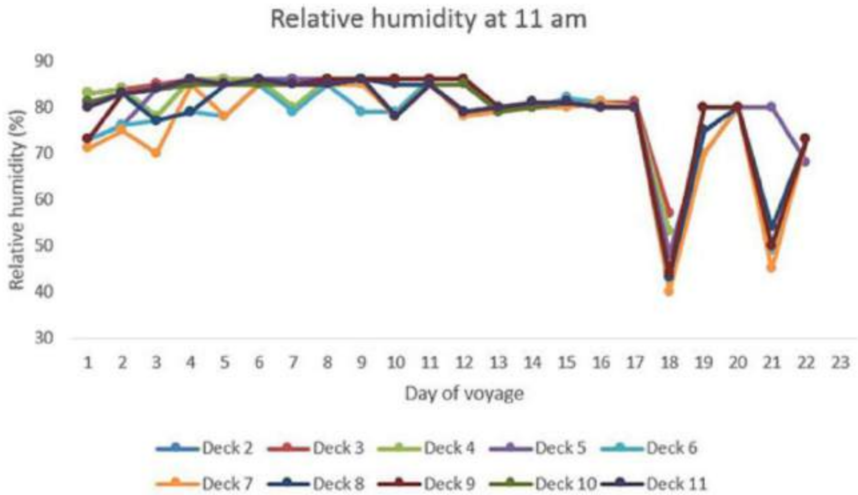

Figure J.1. ***Comparison of relative humidity on different decks, by day of voyage (source: Mortality Investigation Report 65, Fremantle to Qatar, Kuwait, the United Arab Emirates and Oman, July 2016; amended January 2018).***

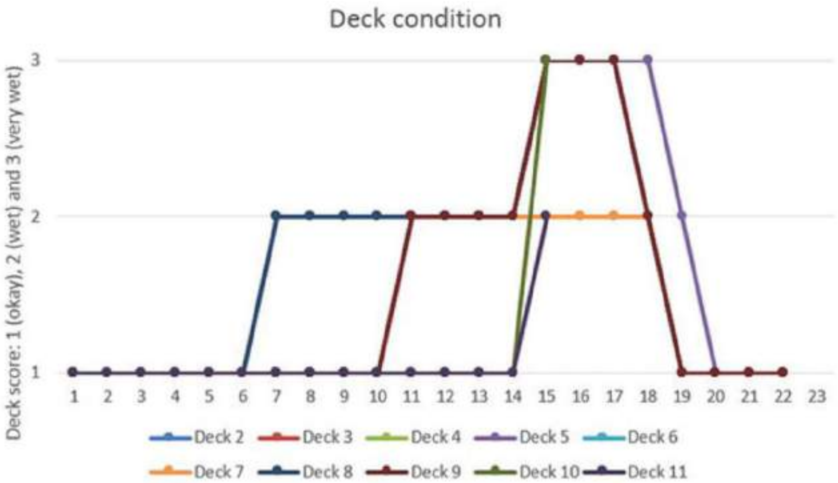

Figure J.2. ***Comparison of Deck Score on different decks of ship, by day of voyage (source: Mortality Investigation Report 65, Fremantle to Qatar, Kuwait, the United Arab Emirates and Oman, July 2016; amended January 2018).***

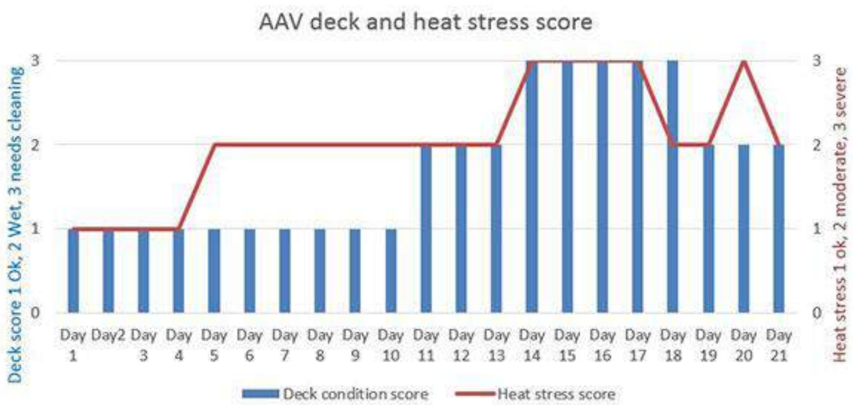

Figure J.3. ***Comparison of Deck Score with Heat Stress scores, by day of voyage (source: Mortality Investigation Report 69, Fremantle to Qatar, Kuwait and United Arab Emirates, August 2017).***

Appendix K

Excerpt from Export of Live Sheep from Australia; Report by the Senate Select Committee on Animal Welfare, Commonwealth of Australia, 1985 (source: https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Significant_Reports/animalwelfarectte/exportlivesheep/index on 24/4/18).

General Conclusions

The live sheep trade transfers the place of slaughter of six or seven million sheep a year from Australia to the Middle East, which necessitates the transportation of those sheep at least 10 000 kilometres. The Australian Veterinary Association and the Royal Society for the Prevention of Cruelty to Animals argued, on animal welfare grounds, that livestock should be slaughtered as close as possible to the point of production. There is little doubt that sheep suffer during the journey from an Australian farm to an abattoir in the Middle East. Any form of transport puts stress on livestock. Even if sheep were to adapt to the confined conditions on sheep carriers, they would still undergo stress, or other forms of suffering, during the process of adaptation to those conditions, or under particular adverse conditions encountered on the journey. In addition, the conditions under which sheep are slaughtered in the Middle East do not match the conditions in Australian abattoirs, which have regulations to ensure a higher standard of animal welfare.

The Committee came to the conclusion that, if a decision were to be made on the future of the trade purely on animal welfare grounds, there is enough evidence to stop the trade. The trade is, in many respects, inimical to good animal welfare, and it is not in the interests of the animal to be transported to the Middle East for slaughter.

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