Australian Government
Department of Agriculture, Fisheries and Forestry

# Review of live sheep exports by sea to, or through, the Middle East during the Northern Hemisphere summer

## Final Report: September 2022

**Department of Agriculture, Fisheries and Forestry**

**Cataloguing data**

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**Accessibility**

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**Confidentiality**

The department notes that legal requirements for confidential information management have limited the amount of detailed voyage reporting published in this report. Consequently, every effort has been made to de-identify the specific source of voyage data and other reporting.

**Acknowledgement of Country**

We acknowledge the Traditional Custodians of Australia and their continuing connection to land and sea, waters, environment and community. We pay our respects to the Traditional Custodians of the lands we live and work on, their culture, and their Elders past and present.

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# Summary

The Department of Agriculture, Fisheries and Forestry has prepared this report of its review of live sheep exports by sea to, or through, the Middle East during the Northern Hemisphere summer (1 May-31 October inclusive). The review assessed the adequacy of the regulatory settings implemented in 2020 in reducing the risk of heat stress in sheep exported on voyages to the Middle East during the Northern Hemisphere summer. The review concluded that to maintain or improve the welfare of exported sheep, an absolute prohibition period during the hottest, most humid part of the Northern Hemisphere summer should remain and that a conditional prohibition period for some Persian Gulf destinations should be introduced. The review also found that welfare of exported sheep could be maintained with a shortening of the length of the absolute prohibition period for Qatar, Oman and destinations to, or through, the Red Sea.

In undertaking the review, the department analysed updated climatology data based on 42 years of accumulated data from 1979 to 2021 from the Bureau of Meteorology (BOM) (2021 BOM report), which included a wet bulb temperature (WBT) analysis along voyage routes and at destination ports in the Middle East area of interest (MEAI). The department reviewed reports from the 15 voyages that travelled to the Middle East during the Northern Hemisphere summer from 2019 to 2021, which provided mortality data and health and welfare information. In addition, the department analysed data from loggers placed on all decks housing sheep, and considered scientific literature, industry research, internal and external stakeholder feedback and other relevant information. The department undertook public consultation on a draft report of findings from 17 December 2021 to 28 January 2022. Following the public consultation, additional stakeholder engagement was undertaken in March 2022 due to high levels of interest, the complexity of the issues, the important implications for animal welfare and the practical requirements of any change to export processes.

The review found that the regulatory settings implemented in 2020 have been effective in reducing the risk of vessels travelling through ambient WBTs of 29°C or above (typically leading to deck WBTs of 30°C to 32°C). The review also concluded that the regulatory settings introduced in 2020 have been effective in minimising the risk of heat stress and heat stress mortalities and improving animal welfare outcomes for sheep exported to the Middle East during the Northern Hemisphere summer. These findings support the ongoing use of a 95th percentile maximum ambient WBT threshold of 29ºC, first implemented by the department in 2019 and confirmed through the Regulation Impact Statement (RIS) process in 2020. A 95th percentile WBT threshold means that 95% of all recorded temperatures at a specific location are below this threshold. The review found that this threshold remained appropriate to manage the risk of heat stress in sheep on export voyages to, or through, the Middle East.

The climate data presented in the 2021 BOM report provided updated information from a greater number of locations along voyage routes, and at more destination ports and locations in the Middle East, compared to information provided in a 2019 BOM report. The updated WBT data was presented in 'grid cell' style climatology maps, with each grid cell representing a 30 x 30-kilometre square patch of the earth's surface, depicting WBT data in weekly blocks of time. This updated information enabled improved delineation of prohibition dates and led to amendments to the Export Control (Animals) Rules 2021 (Animals Rules) in April 2022. To manage heat stress risks that were not previously evident, and pending finalisation of the

review, the department introduced a conditional prohibition period for sheep exports to Persian Gulf destinations, other than Kuwait and Oman, for voyages departing Australia from 22 May to 31 May (typically arriving at these ports in June). For this conditional prohibition period, additional requirements were implemented to improve sheep heat tolerance or decrease the WBT on sheep decks. The data indicated risks for Qatar were similar to other Persian Gulf destinations (other than Kuwait and Oman), so the prohibition periods for Qatar were aligned with these. The data also indicated a reduced heat stress risk, not previously evident, for voyages to, or through, the Red Sea in June, so the prohibition start date was moved to 15 June. These changes to the Rules came into effect on 6 April 2022.

In finalising the review, the department conducted further analyses, considered feedback received during consultation, and the available science and evidence. Recommendations in this report are based on the same risk parameters implemented in regulation in 2020 and consistent with the rationale that informed the changes to the Animals Rules in April 2022. Detailed explanations for each recommendation are outlined in the relevant section of the report.

# General findings

- Regulatory settings introduced in 2020, including an absolute prohibition period during the hottest, most humid part of the Northern Hemisphere summer, were effective in improving animal welfare outcomes and minimising the risk of heat stress and heat stress mortalities for sheep exported to the Middle East.
- Updated climate analysis identified options for modifications to Northern Hemisphere prohibition dates and conditions.

# 2021 Bureau of Meteorology data findings

- The risk of sustained WBTs above the 29˚C threshold is higher than previously understood at Persian Gulf ports (other than Kuwait and Oman) for voyages arriving at these destinations in June. Voyages typically arrive at these ports 17-19 days after departing Australia.
    - Ambient WBTs are up to 1.5˚C higher than the 29ºC threshold for voyages arriving at these destinations in June, impacting environmental conditions at ports including Hamad, Qatar and Jebel Ali, UAE.
    - The data indicate the heat stress risks at Qatar are similar to other Persian Gulf destinations (other than Kuwait and Oman).
- WBTs are typically slightly higher in 'offshore' locations than at 'port' locations, reflecting the higher humidity in the maritime environment.
    - This trend is most pronounced at Kuwait port which experiences a markedly cooler microclimate (typically 2-3˚C cooler) than the surrounding maritime environment for most of the Northern Hemisphere summer.
- The risk of sustained WBTs above the threshold is lower than previously understood at Muscat port for voyages arriving in late August. Voyages typically arrive at Muscat port 13-14 days after departing Australia.
    - Data from Muscat offshore and Muscat port indicate a reduced heat stress risk in late August (typically around 2˚C cooler than previously understood).

- The risk of sustained WBTs above the threshold is lower than previously understood at Red Sea locations for voyages arriving in late June and September. Voyages typically arrive in the Red Sea 14 days after departing Australia and at Red Sea destination ports 18-19 days after departing Australia.
- In general, WBTs in the Red Sea start increasing earlier in the Northern Hemisphere summer than those in the Persian Gulf and maximum WBTs in the Red Sea are milder for the entirety of the Northern Hemisphere summer.

## Data logger findings

- Ambient WBT data (measured on the bridge) along voyage routes and at destination ports closely aligns with data from the 2021 BOM report.
- Analysis of logger data provided a record of the incidence of elevated deck WBTs on the voyages analysed:
  - 99.8% of all readings (approximately 429,600) recorded deck WBTs less than 32˚C
  - 99% of all readings (approximately 425,600) recorded deck WBTs less than 31˚C
  - 96% of all readings (approximately 412,200) recorded deck WBTs less than 30˚C.
- Voyages in 2020 and 2021 recorded lower maximum and average WBTs on sheep decks compared to voyages in 2019, with the 3 voyages recording the hottest deck conditions occurring in 2019 and the 3 voyages recording the coolest deck conditions occurring in 2021. This is likely due to improvements in the ventilation capacity of vessels after mandated ventilation upgrades at the start of 2020 and the phasing out of twin-tier vessels.

## Voyage reporting findings

- Behavioural and physiological response to heat (including panting) were reported on 60% of voyages (9 out of 15 voyages).
- Voyages travelling through the Red Sea reported fewer behavioural and physiological responses to heat than those travelling to the Persian Gulf.
- Underlying health conditions, including inanition and respiratory disease, were reported to possibly contribute to mortalities during elevated WBTs on 1 voyage.
- Inconsistent reporting of heat stress symptoms was identified on some voyages.
  - Independent observers (IOs) generally recorded higher panting scores than accredited veterinarians (AAVs) when observing the same pens of sheep.
  - There were a number of different scoring systems used to assess heat stress.

## Mortality data findings

- No mortalities due to heat stress were reported on the 15 voyages.
- The most frequently reported causes of mortality during 2019-2021 were inanition and gastro-enteric diseases.
- There has been a 77.5% reduction in sheep mortality rates during the Northern Hemisphere summer (1 May to 31 October inclusive) after specific regulatory changes to mitigate heat stress and improve animal welfare were introduced over the period 2018

to 2020. Voyage mortality rates for Northern Hemisphere summer voyages have now stabilised within a narrow range, averaging 0.2%. This strongly indicates that regulatory changes have been effective in reducing the risk of heat stress and associated mortalities.

- In May, September and October (Northern Hemisphere summer months outside the prohibition period) there has been a 67% reduction in sheep mortality rates. This indicates that, independent to a prohibition, regulatory changes, including allometric pen space allowances, independent verification of PAT scores and automated watering systems, have been effective in reducing the risk of heat stress and heat stress mortalities.
- In 2015-17, the highest mortality rates occurred during June, July and August. The prohibition has prevented exports departing Australia during these high-risk months.

The department notes that lower mortality rates alone do not reflect adequate animal welfare outcomes during live export by sea; however, if mortality rates significantly decline, it is reasonable to deduce that morbidity rates will also have declined and that other welfare parameters will have improved.

In summary, the review concluded that the regulatory settings introduced in 2020 have been effective in minimising the risk of heat stress and heat stress mortalities and improving animal welfare outcomes for sheep exported to the Middle East during the Northern Hemisphere summer. The review also concluded the use of prohibition periods to reduce the risk of heat stress in sheep during export to, or through, the Middle East by sea during the hottest part of the Northern Hemisphere summer, remains appropriate.

# Recommendations and findings

The findings and recommendations of this review relate to updated BOM data, logger data, internal and external consultation and voyage reporting from the 15 voyages that travelled to the Middle East during the Northern Hemisphere summers of 2019 - 2021.

## Recommendations

The core objective underlying the recommendations of the review is that in all cases, sheep welfare will be maintained or improved. The recommendations are based on the same risk parameters implemented in regulation in 2020 and are consistent with the rationale that informed the changes to the Animals Rules in April 2022.

Recommendations presented in this section are based on the findings of the review, and specifically address the appropriateness of prohibition dates. Key factors considered when determining prohibition dates included voyage length, destination port, date of arrival, time spent at destination port and additional conditions to mitigate the risk of heat stress.

The recommendations are summarised in Table 1 and Figure 1.

### Prohibition dates

#### General

1) The principle of an absolute prohibition on the export of all sheep to or through the Middle East during the hottest, most humid part of the Northern Hemisphere summer remains appropriate as a key strategy to effectively manage the risk of heat stress in sheep.

#### Kuwait

2) The absolute prohibition period from 1 June to 14 September should continue (no change from current rules).

#### Persian Gulf destinations (other than Kuwait and Oman)

3) The absolute prohibition period from 1 June to 14 September should continue (no change from the current rules for most Persian Gulf destinations). Qatar should also have this prohibition period (currently has an absolute prohibition period from 1 June to 21 September).

4) In addition, voyages should only depart Australia from 22-31 May if additional conditions to mitigate heat stress risks can be met. These conditions should only apply to sheep destined for Persian Gulf ports other than Kuwait and Oman. This recommendation was implemented in the Animals Rules April 2022 amendment.

#### Oman

5) The absolute prohibition period should be from 8 May to 14 August (change from current rules, which prohibit export to Oman from 8 May to 14 September).

6) Where Oman is one of multiple Persian Gulf destination ports, exporters may discharge sheep in Oman first, en route to other destinations, provided the prohibition dates for Oman are abided. The prohibition end dates for the other Persian Gulf ports should also apply.

**Red Sea destinations**

7) The absolute prohibition period should be from 15 June to 7 September (currently from 15 June to 14 September). Prior to April 2022, the prohibition period was from 1 June to 14 September. The recommended date change from 1 June to 15 June was implemented via the Animals Rules April 2022 amendment.

8) Voyages that travel through the Red Sea to destinations such as Russia, Turkey and Lebanon are subject to the same prohibition dates as voyages discharging at Red Sea ports.

**Port of departure**

9) Voyages departing from ports other than Fremantle should comply with prohibition date recommendations and be required to be west of a longitude of 116 East, no later than 31 May if travelling to the Persian Gulf or no later than 14 June if traveling to the Red Sea.

**Use of bridge loggers**

10) Each vessel exporting sheep must deploy a minimum of 1 data logger on the bridge to record ambient (bridge) WBTs.

**Provision of fodder**

11) Sheep should be fed a minimum of 3% of their liveweight daily while on vessels travelling to or through the Middle East during the Northern Hemisphere summer.

## Additional conditions

12) Sheep may be exported to Persian Gulf ports (other than Kuwait and Oman) during the conditional prohibition period (22 May – 31 May) only if the following additional conditions are met:

    a) For heat tolerant breeds (e.g. Awassi, Damara, Dorper):

        i) each sheep must have a maximum liveweight of 66kg

        ii) each sheep has wool or hair length no longer than 25mm at the time of loading for transport to the Australian departure port.

    b) For less heat tolerant breeds (e.g. Merinos and Merino crosses):

        i) each sheep must have a maximum liveweight of 56kg

        ii) each sheep has wool or hair length no longer than 20mm at the time of loading for transport to the Australian departure port.

    c) Sheep must be provided with at least 3% of liveweight of feed per head per day during the voyage.

    d) The pen air turnover (PAT) for the vessel must be:

        i) a minimum of 180 $m^3$/hr per square metre of pen space (referred to in the remainder of this report as $m^3$/hr) when the vessel is in port; or

        ii) a minimum of 160 $m^3$/hr when the vessel is in port and the sheep must be allocated an additional 10% space (above the minimum pen space allocation specified in the Australian Standards for the Export of Livestock (ASEL) standard 5.5); or

        iii) a minimum of 140 $m^3$/hr when the vessel is in port and the sheep weigh 56kg or less and have wool or hair length no longer than 10mm.

Note: the new additional conditions do not apply to sheep exported to Kuwait or Oman, where Oman is the first port of discharge.

This recommendation was implemented in the Animals Rules April 2022 amendment.

### Table 1 Summary of prohibition dates

| Destination | Prohibition introduced in 2020 | Changes introduced April 2022 | Recommended NHS prohibition periods | | |
|---|---|---|---|---|---|
| | | | Absolute prohibition period | Conditional prohibition period | Summary of changes |
| Kuwait | 1 June to 14 September | Nil | 1 June to 14 September | N/A | Nil |
| Oman (via Persian Gulf) | 8 May to 14 September | Nil | 8 May to 14 September | N/A | Nil |
| Oman (single discharge port) | 8 May to 14 September | Nil | 8 May to 14 August | N/A | Prohibition shortened by 31 days |
| Persian Gulf (other than Kuwait and Oman)[1] | 1 June to 14 September | Conditional Exports 22 - 31 May | 1 June to 14 September | 22 - 31 May | 10 days with additional conditions |
| Qatar (now included in Persian Gulf) | 22 May to 22 September | Conditional Exports 22 - 31 May | 1 June to 14 September | 22 - 31 May | 10 days with additional conditions |
| Red Sea (to, or through) | 1 June to 14 September | Prohibition to start 15 June | 15 June to 7 September | N/A | Prohibition shortened by 21 days |

1. Bahrain, Iran, Iraq, Saudi Arabia via the Persian Gulf, the United Arab Emirates and Qatar.
Note: Dates in Table 1 and Figure 1 are final recommendations and may differ from dates proposed during earlier consultation. The rationale for any differences and for final recommended prohibition dates is outlined in Section 2.

**Figure 1 Graphic of prohibition dates**


# Findings

## General

1) Regulatory settings introduced in 2020, including an absolute prohibition period during the hottest, most humid part of the Northern Hemisphere summer, were effective in improving animal welfare outcomes and minimising the risk of heat stress and heat stress mortalities for sheep exported to the Middle East.

2) Updated climate analysis identified options for modifications to Northern Hemisphere prohibition dates and conditions.

## 2021 Bureau of Meteorology data findings

3) The risk of sustained WBTs above the 29°C threshold is higher than previously understood at some Persian Gulf ports (other than Kuwait and Oman) for voyages arriving at these

destinations in June. Voyages typically arrive at these ports 17-19 days after departing Australia.

a) Ambient WBTs are up to 1.5˚C higher than the 29°C threshold for voyages arriving at these destinations in June, impacting environmental conditions at ports including Hamad, Qatar and Jebel Ali, UAE.

b) The data indicate the heat stress risks at Qatar are similar to other Persian Gulf destinations (other than Kuwait and Oman).

4) WBTs are typically slightly higher in 'offshore' locations than at 'port' locations, reflecting the higher humidity in the maritime environment.

a) This trend is most pronounced at Kuwait port which experiences a markedly cooler microclimate (typically 2-3˚C cooler) than the surrounding maritime environment for most of the Northern Hemisphere summer.

5) The risk of sustained WBTs above the threshold is lower than previously understood at Muscat port for voyages arriving in late August. Voyages typically arrive at Muscat port 13-14 days after departing Australia.

a) Data from Muscat offshore and Muscat port indicate a reduced heat stress risk in late August (typically around 2˚C cooler than previously understood).

6) The risk of sustained WBTs above the threshold is lower than previously understood at Red Sea locations for voyages arriving in late June and September. Voyages typically arrive in the Red Sea 14 days after departing Australia and at Red Sea destination ports 18-19 days after departing Australia.

7) In general, WBTs in the Red Sea start increasing earlier in the Northern Hemisphere summer than those in the Persian Gulf and maximum WBTs in the Red Sea are milder for the entirety of the Northern Hemisphere summer.

## Data logger findings

### Ambient wet bulb temperatures

8) Ambient WBT data (measured on the bridge) along voyage routes and at destination ports closely aligns with data from the 2021 BOM report.

### Deck wet bulb temperatures

9) Analysis of logger data provided a reliable record of the incidence of elevated deck WBTs on the voyages analysed:

a) 99.8% of all readings (approximately 429,600) recorded deck WBTs less than 32˚C

b) 99% of all readings (approximately 425,600) recorded deck WBTs less than 31˚C

c) 96% of all readings (approximately 412,200) recorded deck WBTs less than 30˚C.

10) Voyages in 2020 and 2021 recorded lower maximum and average WBTs on sheep decks compared to voyages in 2019, with the 3 voyages recording the hottest deck conditions occurring in 2019 and the 3 voyages recording the coolest deck conditions occurring in 2021. This is likely due to improvements in the ventilation capacity of vessels after mandated ventilation upgrades at the start of 2020 and the phasing out of twin-tier vessels.

## Voyage reporting findings

11) Behavioural and physiological response to heat (including panting) were reported on 60% of voyages (9 out of 15 voyages).

12) Voyages travelling through the Red Sea reported fewer behavioural and physiological responses to heat than those travelling to the Persian Gulf.

13) Underlying health conditions including inanition and respiratory disease were reported to possibly contribute to mortalities during elevated WBTs on 1 voyage.

14) Inconsistent reporting of heat stress symptoms was identified on some voyages.

    a) IOs generally recorded higher panting scores than AAVs when observing the same pens of sheep.

    b) There were a number of different scoring systems used to assess heat stress.

## Mortality data findings

15) No mortalities due to heat stress were reported on the 15 voyages.

16) The most frequently reported causes of mortality during 2019-2021 were inanition and gastro-enteric diseases.

17) There has been a 77.5% reduction in sheep mortality rates during the Northern Hemisphere summer (1 May to 31 October inclusive) after specific regulatory changes to mitigate heat stress and improve animal welfare were introduced over the period 2018 to 2020. Voyage mortality rates for Northern Hemisphere summer voyages have now stabilised within a narrow range, averaging 0.2%. This strongly indicates that regulatory changes have been effective in reducing the risk of heat stress and associated mortalities.

18) In May, September and October (Northern Hemisphere summer months outside the prohibition period) there has been a 67% reduction in sheep mortality rates. This indicates that, independent to a prohibition, regulatory changes, including allometric pen space allowances, independent verification of PAT scores and automated watering systems, have been effective in reducing the risk of heat stress and heat stress mortalities.

19) In 2015-17, the highest mortality rates occurred during June, July and August. The prohibition has prevented exports departing Australia during these high-risk months.

# 1 Introduction

This report addresses the Australian Government's commitment to review the effectiveness of the regulatory settings implemented for sheep exports by sea to, or through, the Middle East during the Northern Hemisphere summer (1 May to 31 October). These settings were implemented followed a Regulation Impact Statement (RIS) process, finalised in 2020. Similar interim regulatory settings were in place in 2019.

The primary objective of live sheep export reform since 2018 has been to improve animal welfare outcomes by reducing the risk of heat stress in sheep exported to, or through, the Middle East during the Northern Hemisphere summer to a very low level. The focus of reform has been to:

- reduce the risk of heat stress in sheep to a very low level
- reduce to 5% the risk of exposure to ambient WBTs of 29°C or higher
- maintain a viable live sheep export trade supported by improved animal welfare outcomes
- uphold Australia's reputation as an exporter of high-quality livestock.

The department acknowledges that heat stress management is an area of ongoing scientific research, including by industry, and that new technologies could provide valid heat stress mitigation options. The department also acknowledges that changes in climate may have significant implications for sheep exports in the future. New developments in heat stress management, upgrades to the heat stress risk assessment (HSRA) model (HotStuff) and updates to Middle East climate analyses, relevant to the live export of sheep, will be considered as they become available.

## 1.1 Purpose of the review

The review assessed the adequacy of the current regulatory settings in minimising the risk of heat stress in sheep exported on voyages to the Middle East during the Northern Hemisphere summer.

The purpose of the review was to consider:

- the effectiveness of the current regulatory settings in reducing the risk of heat stress and heat stress mortalities for sheep exported to the Middle East during the Northern Hemisphere summer
- whether the current regulatory settings are maintaining or improving animal welfare outcomes, and supporting the sustainability of the live sheep export industry and
- whether there is evidence supporting modification of the current regulatory settings.

The recommendations presented in this report are intended to support animal welfare by continuing to limit the risk of heat stress in sheep exported to the Middle East during the Northern Hemisphere summer.

### 1.1.1 Background

The high temperatures and humidity in the Middle East region during the hottest part of the Northern Hemisphere summer give rise to conditions which have the potential to cause heat stress in sheep and negatively impact their welfare. Highly publicised heat stress events in sheep exported in 2017 raised awareness about the onboard welfare of sheep and increased public scrutiny of the livestock export trade.

Following the publicised heat stress events, the *Independent review of conditions for the export of sheep to the Middle East during the Northern Hemisphere summer* (McCarthy 2018) was undertaken. Recommendation 3 of the McCarthy Review was that 'industry should move from a risk assessment based on mortality to a risk assessment based on animal welfare'. In addition to the McCarthy Review, the *Review of the Regulatory Capability and Culture of the Department of Agriculture and Water Resources in the Regulation of Live Animal Exports* (Moss 2018) acknowledged that the welfare of exported animals is of significant interest to the Australian community.

The department recognised that improving animal welfare outcomes for exported sheep was of critical importance, for the direct benefit of animals undergoing transport and to support a viable export sheep trade. The department also sought advice from an independent HSRA Technical Reference Panel (HSRA review) on aspects of the assessment of heat stress risk in the live sheep export trade.

In response to the McCarthy Review, the department implemented the Australian Meat and Live-stock Industry (Export of Sheep by Sea to Middle East) Order 2018 (Middle East Order 2018) which came into effect from 7 July 2018. The Middle East Order 2018 introduced a range of additional voyage conditions to improve welfare outcomes for exported sheep including increased pen space allowances based on allometric calculations, independent verification of a vessel's PAT scores, automated watering systems and a heat stress management plan to be in place for each voyage.

However, during the height of the Northern Hemisphere summer when temperatures and humidity reach maximum levels, no combination of additional space, ventilation or other measures can effectively mitigate the risk of heat stress. Both the department and the Australian Livestock Exporters Council (ALEC) recognised the heightened risk of heat stress during this period. Taking effect from 1 July 2019, ALEC announced a 3-month moratorium on live sheep exports during June, July and August, and the department implemented an interim prohibition on sheep exports from 1 June to 22 September, pending completion of a RIS process.

In undertaking the RIS process, the department analysed the economic benefits and impacts of 3 regulatory options to limit the risk of heat stress in live sheep exported to, or through, the Middle East, during the Northern Hemisphere summer. The RIS outlined the best available science and evidence including a climate analysis conducted by the Bureau of Meteorology (BOM) in 2019, the HSRA review, industry research and voyage reports from May 2019 voyages.

Using a risk-based analysis through the RIS process, the department determined that setting prohibition dates based on a 95$^{th}$ percentile maximum ambient WBT of 29°C was appropriate to manage heat stress risks to sheep on export voyages to, or through, the Middle East. A 95$^{th}$ percentile WBT threshold means that 95% of all recorded temperatures at a specific location are below this threshold. By extension, 5% of all recorded temperatures at the specific location are higher than this threshold.

The preferred option identified during the RIS process most effectively addressed the Australian public's expectations for permanent action to improve animal welfare during live sheep export, by limiting the risk of heat stress, while also supporting a viable live sheep trade and those dependent upon it. The RIS was published in April 2020.

In 2020, based on the RIS analysis, a prohibition period was introduced under the AMLI (Prohibition of Export of Sheep by Sea to Middle East—Northern Summer) Order 2020 (Northern Summer Order 2020), from 1 June to 14 September with additional prohibition periods for Qatar and Oman, combined with additional conditions for the permitted periods between May to October (inclusive). The Northern Summer Order 2020 came into force on 1 May 2020 and aimed to reduce the risk of heat stress to a very low level, by preventing live sheep exports to, or through, the Middle East during the highest heat stress risk period. The additional conditions included body condition score and automated watering system requirements. The independent verification and reporting of the PAT scores of a vessel was also required. The review found that these additional conditions should remain.

## 1.2 Scope of the review

The review assessed the adequacy of the current regulatory settings in reducing the risk of heat stress in sheep exported on voyages to the Middle East during the Northern Hemisphere summer. In conducting the review, the department collated and analysed a range of data relevant to the assessment of heat stress risk in sheep including:

- voyage reports from the 15 voyages that occurred in the Northern Hemisphere summer periods 2019-2021
- data and observations of animal behaviour and welfare outcomes provided by IOs, AAVs and ship Masters
- over 430,000 WBT measurements from environmental data loggers (loggers) placed on every deck where sheep were penned, for the entire duration of all 15 voyages
- an updated BOM Middle East climatology report
- mortality data
- a scientific literature review.

Of the 15 voyages, 5 voyages departed in 2019, 4 voyages departed in 2020 and 6 voyages departed in 2021. All voyages departed from Fremantle. These voyages transported a total of 684,824 sheep from Australia to 6 destination countries in the Middle East namely Israel, Jordan, Kuwait, Oman, Qatar and the United Arab Emirates (UAE) (table 2).

**Table 2 Middle East destinations by volume (head) during the 2019-21 Northern Hemisphere summer periods**

| Destination | 2019 | 2020 | 2021 | Total |
|---|---|---|---|---|
| Bahrain | 0 | 0 | 0 | 0 |
| Israel | 10,000 | 0 | 5,039 | 15,039 |
| Jordan | 78,343 | 54,523 | 7,150 | 140,016 |
| Kuwait | 114,873 | 107,251 | 172,971 | 395,095 |
| Oman | 0 | 0 | 6,000 | 6,000 |
| Qatar | 15,000 | 20,000 | 0 | 35,000 |
| UAE | 40,000 | 15,000 | 38,674 | 93,674 |
| Total | 258,216 | 196,774 | 229,834 | 684,824 |

All 15 voyages sailed under similar regulatory settings, including a prohibition period from 1 June to 14 September with additional prohibition periods for Qatar (from 22 May to 22 September) and Oman (from 8 May to 14 September). Onboard loggers were deployed, and allometric pen space allowances were calculated using a $k$ value=0.033.

## 1.3 Regulatory framework

Prior to 28 March 2021, the government regulated the live animal export trade under the *Australian Meat and Live-stock Industry Act 1997* (the AMLI Act), the *Export Control Act 1982* and associated orders, regulations, and standards. Included in the regulatory framework is ASEL and the Exporter Supply Chain Assurance System (ESCAS).

Livestock sourced for export also needs to meet all requirements under relevant state and territory legislation, including animal welfare law.

### 1.3.1 Regulation introduced in 2018

In response to the McCarthy Review, in 2018 the department implemented the Middle East Order to more adequately address the risk of heat stress during the Northern Hemisphere summer. Requirements included that the PAT scores for each vessel be verified by an independent mechanical engineer, increased pen space allowances based on allometric calculations, automated watering systems on all vessels and exporters to have a heat stress management plan in place for each voyage. The Australian Meat and Livestock Industry (Standards) Order 2005 was also amended which implemented a reduction in the reportable mortality rate in ASEL from 2% to 1%.

### 1.3.2 Interim regulation in 2019

As an interim measure, while the department was conducting a RIS process, the AMLI (Prohibition of Export of Sheep by Sea to Middle East—Northern Summer) Order 2019 (Northern Summer Order 2019) was implemented. Under this order the holder of a sheep export licence was not permitted to export a consignment of sheep from Australia by sea on a vessel that left an Australian port between 1 June 2019 and 22 September 2019 (inclusive) and that would travel through waters in the Arabian Sea north of latitude 11˚N at any time during the voyage. Outside of the prohibition period, conditions under the Middle East Order applied.

### 1.3.3 Regulation in 2020 and 2021

At the completion of the RIS process, a prohibition period was introduced under the AMLI (Prohibition of Export of Sheep by Sea to Middle East—Northern Summer) Order 2020 (Northern Summer Order 2020). The order came into force on 1 May 2020 and included a prohibition on departures of live sheep exports from Australia to, or through, the Middle East for a period of 3.5 months (1 June to 14 September). The order included extended periods of prohibition for departures from Australia to Oman from 8 May to 14 September and Qatar from 22 May to 22 September.

### 1.3.4 Changes to the Export Control Act

On 28 March 2021, the *Export Control Act 2020* and Export Control (Animals) Rules 2021 (Animals Rules) came into force, replacing the *Export Control Act 1982*, the AMLI Act and various subordinate orders in the regulation of live animal exports. Amended Animals Rules came into force on 6 April 2022, introducing a conditional prohibition period for voyages departing Australia from 22 May-31 May for certain countries in the Middle East.

The conditions that currently apply to the exports of sheep by sea to, or though, the Middle East are set out in Chapter 6 of the Animals Rules. Live sheep exports by sea to, or through, the Middle East are prohibited from 1 June to 14 September for most ports with additional prohibition periods and conditions as follows:

- departures for Oman prohibited from 8 May to 14 September
- departures for Persian Gulf destinations (other than Kuwait and Oman) are prohibited from 22 May to 31 May unless additional conditions to mitigate heat stress risks are met
- there must be no more than 2 ports of discharge for voyages arriving in the Persian Gulf after 1 June and departing Australia between 15 and 30 September
- departures for Red Sea destinations are prohibited from 15 June to 14 September.

Chapter 6 also sets out other conditions that apply to exports during the Northern Hemisphere summer, including minimum pen air turnover requirements for vessels, wool length limits, liveweight limits, body condition score limits and feeding requirements.

The department notes that for the prohibition period to Qatar, the reference to 22 September was a drafting error. It was corrected to 21 September when amendments were made to the Animals Rules in April 2022.

### 1.3.5 Relevant Australian Standards for the Export of Livestock history

Livestock export licence holders are required to comply with the ASEL, which set out minimum requirements to ensure animals are fit to export from Australia, and their health and welfare is managed throughout the voyage.

ASEL 2.3 was reviewed in 2018 and 2019 (ASEL sea review and ASEL air review) by a Technical Advisory Committee (TAC). The updated version, ASEL 3.0, was implemented on 1 November 2020.

The 9 voyages that travelled in the Northern Hemisphere summer of 2019 and 2020 operated under ASEL 2.3. The 6 voyages that travelled in the Northern Hemisphere summer of 2021 operated under ASEL 3.0. Additional conditions introduced in ASEL 3.0 include:

- changes to the minimum length of time that sheep must remain in a registered establishment (RE) prior to departure (sheep must spend 5 clear days at an RE)
- changes to the notifiable mortality rate for livestock (already implemented for sheep following the McCarthy Review) and the requirements for notification
- a new definition of 'voyage length' with related changes for personnel, bedding and feed requirements inclusion and extension of additional management plans for sea exports.

ASEL 3.1 was released following the introduction of the *Export Control Act 2020* and the Animals Rules to align the text of the standards with new legislative references. ASEL 3.2 superseded ASEL 3.1 on 18 November 2021.

The ASEL is now regularly reviewed and updated, where appropriate.

### 1.3.6 Independent observers

The department administers an independent observer (IO) program for livestock export voyages by sea to provide additional assurance of the effectiveness of exporters' arrangements in managing animal health and welfare. IOs are deployed on livestock export voyages by sea to 'monitor, observe and report on activities in approved export programs for the purpose of ensuring the health and welfare of live animals in the course of export activities' (DAWE 2021).

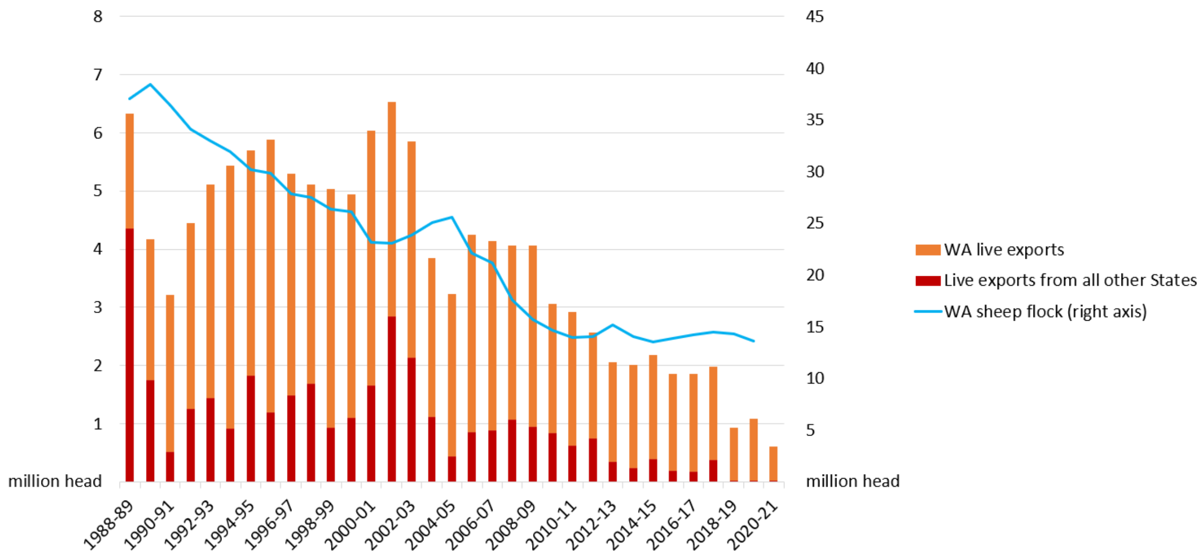
Due to the national and international response to COVID-19, including the government's advice to reconsider non-essential international travel, the department paused the deployment of IOs on all livestock vessels in March 2020. Of the 15 voyages in this review, IOs travelled on all 5 of the 2019 voyages. However, COVID-19 restrictions meant that IOs were able to travel on only 1 of the 10 voyages during 2020 and 2021. In total, the department reviewed 6 IO reports from the 2019-2021 Northern Hemisphere summer periods.

The IO program recommenced from 1 May 2022 (EAN 2022/09) with the department continuing to monitor the COVID-19 situation closely for each country to ensure it is safe and practical to deploy an independent observer.

## 1.4 Changes in the Australian sheep industry

ABARES (2021) states the sheep flock size in Western Australia (WA) stands at 13.7 million for 2019-20, down from approximately 25 million in 2004-5 (Figure 2). The WA sheep flock size has continued to trend downwards in 2020-21, as a result of a number of factors. MLA Industry Projections (2021) reports that eastern states are driving a very high demand for WA sheep. During 2020, the eastern states of Australia experienced drought-breaking rain, resulting in abundant feed and favourable conditions to increase flock size. At the same time, WA seasonal conditions were dry, leading to the possibility of low water supplies in dams during the following summer months, further encouraging producers to reduce stock numbers. It is estimated that approximately 2.3 million sheep were transported from dry conditions in Western Australia to the east coast between January 2020 and July 2021, as eastern producers worked to rebuild their drought-depleted flocks (Oldfield 2021). Existing modelling on this trend suggests that transfers of this nature can have significant long-term effects, with the possibility that WA sheep flocks will decline significantly over a 10-year period, making it difficult to supply the meat and wool industries (Pritchett 2019). This could have flow on effects for the live animal export trade, reducing the number of sheep to be exported due to high domestic demand.

**Figure 2 Australian live sheep exports and Western Australian sheep flock, 1988-89 to 2020-21**




Source: ABARES 2021

Mecardo reported that interstate transfers overtook live sheep exports in terms of WA sheep turnoff in 2019-20, for the first time in at least a decade, with the trend expected to remain in 2020-21 (Oldfield 2021).

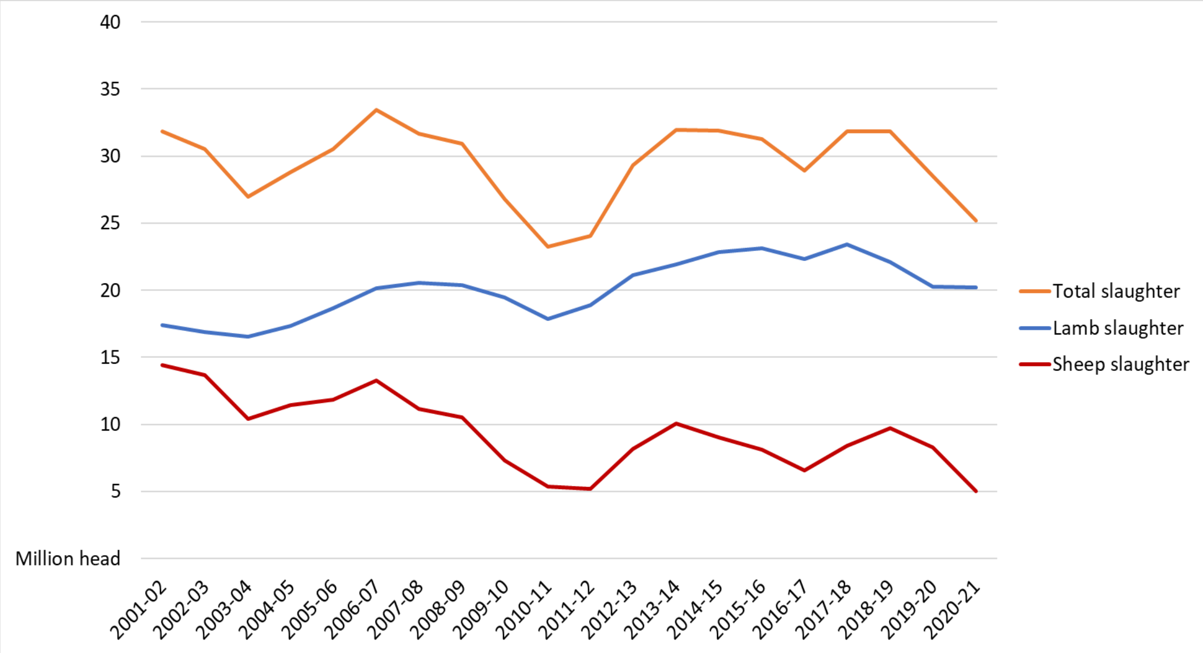
These combined factors significantly depleted the pool of available sheep for the live export trade. Historically the live export sector provided around 30% of the turnoff options for WA sheep producers, with this ratio declining to less than 20% in 2021 (Dalgleish 2021).

In 2020-21, live sheep exports fell by 45% to 602,000 head (Figure 2) and is forecast to rise by 10% in 2021-22 (ABARES 2021). The reduction was due in part to limited supply in WA, as discussed earlier in this chapter, but also due to weaker demand from traditional Middle Eastern markets, where economies have been dampened by the COVID-19 pandemic (ABARES 2021). The removal of the Qatar subsidy on sheep meat from imported Australian sheep locally slaughtered, came into effect from 31 December 2020 (MLA 2021). This change reduced demand for live sheep into the region and resulted in no sheep being exported to Qatar in 2021-22. Prior to the subsidy change, Qatar had been Australia's second largest live sheep export market. ABARES (2021) estimates that in 2020-21 90% of Australian live sheep exports were sent to Kuwait, Qatar, Jordan, and the UAE.

The prohibition on the export of live sheep during the Northern Hemisphere summer may also be another influence by reducing the months exporters can send sheep to, or through, the Middle East.

Flock rebuilding also resulted in reduced sheep slaughter numbers in 2020-21 (Figure 3). Slaughter has decreased in New South Wales, Victoria and Western Australia in the last 2 – 3 years as more ewes have been retained for breeding, due to favourable production conditions for flock rebuilding purposes (ABARES 2021).

**Figure 3 Lamb and sheep slaughter in Australia, 2001-21**

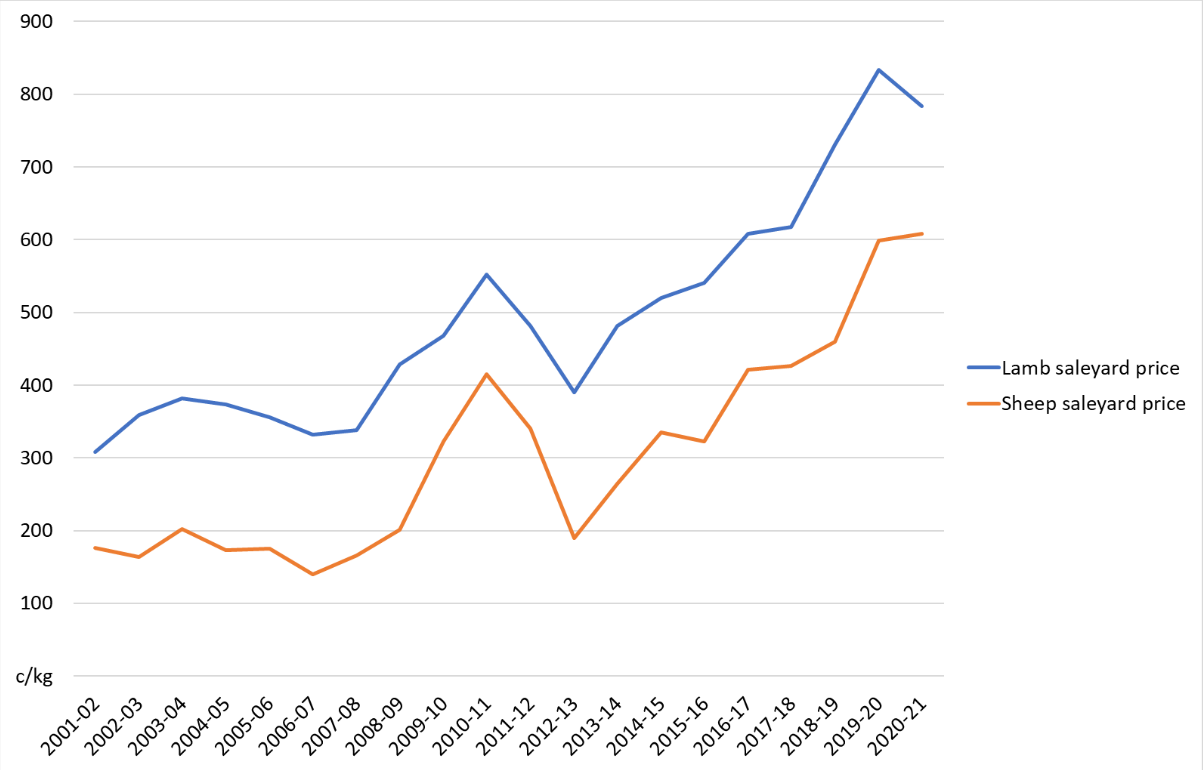



Source: ABARES 2021

### 1.4.1 Rising lamb and sheep prices

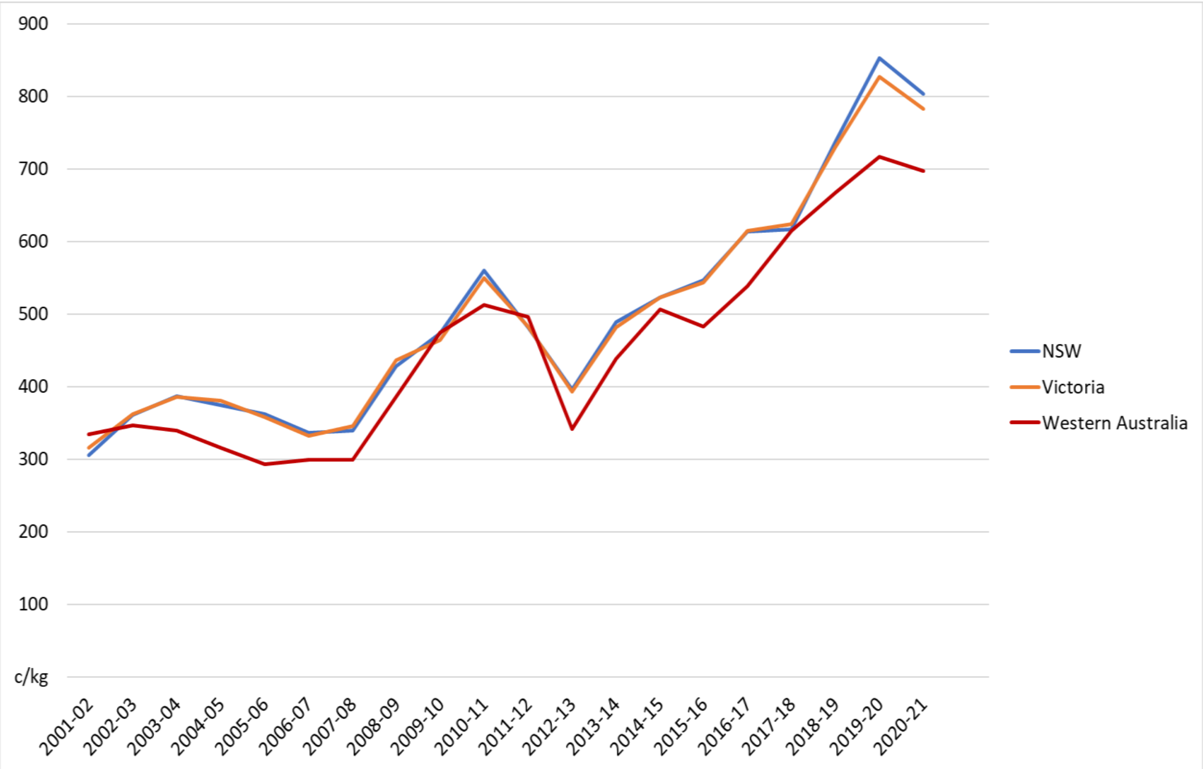
Tight supply in Western Australia, combined with the increased demand for exported sheep meat by China supported a strong price surge in lamb and sheep saleyard prices since 2017 (MLA 2019) (Figure 4). These effects were compounded in 2020 by market changes associated with COVID-19 and the higher Australian dollar during the second half of 2020. Whilst WA sheep and lamb prices have historically been lower than those in eastern states, prices in 2019 and 2020 outperformed those in 2018 and were higher than the previous five-year average (MLA 2019). These high prices have been mirrored in the eastern states with the gap in prices between the two regions appearing to grow with time as a direct response to the movement of sheep across the regions. Lamb saleyard prices in the eastern states started to diverge significantly from prices in Western Australia in August 2019, with saleyard prices for lambs in Western Australia generally remaining below saleyard prices in the eastern states since then (Figure 5). In another example, in early 2021, the Eastern States Trade Lamb Indicator was 100c/kg higher than the Western Australian Trade Lamb Indicator (Oldfield 2021).

**Figure 4 Lamb and sheep saleyard prices in Australia, 2001-02 to 2020-21**




Source: ABARES 2021

**Figure 5 Lamb saleyard prices in New South Wales, Victoria, and Western Australia 2001-02 to 2020-21**




Source: ABARES 2021

With market pressures and the rebuilding of flocks continuing, it is expected that higher prices will also continue. In 2021-22, live export sheep prices are forecast to rise by 5% to $162/head (ABARES 2022). This is expected to be the highest price ever recorded in nominal terms, and the second highest price in real terms (ABARES 2022). An update to these forecasts is provided in the June 2022 Agricultural Commodities Report, from ABARES.

### 1.4.2 Impact of the prohibition

The RIS assessed the economic impacts of a range of policy options, including the possibility that a prohibition could reduce the demand for exported sheep to international markets. ABARES concluded the economic impact of restrictions on the live sheep export trade had been offset by the increasing demand for Australian sheep meat internationally (ABARES 2020). The ABARES analysis also identified that live sheep export volumes have declined outside of the prohibition period, indicating a decline in the trade as a whole. As discussed in Section 1.4.1, this has likely been driven by domestic movements of sheep, higher sheep prices, the strong Australian dollar, and the impact of the COVID-19 pandemic. However, this conclusion has been disputed in some industry publications. For example, the MLA Industry Projections (2021) report states ‘a major factor accelerating the long-term decline in Australian live sheep exports in recent years has been the government ban on exporting to the Gulf during the Northern Hemisphere summer’ (MLA 2021).

# 2 Climate analysis

The department has reviewed and analysed climatology data from a 2019 Bureau of Meteorology report (2019 BOM report) and an updated 2021 Bureau of Meteorology report (2021 BOM report) to assist in determining the appropriateness of the current regulatory settings in place during the Northern Hemisphere summer. All WBT data received in the BOM reports and discussed in this section refer to ambient WBTs.

## 2.1 Meteorological reports

The 2019 BOM report presented WBT data from selected locations along voyage routes and at Middle Eastern destination ports from April to November for the period 1990 to 2018. Data were presented in a series of graphs depicting the 95th percentile WBT readings, maximum and minimum daily WBTs, plus the highest and lowest on record. These graphs were used to determine dates when there was a 5% or greater likelihood that ambient WBTs at specific locations would be higher than 29°C. The prohibition periods implemented in 2020 for live sheep exports to or through the Middle East during the Northern Hemisphere summer were based on these dates.

The 2021 BOM report provided updated climatology data based on 42 years of accumulated climate data from 1979 to 2021, including a WBT analysis along voyage routes and at destination ports in the MEAI. The 2021 BOM report uses hourly WBT measurements which are aggregated into 7-day periods by date, where 1 May is the start of a 7-day period (and the beginning of the Northern Hemisphere summer). The BOM grouped data into 7-day intervals to maximise the statistical significance of the WBT analysis for each location.

The 2021 BOM report provided WBT climatology maps and graphs for 21 locations in the MEAI, including in the Persian Gulf, the Strait of Hormuz, the Gulf of Oman and in the Red Sea. The WBT maps are displayed in a 'grid cell' style for each of the 27 weeks of the Northern Hemisphere summer, staring on 1 May. Each grid cell represents a 30 x 30-kilometre square patch of the earth's surface and depicts 95th percentile maximum WBTs in weekly blocks of time. Grid cells on the WBT maps are colour-coded to represent different maximum WBTs, for example, yellow grid cells represent areas where 95th percentile maximum WBTs are below 28°C (and above 27°C) while purple grid cells represent areas where the 95th percentile maximum WBTs are over 31°C. Areas with 95th percentile maximum WBTs below 27°C are shown in greyscale.

The WBT graphs depict 95th percentile maximum WBTs for each month of the year, average daily maximums, average daily minimums, the 2019 and 2020 daily maximums and highest on record daily maximum. The orange (stepped) line in the graphs represents the 95th percentile daily maximum WBT, calculated in weekly blocks of time. This means that on 95% of days over the 42 years of accumulated data, the WBT is less than the threshold value; conversely, on 5% of days the WBT exceeds the threshold value.

The climate statistics and recommendations presented in Section 2.4 consider voyage duration to each destination port, the updated climatology data in the 2021 BOM report and the 95th percentile maximum WBT threshold of 29˚C, determined through the RIS process. This threshold was used to determine prohibition dates, implemented in new regulation in 2020, which limited vessels arriving in the Middle East when there was a greater than 5% likelihood that temperatures would exceed the WBT threshold of 29˚C for a sustained period.

## 2.2 The impact of climate change

Several articles in the literature review identified that the future climate is expected to be more variable with greater frequencies and intensities of very hot periods (Tadesse et al. 2019, Thornton et al. 2021, Zhang & Phillips 2019). For example, Thornton et al. (2021) predicts that by 2050 the number of days per year of extreme heat and risk of heat stress will have at least doubled, imposing increased pressure on the existing capacity of ruminant livestock to adapt to extreme environmental conditions. These papers, however, represent general climate assessments whereas heat stress risk is location specific. If drier conditions occur in the future, then WBTs may decrease in some areas.

The department discussed with the BOM the different types of climate analysis that would best consider the impact of climate change. One possibility was to run an analysis on a short period of recent data, for example, the previous 5-10 years, to gain an indication of how climate change affects WBTs in the MEAI. The BOM advice was that data from such a small number of years would lack the necessary statistical robustness to support the review and may exclude 'outlier' measurements.

In consultation with the BOM, it was agreed the most accurate analysis would be a comprehensive data review based on 42 years of accumulated data from 1979 to 2021. A data period of this length means there is a greater chance of capturing a 'once in a decade' temperature extreme within the analysis. If these extreme temperatures occur, they will exert a statistical effect in the calculation of 95$^{th}$ percentile temperatures. In addition, any recent climate change effects would be included and contained in the analysis outputs.

Therefore, while the department will continue to monitor climatic conditions, the 2021 BOM report provides the most up-to-date data available and underpins the evidence-based recommendations of this review.

## 2.3 Voyage lengths and departure dates

The department analysed typical voyage lengths for the 15 voyages in the review. All voyages departed from Fremantle and travelled to either the Persian Gulf or the Red Sea. This allowed likely arrival dates at destination ports to be determined, and from this, appropriate departure dates that limit vessels arriving in the Middle East when there is a greater than 5% likelihood that temperatures will exceed WBT threshold of 29˚C for a sustained period.

Table 3 shows voyages from Fremantle to the Persian Gulf typically reach the Gulf of Oman 13 days after departure, transiting the Strait of Hormuz 13-14 days after departure and Kuwait port 14-15 days after departure. Discharging of sheep can take up to 2 days before the vessel travels onwards to secondary ports. Voyages to the Red Sea typically reach the Gulf of Aden 14 days after departure, the Bab al Mandab Strait 14-15 days after departure and arrive at destination ports around 18-19 days after departure.

**Table 3 Typical voyages from Fremantle to the Persian Gulf and Red Sea**

| Persian Gulf route | Day of voyage | Red Sea route | Day of voyage |
|---|---|---|---|
| Gulf of Oman | 13 | Gulf of Aden | 14 |
| Arrival Kuwait | 14-15 | Bab Al Mandab Strait | 14-15 |
| Complete discharge Kuwait | 16-18 | Arrive at first port (Eilat or Aqaba) | 18 |
| Arrive at second port | 17-19 | Arrive at second port | 18-19 |
| Complete discharge at second port | 19-21 | Complete discharge at second port | 19-21 |

The department notes that, in the future, sheep may be exported from ports other than Fremantle (such as Portland or Port Adelaide). Voyage lengths may be up to 5 days longer from these departure ports, meaning sheep could arrive in the Middle East on dates later than predicted in this report, when conditions are hotter and more humid. To limit this possibility, the department recommends that vessels departing from ports other than Fremantle should comply with prohibition date recommendations and be required to be west of a longitude of 116 East, no later than 31 May if travelling to the Persian Gulf, or no later than 14 June if travelling to the Red Sea.

## 2.4 Wet bulb temperature at specific Middle East locations

The 2021 BOM report demonstrated that Persian Gulf locations were generally hotter, with higher WBTs, than Red Sea locations. For several destinations, a 'port' location was examined, as well as an 'offshore' location. This showed that in general, WBTs are slightly higher in the 'offshore' locations than at 'port' locations, reflecting the higher humidity in the maritime environment. This is particularly notable at Kuwait port compared to Kuwait offshore (Figures 6 and 7). The difference between offshore and port WBTs also aligns with HotStuff modelling which identifies separate heat stress risk for ports and heat stress risk while sailing.

The 2021 BOM report also indicated that there are some passages along voyages routes where 95th percentile maximum WBTs may exceed 29˚C for short periods of time. For example, the Strait of Hormuz is typically the hottest part of a voyage to the Persian Gulf, and the Bab al Mandab Strait is typically the hottest part of a voyage to the Red Sea. Transiting each strait represents around 6-12 hours of travel time, before a vessel travels on to cooler conditions. The risk of heat stress is mitigated by the relatively short period of time at temperatures which may exceed 29˚C and the reliable respite after this period (also identified in voyage reports).

All temperature maps and graphs in the following section have been provided in the 2021 BOM report. The complete BOM report can be viewed here.

### 2.4.1 Kuwait

The majority of live sheep exported from Australia to the Middle East are exported to Kuwait. In 2021, 75% of live sheep exports to the Middle East were discharged at Kuwait. Current rules require that if Kuwait is one of the destinations, then Kuwait must be the first port of discharge. Therefore, voyages travel first to Kuwait, where the majority of sheep are discharged, before travelling on to other hotter, more humid Persian Gulf ports.

Kuwait port experiences a markedly cooler microclimate than the surrounding maritime environment for most of the Northern Hemisphere summer (2021 BOM report). Figures 6 and Figure 7 demonstrate that WBTs at Kuwait port are typically 2-3˚C cooler for all periods of the Northern Hemisphere summer, compared to the offshore areas in the north-western Persian Gulf, and other Persian Gulf ports (including Jebel Ali, UAE and Hamad, Qatar). This cooler microclimate provides reliable respite and reduces the risk of heat stress for sheep during the discharge process.

Voyages en route to Kuwait must travel through the Strait of Hormuz and the eastern Persian Gulf, which are typically the hottest part of the journey and represent around 12-24 hours of travel time. Climatology data identify that these regions become hotter and more humid earlier than the north-western Persian Gulf around Kuwait, posing additional heat stress risks to consider.

Voyages departing Australia on 30-31 May reach the Strait of Hormuz around 12-13 June where the 95th percentile maximum WBT exceeds 30˚C (Figures 8 and 9). Transiting the Strait of Hormuz typically takes 6-12 hours, after which vessels travel onto cooler parts of the Persian Gulf, reaching Kuwait port approximately 1 day later (around 14 June) where the 95th percentile maximum WBT drops to around 25˚C and average conditions are likely to provide reliable respite (Figures 7 and 9). This means 95% of WBT records at Kuwait port are less than 25˚C around 14 June.

Voyages departing Australia on or shortly after 15 September reach the Strait of Hormuz around 27-28 September and Kuwait port around 29 September (Figure 10). At this time, 95% of WBTs recorded at Kuwait port are less than 27˚C (Figure 7). Although WBTs are around 2˚C higher at Kuwait port at the end of September (compared to mid-June), the climate en route to Kuwait, through the Strait of Hormuz has cooled, with a 95th percentile maximum WBT around 29°C (Figures 8 and 10). This means 95% of WBT records in the Strait of Hormuz are less than 29°C in late September.

Therefore, taking route and port WBTs into account, the heat stress risk for voyages departing Australia on or shortly after 15 September is assessed as similar to the heat stress risk for voyages departing Australia in the last week of May. Temperatures at destination ports can impact heat stress risk significantly, because sheep spend longer at destination ports than at other locations during the voyage.

**Climate en route to Kuwait, at Kuwait offshore and Kuwait port**

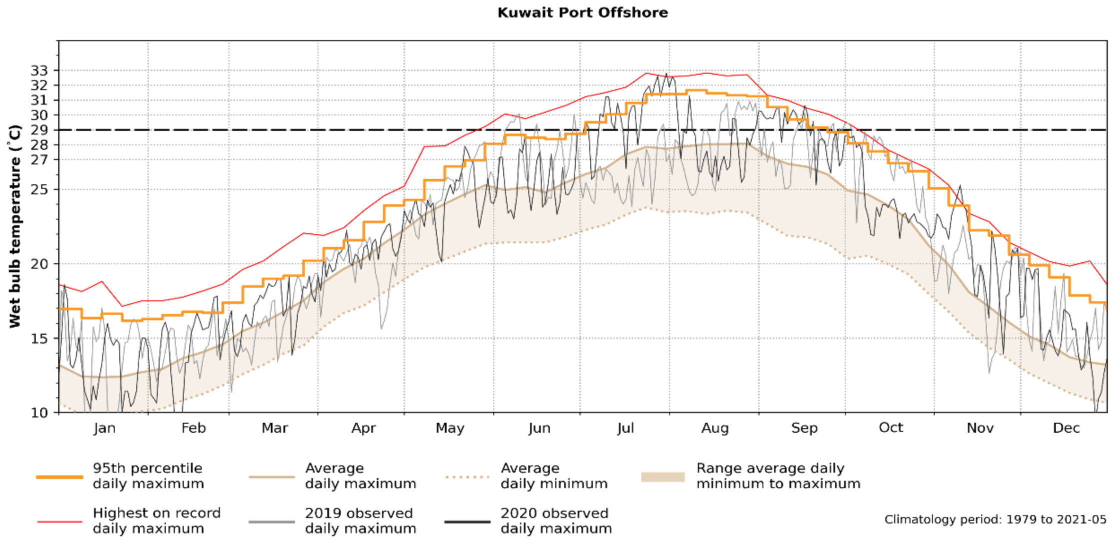
At the beginning of the Northern Hemisphere summer:

- the 95th percentile maximum WBT in the Strait of Hormuz first exceeds 29˚C in the week starting 15 May (Figure 8)
- the 95th percentile maximum WBT at Kuwait offshore remains relatively constant throughout June at 28-29˚C (Figure 6)
- the 95th percentile maximum WBT at Kuwait offshore first exceeds 29˚C in the week starting 3 July (Figure 6)
- the 95th percentile maximum WBT at Kuwait port exceeds 29˚C around 28 August for approximately 1 week only, before subsequently declining (Figure 7).

At the end of the Northern Hemisphere summer:

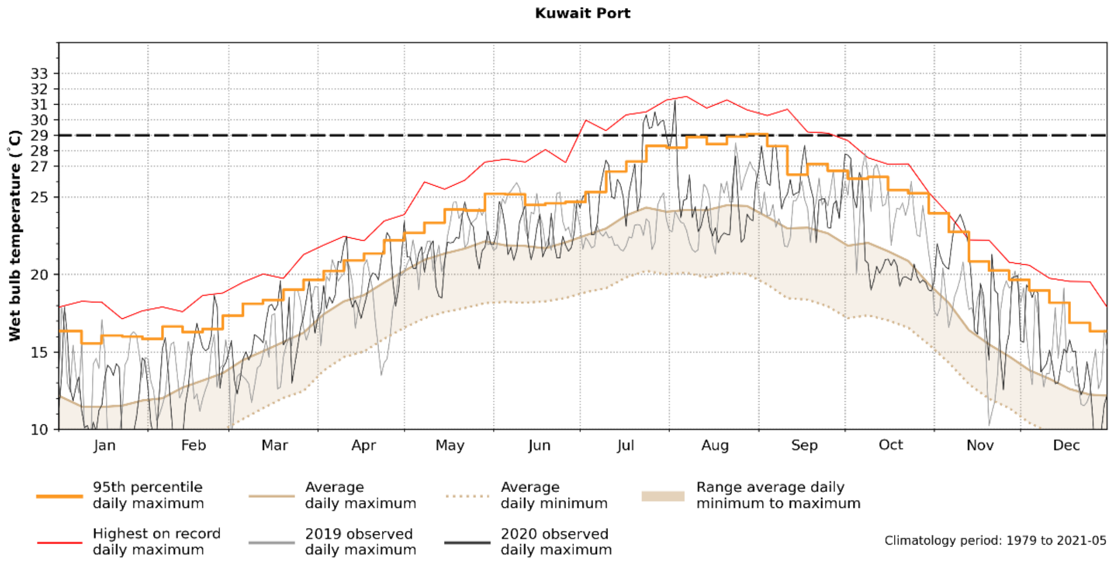
- the 95th percentile maximum WBT in the Strait of Hormuz drops to approximately 29˚C in the week starting 18 September (Figure 8)
- the 95th percentile maximum WBT at Kuwait port offshore drops to approximately 29˚C in the week starting 18 September (Figure 6).

## Figure 6 Wet bulb temperatures for Kuwait offshore



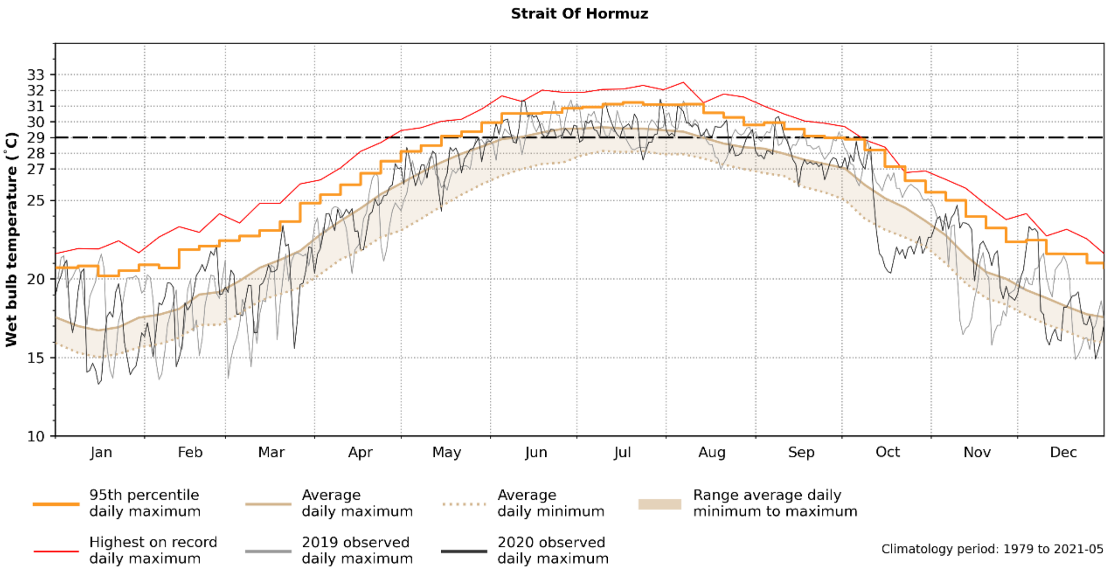

Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

## Figure 7 Wet bulb temperatures for Kuwait Port



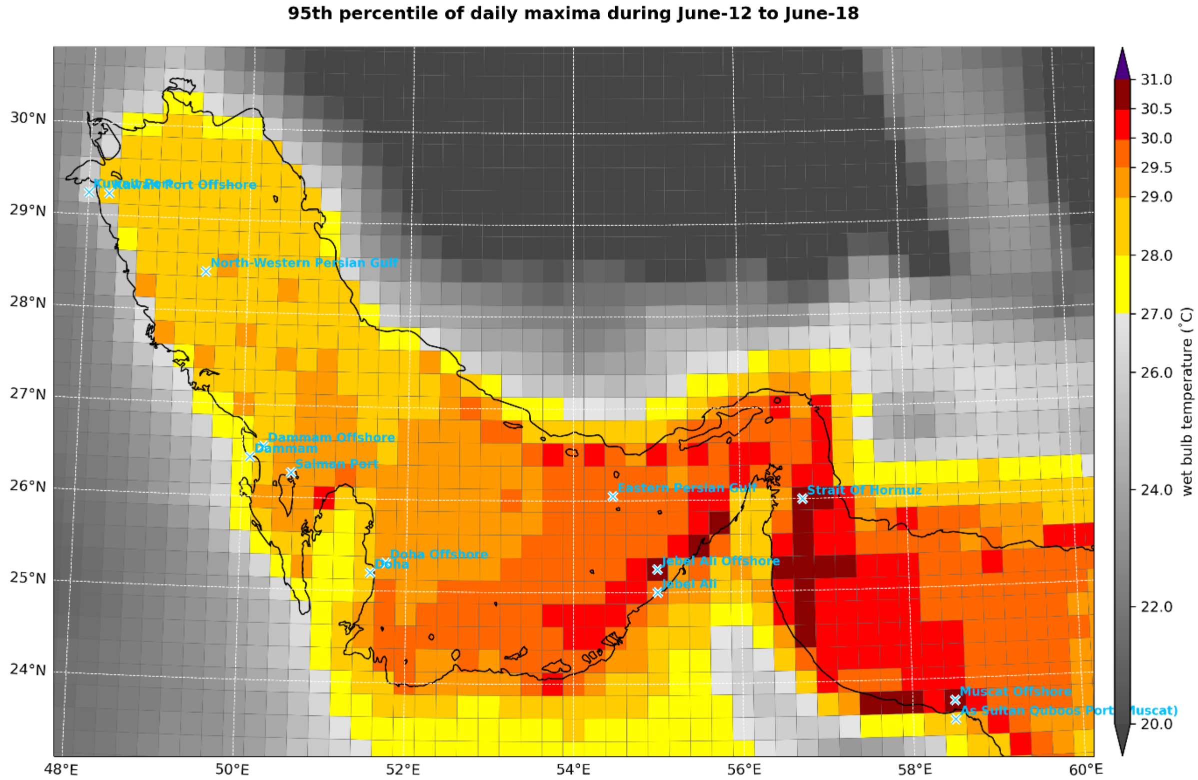

Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

## Figure 8 Wet bulb temperatures for Strait of Hormuz



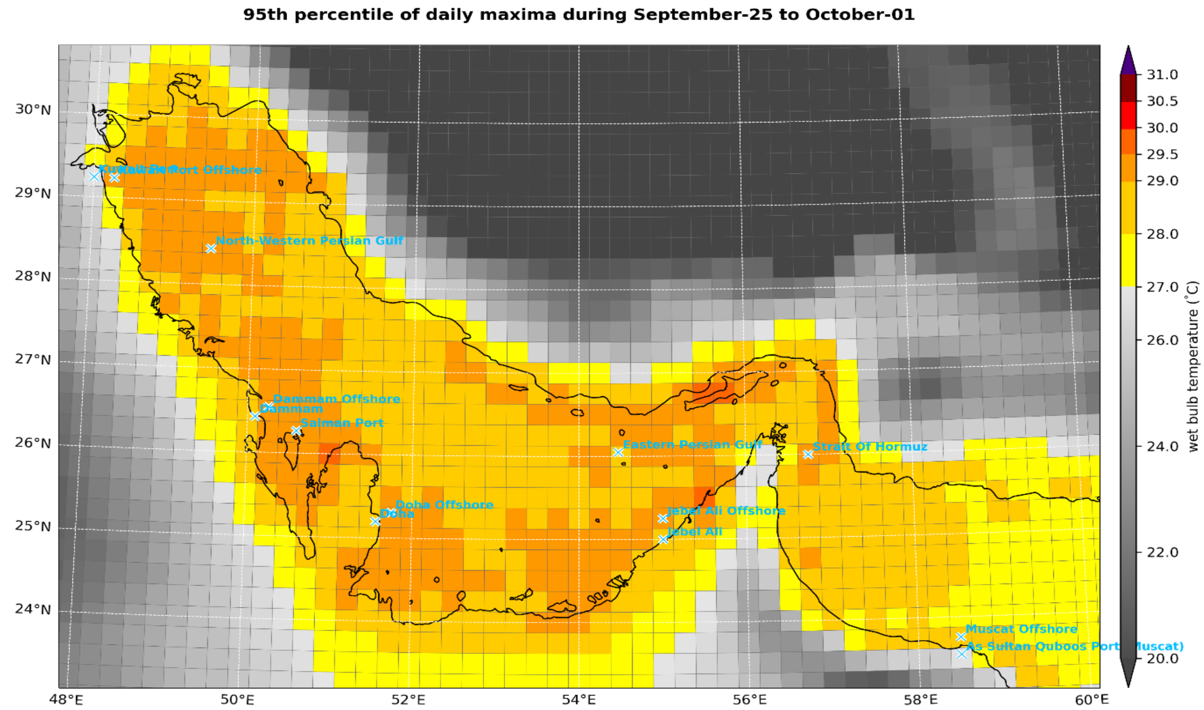

Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

## Figure 9 95th percentile maximum wet bulb temperature from 12 to 18 June Persian Gulf




Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

**Figure 10 95th percentile maximum wet bulb temperature from 25 September to 1 October Persian Gulf**




Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

**Development of the recommendations for Kuwait**

The draft report proposed to change the absolute prohibition dates to 15 June – 7 September, and to introduce 2 conditional prohibition periods from 1 – 14 June and from 7 – 13 September where exports to Kuwait would be permitted provided additional heat-mitigating conditions could be met. For departures up to 14 June, vessels would arrive in the Persian Gulf in late June, when WBTs may be up to 2˚C above the threshold for extended periods in the Gulf of Oman, Strait of Hormuz and eastern Persian Gulf.

For departures around 7 September, vessels would arrive in the Persian Gulf when WBTs may be up to 1˚C higher than the threshold, but more importantly, at this time conditions at Kuwait port have not significantly cooled after the heat accumulation over summer. Wet bulb temperatures at Kuwait port are up to 2˚C higher for voyages departing Australia in early September and do not offer the respite during the discharge process, compared to voyages departing Australia in late May. This increases the risk of heat stress as animals spend longer at destination ports than at other locations en route. In addition, sheep travelling in September are fully winter acclimatised, compared to those departing Australia in late May, reducing their heat tolerance further.

Therefore, after closer examination of the climate data, the department reconsidered the proposed dates presented in the draft report and determined that the heat stress risks to sheep were not able to be effectively mitigated at the end of June and earlier in September, even with the application of heat stress mitigation measures. The current recommended dates are summarised below.

**Recommendation – prohibition dates for Kuwait**

- The prohibition period should continue to be from 1 June to 14 September (no change from current dates).

**Summary – voyages to Kuwait**

- Voyages departing Australia around 31 May arrive in the Strait of Hormuz around 12-13 June and at Kuwait port around 14 June.
- Voyages departing Australia on 15 September arrive in the Strait of Hormuz around 27-28 September and at Kuwait port around 29 September.

### 2.4.2 Persian Gulf destinations (other than Kuwait and Oman)

In the 2019 BOM report, Qatar was identified to have a hotter and more humid climate than other Persian Gulf locations, resulting in an extended prohibition of sheep exports to Qatar from 22 May to 22 September. Climatology data from the 2021 BOM report indicate additional heat stress risk areas on the south-eastern coastline of the Persian Gulf that were not evident in the 2019 BOM report. These areas get hotter and more humid up to 4 weeks earlier than at Kuwait port (Figure 9), impacting environmental conditions at ports including Hamad, Qatar and Jebel Ali, UAE. The 2021 BOM report indicates WBTs (and therefore the risks of heat stress) are likely to be similar at Qatar and other non-Kuwait Persian Gulf ports such as Jebel Ali in the UAE. For this reason, it is recommended Qatar be aligned with Persian Gulf destinations (other than Kuwait and Oman) and not considered a unique heat stress risk that warrants separate consideration.

In addition, the 2021 BOM report identified that none of the other Persian Gulf ports had a cooler microclimate, as experienced at Kuwait port. This is significant when considering heat stress risk during the discharge process. If respite from high WBTs is unlikely when the vessel is discharging (as occurs at Kuwait port), the heat stress risk is amplified because vessels spend more time at and near discharge ports than at any other points during the voyage. The voyage length, date of arrival and time spent at destination ports are, therefore, key factors when considering prohibition dates. Voyages typically complete discharge at secondary Persian Gulf ports around 19-21 days after departure from Australia.

The increased temperatures at Persian Gulf ports other than Kuwait in June indicate that additional heat stress-mitigating conditions are warranted, to more effectively manage the risk of heat stress in sheep exported to these ports.

Vessels departing Australia around 31 May arrive at secondary Persian Gulf ports (after discharging at Kuwait) around 16-18 June (Figure 9). At this time the 95$^{th}$ percentile maximum WBTs for non-Kuwait Persian Gulf ports including Hamad, Qatar and Jebel Ali, UAE are up to 1.5 ˚C higher than the 29˚C threshold. To mitigate the heat stress risks posed by the hotter conditions at these ports the department recommends introducing a conditional prohibition period where exports can only occur if additional conditions are met. During the last 3 Northern Hemisphere summer periods, exports were permitted to these destinations, with no restrictions. The additional conditions are designed to decrease the deck WBT rise and to improve the heat tolerance of sheep. Section 3.2 outlines the proposed heat stress-mitigating conditions.

Voyages departing Australia on 15 September arrive at secondary Persian Gulf ports, after discharging at Kuwait, around 1 October-3 October. The 95$^{th}$ percentile maximum WBTs are around 29˚C at this time (Figures 11, 12, 13, 14 and 15). This means 95% of WBT records at Persian Gulf ports (other than Kuwait and Oman) are less than 29˚C.

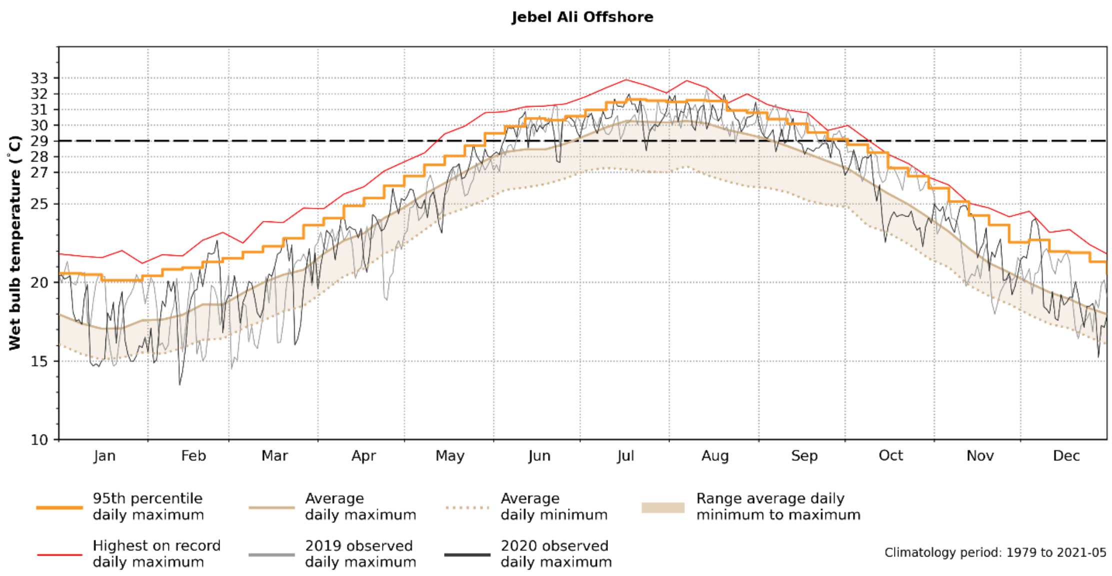
At the beginning of the Northern Hemisphere summer:

- the 95th percentile maximum WBT at Jebel Ali offshore first exceeds 29˚C in the week starting 29 May (Figure 11)
- the 95th percentile maximum WBT at Jebel Ali port first exceeds 29˚C in the week starting 5 June (Figure 12)
- the 95th percentile maximum WBT at Doha offshore first exceeds 29˚C in the week starting 19 June (Figure 13)
- the 95th percentile maximum WBT at Doha port first exceeds 29˚C in the week starting 3 July (Figure 14).

At the end of the Northern Hemisphere summer:

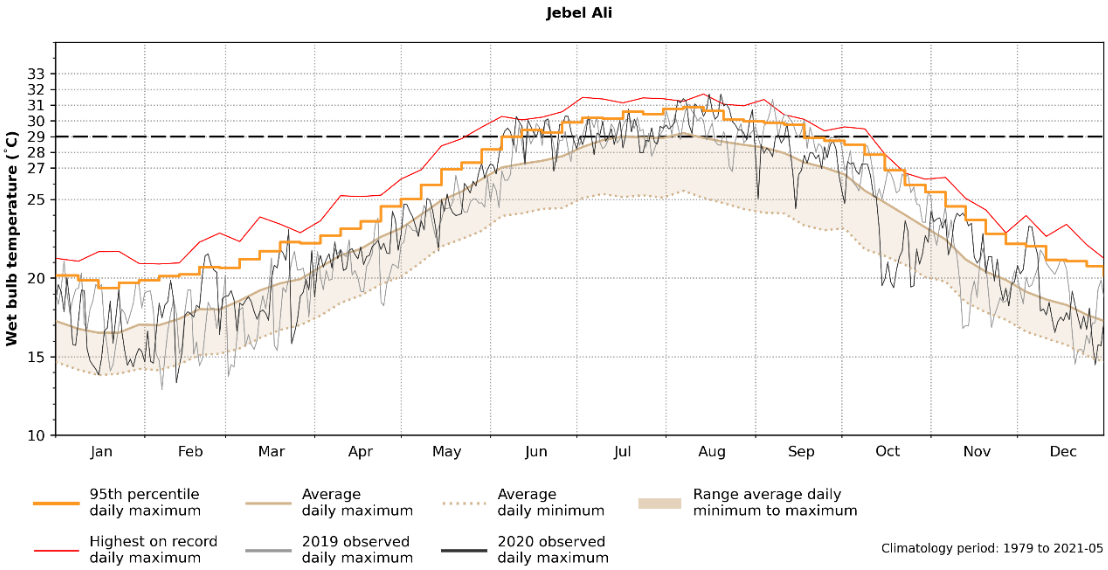
- the 95th percentile maximum WBT at Jebel Ali offshore drops to approximately 29˚C in the week starting 2 October (Figure 11)
- the 95th percentile maximum WBT at Jebel Ali port drops to approximately 29˚C in the week starting 11 September (Figure 12)
- the 95th percentile maximum WBT at Doha offshore drops to approximately 29˚C in the week starting 18 September (Figure 13)
- the 95th percentile maximum WBT at Doha port drops to approximately 29˚C in the week starting 11 September (Figure 14).

### Figure 11 Wet bulb temperatures for Jebel Ali offshore



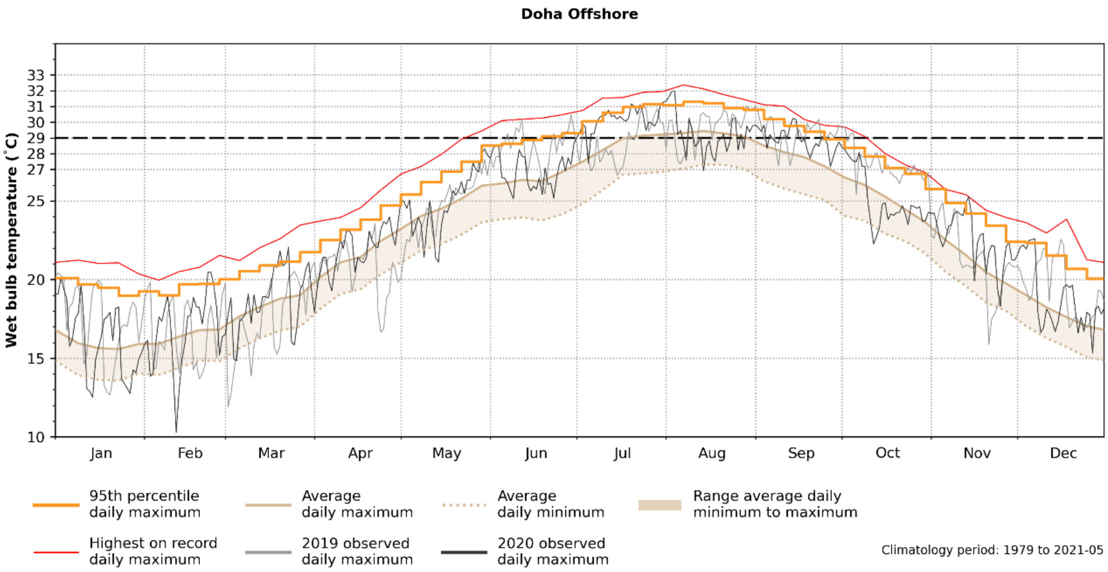

Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

## Figure 12 Wet bulb temperatures for Jebel Ali port



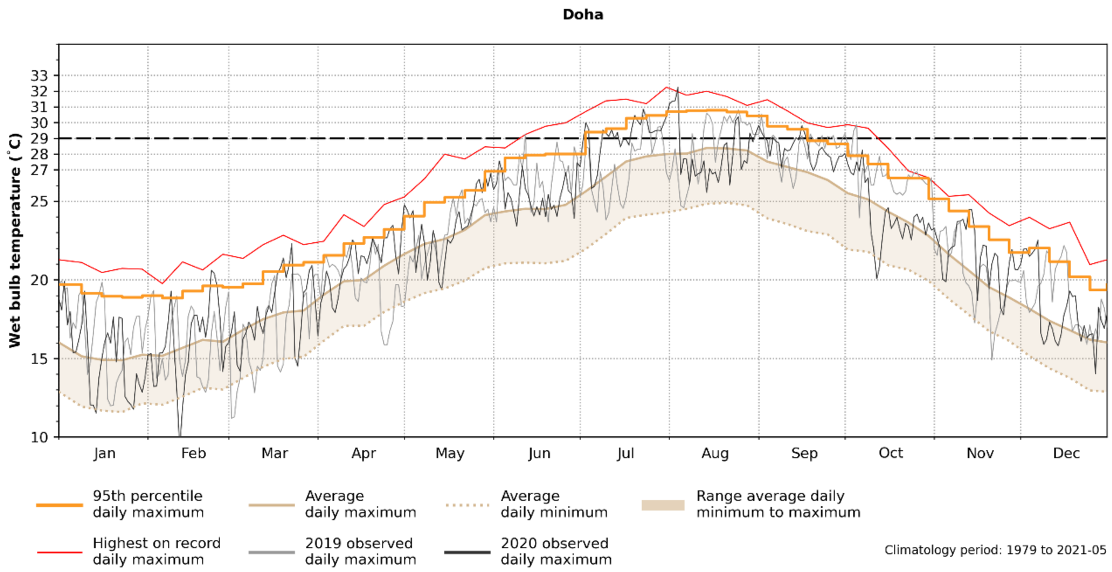

Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

## Figure 13 Wet bulb temperatures for Doha offshore



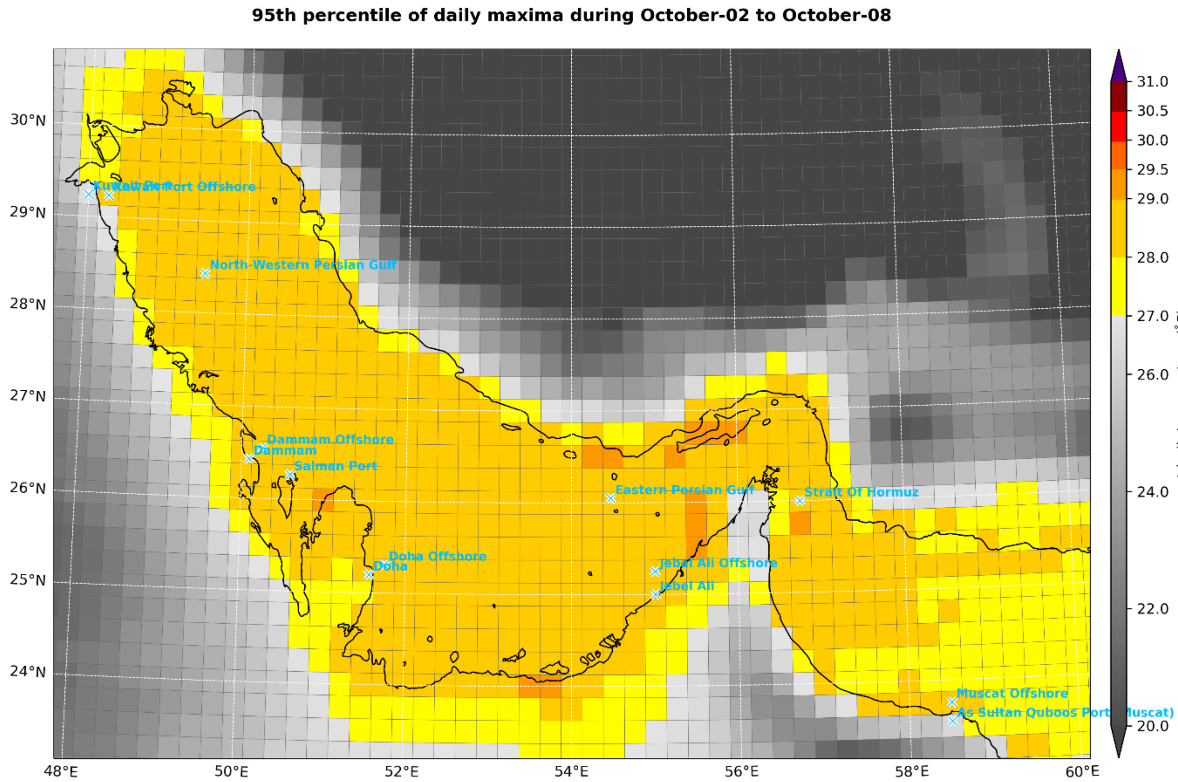

Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

## Figure 14 Wet bulb temperatures for Doha port




Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

## Figure 15 95th percentile maximum wet bulb temperature from 2 October to 8 October Persian Gulf




Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

**Development of recommendations for Persian Gulf ports (other than Kuwait and Oman)**
The draft report proposed no change to the absolute prohibition for Persian Gulf ports (other than Kuwait and Oman) but recommended the introduction of 2 conditional prohibition periods for voyages departing Australia from 22 – 31 May and from 15 – 21 September.

The conditional prohibition period from 22 – 31 May was implemented into legislation in April 2022 and applied additional heat stress mitigation measures to manage WBTs up to 1.5˚C above the threshold. In contrast, for voyages departing Australia from 15-21 September, WBTs would be no more than 0.5˚C above the threshold and only for limited periods. As the majority of sheep are typically discharged first in Kuwait, sheep that travel onto other Persian Gulf ports will receive additional pen space, allowing for improved ventilation and removal of metabolic heat, as well as improved access to food and water troughs. These factors are expected to reliably mitigate for WBTs up to 0.5˚C above the threshold.

The department reconsidered this information and determined that a conditional prohibition period was only necessary for voyages departing Australia from 22-31 May.

**Recommendation – prohibition dates for Persian Gulf ports (other than Kuwait and Oman)**

- Absolute prohibition dates should be from 1 June to 14 September (no change from current rules for most Persian Gulf destinations. Change for Qatar to bring in line with other Persian Gulf destinations).
- Voyages should depart Australia up to 21 May with no additional conditions.
- Voyages should only depart Australia from 22 May to 31 May provided additional conditions to mitigate the increased risks of heat stress, associated with a 95$^{th}$ percentile WBT rise of up to 1.5˚C above the threshold, can be met.
- Voyages should recommence from 15 September with no additional conditions.

**Summary – voyages to Persian Gulf ports (other than Kuwait and Oman)**

- Voyages departing Australia around 31 May arrive at secondary Persian Gulf ports around 16-18 June
- Voyages departing Australia on 15 September arrive at secondary Persian Gulf ports around 1 October-3 October, after discharging first at Kuwait.

### 2.4.3 Oman

Although the Gulf of Oman (bounding Oman and Muscat port) becomes hotter earlier in the Northern Hemisphere summer compared to the Persian Gulf (Figure 18), WBTs are less extreme and cool earlier at the end of the Northern Hemisphere summer. Aligning with trends at other ports, WBTs at Muscat offshore are also slightly higher than at Muscat port.

The 2021 BOM report provided WBT readings from 2 additional locations (Muscat port and Muscat offshore) compared to the 2019 BOM report, which provided data only from Muscat International Airport. The new data indicated that the heat stress risks for voyages to Muscat port were not as high as previously understood.

Voyages take around 13 days to arrive in Oman. Voyages departing Australia on 7 May arrive at Muscat port around 19 May, where 95% of WBT records at Muscat offshore are less than 29.5˚C. (Figures 16, 17 and 18). While WBTs are up to 2˚C cooler at Muscat port compared to offshore, vessels must travel through the more humid maritime environment where heat stress risks can be higher.

Voyages departing Australia on 15 August would arrive at Muscat port around 27 August, where 95% of WBT records at Muscat port are less than 28˚C, though they may be 1 – 2˚C higher offshore (Figures 16, 17 and 19).

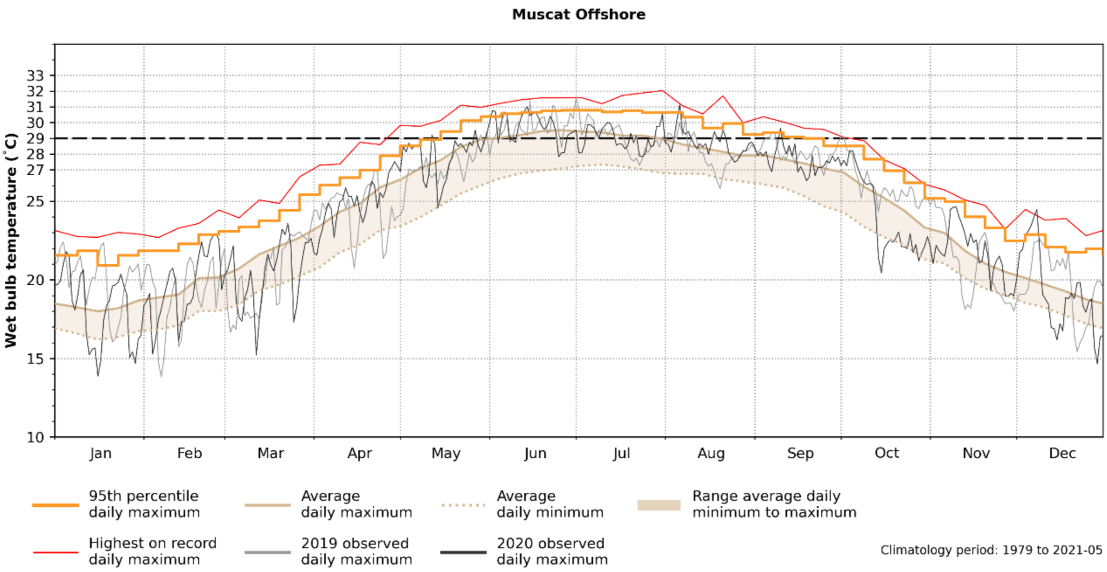
At the beginning of the Northern Hemisphere summer:

- the 95th percentile maximum WBT at Muscat offshore reaches 29˚C around 15 May (Figure 16)
- the 95th percentile maximum WBT at Muscat port reaches 29˚C in early July for approximately 2 weeks only, before declining (Figure 17).

At the end of the Northern Hemisphere summer:

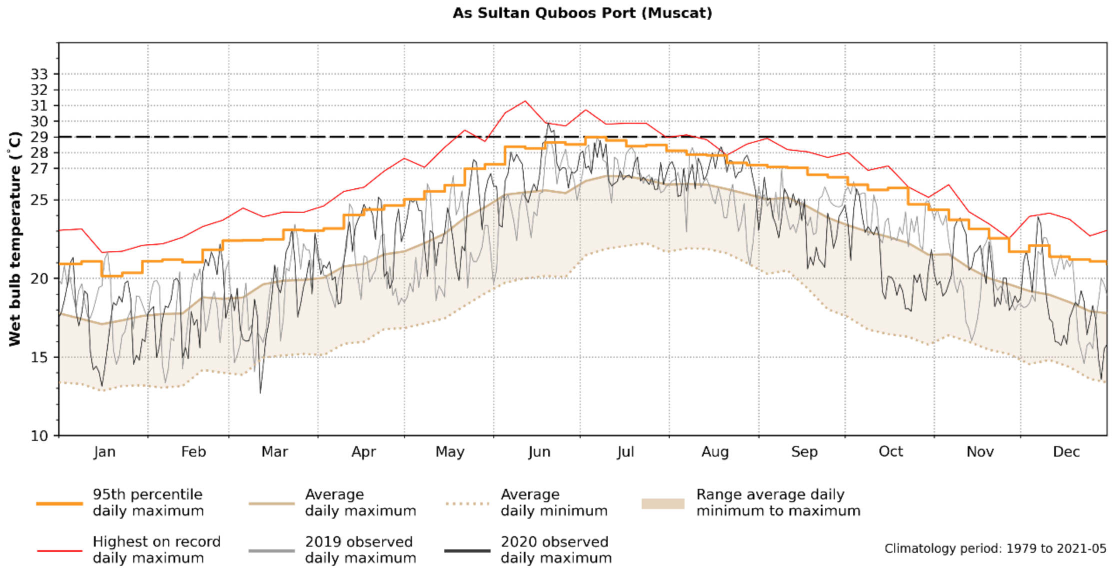
- the 95th percentile maximum WBT at Muscat offshore drops to approximately 29˚C by 11 September (Figure 16)
- the 95th percentile maximum WBT at Muscat port drops below 29˚C by mid-July (Figure 17).

**Figure 16 Wet bulb temperatures for Muscat offshore**



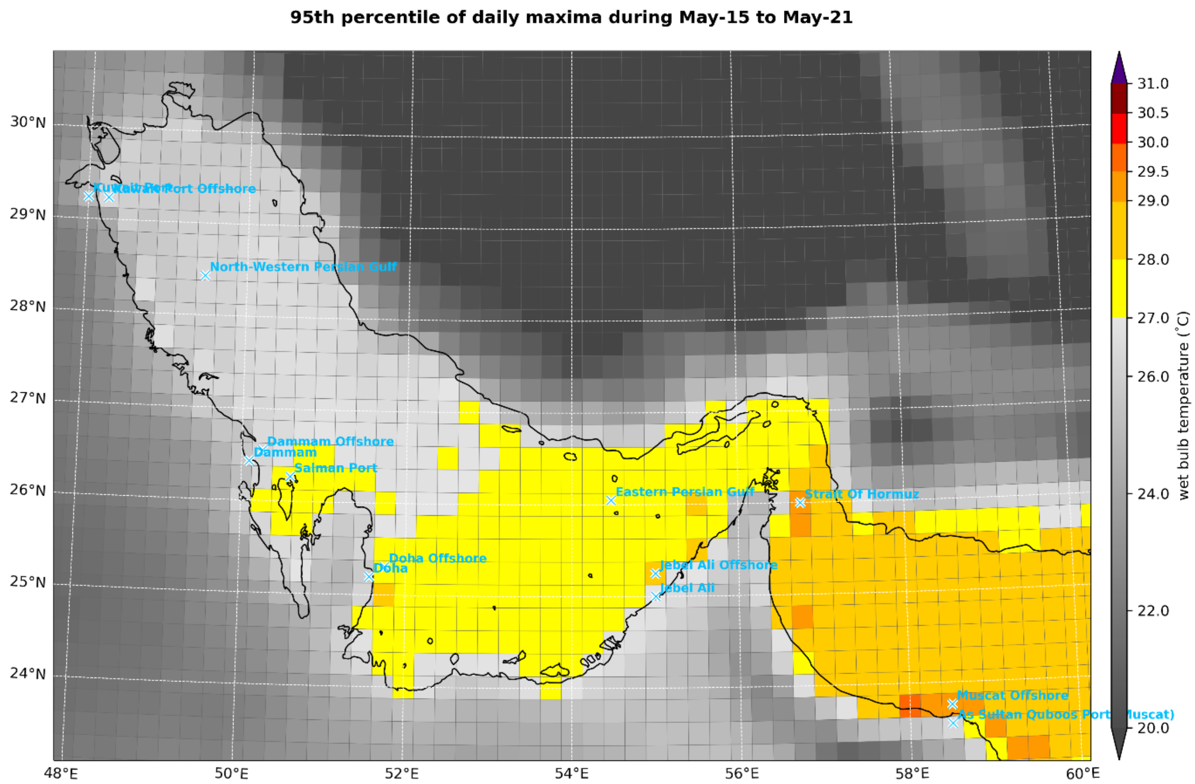

Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

## Figure 17 Wet bulb temperatures for Muscat port



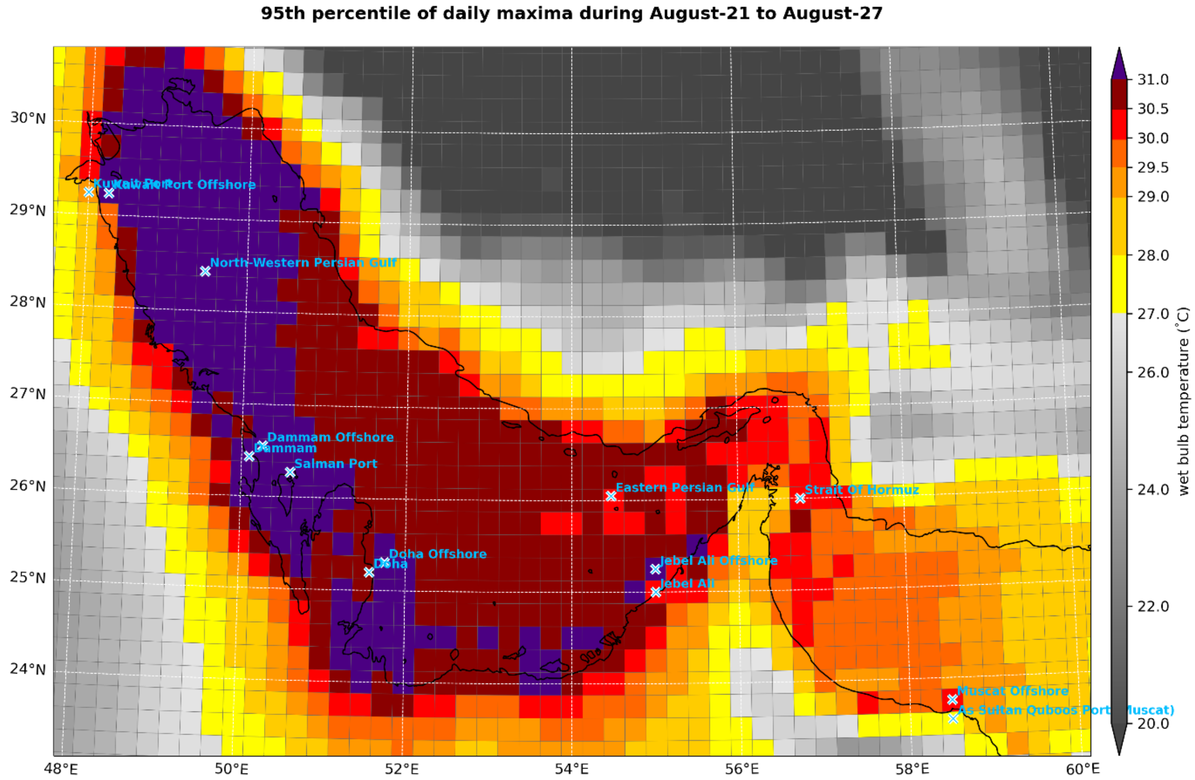

Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

## Figure 18 95th percentile maximum wet bulb temperature from 15 to 21 May Persian Gulf




Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

**Figure 19 95th percentile maximum wet bulb temperature from 21 August to 27 August Persian Gulf**




Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

**Development of the recommendations for Oman**

The draft report proposed that exports to Oman be prohibited from 8 May – 14 August, which aligns with the prohibition dates recommended in this final report.

**Recommendation – prohibition dates for Oman**

- Where Oman is the sole port of discharge, the absolute prohibition period should be from 8 May to 14 August (change from current rules which prohibit export from 8 May to 14 September).
- Where Oman is one of multiple Persian Gulf destination ports, prohibition dates for the other Persian Gulf destinations should apply.
- Where Oman is one of multiple Persian Gulf discharge ports, exporters may discharge sheep in Oman first, en route to other destinations. This limits the time these sheep spend on voyages.

**Summary – voyages to Oman**

- Voyages departing Australia around 7 May arrive in Oman around 19 May.
- Voyages departing Australia on 15 August arrive in Oman around 27 August.

## 2.4.4 Red Sea

Red Sea destination voyages analysed in this review were Eilat, Israel and Aqaba, Jordan. Voyages travelling to destinations in the Mediterranean Sea and Black Sea, such as Russia, Turkey and Lebanon, usually pass through the Red Sea and are subject to the same heat stress considerations en route as voyages discharging in Red Sea ports.

The 2021 BOM report provided WBT readings from 2 additional locations (Jeddah and Jeddah offshore) compared to the 2019 BOM report. This data indicates that heat stress risks for voyages to or through the Red Sea were not as high in June as previously understood. The data also indicates that, in general, WBTs in the Red Sea increase earlier in the Northern Hemisphere summer than in the Persian Gulf and are milder for the entirety of the Northern Hemisphere summer. For example, at the northern end of the Red Sea, near the ports of Aqaba and Eilat, 95$^{th}$ percentile maximum WBTs do not reach 27˚C at any time of the year (Figure 22). However, voyages to these ports must travel through the Bab al Mandab Strait which is typically the hottest part of the voyage and represents around 6-12 hours of travel time.

Voyages to the Red Sea take around 14-15 days to arrive at the Bab al Mandab Strait and arrive at destination ports around 18-19 days after departure. Therefore, voyages departing Australia on 14 June arrive at the Bab al Mandab Strait around 27-28 June and at destination ports around 1-2 July. At this time, 95% of WBT records in the Bab al Mandab Strait are below 29˚C with some areas of the southern Red Sea less than 0.5˚C above the threshold, before WBTs decline to the mid to low 20s around destination ports, providing reliable respite. At destination ports, 95% of WBT records are below 25˚C (Figures 20, 21, 22 and 23).

Voyages departing Australia on 8 September arrive at the Bab al Mandab Strait around 21-22 September and at destination ports around 25-26 September. At this time, 95% of WBT records in the Bab al Mandab Strait are below 30˚C (representing 6-12 hours of travel time) and 95% of WBT records at destination ports are around 22-23˚C (Figures 20, 21, 22 and 24).

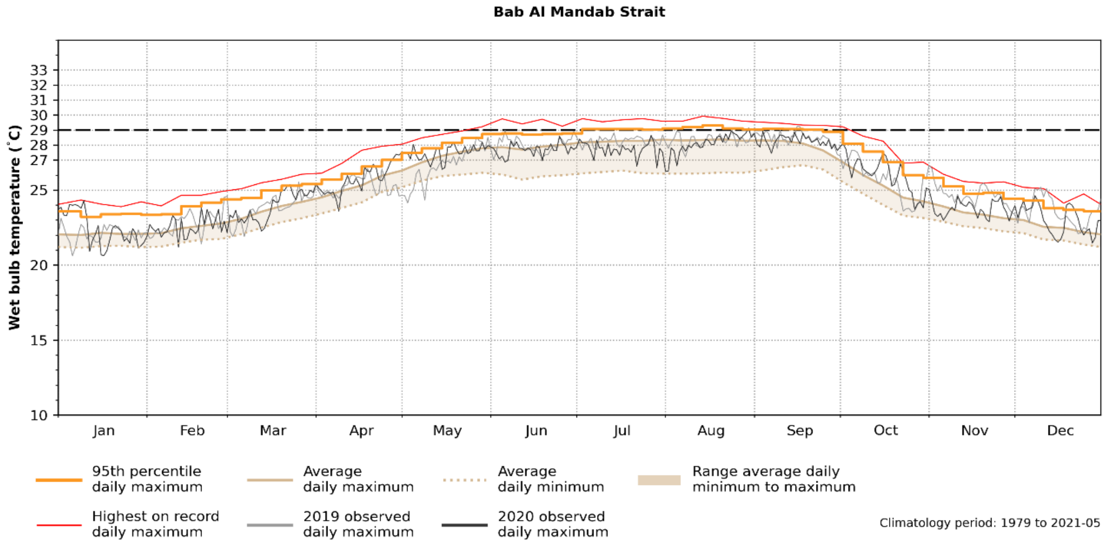
At the beginning of the Northern Hemisphere summer:

- the 95$^{th}$ percentile maximum WBT in the Gulf of Aden remains below 29˚C for the entire Northern Hemisphere summer
- the 95$^{th}$ percentile maximum WBT in the Bab al Mandab Strait reaches 29˚C by around 3 July (Figure 20)
- the 95$^{th}$ percentile maximum WBT in the southern Red Sea reaches 29˚C by around 3 July (Figure 21).

At the end of the Northern Hemisphere summer:

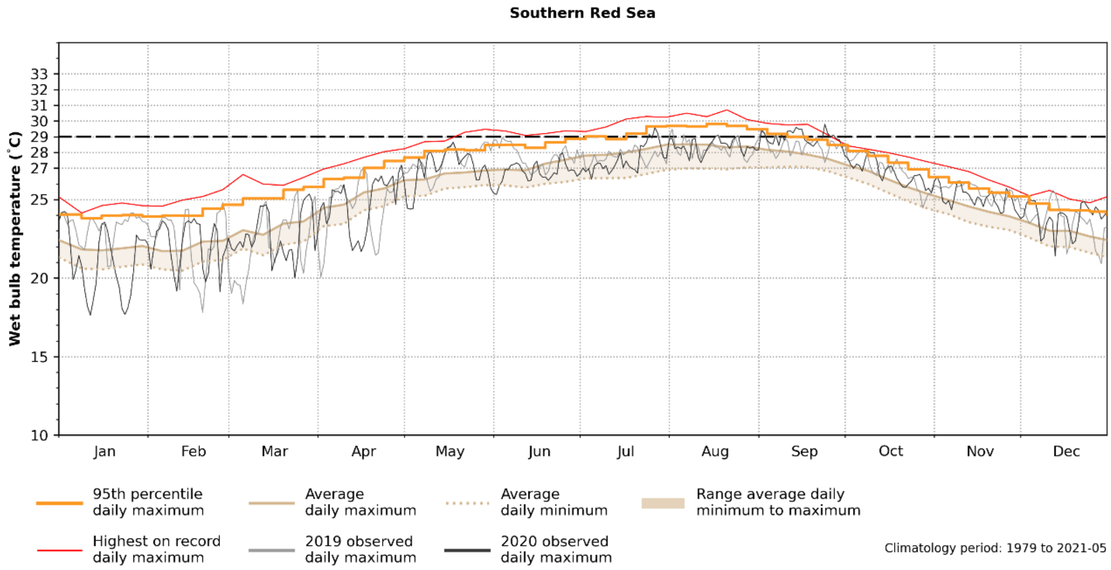
- the 95$^{th}$ percentile maximum WBT in the Bab al Mandab Strait drops to approximately 29˚C by around 18 September (Figure 20)
- the 95$^{th}$ percentile maximum WBT in the southern Red Sea drops to approximately 29˚C by around 11 September (Figure 21).

## Figure 20 Wet bulb temperatures for Bab al Mandab Strait



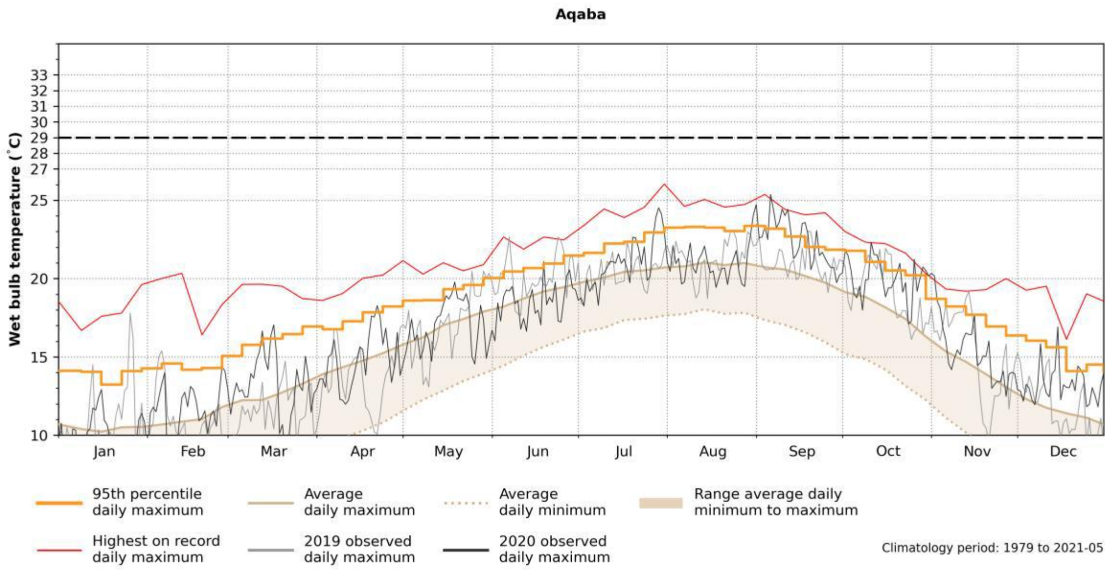

Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

## Figure 21 Wet bulb temperatures for southern Red Sea




Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

### Figure 22 Wet bulb temperatures for Aqaba port




Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

**Development of the recommendations for the Red Sea**

The draft report proposed to change the absolute prohibition for Red Sea voyages to 1 July – 7 September, and to introduce 2 conditional prohibition periods from 15 – 30 June and from 7 – 14 September where exports would be permitted provided additional heat-mitigating conditions could be met.

On closer examination, the department reconsidered the climate data, which showed WBTs are less than 1˚C above the threshold for large areas of the southern Red Sea for voyages departing Australia between 15-30 June and arriving in the Red Sea in late June to mid-July. This area of the southern Red Sea represents approximately 24 hours of travel time. Due to the duration at WBTs above the threshold, the department considered that heat stress risks in exported sheep could not be effectively mitigated and that exports during this period should be prohibited. For voyages departing Australia in mid-September, WBTs are up to 1˚C above the threshold in the Bab al Mandab Strait in late September. The Bab al Mandab Strait represents 6-12 hours of travel time where WBTs may be up to 1˚C above the threshold, after which WBTs transition to the mid to low 20s, providing reliable respite. Therefore, taking duration, route and port WBTs into account, the department reconsidered the draft report recommendations and amended the proposed dates.

The current recommended prohibition dates are summarised below. The recommendations consider are based on the same risk parameters implemented in regulation in 2020 and are consistent with the rationale that informed the changes to the Animals Rules in April 2022.

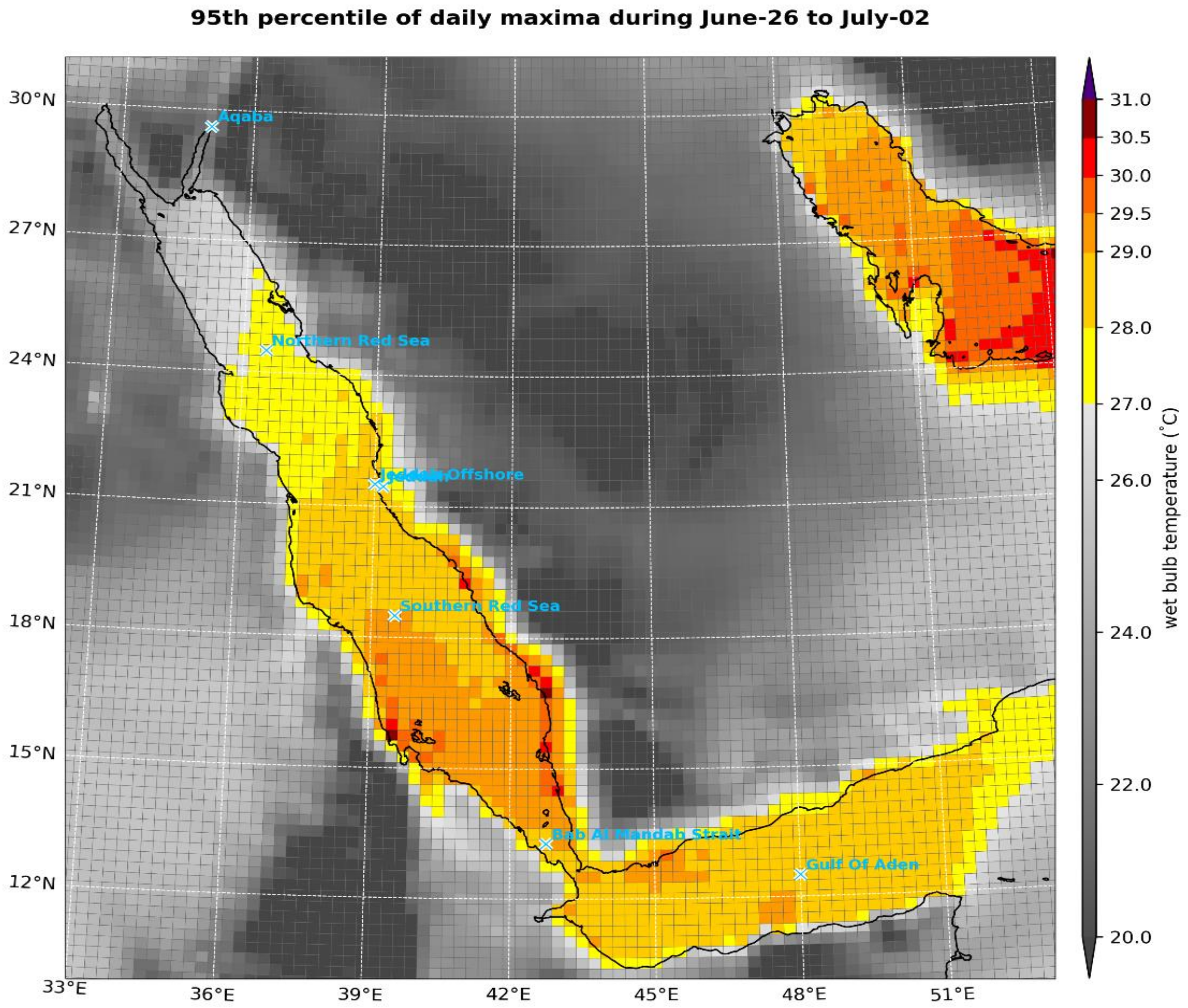
**Recommendation – prohibition dates for Red Sea destinations**

- The absolute prohibition period should be from 15 June to 7 September (change from current rules which prohibit export from 15 June to 14 September, and prior to April 2022 prohibited export from 1 June to 14 September).

**Summary – voyages to Red Sea destinations**

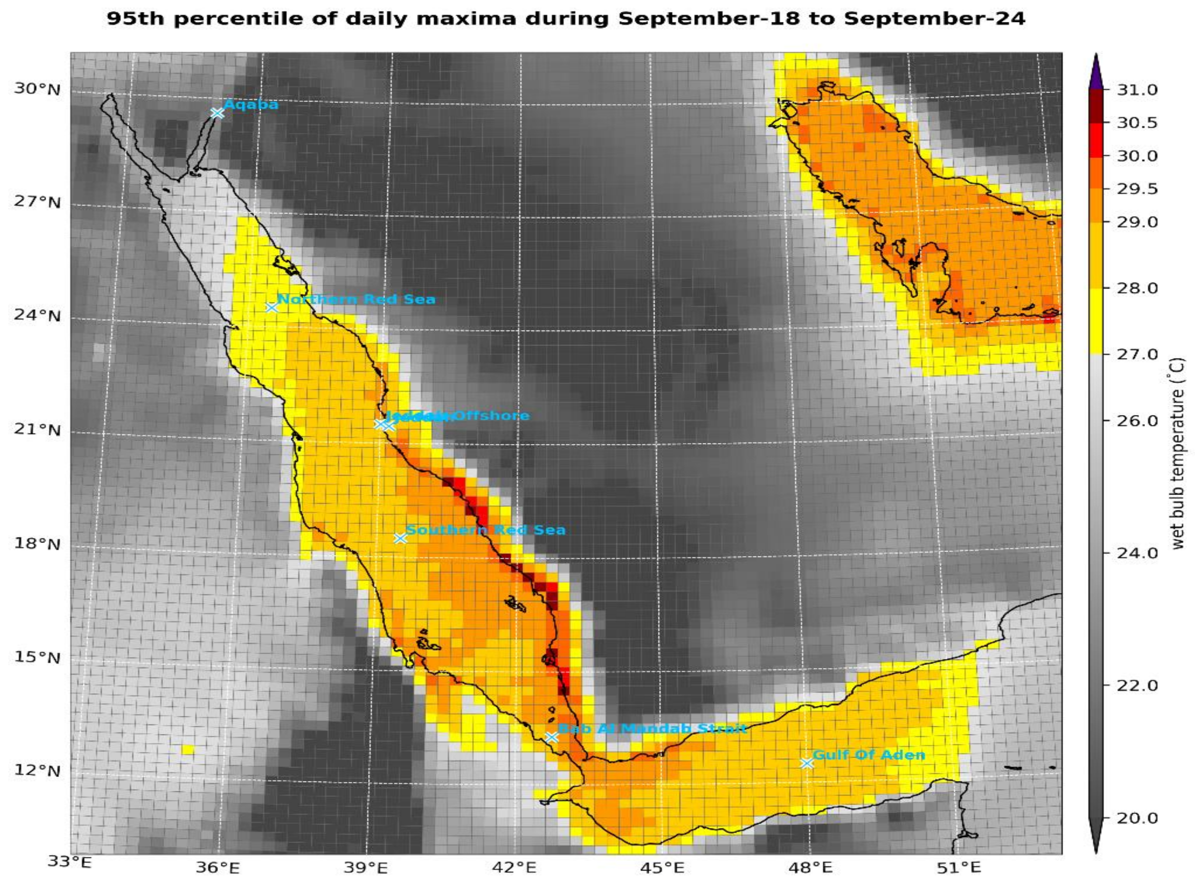
- Voyages departing Australia around 14 June arrive at destination ports in the Red Sea around 1 July.
- Voyages departing Australia on 8 September arrive at destination ports in the Red Sea around 25 September.

## Figure 23 95th percentile maximum wet bulb temperature from 26 June to 2 July Red Sea




Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

**Figure 24 95th percentile maximum wet bulb temperature from 18 September to 24 September Red Sea**




Source: Middle East live sheep trade climate analysis, Bureau of Meteorology 2021

### 2.4.5 Climatology during prohibition months

The **Error! Reference source not found.**2021 BOM report shows the extreme nature of WBTs during July, August and part of September in the MEAI, with most of the Persian Gulf likely to experience continuous 95th percentile maximum WBTs of 31˚C or above. This represents sound evidence that an absolute prohibition during the hottest months of the Northern Hemisphere summer is required to minimise heat stress risks in exported sheep.

## 2.5 Summary of 2021 Bureau of Meteorology data findings

- The risk of sustained WBTs above the 29˚C threshold is higher than previously understood at Persian Gulf ports (other than Kuwait and Oman) for voyages arriving at these destinations in June. Voyages typically arrive at these ports 17-19 days after departing Australia.
    - Ambient WBTs are up to 1.5˚C higher than the 29°C threshold for voyages arriving at these destinations in June, impacting environmental conditions at ports including Hamad, Qatar and Jebel Ali, UAE.
    - The data indicate the heat stress risks at Qatar are similar to other Persian Gulf destinations (other than Kuwait and Oman).
- WBTs are typically slightly higher in 'offshore' locations than at 'port' locations, reflecting the higher humidity in the maritime environment.

    - This trend is most pronounced at Kuwait port which experiences a markedly cooler microclimate (typically 2-3˚C cooler) than the surrounding maritime environment for most of the Northern Hemisphere summer.
- The risk of sustained WBTs above the threshold is lower than previously understood at Muscat port for voyages arriving in late August. Voyages typically arrive at Muscat port 13-14 days after departing Australia.
    - Data from Muscat offshore and Muscat port indicate a reduced heat stress risk in late August (typically around 2˚C cooler than previously understood).
- The risk of sustained WBTs above the threshold is lower than previously understood at Red Sea locations for voyages arriving in late June and September. Voyages typically arrive in the Red Sea 14 days after departing Australia and at Red Sea destination ports 18-19 days after departing Australia.
- In general, WBTs in the Red Sea start increasing earlier in the Northern Hemisphere summer than those in the Persian Gulf and maximum WBTs in the Red Sea are milder for the entirety of the Northern Hemisphere summer.

# 3 Science of heat stress

## 3.1 Physiology of heat stress

Animals subjected to hot environmental conditions, especially when accompanied by high humidity, cannot remove heat generated by metabolic processes in the body. Collins, Hampton & Barnes (2018) describe that these conditions can result in 'high thermal load' in animals. A possible outcome of high thermal load is heat stress, for which various definitions are available in scientific papers. According to De Rensis et al. (2015) heat stress occurs when an animal's normal biological responses to hot conditions can no longer maintain body temperature at its resting level. The Meat and Livestock Australia Veterinary Handbook describes heat stress as a state where animals are responding to excessive heat load (Jubb & Perkins 2019). A definition is also provided by Barnes et al. (2004):

> Heat stress is a term used to denote a state where an animal is responding to adverse hot conditions. Under such conditions an animal can respond to the heat by making physiological changes and adjustments within the body, so that it can survive in that environment. These changes will act to keep critical systems and mechanisms within the body functioning. However, if the heat load experienced by the animal becomes excessive, the critical functions may no longer be maintained, and clinical disease, collapse and even death can result. Such a situation may be described as severe or clinical heat stress.

The effects of hot environments on sheep depend on a range of biological factors including breed, sex, age, body condition, hair/wool covering, nutrition, acclimatisation and physiological state (for example, pregnancy). Within these variables there also exists the potential for further individual variation. Physiological responses to increased environmental heat include increased cutaneous blood flow, increased respiratory rate or panting resulting in evaporative heat loss and behavioural thermoregulation (Baida et al. 2021, Marai et al. 2008, McManus et al. 2020, HSRA Technical Reference Panel 2019). An animal's behavioural and physiological response to high levels of heat seeks both to increase heat loss and decrease heat gain. The type and magnitude of the physiological and behavioural adjustments influence how well the animal is able to respond to hot conditions.

Sheep primarily lose heat via evaporation from their respiratory surfaces (HSRA Technical Reference Panel 2019). McManus et al (2020) determined that woolled sheep do sweat but that this method of heat loss is much less important than respiratory evaporation as the presence of a wool coat impedes evaporation from the body surface. When a sheep is observed to have increased respiratory effort in warm conditions it is the equivalent to sweating in many other mammals and may not necessarily be a sign of poor welfare. However, if there is high humidity, heat loss from panting becomes less efficient as there is little or no evaporative capacity (Sparke et al. 2001). Therefore, it is very humid conditions that pose the greatest challenges for heat loss. If there is insufficient heat loss, the body temperature will rise, stimulating escalated physiological responses. For more discussion on heat stress and its impact on sheep physiology please refer to the Live sheep exports, to, or through, the Middle East-Northern Hemisphere summer RIS (DAWE 2020) and the Final Report by the HSRA Technical Reference Panel (HSRA Technical Reference Panel 2019).

When considering live sheep exports, WBT is the most useful combination measure of environmental conditions because it closely influences the physiological impacts of heat on the animal. On vessels, WBT is a useful and relevant measure to indicate the risk of heat stress in sheep, as it relates to the capacity of livestock to lose heat. The use of WBT for this purpose was recommended in the Final Report by the HSRA Technical Reference Panel.

Assessment of the respiratory rate and character of sheep remains a useful measure of the effects of heat on animals. The HSRA Technical Reference Panel stated 'panting is probably the best of the current measures although panting is both a response to increased thermal exposure, and an indication that the animal continues to require heat loss to maintain homeostasis'. Some sources note that measuring respiratory rate through panting score alone is subjective and not always well correlated with breed or core body temperature and can be partly an adaptive process (Baida et al. 2021, Belhadj Slimen et al. 2019, Marai et al. 2008).

The department notes that there are differing views on what constitutes whether an animal is 'heat stressed'. Despite much scientific research over many years on the subject of heat stress in livestock, there is yet to be any scientific consensus that clearly identifies the point when an animal changes from responding to increased heat (being heat affected) to being 'heat stressed'. Heat stress at the extremes appears to be clearly identified, however, the transition point and the impact of duration and respite remain undefined.

In the Animal Welfare Indicators Pilot for the Livestock Export Industry Supply Chain (Collins et al. 2021), industry proposed a range of indicators to assess the ability of livestock to cope with periods of heat and humidity and to better understand the welfare impact of heat. Indicators included panting score, feeding behaviour score, posture, resting, drinking and ruminating. This pilot proposed twice daily recording of panting scores and other measures during voyages, to improve the 'understanding of the welfare impacts of thermal loading in a live export context, as well as the degree and duration of heat that types of livestock can cope with and respond to'.

## 3.2 Factors influencing sheep heat management

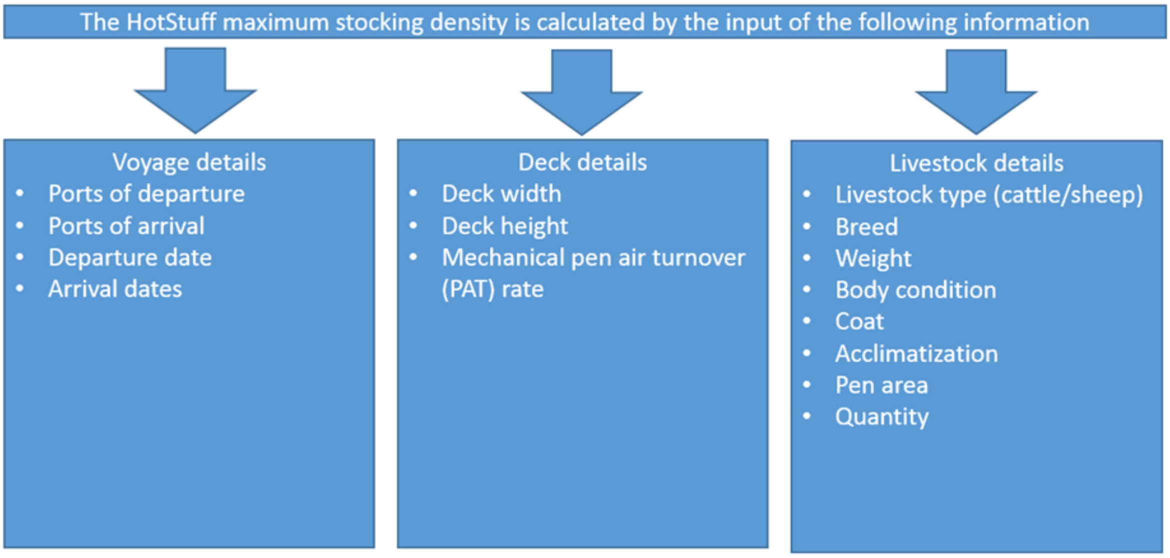
The current scientific evidence indicates that sheep heat management can be influenced by animal factors (including body weight, wool length and body condition score) and by environmental factors (including stocking density and ventilation rate or PAT score). Wool length limits, body weight limits and body condition score limits can increase the heat stress threshold of sheep, while stocking density limits and minimum PAT score requirements can limit deck WBT rise.

Some of these factors are already used in the management of heat stress risk in exported sheep (such as wool length limits) and form the basis of rules currently in place. However, the 2021 BOM report indicated additional heat stress risks in some parts of the Persian Gulf for voyages departing Australia in late May, that were not previously evident. Voyages that depart Australia during approximately 10 days in late May will reach the Persian Gulf when 95$^{th}$ percentile maximum WBTs for some Persian Gulf ports (including Hamad, Qatar and Jebel Ali, UAE) are 30.5˚C, up to 1.5 ˚C higher than the 29˚C threshold. This means that 95% of WBT records at these locations are less than 30.5˚C and 5% of WBT records exceed 30.5˚C. In order to mitigate the small chance of increased WBTs, the department reconsidered the factors influencing sheep heat tolerance in further detail to determine how they could be applied, either on their own or in combination, to improve sheep heat tolerance during this period.

Some elements relating to ship ventilation and animal factors discussed in this section are derived from the research incorporated into the HotStuff model (Figure 25). Developed by industry, the HotStuff model adjusts stocking densities to limit the total metabolic heat production by sheep, to ensure deck conditions experienced by livestock remain within agreed risk parameters. Current pen space allocations are calculated using an allometric equation (using a k-value of 0.033) which provides additional pen space over and above that provided using HotStuff. However, the underlying research informing HotStuff remains useful for providing science-based parameters for determining the heat tolerance of sheep. Alternate scientific evidence has also been considered by the department, where relevant and available.

The department notes that the ASEL sea review (2019) recommended the HotStuff model be updated, and we understand this work is currently being undertaken by LiveCorp.

**Figure 25 HotStuff inputs**



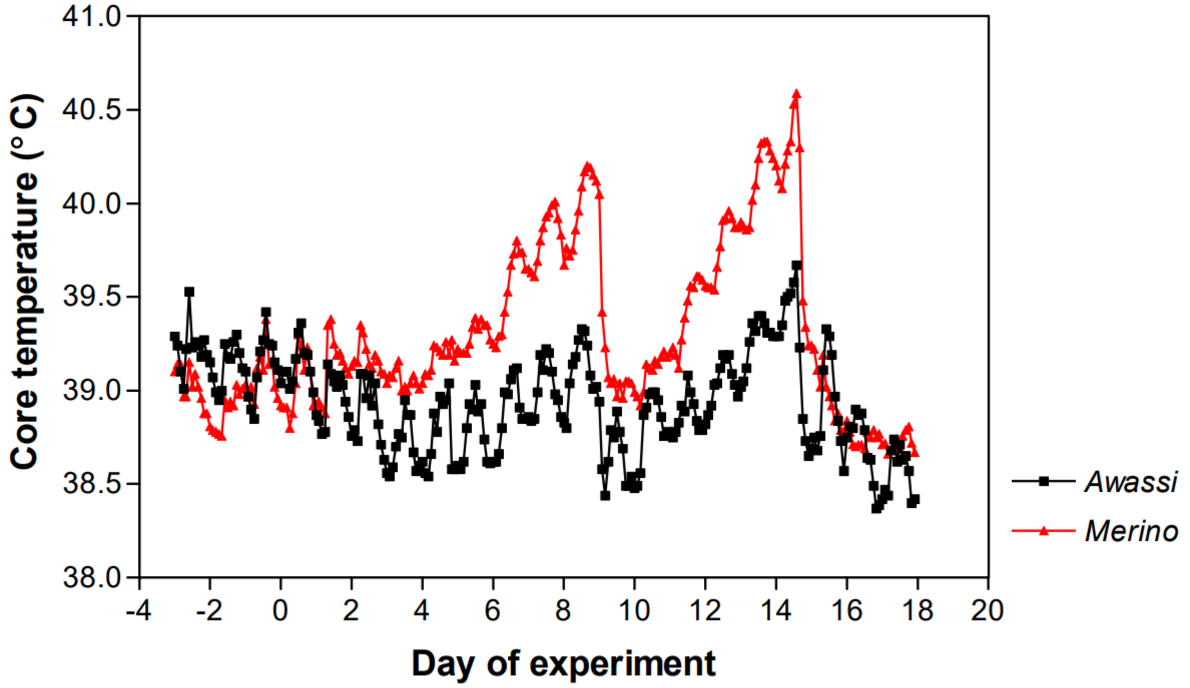

Source: Maunsell 2003

### 3.2.1 Breed

Moderate climate zone breeds such as Merinos and their crosses, are less heat tolerant than dry climate zone breeds such as Awassi and Dorper sheep (Belhadj Slimen et al. 2019, Marai et al. 2008). Differences in heat stress thresholds (HST) between moderate and dry climate zone breeds can be significant. Maunsell (2003) determined that a 40kg, BCS 3, hairy adult Awassi sheep has a HST 1.3°C higher than an equivalent shorn Merino sheep.

Barnes et al. (2004) found that Awassi rams had a higher HST than Merino wethers (with average weights of 53kg). In this study, Merino wethers had elevation of their core body temperatures above 39.5°C once WBT reached 30°C on day 6 of the experiment (Figure 26). The core body temperature of Awassi rams did not rise above 39.5°C until the WBT neared 32°C on day 14 of the experiment, demonstrating a HST up to 2°C higher for Awassi sheep. In addition, no Awassi rams demonstrated open mouthed panting at any point during the study. HSTs are also dependent on other factors including acclimatisation, BCS and wool length, however, these factors could not be assessed from the information provided in the study.

**Figure 26 Sheep core body temperatures**




Source: Barnes et al. 2004

The majority of sheep produced in Australia and exported by sea are Merino or Merino crossbreeds (MLA 2020). The review did not consider it was necessary to limit the export of certain breeds of sheep, however recommendations are made to apply weight limits and wool length limits to address the lower heat tolerance of Merinos and their crosses. These recommendations are addressed in the sections covering weight and wool factors.

**Summary-recommendations for export conditions related to breed**

- No sheep breed restrictions are recommended.

### 3.2.2 Age

Literature indicates that HSTs can vary depending on the age of sheep. Thwaites (1967) concluded that the adult heat tolerance of sheep is reached at or soon after they are 1 year old. Stockman (2006) found that 8-month-old juvenile sheep are more sensitive to heat stress than adult sheep. Another study by Belhadj Slimen et al. (2019) determined that growing lambs, pregnant and lactating ewes can be highly susceptible to heat stress, however this study did not define the age or weight of a 'growing lamb'.

Maunsell (2003) demonstrated that lamb and adult Merino and Awassi sheep have minimally different HSTs. In Merinos, adult sheep HSTs were shown to be 0.3°C higher than lamb HSTs and 0.2°C higher in adult Awassi sheep compared to Awassi lambs. Maunsell did not state the age of lambs in this study but stated their liveweight was 38kg.

In Australia, a lamb is defined as 'an ovine animal that is under 12 months of age; or does not have any permanent incisor teeth in wear' (Sheep Producers Australia 2019). MLA has defined lambs as 'male or female ovine with no secondary sexual characteristics. Generally weaned, shorn with no permanent incisor teeth in wear. Normally older than 5 months and under 12 months' (MLA 2021).

MLA has also used bodyweight as an indicator of age, defining the following weight categories of lambs:

- light lambs (under 16kg)
- trade lambs (between 18kg and 22kg)
- heavy lambs (over 24kg).

There are a number of variable factors which can influence the weight of sheep including breed, genetic profile, whether a single or multiple birth and plane of nutrition. Consequently, it is difficult to definitively correlate the weight of a sheep with its age.

Industry practices commonly rely on bodyweight rather than age as this measurement is easier to verify and can impact more significantly on management factors such as allometric pen space allowances, fodder requirements and behaviours such as group hierarchy. Feedback from industry consultation identified that young sheep, typically between 38-48kg and at least 12 months old, make up the greatest proportion sourced for live export. In addition, voyage reporting from the 15 voyages during the 2019-2021 Northern Hemisphere summer consistently indicated younger sheep were less heat affected than older sheep.

Under the ASEL, there are no minimum age restrictions for the export of sheep, however sheep must have a minimum individual liveweight of 32kg to be sourced for export by sea. This prevents the export of very young lambs that are more susceptible to heat stress. The review concluded that this requirement was sufficient to manage heat stress risks in young sheep.

**Summary-recommendations for export conditions related to age**

- No restrictions apply to sheep age.

### 3.2.3 Weight

Limiting the maximum bodyweight of exported sheep aims to prevent the export of heavier, less heat-tolerant sheep. However, scientific studies relating the influence of sheep body weight on heat tolerance are limited and often confounded by other factors. McManus et al. (2020) found that sheep HSTs generally decreases as bodyweight increases, particularly in less heat tolerant breeds such as Merinos. McManus et al (2010) identified that smaller animals have a greater surface area, facilitating heat loss more effectively than larger animals. In contrast, Correa et al. (2012) determined that size did not significantly affect heat tolerance in animals.

**Less heat tolerant breeds**

Table 4 indicates the HST for a range of sheep weights. This data shows that for moderately sized sheep (40-56 kg), the HST varies by 0.7°C (Maunsell 2003). Where acclimatisation and other parameters are the same, a 45kg Merino has a HST 1°C higher than a 70kg Merino.

### Table 4 Hotstuff heat stress threshold for adult Merino rams acclimatised to May conditions

| Weight (kg) | HST (°C) |
|---|---|
| 40 | 30.0 |
| 45 | 29.8 |
| 50 | 29.5 |
| 56 | 29.3 |
| 60 | 29.1 |
| 65 | 29.0 |
| 70 | 28.8 |
| 90 | 28.2 |

Source: Maunsell 2003

Australian Maritime Safety Authority (AMSA) data for consignments to the Middle East during the Northern Hemisphere summer 2019-2021 indicate the average weight of exported Merinos is 47.4kg (the range of voyage averages was 38kg to 55.7kg). This is consistent with data from MLA which states ‘the average liveweight of live export sheep since 2000 has been 48.1kg (MLA 2019)’.

**Heat tolerant breeds**

Section 3.2.4 outlines evidence that indicates a 40kg Awassi sheep has a HST 1.3°C higher than an equivalent Merino. For a 53kg sheep, the HST for an Awassi sheep is 1-2°C higher than a Merino. There is no definitive data available on the HST of a 66kg heat tolerant breed sheep, although it is likely they can tolerate heat better at all weights compared to less heat tolerant breeds. Data from the 2018-2019 Northern Hemisphere summer indicate the average weight of exported Awassi and Damara sheep is < 44kg.

Therefore, the available evidence indicates limiting the export of heavier sheep is considered a practical and reasonable measure to manage the risk of heat stress in sheep during the conditional prohibition period, by preventing the export of more heat sensitive, heavier sheep. As heat tolerant breeds have a higher HST, it is reasonable to implement different maximum weight limits for different breeds of sheep.

**Summary-recommendations for export conditions related to weight**

- Maximum weight limits be implemented to manage heat stress risk in exported sheep during the conditional prohibition period, and that those maximum weight limits should differ for heat tolerant and less heat tolerant breeds.
- A maximum weight limit of 56kg is implemented for less heat tolerant breeds during the conditional prohibition period.
- A maximum weight limit of 66kg is implemented for heat tolerant breeds during the conditional prohibition period.

### 3.2.4 Wool/fleece length

Baida et al (2021) state that environmental heat exchange is heavily impacted by fleece length and that 'shorn sheep tolerate hot-humid conditions better than fleeced sheep'. The upper critical temperature threshold for 'woolled sheep' is reported to be between 25˚C to 30˚C and is also affected by humidity (Tadeese et al. 2019, Furquay 1981).

Maunsell (2003) also determined that wool length can adjust the HST of sheep. In the Hotstuff model, wool length is 'built in' as a parameter that establishes a scaling factor for estimating HSTs and mortality limits (ML). HotStuff applies 3 different scaling factors related to 3 different wool lengths. (Table 5).

**Table 5 HotStuff wool length parameters**

| Coat type | Scaling factor |
|---|---|
| Shorn (< 10mm) | 1 |
| Mid (10-25mm) | 1.08 |
| Woolly (>25mm) | 1.12 |

Source: Maunsell 2003

Applying the scaling factors in Table 5, Maunsell (2003) determined that a woolly 54kg Merino sheep has a HST 1.5°C lower than an equivalent 52kg shorn Merino sheep. Interpolation of this data estimates an equivalent weight sheep with mid wool will have a HST 1°C lower than if it was shorn.

McManus et al. (2020) and Belhadj Slimen et al. (2019) found that shorn Merino sheep are less heat tolerant than equivalent weight haired heat-tolerant breeds. A 40kg adult shorn Merino sheep has a HST 1.3°C lower than an equivalent weight hairy Awassi sheep (Maunsell, 2003).

Feedback during industry consultation indicated that sheep being prepared for export to the Middle East during the Northern Hemisphere summer may be shorn either on-farm or at the RE. An RE may have the capacity to shear up to 10,000 sheep per week, prior to export. A review of HSRAs submitted to the department over the last 3 years showed that over 96% indicate that merinos and their crosses are exported with a wool length <10mm. According to Australian Wool Innovation, wool grows at about 6mm per month and a close comb shear cuts to approximately 3mm. To meet a wool length requirement of no longer than 20mm, sheep must be shorn within 2.5 months prior to export. To meet a wool length requirement of no longer than 10mm, sheep must be shorn no longer than 1 month prior to export. Industry feedback indicated some welfare concerns when re-shearing sheep with a fleece length of 20mm or less. This is discussed in Section 7.

Under the ASEL, all sheep exported by sea must have wool or hair no longer than 25mm in length at the time of loading for transport to the port of embarkation. There is also a requirement for 2 clear days between shearing and export.

Therefore, the available evidence indicates that wool length impacts heat tolerance and implementing wool length limits is considered a practical and reasonable measure to manage the risk of heat stress in sheep during the conditional prohibition period. As heat tolerant breeds have a higher HST, it is reasonable to implement different wool length limits for different breeds of sheep.

**Summary-recommendations for export conditions related to wool length**

- Maximum wool length limits be implemented to manage heat stress risk in exported sheep during the conditional prohibition period, and that those maximum wool length limits should differ for heat tolerant and less heat tolerant breeds.
- Less heat tolerant breeds are recommended to have a wool length no longer than 20mm at the time of loading for export during the conditional prohibition period.
- Heat tolerant breeds must be shorn to the ASEL requirements.
- For sheep travelling on a vessel with a minimum PAT score of 140 $m^3$/hr there are additional wool length requirements.

### 3.2.5 Acclimatisation

Animal heat tolerance changes throughout the year depending on seasonal temperature exposure (HSRA Technical Reference Panel 2019), however, the panel stated it is not known how long sheep take to acclimatise to new weather conditions. Other species have demonstrated some acclimatisation to hot, humid conditions over a 2 to 3-week period.

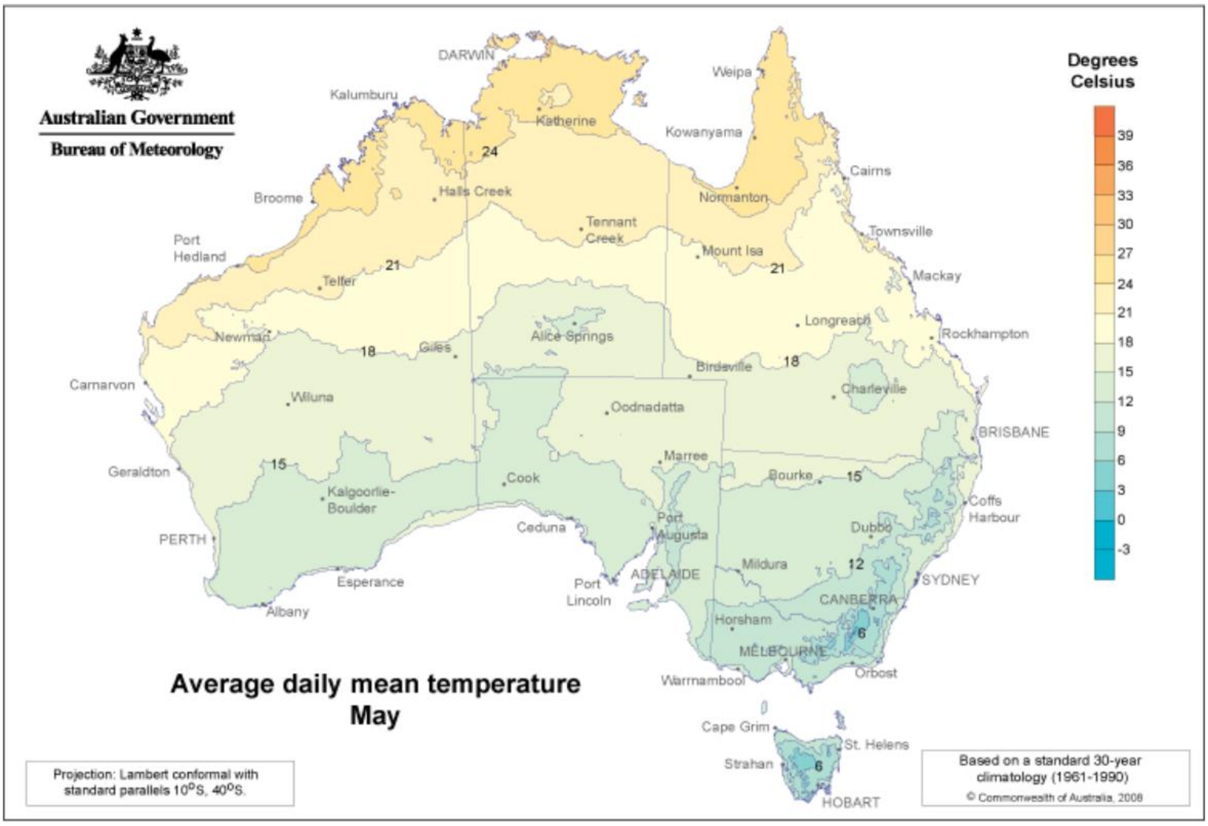
McCarthy (2018) noted that sheep loaded during winter will have a lower tolerance for heat than sheep prepared for export in warmer months. McCarthy also stated that acclimatisation plays a significant role in adjustments to sheep metabolism, which in turns affects their heat tolerance. There is a lag in the way sheep adjust their metabolic rate in response to new weather conditions, with winter-acclimatised sheep the least able to adapt to hotter temperatures. This increases their risk of inanition and salmonellosis (McCarthy 2018).

### 3.2.6 Temperatures at departure

Sheep exported by sea are primarily sourced from Western Australia. For sheep that are sourced from the southwest of the state, the daily mean temperature range encountered during the months of May, June, August and September is 9-12°C.

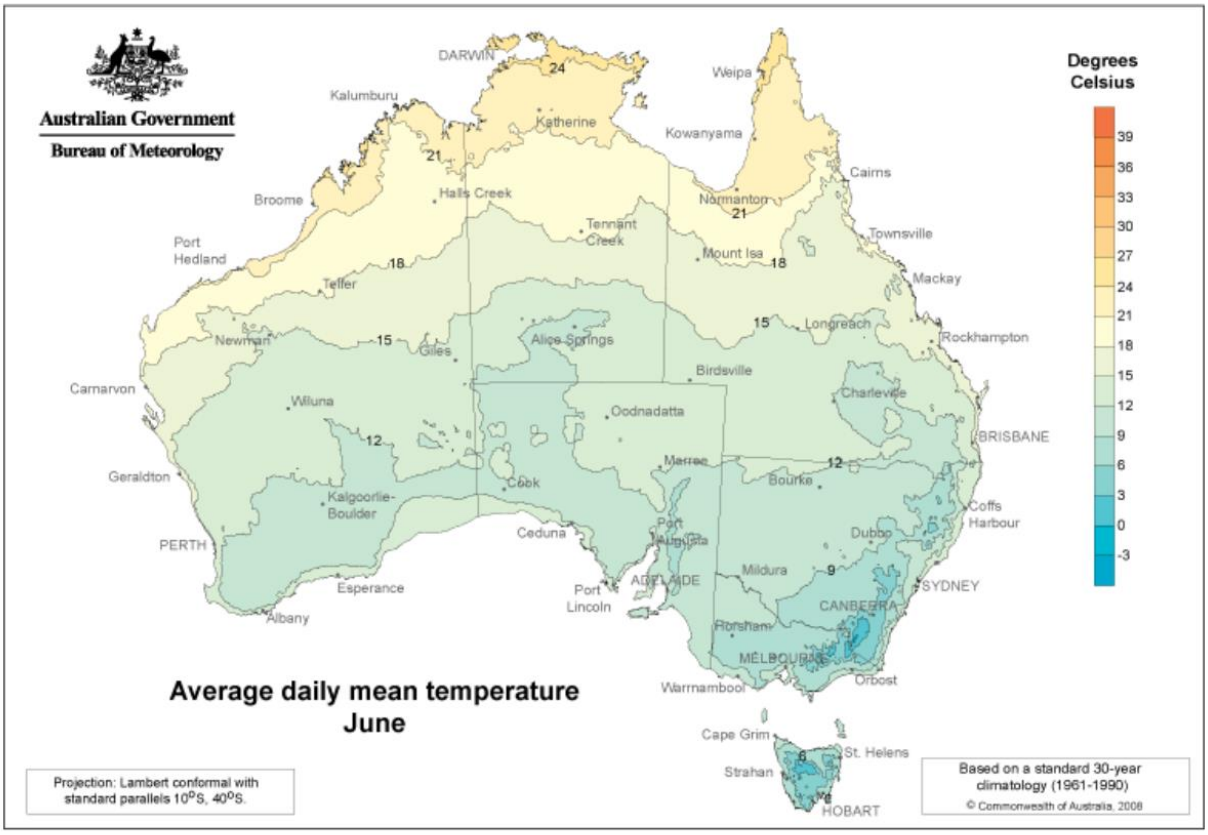
Average daily mean temperatures in Australia for May, June, August and September are presented in Map 1, Map 2, Map 3, and Map 4. Theses maps indicate the weather conditions likely to be experienced by sheep before and after the current prohibition periods.

## Map 1 Average daily mean temperatures for May



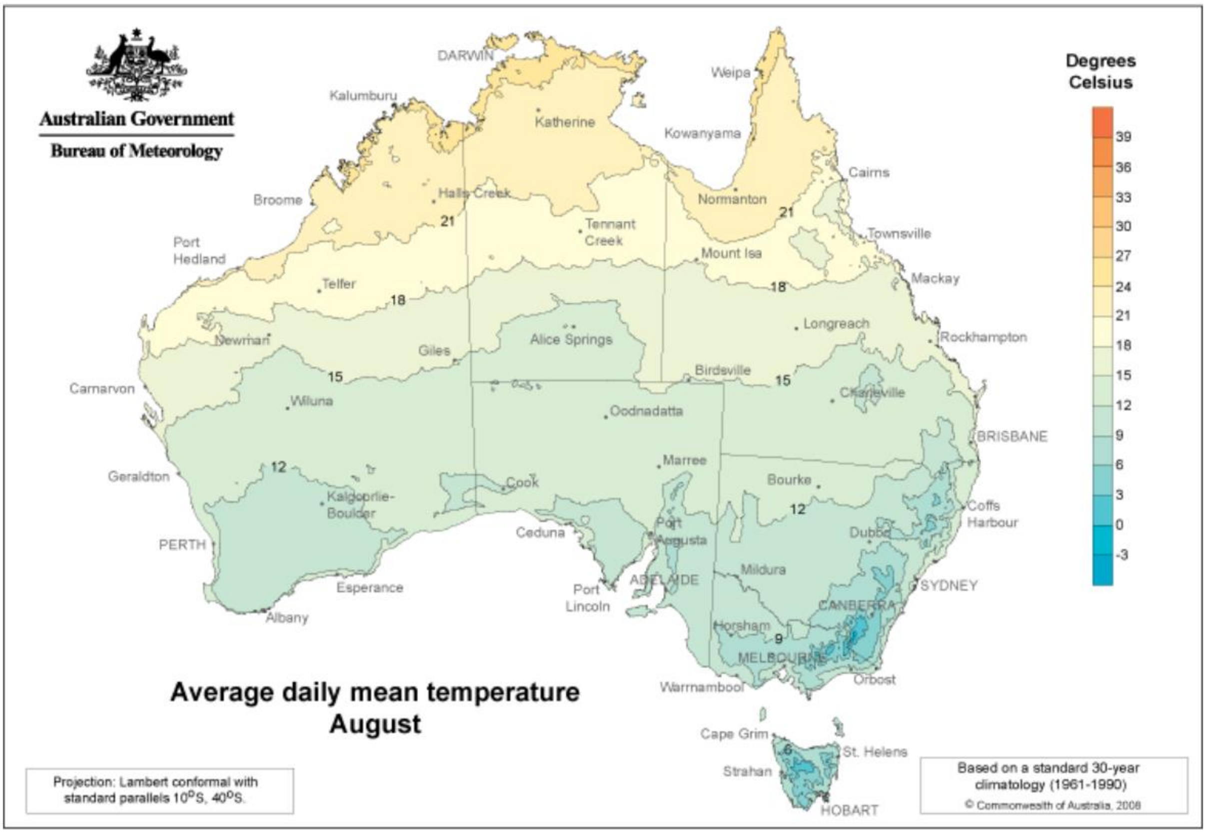

Source: Bureau of Meteorology 2021

## Map 2 Average daily mean temperatures for June



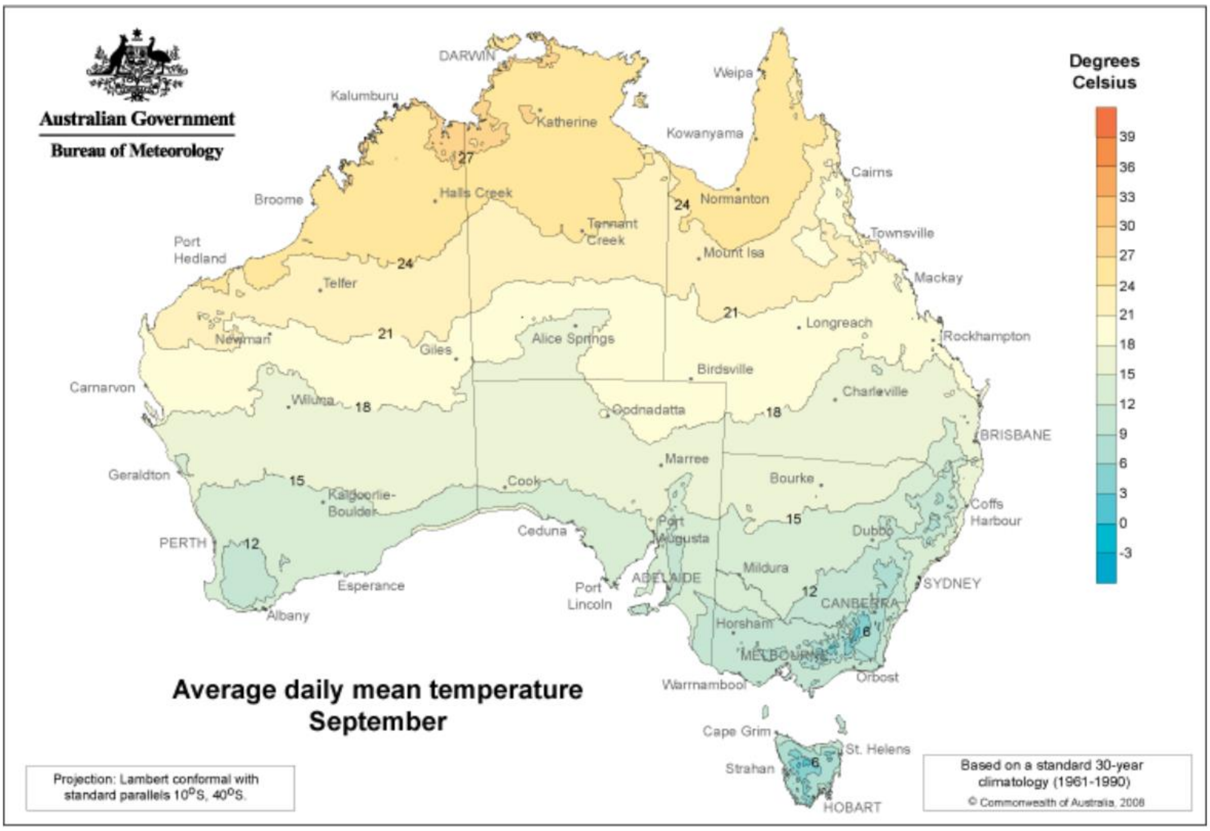

Source: Bureau of Meteorology 2021

## Map 3 Average daily mean temperatures for August




Source: Bureau of Meteorology 2021

## Map 4 Average daily mean temperatures for September




Source: Bureau of Meteorology 2021

The HotStuff model identifies that acclimatised temperature can impact the HST of sheep (Table 6).

**Table 6 Acclimatisation thresholds using the HotStuff model**

| Example | Breed | Weight | Maturity | Acclimatised temperature | HST |
|---|---|---|---|---|---|
| A | Awassi | 38kg | Lamb | 12°C WBT | 0.6°C lower than example B |
| B | Awassi | 40kg | Lamb | 15°C WBT | 0.6°C higher than example A |
| C | Merino | 52kg | Adult | 12°C WBT | 1.1°C lower than example D |
| D | Merino | 40kg | Adult | 15°C WBT | 1.1°C higher than example C |

Source: Maunsell 2003

For example, Table 6 shows that a 52kg adult Merino acclimatised to 12°C WBT has a HST 1.1°C lower than a 40kg adult Merino acclimatised to 15°C WBT. Some of the challenges associated with this modelling include limited data with confounding factors (such as differences in weight) which can make like-for-like comparison difficult. The HotStuff model applies a minimum acclimatisation temperature of 12°C WBT.

Currently, nearly all sheep sourced for export are from Western Australia, which experiences warmer winter temperatures than eastern states. Whilst sourcing restrictions based on property of source location do not currently apply, consideration could be given to acclimatisation if exporters source sheep from eastern states in the future.

**Summary-recommendations for export requirements related to acclimatisation**

- No acclimatisation restrictions are proposed.

### 3.2.7 Pen space, ventilation and pen air turnover

Due to the inter-relationship between pen space allowance, ventilation rate and associated deck WBT rise, these factors are jointly evaluated in this section.

McCarthy (2018) identified that the central issues relevant to reducing the risk of heat stress in sheep during shipping to the Middle East in the Northern Hemisphere summer are stocking density and ventilation. Providing adequate pen space for sheep assists in improving the circulation of air across the animal's surface for elimination of excessive heat through respiration and evaporation. Deck WBTs on board live sheep export vessels are higher than ambient temperatures, typically by 1-3°C, due to the metabolic heat created by the animals. The deck WBT rise depends on the stocking density and the rate and effectiveness of ventilation on the vessel.

An allometric pen space using a *k*-value of 0.033 has been shown to provide sheep with adequate space to eat, drink and lie down (McCarthy 2018, Petherick & Phillips 2009). McCarthy (2018) stated that increasing the pen space allowances using an allometric equation and a *k*-

value of 0.033 'will assure the health and welfare for sheep being transported to the Middle East during the northern hemisphere summer'. For a 50kg sheep the provision of additional pen space up to a $k$-value of 0.047 may alleviate stress however, provision of further space beyond this value appears to add little extra amenity (McCarthy 2018).

Pen air turnover is a measure of a vessel's ventilation efficiency, measured in $m^3$/hour. Recommendation 11 from the McCarthy Review (2018) stated:

> It would be a condition of an approved arrangement that all livestock vessel's PAT information has been independently verified where the vessel is destined for the Middle East during the northern hemisphere summer.

In response to Recommendation 11 the department implemented a requirement that all vessels transporting sheep to the Middle East during the Northern Hemisphere summer must undergo independent verification of the PAT scores. Section 6-17 of the Animals Rules states that each vessel's PAT scores must be verified by an independent qualified mechanical engineer every 5 years, or whenever a vessel has undergone a structural change. In addition, the department must be provided with a written notice stating the most recent verified PAT scores for the vessel, including a description of the method used to evaluate the PAT score. The requirement to report PAT scores to the department was also in response to recommendations in the McCarthy Review (2018).

Minimum ventilation performance of sheep export vessels has improved over the last 3 years due to factors including:

- the implementation of minimum ventilation standards established by AMSA under Marine Order 43, which has resulted in vessel ventilation upgrades, and
- the phasing out of twin-tier vessels.

The PAT score may be impacted by movement of the vessel by allowing air to move through open decks, increasing ventilation (this does not occur on closed decks). In an audit report provided to the department on livestock ventilation, ventilation engineering company Stacey Agnew states that when sailing, exhaust air from the decks of a vessel is blown away by air moving past the vessel. When a vessel is stationary, exhaust air from open decks will rise and form an envelope over the vessel and be partially re-ingested by supply fans. This means the re-ingested air enters the 'intake' ventilation, reducing the proportion of fresh air reaching livestock on decks. Stacey Agnew considers applying a value of 20% for re-ingestion is appropriate. Accordingly, some vessels may have different PAT scores when sailing (sailing PAT) compared to when stationary (port PAT). This means that for some vessels, port PAT scores may be around 20% lower than sailing PAT scores.

At Persian Gulf ports (other than Kuwait with its cooler microclimate), the period of time spent discharging animals means that a vessel's port PAT score is likely to have a greater influence than the sailing PAT score, on the WBTs experienced by sheep. Accordingly, the port PAT score is likely to impact more significantly on an animals' ability to tolerate hot and humid conditions.

McCarthy (2018) reported that the higher the PAT score on a deck, the lower the deck WBT rise. It is typical for the WBT on sheep decks to be 1-3°C higher than the ambient (bridge) WBT due to the metabolic heat created by the animals. This WBT differential is called the deck WBT rise and means a predictable relationship can be determined between ambient WBT and the likely

WBTs experienced by the sheep on decks. For example, when the ambient (bridge) WBT is 29°C, deck WBTs experienced by livestock is likely to be between 30˚C to 32˚C WBT.

Higher ventilation rates are more efficient at removing the metabolic heat generated by sheep on a deck, which in turn, limits the deck WBT rise. McCarthy (2018) stated that doubling the PAT score halves the deck WBT rise, noting that McCarthy's assessments were based on historic higher stocking densities. However, McCarthy determined that even with high ventilation rates and PAT scores (400 $m^3$/hour per square metre of pen space), vessels would need to be significantly destocked from June to September, due to high ambient temperatures in the Middle East. The ASEL now requires a lower stocking density (based on allometric pen space using a *k*-value of 0.033), but the principle of minimum PAT score requirements to reduce deck WBT rise remains relevant.

MAMIC (2001) presented data from vessels with varying PAT scores and demonstrated how the different PAT scores can limit the deck WBT rise. The reduction in deck WBT rise (relative to a PAT of 120 $m^3$/h) from increasing PAT scores is represented in Table 7.

**Table 7 Reduction in deck wet bulb rise by increase pen air turnover score at a *k*-value of 0.033**

| PAT score | Reduction in wet bulb rise |
|---|---|
| 140 $m^3$/h | ~0.3°C |
| 160 $m^3$/h | ~0.4-0.5°C |
| 180 $m^3$/h | ~0.6-0.7°C |
| 200 $m^3$/h | ~0.7-0.8°C |

Note: the above figures are for sheep weights of 40kg to 60kg)
Source: MAMIC 2001

For example, improving the PAT scores of a vessel from a rate of 140$m^3$/h to 200$m^3$/h can result in a decrease of up to 0.5°C in the deck WBT rise. If sheep are provided with extra space, such as 10% space above the ASEL requirement, the deck WBT rise will reduce even further. The reduction in deck WBT rise (as PAT score increases) is more pronounced at lower PAT scores (Table 8).

**Table 8 Reduction in deck wet bulb temperature rise by increasing pen air turnover score at a *k*-value of 0.033+10% relative to a PAT score 120 $m^3$/h**

| PAT score | WBT rise reduction |
|---|---|
| 140 $m^3$/h | ~0.2-0.6°C |
| 160 $m^3$/h | ~0.2-0.5°C |
| 180 $m^3$/h | ~0.2-0.4°C |
| 200 $m^3$/h | ~0.2-0.4°C |

Note: the above figures are for sheep weights of 40kg to 60kg
Source: MAMIC 2001

Based on available data for vessels used to transport sheep to the Middle East since 2019, port PAT scores ranged from 53 $m^3$/h to 292 $m^3$/h, with one vessel having scores of 191 $m^3$/h and above on all decks. PAT audits indicate the majority of vessels had port PAT scores >160 $m^3$/h. Since 1 January 2020, the lowest PAT score for a single-tier vessel in this review is 165 $m^3$/h. The draft report proposed permitting exports only on vessels with a minimum sailing PAT scores of 200 $m^3$/h. Based on further analysis, port PAT scores appear to have greater influence on temperatures experienced by sheep because sheep spend longer at destination ports than at other locations during the voyage. In addition, it is at southern Persian Gulf ports where temperatures are at their highest during the journey and can impact heat stress risk significantly.

**Summary-recommendations for export conditions relating to pen air turnover and pen space allowance**

- Combinations of port PAT and pen space allowance (along with additional heat mitigating conditions such as weight limits and wool length limits) should be implemented during the conditional prohibition period so their combined impact sufficiently reduces deck WBT rise, which in turn limits the risk of heat stress in sheep.
  - During the conditional prohibition period sheep are recommended to be exported on a vessel with a minimum PAT score of 180 $m^3$/hr when the vessel is in port, or
  - a minimum PAT score of 160 $m^3$/hr when the vessel is in port AND the sheep must be allocated an additional 10% space (above the minimum pen space allocation specified in the ASEL standard 5.5), or
  - a minimum PAT score of 140 $m^3$/hr when the vessel is in port AND the sheep weigh 56kg or less AND have wool or hair length no longer than 10mm.

Acknowledging the range of factors that can mitigate the risk of heat stress in sheep, changes to the Animals Rules came into effect on 6 April 2022 which specified these minimum port PAT score requirements (and other additional heat mitigating conditions). These requirements are intended to minimise deck WBT rise and the impact of increased ambient temperatures at southern Persian Gulf ports and are recommended to remain in place.

### 3.2.8 Diet transition and inanition management

Barnes et al. (2008) reported it may take generally around 2 weeks for all sheep to become adapted to a new diet. Shy feeding (animals reluctant to eat pelleted rations) has been linked to loss of condition, inanition, enteritis and other problems which may be further exacerbated by heat (Barnes et al. 2008; Phillips 2016). Consequently, providing sheep with an adequate transition period to a new diet and preventing inanition is vital to ensuring better welfare outcomes for sheep onboard vessels. Belhadj Slimen et al. (2019) found that water and nutritional restrictions aggravated heat stress responses. Voyage reporting during the 2019-21 Northern Hemisphere summer indicated that feeding either ad lib or well above the ASEL requirements occurred on 80% of voyages, indicating that industry may also see the benefits of increased available fodder in limiting heat stress responses.

Providing additional feed can be an effective preventative measure for shy feeding and inanition. (Jubb & Perkins 2021). Feeding quantities above the ASEL requirements or ad lib feeding is likely to assist in shy feeder management on board, as food would still be available after more aggressive feeders have finished eating.

Multiple literature sources report a decrease in dry matter intake by sheep in response to increased temperature, however, this can vary with breed, with some reported to increase their dietary intake (Belhadj Slimen et al. 2019, Tadesse et al. 2019, Marai et al. 2007, Barnes et al. 2004).

Under the ASEL, sheep must spend 5 clear days in an RE and be fed a ration equivalent to the shipboard ration ad lib for at least the final 3 days. Feedback from stakeholders indicated that sheep in REs are routinely provided with shipboard rations from day 1 and often spend longer than 5 days in the RE. The provision of extra time to adapt to the shipboard ration is likely to minimise the incidence of ‘shy feeders’ on voyages.

The ASEL feed requirements on voyages are based on liveweight percentages. Sheep with more than 4 permanent incisors must be fed a minimum of 2% of their liveweight, and younger sheep must be fed a minimum of 3% of their liveweight.

Voyage reporting during the 2019-21 Northern Hemisphere summer indicated that feeding either ad lib or well above the ASEL requirements (up to 3.7% of liveweight) occurred on:

- 100% of voyages to the Persian Gulf (all 10 voyages) and
- 40% of voyages to the Red Sea (2 of 5 voyages).

In total, 12 of 15 voyages (80%) reported feeding well above ASEL minimum requirements. The provision of more feed above ASEL increases the likelihood of all sheep, including shy feeders, accessing sufficient feed. There is likely to be less competition for fodder as aggressive feeders have already eaten.

Stakeholder feedback indicated that this additional feeding may be due to the majority of sheep being younger or because exporters find positive welfare outcomes in feeding more than is required under the ASEL.

**Summary-recommendations for export conditions related to diet**

- Sheep should be fed a minimum of 3% of their liveweight daily while on the vessels travelling to or through the Middle East during the Northern Hemisphere summer.

### 3.2.9 Body condition score

Body condition score is a rating of the fat cover on an animal, using a scale from 1 (emaciated) to 5 (overfat). This scale provides a simple and practical approach to body condition scoring. Details of this scoring system can be found in the ASEL.

Industry research recognises that body condition score can impact on a sheep's heat tolerance. A 2005 report by MLA noted that 'fatter animals have a number of extra risk factors and have more difficulty adjusting to extreme heat. This is especially an issue for sheep and cattle travelling from southern Australia in winter to a much hotter Northern Hemisphere summer such as the Middle East' (Maunsell 2003).

During the RIS consultation process, ALEC indicated that most exported sheep to the Middle East would be in body condition scores of 2 or 3.

Regulation introduced in 2020 required that the body condition score of exported sheep must be 2 or more and less than 4, on a scale of 1 to 5. This promotes selection of sheep with optimum heat tolerance characteristics.

**Summary-recommendations for export conditions related to body condition score**

- No change to the current requirements for body condition score is recommended.

**Summary of findings-factors influencing heat tolerance**
**Breed, age and weight heat stress thresholds**

- Heat tolerance varies between different sheep breeds. A 53kg Awassi sheep has a HST 1-2°C higher than a similar weight Merino sheep.
- There is difference of around 0.2°C in the HST between export weight lambs (minimum 32kg) and adult sheep.
- There is difference in the HST between a 45kg and a 56kg adult Merino (0.5°C).

**Wool length**

- A woolly (>25mm wool) 54kg Merino sheep has a HST around 1°C lower than an equivalent sheep with mid-length wool (10-25mm) and 1.5°C lower than an equivalent 52kg shorn (<10mm wool) merino sheep.
- A 40kg adult shorn (<10mm) Merino sheep has a HST 1.3°C lower than an equivalent hairy Awassi sheep.
- To meet a wool length requirement of no longer than 20mm, sheep must be shorn within 2.5 months prior to export. To meet a wool length requirement of no longer than 10mm, sheep must be shorn within 1 month prior to export.

**Acclimatisation**

- Winter-acclimatised sheep have a lower heat tolerance than sheep acclimatised to warmer weather.

**Pen air turnover and pen space**

- Doubling the PAT score is estimated to halve the deck WBT rise.
- Increasing the PAT score from 120 $m^3$/h to 180 $m^3$/h will reduce deck WBT rise by up to 0.7°C.

- Sheep are more likely to experience hot and humid temperatures when a vessel is stationary, such as in port, as the port PAT score may be lower than the sailing PAT score.

**Dietary transition and on-board feeding**

- A transition time of up to 2 weeks may be required for all sheep to adapt to a new dietary source.
- Sheep who have been well-adapted to the shipboard ration are less likely to become 'shy feeders' and should have a lower incidence of inanition.
- The provision of more feed (above ASEL) increases the likelihood of all sheep, including shy feeders, accessing sufficient feed.
- Inanition was reported as the cause of 30% of mortalities during the 2019-21 Northern Hemisphere summer.
- 100% of voyages to the Persian Gulf in the Northern Hemisphere summer from 2019-21 reported feeding ad libitum or above the ASEL requirements.

**Body condition score**

- Sheep in fatter body condition are less heat tolerant than leaner sheep.

### 3.2.10 Development of factors influencing sheep heat tolerance and deck wet bulb temperature rise

The draft report proposed a range of heat stress-mitigating conditions be applied during the proposed conditional prohibition periods, including upper weight limits of 50kg for less heat tolerant breeds and 60kg for heat tolerant breeds, minimum sailing PAT scores of 200 $m^3$/hr and wool length limits.

Stakeholder feedback identified practical and welfare implications of the draft report proposal that less heat-tolerant sheep must be off-shears (shorn within 14 days of loading for export). Advice received during additional stakeholder engagement indicated that re-shearing a short-wool sheep (fleece 20mm or less) was impractical and raised welfare concerns as the shears can pull and cut the skin rather than shear the fleece. In addition, an RE may have the capacity to shear up to 10,000 sheep per week, limiting the ability to meet the proposed requirement. In response to this feedback and recognising the practicalities of shearing sheep prior to export, the department determined that setting the wool length requirement of no longer than 20 millimetres for less heat tolerant sheep would mitigate the risk of heat stress (in combination with other measures) for sheep being exported during the conditional prohibition period.

Some submissions stated the minimum sailing PAT score suggested in the draft report of 200 $m^3$/h was inflexible, unachievable and didn't account for the other proposed heat-mitigating factors. In addition, it was determined that a vessel's port PAT scores were likely to impact more significantly on an animals' ability to tolerate hot and humid conditions than sailing PAT scores, as vessels spend longer discharging animals at ports than at other locations during the voyage. In response to this feedback, the department incorporated a number of different ways to achieve lower deck WBT rises to account for vessels that have lower PAT scores. These are outlined in the Additional conditions section.

After stakeholder feedback and further examination of the climate data and sheep heat management science, the department reconsidered the proposed additional conditions in the draft report. The department determined that applying maximum weight limits and other additional heat mitigating conditions outlined above, in combination and at the levels outlined in this report, can improve sheep heat tolerance by up to 1.5°C. The additional conditions are intended to mitigate the 5% chance that WBTs in some Persian Gulf destinations can reach 30.5°C for voyages that depart Australia from 22 May to 31 May.

## 3.3 Literature review update

A scientific literature review focusing on papers published since 2019 was conducted to ascertain new perspectives of heat stress in sheep, including during live animal transport by sea.

Multiple articles identify that the future climate is expected to be more variable with greater frequencies and intensities of very hot periods (Tadesse et al. 2019, Thornton et al. 2021, Zhang & Phillips 2019). For example, Thornton et al. (2021) predicts that by 2050 the number of days per year of extreme heat and risk of heat stress will have at least doubled, imposing increased pressure on the existing capacity of ruminant livestock to adapt to extreme environmental conditions.

Studies published since 2019 identified climatic influences and the effects of heat stress on sheep during live export by sea (Zhang & Phillips 2019, Carnovale & Phillips 2020). This literature included observational studies conducted on vessels and simulated studies using historical data for voyages occurring between 2005 and 2018, prior to the introduction of the prohibition and prior to changes to the ASEL. One retrospective study of voyages occurring between 2005 and 2015 demonstrated a seasonal mortality pattern, with higher mortality occurring on sea voyages leaving Australia in the Southern Hemisphere winter or spring than those departing in the Australian summer or autumn. Inanition related to heat stress and/or salmonellosis were the stated reasons for high mortality rates (Zhang & Phillips 2019).

The second retrospective study of 14 voyages occurring from May to December 2016-2018 stated that 'heat stress is first evident at temperatures of approximately 27.5˚C WBT at the bridge' but also concluded that 'the threshold temperature when welfare problems occur is not well understood' (Carnovale & Phillips 2020). The department notes that the heat stress issues identified in these studies have, at least in part, been addressed by the implementation of recent legislation, outlined in Section 1.3. This includes increases to minimum ventilation rates and reduction in stocking densities, both of which limit deck WBT rise.

The Dehumidification Research Trial Final Report (LiveCorp 2021), focused on the removal of the heat and moisture in the air that creates humidity. LiveCorp stated 'the field trial provided a successful proof of concept for the use of dehumidifiers to reduce the heat and humidity within an empty livestock transport ship.' It was, however noted that the effectiveness of the dehumidifiers was diluted by air flow from ventilation fans, which are currently used by industry to blow fresh air from the outside through decks to remove heat and other pollutants such as ammonia and carbon dioxide. The trial also predicted that to meaningfully reduce heat stress risk for sheep on board, the dehumidification capacity used in the field trial would need to be tripled, and current technology is unable to achieve this.

Dunston-Clarke et al. (2020) describe an animal welfare protocol designed for pen assessments of sheep (and cattle) at pre-export and destination feedlots as well as during sea transport. This study builds on stakeholder and public concerns that mortality rates alone do not assure adequate animal welfare outcomes during live export by sea. The authors propose a list of health and welfare indicators incorporating environmental, resource, management and animal-based measures. Key to the welfare indicators are welfare principles of 'good feeding', 'good housing', 'good health' and 'appropriate behaviour'. Some of the measures are already requirements in the ASEL and monitored in the industry setting, for example, deck WBT, respiratory panting scores, BCS and recording of certification of stock handler training in low stress handling. The authors suggest other measures could be developed and integrated into a benchmarking system for future improvements, such as remote technologies for environmental and physiological monitoring.

The results of a study by Belhadj Slimen et al. (2019) confirmed that heat tolerance is breed-dependent, with breeds from tropical and dry climate zones the most adapted to heat. Crossing heat tolerant breeds with heat stress sensitive breeds may improve the performances of the latter. This study also found respiration rate, rectal temperature and heart rate vary significantly between breeds in response to increases in the temperature humidity index. Mechanical heat relieving strategies (offering shade, ventilation, showering and shearing) alleviated some of the effects of hyperthermia, while nutritional heat abatement strategies slightly enhanced the responses to mechanical heat relieving strategies. Nutritional strategies used in this study included simultaneous supplementation of antioxidants (vitamin E, Vitamin C, Se) and minerals (phosphorus, sodium, potassium). Water and nutritional restrictions aggravated heat stress responses.

# 4 Data logger analysis

The primary objective of the deployment of data loggers on sheep decks is to demonstrate actual deck conditions experienced by sheep. Prior to 2019, WBT data was collected manually once per day per deck and from the bridge (at no pre-set or consistent time). This limited the ability to determine the range of WBTs experienced by sheep on decks, the effect of duration of high WBTs and the impact of periods of respite.

Since May 2019, exporters have been required to place multiple data loggers on all decks housing sheep on vessels travelling to the Middle East during the Northern Hemisphere summer, and to collect and report this data to the department. This requirement was implemented following recommendation 23 of the McCarthy Review which stated:

> All vessels travelling to the Middle East during the 2019 northern hemisphere summer and after should have automated continuous environmental monitoring equipment installed as a condition of any approved arrangement.

The requirement to deploy data loggers has been incorporated into the Animals Rules.

Loggers directly measure and record parameters such as dry bulb temperature (DBT), relative humidity and atmospheric pressure. Algorithms are then used to automatically calculate parameters including WBT. The use of loggers has provided a detailed picture of environmental conditions on sheep decks, particularly regarding the range and duration of deck WBTs experienced throughout the journey.

Current regulations require the AAV to place 2 to 3 loggers on each deck of the vessel where sheep are housed. They are placed as close as possible to sheep pens and at a height that will accurately reflect the environmental conditions experienced by sheep. There is also a requirement for 3 additional loggers to be placed at locations identified as hotspots. Data can be downloaded from loggers via Bluetooth connections, enabling AAVs to check deck WBT records at any stage during the voyage, and to download the entire journey's data at the end of the voyage. Loggers are required to be set to record environmental conditions every 20 minutes throughout the voyage, providing 72 sets of records per logger per 24-hour period.

A typical sheep export vessel will have 30 to 35 loggers collecting environmental information at any one time. Vessels with fewer decks or carrying smaller numbers of sheep will have proportionally fewer loggers deployed. In addition to loggers placed near pens and in hotspots, 10 of the 15 voyages deployed a logger on the bridge, to measure ambient (bridge) temperatures.

## 4.1 Maximum wet bulb temperature readings

In total, the department collated and analysed around 430,000 WBT readings from loggers placed on every deck housing sheep, for the entire duration of all 15 voyages. A small number of WBT readings were unsuitable to use because of operational issues such as flat batteries, incorrect date settings or incorrect time interval settings.

Table 9 shows the number of loggers placed per voyage and the maximum deck WBTs readings per voyage.

Voyages in Table 9 are numbered sequentially with Voyage 1 recording the highest maximum deck WBT and Voyage 15 recording the lowest maximum deck WBT. Voyages 13 and 14 carried less than 5000 sheep and consequently used fewer data loggers.

**Table 9 Maximum wet bulb temperature recordings from data loggers**

| Voyage No. | Year | No. of Data Loggers | No. of WBT readings | Maximum WBT°C |
|---|---|---|---|---|
| Voyage 1 | 2019 | 34 | 43,830 | 33.5 |
| Voyage 2 | 2019 | 23 | 41,657 | 33.4 |
| Voyage 3 | 2019 | 30 | 33,253 | 33.4 |
| Voyage 4 | 2020 | 28 | 38,278 | 32.4 |
| Voyage 5 | 2020 | 15 | 24,439 | 32.3 |
| Voyage 6 | 2020 | 25 | 27,758 | 32.0 |
| Voyage 7 | 2021 | 32 | 40,508 | 31.6 |
| Voyage 8 | 2021 | 32 | 36,299 | 31.5 |
| Voyage 9 | 2019 | 10 | 15,020 | 31.4 |
| Voyage 10 | 2019 | 28 | 25,089 | 31.1 |
| Voyage 11 | 2020 | 28 | 30,043 | 31.0 |
| Voyage 12 | 2021 | 29 | 31,837 | 30.6 |
| Voyage 13 | 2021 | 2 | 3,014 | 30.3 |
| Voyage 14 | 2021 | 2 | 2,347 | 29.3 |
| Voyage 15 | 2021 | 32 | 37,221 | 28.4 |
| All voyages | – | 350 | 430,593 | 33.5 |

## 4.2 Voyage wet bulb temperature analysis

The department analysed logger data for all 15 voyages in the scope of this review. From this data we collated and graphed deck WBT readings from loggers on 3 representative voyages, chosen as they most clearly highlighted typical WBT trends during the course of a voyage. (Table 10). For each of the 3 representative voyages, we graphed WBT data from loggers that recorded the highest deck WBTs (high deck WBT logger), loggers that recorded the lowest deck WBTs (low deck WBT logger) and if present, ambient WBT data from the bridge logger.

**Table 10 Representative voyages travelling during the 2019-21 Northern Hemisphere summer by year**

| Voyage No. | Destination/s | Region | Year | Type |
|---|---|---|---|---|
| A | Kuwait, UAE and Qatar | Persian Gulf | 2019 | Multi-port |
| B | Israel and Jordan | Red Sea | 2020 | Multi-port |
| C | Kuwait, UAE and Oman | Persian Gulf and Oman | 2021 | Multi-port |

The WBT patterns for the 3 representative voyages are depicted in Figures 27-29. This enables visualisation of WBT patterns throughout voyages and highlights factors including:

- hotter geographical locations
- typical deck WBT rise
- ambient and deck WBT diurnal variation.

This data has allowed the department to identify where the risks of heat stress in sheep are greatest during a voyage. The data also helps to determine the variability in deck WBTs over 24-hour periods and the variability between hotter and cooler decks, likely reflecting ventilation differences across a vessel.

Bridge loggers directly record changes in ambient temperature and therefore typically show greater diurnal and day-to-day variation than loggers on sheep decks. By contrast, loggers on decks show less diurnal and other variation due to the vessel infrastructure and the presence of metabolic heat generated by sheep. Differences between ambient (bridge) WBTs and deck WBTs typically ranged from 1°C to 3°C.

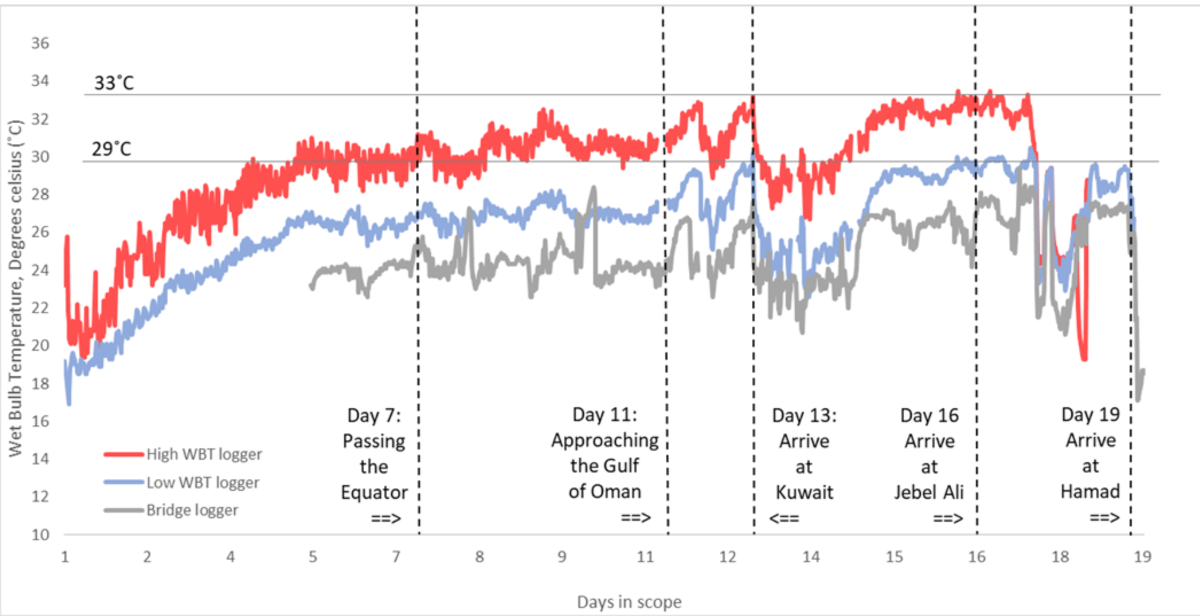
### 4.2.1 Voyage A Kuwait, UAE and Qatar in the Persian Gulf

Of the 15 voyages analysed, voyage A recorded the hottest deck WBTs (Figure 27).

**Key findings for voyage A**

- Ambient (bridge) WBTs were relatively moderate throughout the voyage, rarely getting above 28°C.
- High deck WBT loggers often read 4 – 5°C higher than ambient WBTs. This indicates that high deck WBTs were likely related to the relatively low PAT scores on this vessel (less than 150m3/h) rather than high ambient temperatures.
- Deck WBTs dropped sharply, by up to 5°C, on day 13 upon arrival in Kuwait port, reflecting the significantly reduced humidity.
- Deck WBTs rose after departing Kuwait and remained around 32°C en route to and after arrival at Jebal Ali port, UAE.
- After all sheep were discharged, deck WBTs dropped to levels close to ambient (bridge) WBTs.
- The WBT patterns of this voyage, dropping by up to 5°C on entry to Kuwait port but remaining elevated en route to and after arrival at Jebel Ali port, closely align with what would be expected, based on data in the 2021 BOM report.

**Figure 27 Wet bulb temperature readings for voyage A**




The cooler 'microclimate' and lower humidity at Kuwait port was consistently reported on voyages travelling during the 2019-2021 Northern Hemisphere summers, typically providing reliable respite for sheep.

This data reinforces the importance of a vessel's ventilation system in removing heat generated by animals on decks. Minimum PAT scores on vessels have improved since 2019, since undergoing upgrades to improve ventilation capacity. The department notes that all vessels that export livestock must meet standards stipulated in Australian Maritime Safety Authority (AMSA) Marine Order 43 which requires that 'the mechanical ventilation system must provide air from a source of supply, with a velocity across a pen of at least 0.5m/s.

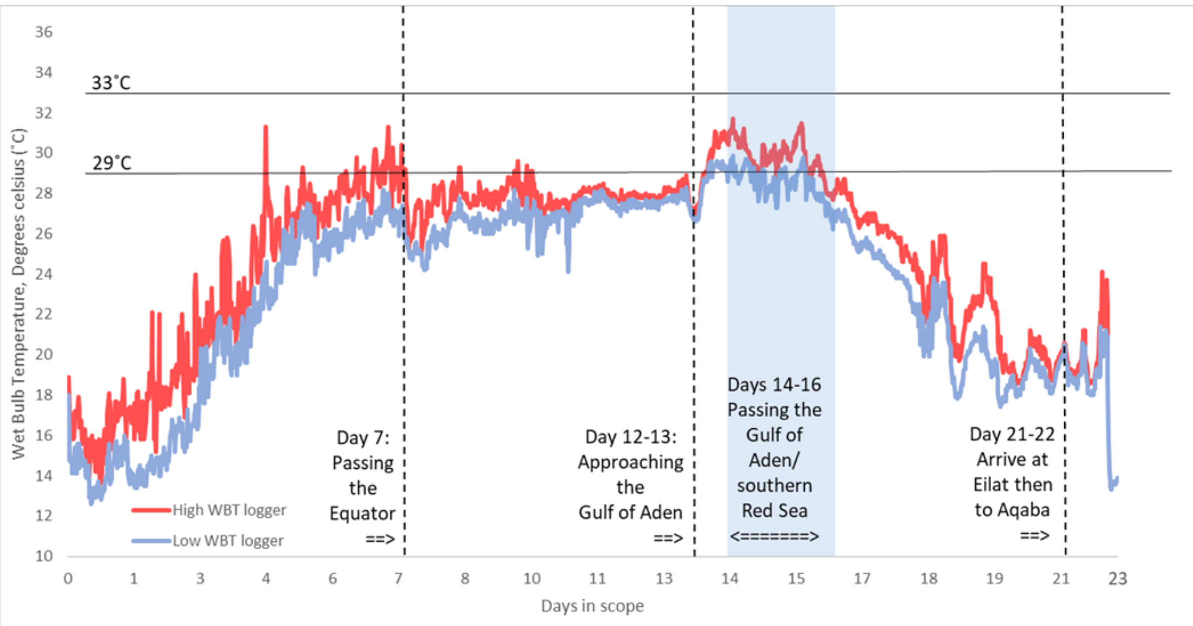
### 4.2.2 Voyage B Eilat and Aqaba via the Red Sea

Voyage 2 had several twin-tier decks, which have been associated with poorer ventilation performance and low PAT scores (less than 150 $m^3/h$). This is reflected in the small differences between high deck WBT logger readings and low deck WBT readings (Figure 28).

**Key findings for voyage B**

- The hottest part of the voyage was through the Gulf of Aden and Bab al Mandab Strait where deck WBT peaked at around 31.5°C for a period of approximately 6-12 hours.
- Deck WBTs dropped by up to 10°C as the vessel sailed into the northern Red Sea.
- Unlike voyages to the Persian Gulf, deck WBTs during the last few days of the voyage and during discharge were relatively moderate, around 20-22°C.
- This voyage did not deploy a logger on the bridge, meaning it was not possible to calculate deck WBT rise. However, the relatively low ventilation performance of this twin-tier vessel would suggest a higher deck rise is likely (3°C or more), particularly during the Northern Hemisphere summer.
- The WBT patterns of this voyage, showing cooler WBTs in the low 20s at destination ports, closely align with what would be expected, based on data in the 2021 BOM report.

**Figure 28 Wet bulb temperature readings for voyage B**




Note 1: Bridge data was not provided for this voyage

Due to improvements in the ventilation capacity of vessels after ventilation upgrades and the phasing out of twin-tier vessels, it is reasonable to expect future voyages, sailing in similar conditions as experienced on Voyage B, would record lower deck WBTs.

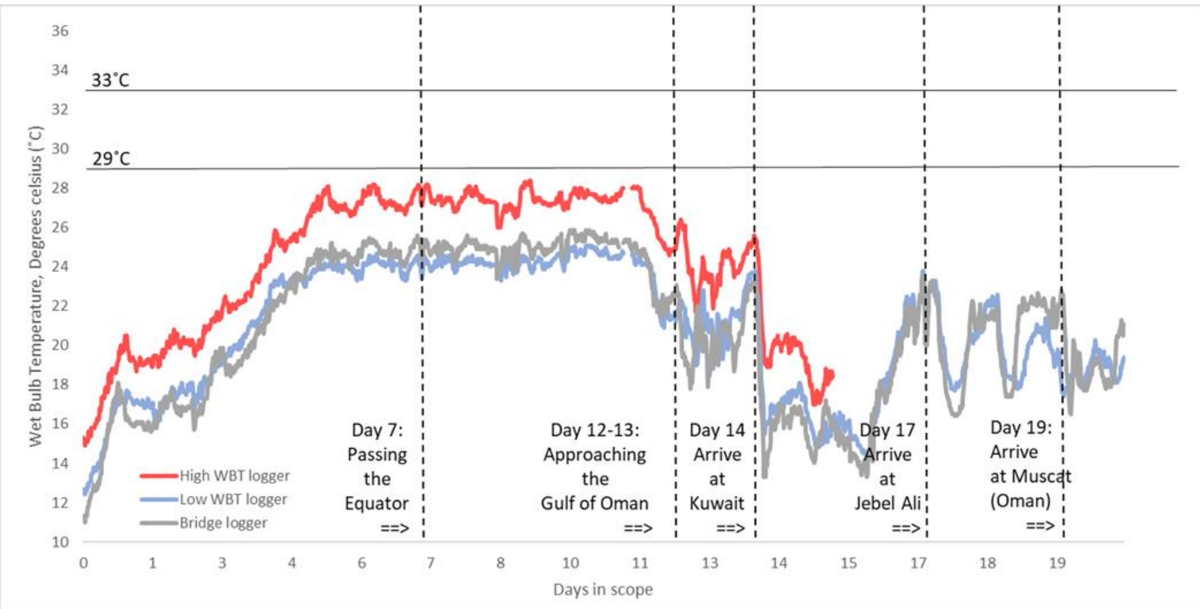
### 4.2.3 Voyage C Kuwait, UAE and Oman

Data for voyage C was consistent with expected 95th percentile ambient WBTs in the Persian Gulf, dropping below 29°C from early October (Figure 29).

**Key findings for voyage C**

- Ambient and deck WBTs dropped significantly in the Persian Gulf at the end of September.
- The hottest part of the voyage occurred from the equator to the north Arabian Sea, not in the Persian Gulf. 95th percentile ambient WBTs are around 25-26°C at this time.
- Some decks had a very low deck WBT rise, demonstrated by similarity in readings between the bridge logger and the low deck WBT logger.
- The WBT patterns on this voyage closely align with what would be expected, based on data in the 2021 BOM report.

**Figure 29 Wet bulb temperature readings for voyage C**




## 4.2.4 Notable observations from voyage wet bulb temperature analysis of Voyages A-C.

The following observations findings are based on the WBT patterns recorded from Voyages A-C in Figures 27, 28 and 29. The department notes that some high deck WBT readings are likely related to the relatively low PAT scores on some vessels (less than 150m$^3$/h) rather than high ambient temperatures.

**Persian Gulf (voyages A & C)**

- Deck WBTs in the MEAI remain below 29°C along voyage routes until the Gulf of Oman.
- The hottest part of the voyage is typically when transiting the Strait of Hormuz where deck WBTs can spike up to 32°C for up to 12 hours.
- Deck WBTs can remain above 29°C through the eastern Persian Gulf en route to Kuwait.
- Deck WBTs dropped sharply by up to 5°C over 2-3 hours on arrival at Kuwait port.
- Deck WBTs increase again by 2-3°C when the vessel departs Kuwait and sails towards eastern Persian Gulf ports.
- Deck WBTs can remain elevated up to 32°C after arrival at eastern Persian Gulf ports.
- 95th percentile ambient WBTs in the Persian Gulf drop below 29°C from late September. The route from the equator to the Arabian Sea is typically the hottest part of the voyage at this time, recording 95th percentile ambient WBTs of around 25-26°C.

**Red Sea (voyage B)**

- The hottest part of the voyage is through the Bab al Mandab Strait where deck WBTs may peak at around 31.5°C for a period of approximately 6-12 hours.
- Ambient and deck WBTs drop by 5-8°C as the vessel sails into the northern Red Sea.
- Unlike voyages to the Persian Gulf, 95th percentile ambient WBTs for the last 2-3 days of the voyage and during discharge are relatively moderate, around 20-22°C.

## 4.3 Wet bulb temperature frequency and duration

### 4.3.1 Wet bulb temperature frequency

The department analysed the frequency of higher deck WBTs, to assist in determining the effectiveness of current regulatory settings. If higher deck WBTs are infrequent, it is likely that heat stress risk management is effective.

Table 11 displays the frequency of specific deck WBTs on the 15 voyages reviewed for this report. These are numbered sequentially with Voyage 1 recording the highest maximum deck WBT and Voyage 15 recording the lowest maximum deck WBT. Temperature bands have been grouped in one-degree intervals from 28˚C to 31˚C, and in half degree intervals for temperatures higher than 31˚C to highlight high risk temperature ranges.

**Table 11 Frequency of deck wet bulb temperatures by temperature bands per voyage**

| – | Year | Data Logger Readings | Less than 28.0˚C | 28.0˚C to 29.0˚C | 29.0˚C to 30.0˚C | 30.0˚C to 31.0˚C | 31.0˚C to 31.5˚C | 31.5˚C to 32.0˚C | 32.0˚C to 32.5˚C | 32.5˚C to 33.0˚C | 33.0˚C to 33.5˚C | 33.5˚C to 34.0˚C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Voyage No. | – | No. | No. | No. | No. | No. | No. | No. | No. | No. | No. | No. |
| Voyage 1 | 2019 | 43,830 | 29,303 | 5,735 | 4,036 | 2,894 | 768 | 466 | 380 | 187 | 59 | 2 |
| Voyage 2 | 2019 | 41,657 | 27,430 | 4,977 | 4,994 | 2,692 | 757 | 546 | 207 | 49 | 5 | 0 |
| Voyage 3 | 2019 | 33,253 | 22,830 | 4,846 | 2,269 | 2,490 | 464 | 220 | 97 | 29 | 8 | 0 |
| Voyage 4 | 2020 | 38,278 | 25,065 | 7,766 | 4,293 | 1,023 | 98 | 30 | 3 | 0 | 0 | 0 |
| Voyage 5 | 2020 | 24,439 | 18,619 | 3,388 | 1,545 | 809 | 68 | 7 | 3 | 0 | 0 | 0 |
| Voyage 6 | 2020 | 27,758 | 22,621 | 2,088 | 1,267 | 1,355 | 327 | 96 | 4 | 0 | 0 | 0 |
| Voyage 7 | 2021 | 40,508 | 36,487 | 2,119 | 1,518 | 335 | 45 | 4 | 0 | 0 | 0 | 0 |
| Voyage 8 | 2021 | 36,299 | 29,223 | 4,079 | 2,047 | 881 | 68 | 1 | 0 | 0 | 0 | 0 |
| Voyage 9 | 2019 | 15,020 | 10,780 | 2,558 | 1,415 | 262 | 5 | 0 | 0 | 0 | 0 | 0 |
| Voyage 10 | 2019 | 25,089 | 12,648 | 8,178 | 3,907 | 353 | 3 | 0 | 0 | 0 | 0 | 0 |
| Voyage 11 | 2020 | 30,043 | 24,428 | 3,545 | 1,862 | 205 | 3 | 0 | 0 | 0 | 0 | 0 |
| Voyage 12 | 2021 | 31,837 | 29,054 | 1,888 | 836 | 59 | 0 | 0 | 0 | 0 | 0 | 0 |
| Voyage 13 | 2021 | 3,014 | 2,633 | 209 | 167 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| Voyage 14 | 2021 | 2,347 | 2,328 | 18 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Voyage 15 | 2021 | 37,221 | 37,102 | 119 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | – | 430,593 | 330,551 | 51,513 | 30,157 | 13,363 | 2,606 | 1,370 | 694 | 265 | 72 | 2 |

Note: WBT counts represent totals of individual logger readings (recorded at 20-minute intervals).

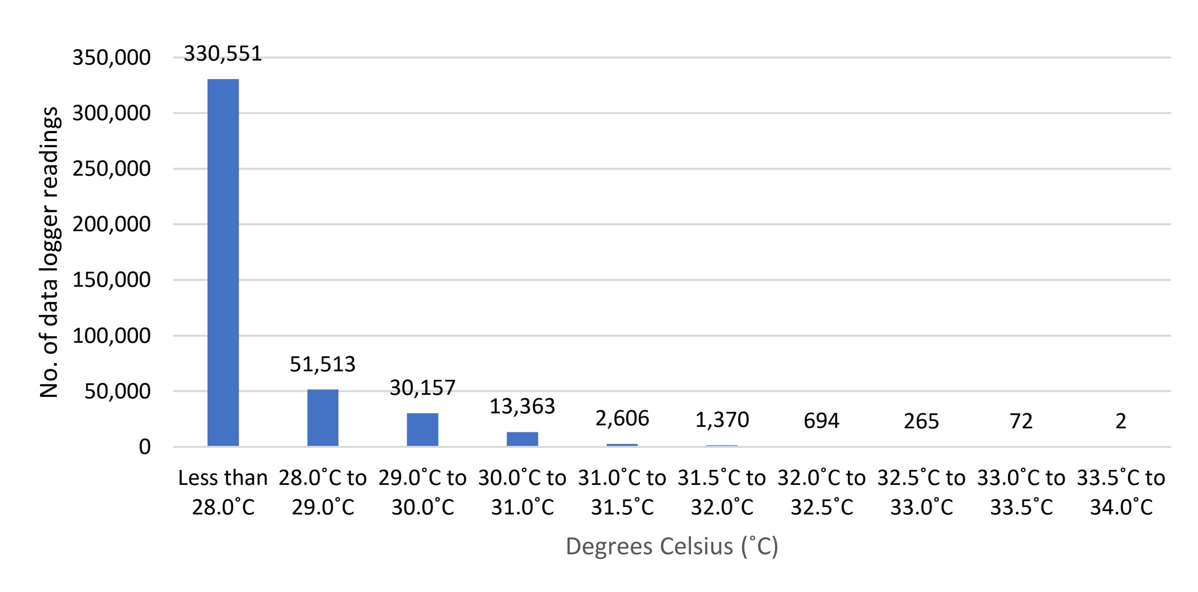
**Notable statistics from deck WBT frequency analysis**

- There has been an overall reduction in deck WBTs since 2019. This is likely due to improvements in the ventilation capacity of vessels after ventilation upgrades and the phasing out of twin-tier vessels.
  - The 3 voyages recording the hottest deck conditions occurred in 2019.
  - The 3 voyages recording the coolest deck conditions occurred in 2021.
- 99.8% of all readings (approximately 429,600) recorded deck WBTs less than 32˚C.
- 99% of all readings (approximately 425,600) recorded deck WBTs less than 31˚C.

- 96% of all readings (approximately 412,200) recorded deck WBTs less than 30˚C.
- 88.7% of all deck WBT readings (approximately 382,000 readings) were 29 ˚C or less.
- 76.8% of all deck WBT readings (approximately 336,000 readings) were less than 28˚C.
- In 2021, only 1 logger recorded a deck WBT above 31.5˚C. This was only recorded on a single reading.

This WBT data indicates that the current regulatory settings have been successful in reducing the risk of exposure to ambient WBTs of 29˚C and higher (deck WBTs of 30-32 ˚C). The relative infrequency of WBT readings, particularly above 30˚C, is reflected in Figure 30.

**Figure 30 Data logger readings by temperature bands**




## 4.3.2 Wet bulb temperature duration

The department collated the number of consecutive deck WBT readings (without interruption) at or above specific WBTs, at 20-minute intervals (Tables 12-14). For example, 18 successive 20-minute readings at a specific WBT equals a duration of six hours at or close to that WBT. From this, we were able to determine the number of loggers recording consecutive WBTs and the maximum duration at these specific WBTs.

Table 12 plots deck WBT ranges from 29˚C to the maximum deck WBT recorded for each voyage, showing time periods based on consecutive readings (in hours) at each temperature.

**Table 12 Maximum time periods (hours) at or above deck wet bulb temperatures (2019-21)**

| – | – | – | WBT in degrees Celsius (˚C) above: | | | | | |
|---|---|---|---|---|---|---|---|---|
| Voyage No. | Year | Max WBT | 29˚C | 30˚C | 31˚C | 31.5˚C | 32˚C | 32.5˚C | 33˚C |
| Voyage 1 | 2019 | 33.5 | 90.3 | 75.0 | 70.0 | 44.0 | 25.0 | 4.7 | 1.3 |
| Voyage 2 | 2019 | 33.4 | 204.3 | 81.7 | 42.7 | 14.0 | 8.3 | 3.3 | 0.7 |
| Voyage 3 | 2019 | 33.4 | 95.3 | 34.7 | 21.3 | 14.7 | 5.7 | 4.3 | 1.3 |
| Voyage 4 | 2020 | 32.4 | 60.7 | 17.3 | 2.7 | 2.3 | 0.7 | 0 | 0 |

| – | – | – | WBT in degrees Celsius (˚C) above: | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Voyage 5 | 2020 | 32.3 | 28.3 | 19.3 | 2.7 | 0.3 | 0.2 | 0 | 0 |
| Voyage 6 | 2020 | 32.0 | 51.3 | 19.7 | 9.7 | 5.0 | 0 | 0 | 0 |
| Voyage 7 | 2021 | 31.6 | 33.0 | 15.0 | 6.0 | 0.7 | 0 | 0 | 0 |
| Voyage 8 | 2021 | 31.5 | 23.3 | 15.7 | 5.0 | 0 | 0 | 0 | 0 |
| Voyage 9 | 2019 | 31.4 | 31.3 | 7.0 | 1.0 | 0 | 0 | 0 | 0 |
| Voyage 10 | 2019 | 31.1 | 48.0 | 4.3 | 0.7 | 0 | 0 | 0 | 0 |
| Voyage 11 | 2020 | 31.0 | 45.3 | 15.0 | 0 | 0 | 0 | 0 | 0 |
| Voyage 12 | 2021 | 30.6 | 23.3 | 2.0 | 0 | 0 | 0 | 0 | 0 |
| Voyage 13 | 2021 | 30.3 | 8.0 | 1.0 | 0 | 0 | 0 | 0 | 0 |
| Voyage 14 | 2021 | 29.3 | 0.7 | 0 | 0 | 0 | 0 | 0 | 0 |
| Voyage 15 | 2021 | 28.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Note: Using this method, each column is not mutually exclusive. For example, readings of over 31.5°C are also included in the count for over 31.0°C.

#### Notable statistics from deck WBT duration analysis

- Duration of maximum deck WBTs have declined since 2019. This is likely due to improvements in the ventilation capacity of vessels after ventilation upgrades, and the phasing out of twin-tier vessels.

For the 3 voyages recording the hottest deck conditions (all in 2019):

- the highest maximum deck WBT recorded was 33.5°C, this was recorded by a single logger one time
- deck WBTs above 32˚C were recorded for 25 hours on voyage 1, 8.3 hours on voyage 2 and for 5.7 hours on Voyage 3
- deck WBTs above 31˚C were recorded for 70 hours on Voyage 1, 42.7 hours on Voyage 2 and for 21.3 hours on Voyage 3
- deck WBTs above 30˚C were recorded for 75 hours on Voyage 1, 81.7 hours on Voyage 2 and 34.7 hours on Voyage 3.

For the 3 voyages recording the coolest deck conditions (all in 2021):

- the maximum deck WBT recorded was 30.6˚C for a period of 2 hours
- deck WBTs above 29˚C were recorded for 23.3 hours on Voyage 12 and 8 hours on Voyage 13
- voyage 15 did not record any deck WBTs above 29˚C.

Table 13 shows the number of times that loggers recorded consecutive WBT readings at a range of thresholds. It shows that periods of sustained (6 hours or longer) WBTs above 32.0°C were not recorded at all for any Northern Hemisphere summer voyage during 2019-2021. This observation is highlighted as, when considered with the absence of reported mortalities due to heat stress for the 15 voyages in this review, it aligns with HotStuff modelling. Hotstuff data indicate that heat stress mortalities are more likely to occur in typical export classes of sheep when the WBT is above 33.5°C. Although duration of exposure is not a parameter included in

Hotstuff, it is likely that heat stress mortality would occur after several hours of exposure to WBTs >33.5°C, rather than from a momentary temperature spike.

**Table 13 Frequency of consecutive deck wet bulb temperature readings (2019, 2020 and 2021)**

| – | – | – | – | WBTs in degrees Celsius (˚C) above: | | | | |
|---|---|---|---|---|---|---|---|---|
| – | 28.0 ˚C | 29.0 ˚C | 30.0 ˚C | 31.0 ˚C | 31.5 ˚C | 32.0 ˚C | 32.5 ˚C | 33.0 ˚C |
| 6 hours | 389 | 285 | 103 | 39 | 19 | 6 | 0 | 0 |
| 12 hours | 136 | 95 | 26 | 3 | 4 | 0 | 0 | 0 |
| 16 hours | 100 | 53 | 15 | 2 | 0 | 0 | 0 | 0 |
| 20 hours | 72 | 41 | 3 | 3 | 0 | 0 | 0 | 0 |
| 24 hours | 144 | 50 | 3 | 1 | 1 | 1 | 0 | 0 |
| 36 hours | 54 | 23 | 3 | 2 | 1 | 0 | 0 | 0 |
| 48 hours | 64 | 18 | 2 | 1 | 0 | 0 | 0 | 0 |
| 72 hours | 27 | 9 | 2 | 0 | 0 | 0 | 0 | 0 |
| 96 hours | 21 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 1,007 | 576 | 157 | 51 | 25 | 7 | 0 | 0 |

Note: Using this method, each column is not mutually exclusive. For example, readings of over 31.5°C are also included in the count for over 31.0°C.

To better compare voyages travelling under the same regulatory settings, we analysed the frequency of consecutive deck WBT readings in various time periods for 2020 and 2021 voyages (removing 2019, the year recording the hottest deck WBTs and the year before the legislated minimum ventilation rate of 0.5 m/s was introduced by AMSA through Marine Order 43). Table 14 shows that exposure to deck WBTs above 30°C occurred infrequently and for limited duration during 2020 and 2021 voyages. For example:

- there were 7 individual 6-hour periods where deck WBTs were above 31°C
- deck WBTs above 31.5°C for longer than 6 hours did not occur at any time during this period.

These findings indicate that the current regulatory settings have been successful at limiting the risk of exposure to WBTs above 32.0°C (ambient WBT 29°C plus a deck rise of 1-3°C).

**Table 14 Frequency of consecutive deck wet bulb temperature readings (2020 and 2021)**

| – | – | – | – | WBTs in degrees Celsius (˚C) above: | | | | |
|---|---|---|---|---|---|---|---|---|
| – | 28.0 ˚C | 29.0 ˚C | 30.0 ˚C | 31.0 ˚C | 31.5 ˚C | 32.0 ˚C | 32.5 ˚C | 33.0 ˚C |
| 6 hours | 186 | 124 | 49 | 7 | 0 | 0 | 0 | 0 |
| 12 hours | 56 | 46 | 10 | 0 | 0 | 0 | 0 | 0 |
| 16 hours | 34 | 26 | 10 | 0 | 0 | 0 | 0 | 0 |
| 20 hours | 29 | 24 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 hours | 87 | 27 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36 hours | 36 | 8 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 hours | 19 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 72 hours | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 96 hours | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 467 | 257 | 69 | 7 | 0 | 0 | 0 | 0 |

Note: Using this method, each column is not mutually exclusive. For example, readings of over 31.5°C are also included in the count for over 31.0°C.

### 4.3.3 General

- Measuring the ambient WBT on the bridge using a data logger is essential to accurately determine deck WBT rise.
- Deck WBT rises have declined since 2019. This is likely due to improvements in the ventilation capacity of vessels after ventilation upgrades and the phasing out of twin-tier vessels.
    - Deck WBT rises of up to 4-5°C occurred on some 2019 voyages on vessels with poorer ventilation capacity.
    - In 2020 and 2021 voyages, deck WBT rise was typically 1-3°C.

The variation in deck WBT rise reinforces the importance of a vessel's ventilation system in removing the metabolic heat generated by animals on decks. All vessels that export livestock must meet standards stipulated in Australian Maritime Safety Authority (AMSA) Marine Order 43, which requires that 'the mechanical ventilation system must provide air from a source of supply, with a velocity across a pen of at least 0.5m/s.

## 4.4 Summary of data logger findings

- Ambient WBT data (measured on the bridge) along voyage routes and at destination ports closely aligns with data from the 2021 BOM report.
- Analysis of logger data provided a reliable record of the incidence of elevated deck WBTs on the voyages analysed:
    - 99.8% of all readings (approximately 429,600) recorded deck WBTs less than 32˚C
    - 99% of all readings (approximately 425,600) recorded deck WBTs less than 31˚C
    - 96% of all readings (approximately 412,200) recorded deck WBTs less than 30˚C.
- Voyages in 2020 and 2021 recorded lower maximum and average WBTs on sheep decks compared to voyages in 2019, with the 3 voyages recording the hottest deck conditions occurring in 2019 and the 3 voyages recording the coolest deck conditions occurring in

2021. This is likely due to improvements in the ventilation capacity of vessels after mandated ventilation upgrades at the start of 2020 and the phasing out of twin-tier vessels.

# 5 Voyage reporting

Voyage reports from AAVs, stockpersons, ship masters and IOs (where available) were analysed for comments relating to general sheep welfare, behavioural or physiological responses to elevated temperatures, heat stress and heat stress mortalities.

Evidence of heat-associated behaviours identified and documented in voyage reports included panting, spreading out, facing ventilation outlets and reduced feed intake.

## 5.1 Independent observer reporting

Due to the pause in the deployment of IOs on all livestock vessels in March 2020 in response to the COVID-19 pandemic, only 6 of the 15 voyages analysed in this review had IOs travelling on the voyage. IOs travelled on all 5 voyages during the Northern Hemisphere summer of 2019 and on 1 voyage during the Northern Hemisphere summer of 2020.

IOs were asked to evaluate and record the panting score of sheep in pens adjacent to data loggers, and to estimate the percentage of sheep in each pen showing each panting score. Panting scores are a commonly used tool for assessing heat load in sheep. The HSRA Technical Reference Panel (2019) stated that 'panting is both a response to increased thermal exposure, and an indication that the animal continues to require heat loss to maintain homeostasis'.

A standardised panting score table was used for this (Table 15).

**Table 15 Standardised panting score table for consignments of sheep by sea**

| Heat stress score | Panting score | Respiratory rate (RR) | Respiratory character | Appearance or demeanour |
|---|---|---|---|---|
| 0-Normal | 0-Normal | 25-80 | Normal | Normal |
| 1-Elevated respiratory rate | 1-Normal (elevated RR) | 80-100 | Increased RR | Normal |
| 2-Heat affected | 2-Mild panting | 100-160 | Rapid RR | Discomfort |
| 3-Onset of heat stress | 3-Open mouth panting | 160-220 | Laboured | Extreme discomfort |
| 4-Severe heat stress | 4-Open mouth panting with tongue out | Usually second stage | Extremely laboured | Distressed |

Source: Export advisory notice – 2018-11 Revised daily report for sheep exports by sea

Some IOs recorded behaviours reflecting positive animal welfare such as cud chewing, resting and interacting socially during times of elevated WBT. All 6 IOs reported heat associated behaviours. IOs generally recorded higher panting scores than AAVs when observing the same pens of sheep.

No IOs reported mortalities linked to elevated WBT conditions.

Whilst some IO reports referenced the WBTs at specific locations, along with a heat stress score or panting scores, 2 of the 6 reports from IOs provided little or no commentary relevant to the scope of this review. The scores used to assess heat stress in sheep were not always consistent, with some IOs referring to heat stress scores and others referring to panting scores (Table 16). This is possibly due to the standardised panting score table (Table 15) which uses both terms.

**Table 16 Example independent observer scoring for 4 voyages in 2019 travelling during the Northern Hemisphere summer to the Middle East**

| Example No. | Region | Maximum WBT (°C) | Maximum heat stress (HS)/pant scores (PS) |
|---|---|---|---|
| 1 | Persian Gulf | 31.7 | HS 2 |
| 2 | Persian Gulf | 32 | PS 3 |
| 3 | Red Sea | 29 | HS 3 |
| 4 | Red Sea | 29.5 | PS 3 |

Comments from IOs on voyages to the Persian Gulf included:

- ‘open mouth breathing was observed in several sheep per deck during the hottest part of the voyage’
- ‘it was common for 40-50% of sheep in a pen to show pant scores of 3 when the WBT was above 31°C’
- ‘panting scores of 3 were especially prevalent on the stretch from the Strait of Hormuz until about 12 hours past Jebel Ali en route to Kuwait and again 12 hours after departing Kuwait’.

Comments from IOs on voyages to the Red Sea included:

- ‘10-20% of sheep in the pens were observed with open mouth panting during the hottest parts of the day. It is possible that the sheep were winter conditioned, contributing to the lower heat tolerance’
- ‘respiration rates rose around the equator and again after entering the Red Sea’
- ‘there was no evidence for heat stress as a cause of death’.

## 5.2 Accredited veterinarian reporting

The daily reports and end of voyage reports from all 15 voyages were analysed for this review. AAVs reported heat associated behaviours on 9 voyages. An IO was present on 3 of these 9 voyages. Comparing the AAV and IO reports provided insights into geographical hotspots, animal factors influencing heat tolerance and identified some reporting disparities.

AAV reporting from 5 of the voyages did not provide any commentary on heat stress behaviours. AAVs on voyages to the Red Sea reported a lower incidence of heat associated behaviours than was reported on voyages to the Persian Gulf.

The reporting of heat stress was not always consistent between AAVs. For example, on one voyage an AAV reported open mouth panting and high respiratory rates but did not report the presence of heat stress. Heat associated behaviours were reported to be more prevalent amongst certain classes of sheep on some voyages whilst AAVs on other voyages reported no breed or age disparities.

Environmental conditions were reported to differ significantly between voyages. One voyage reported rapid weather changes between Kuwait and Jebel Ali, with higher humidity and temperatures at Jebel Ali. Other environmental comments were often limited to wind and sea conditions without detailing the geographical location of these weather changes (though daily reports included longitude and latitude measurements).

The condition of pads was frequently noted in AAV reports. Pads would typically become wetter mid-voyage, which was often associated with crossing the equator. As well as the increased WBTs experienced at the equator, the type of bedding used may have also played a part in this. It was noted on one voyage that whilst sawdust was the best bedding for absorption, it promoted eye injuries and wood shavings were used in preference.

At times there were disparities between the maximum WBT and heat/pant scores reported by IO's and AAVs when reporting on the same voyages, using the same tables (Tables 16 and 17). IOs typically recorded higher panting scores for sheep.

**Table 17 Example accredited veterinarian scoring for 4 voyages in 2019 travelling during the Northern Hemisphere summer to the Middle East**

| Example No. | Region | Maximum WBT (°C) | Maximum heat stress (HS)/pant scores (PS) | Mortality rate |
|---|---|---|---|---|
| 1 | Persian Gulf | 31 | PS3 | 0.17% |
| 2 | Persian Gulf | 32 | HS 2 | 0.20% |
| 3 | Red Sea | 32 | PS 1 | 0.20% |
| 4 | Red Sea | 29.5 | PS 1 | 0.24% |

Comments from accredited veterinarians on voyages to the Persian Gulf included:

- 'open mouth panting observed with occasional protruding tongues'. The end-of-voyage report from the same voyage noted that 'no sheep were showing signs of heat stress'
- 'respiratory rates remain increased with majority of sheep in panting score 2, with a few individuals in panting score 3'
- 'some sheep open mouth panting…after watching them for several minutes their RR would slow and they brought up a cud and began to chew'
- one voyage reported 'elevated panting scores were observed on one day only'
- one voyage reported that 'Damara sheep and younger sheep were less heat affected than older sheep or Merinos'. A definition of what constituted a 'younger sheep' was not provided.

Comments from accredited veterinarians on voyages to the Red Sea included:

- one voyage reported panting scores 'didn't rise above 2' on a scale of 0-4. Some of the sheep were reported to be hot despite WBT not reaching 29˚C. This may have been due to the 'weather conditioning of the sheep'.

## 5.3 Heat stress mortalities

The department reviewed voyage reports for records identifying mortalities either attributed directly to heat stress or where exposure to heat may have been a contributing factor. For the purposes of this review, a heat stress mortality is defined as any mortality where the cause of death was reported by the AAV or stockperson to be due to heat stress or associated with heat stress.

No mortalities due to heat stress were reported in any of the 15 voyages analysed in the review.

Exposure to heat may have been a contributing factor in sheep mortalities on 1 voyage. The AAV reported underlying conditions of inanition and pre-existing respiratory disease as factors possibly contributing to reduced heat tolerance and associated mortality.

## 5.4 Data limitations

The department's analysis of sheep behaviours related to exposure to heat was dependent on voyage reports and therefore limited by the quality and quantity of reported data. Determining the reliability of the reported data was also challenging.

Factors that may influence the reliability and accuracy of sheep observations include:

- the knowledge and experience of personnel recording the observations
- the existence of different scoring systems to assess heat stress
- adherence to standardised reporting protocols, for example standardised panting score tables
- time allocated to the collection of observations
- availability of convenient systems to effectively record observations for example, apps, checklists or videos
- observer bias (different observers may assess subjective criteria differently).

### 5.4.1 Inconsistent reporting

This review identified inconsistent reporting of heat stress symptoms between different IOs, between different AAVs and between IOs and AAVs. For example, a range of different panting score tables and heat stress scores were used in AAV and IO reports. A rating of 3 in one report may indicate the onset of heat stress whilst in another report it could indicate more advanced heat stress. The use of the terms 'panting score' and 'heat stress score' were sometimes used interchangeably. The inconsistent reporting of heat stress scores and panting scores prompted the department to introduce a simplified panting score system when LIVEXCollect was released in November 2020. LIVEXCollect is a data collection, management, reporting and analysis platform developed by LiveCorp for the livestock export industry. Within LIVEXCollect there are only 2 ratings relating to heat stress behaviour that are possible:

- pant type 1: open-mouth panting with jaws separated, tongue in mouth and head up
- pant type 2: open-mouth panting with tongue out and/or head down, distressed appearance.

AAVs are required to report the maximum percentage of sheep on a deck exhibiting these panting types each day.

Other reporting inconsistencies were identified between end-of-voyage reports and daily reports. For example, a daily report for one voyage noted the presence of panting with protruding tongues, yet the end-of-voyage report stated that there was no evidence of heat stress onboard the vessel over the course of the voyage.

The department recognises the importance of promoting consistency in reporting and is working with LiveCorp and industry to develop systems that promote consistency. LIVEXCollect reporting was introduced when ASEL 3.0 came into effect on 1 November 2020. The department will continue to analyse the new reporting system to assess its effectiveness.

### 5.4.2 Observer bias

There were indications of observer bias, with some AAVs consistently reporting lower incidences of heat stress and lower panting scores at elevated WBTs compared to other AAVs. For example, one AAV reported that heat stress may have contributed to mortalities in sheep with underlying conditions such inanition and respiratory disease. AAVs on other voyages with similar or higher WBTs did not identify heat stress as a possible contributing factor in any mortalities.

There was also variability in reporting of heat stress signs between AAVs and IOs, with IOs generally recording higher panting scores when observing the same pens of sheep.

## 5.5 Summary of voyage reporting findings

- Behavioural and physiological response to heat (including panting) were reported on 60% of voyages (9 out of 15 voyages).
- Voyages travelling through the Red Sea reported fewer behavioural and physiological responses to heat than those travelling to the Persian Gulf.
- Underlying health conditions, including inanition and respiratory disease, were reported to possibly contribute to mortalities during elevated WBTs on 1 voyage.
- Inconsistent reporting of heat stress symptoms was identified on some voyages.
    - Independent observers (IOs) generally recorded higher panting scores than accredited veterinarians (AAVs) when observing the same pens of sheep.
    - There were a number of different scoring systems used to assess heat stress.

# 6 Mortality statistics

The mortality statistics presented in this section illustrate improvements to welfare outcomes on live sheep voyages to the Middle East during the Northern Hemisphere summer. Mortality statistics reflect the month of voyage departure from Australia, not month of arrival at the destination port. For example, a voyage may depart Australia in late May and reach its destination in June. Mortality statistics in this case would be aggregated and included in the month of May.

The department acknowledges that lower mortality rates alone do not reflect adequate animal welfare outcomes during live export by sea, however, if mortality rates significantly decline, it is reasonable to deduce that morbidity rates will also have declined and that other welfare parameters will have improved.

Figure 31 shows that for the period 2015 -2017, mortality rates for Northern Hemisphere summer voyages were highly variable (standard deviations between 0.31 and 1.55) and the average mortality rate was 0.89%. In 2018, regulatory changes were implemented which included:

- increased pen space allowances using allometric principles
- automated watering systems
- minimum ventilation standards established by AMSA under Marine Order 43, body condition score limits and
- independent verification of PAT score.

In 2019, the department implemented a prohibition of exports during the hottest and most humid months of the Northern Hemisphere summer. After these regulatory changes, average voyage mortality rates dropped to 0.20% for the period 2019-2021, representing a reduction of 77.25%. In addition, individual voyage mortality rates have stabilised within a narrow range. This provides sound evidence that regulatory changes since 2018 have been effective in reducing mortality rates in sheep exported to the Middle East during the Northern Hemisphere summer. The department also acknowledges that industry practises have likely contributed to reduced mortality rates, including sheep spending longer periods in an RE prior to export, improved rejection criteria for sheep unfit to travel and the provision of more feed above ASEL minimum requirements during voyages.

**Figure 31 Mortality rates for voyages in the Northern Hemisphere summer 2015-21**

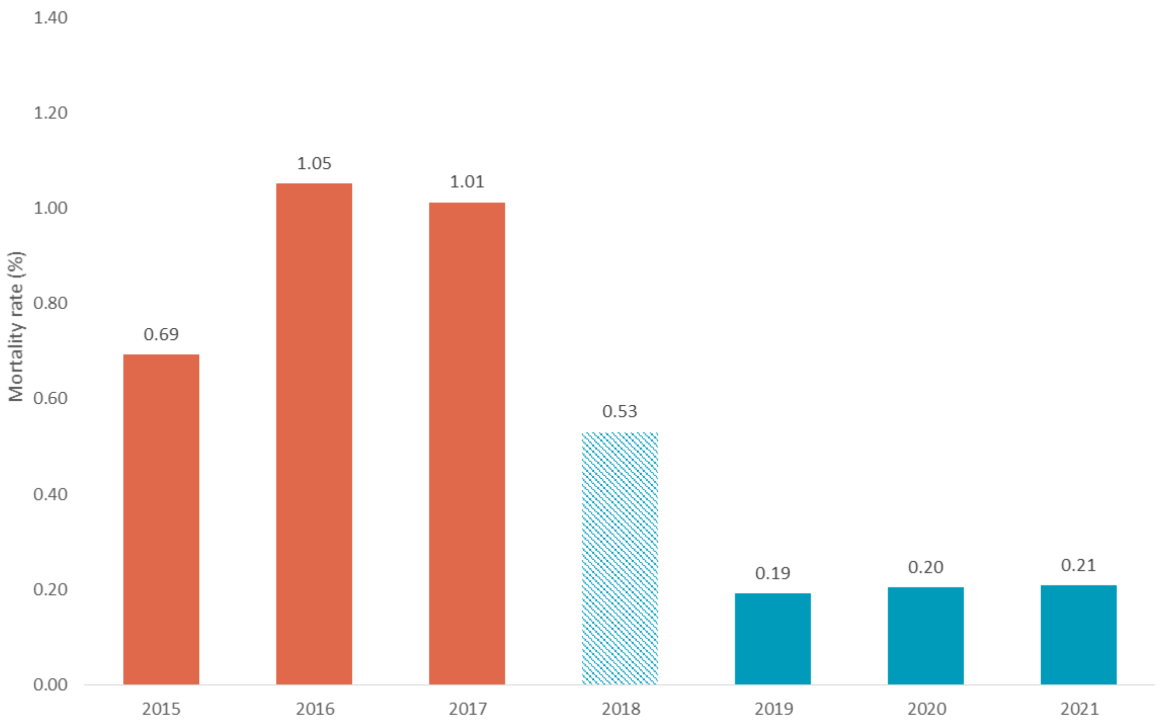

## 6.1 Mortality comparisons

Figure 32 shows the decline in average mortality rate during Northern Hemisphere summer voyages from 2015-2021, reflecting regulatory changes including the Middle East Order and a prohibition. To better compare voyages travelling under the same regulatory settings, the department analysed mortality statistics from voyages exporting sheep to the Middle East during the Northern Hemisphere summer for 3 years before 2018 (2015-2017) and for 3 years after 2018 (2019-2021). Voyages that occurred during 2018 have been omitted from this analysis as they travelled under a number of different regulatory settings, making comparisons difficult.

Figure 33 shows the month-by-month mortality rates for the 2015-2017 Northern Hemisphere summer period (averaging 0.89%) and 2019-2021 Northern Hemisphere summer period (averaging 0.20%). The change in mortality rates represents a reduction of 77.51%. June, July and August were identified as the highest risk months for mortalities in 2015-2017. The prohibition has prevented exports departing Australia during these high-risk months.

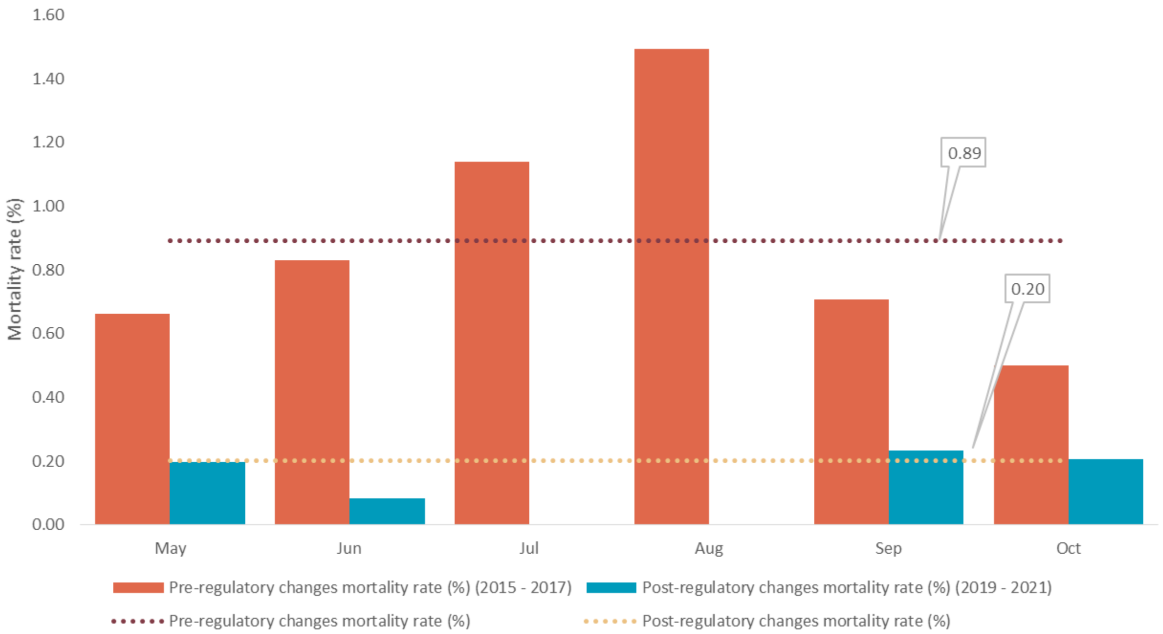
Mortality rates for voyages during the shoulder period months of the Northern Hemisphere summer (May, September and October) have also significantly reduced in 2019-2021 (Figure 34).

**Figure 32 Yearly mortality rates during the Northern Hemisphere summer 2015-2021**




Another contributing factor in the reduction in Northern Hemisphere summer mortality rates over this period may be the fewer voyages and fewer numbers of sheep exported to the Middle East. For example, in 2017, 15 voyages departed for the Middle East carrying 707,658 sheep, compared to 2021 when 6 voyages departed for the Middle East carrying 229,834 sheep (Table 18). From 2013-2017, the Northern Hemisphere summer period represented 51.11% of the total number of sheep exported annually. From 2019-2021, live sheep exported during the Northern Hemisphere summer period represented only 29.71% of the annual trade.

### Figure 33 A comparison of Northern Hemisphere summer mortality rates (%) from 2015-17 and 2019-21 – by month




### Table 18 Load, mortality and voyage counts for Northern Hemisphere summer 2015-21

| – | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|
| Load count | 1134692 | 903082 | 707658 | 211825 | 258216 | 196774 | 229834 |
| Mortality count | 7863 | 9495 | 7165 | 1124 | 494 | 403 | 479 |
| Mortality rate (%) | 0.69 | 1.05 | 1.01 | 0.53 | 0.19 | 0.20 | 0.21 |
| Standard deviation | 0.34 | 0.54 | 0.86 | 0.27 | 0.05 | 0.07 | 0.07 |
| Number of voyages (n) | 21 | 19 | 15 | 6 | 5 | 4 | 6 |

Under current regulations, sheep can be exported to most Middle Eastern destinations from 1-31 May and from 15 September to 31 October, on either side of the Northern Hemisphere summer prohibition period. A comparison of mortality rates in like-for-like periods pre-2018 and post-2018 provides an indication of the impact of regulation changes (other than the prohibition) on sheep mortalities. Figure 34 and Table 19 show the reductions in sheep mortality rates that have been achieved due to these regulatory changes, independent of the prohibition.

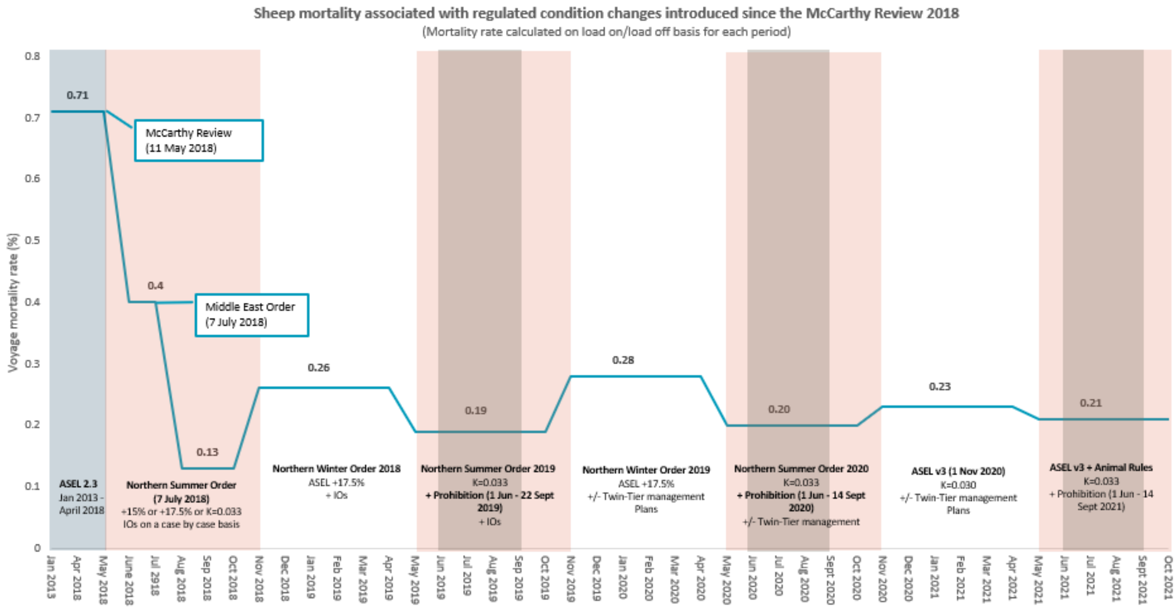
#### Figure 34 Mortality rate (%) for May and 15 September to 31 October (Northern Hemisphere summer shoulder periods)


#### Table 19 Sheep load and mortality data for May and 15 September to 31 October (Northern Hemisphere summer shoulder periods)

| – | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|
| Load count | 573866 | 390677 | 304898 | 145170 | 258216 | 163433 | 229834 |
| Mortality count | 3247 | 3102 | 1710 | 805 | 494 | 375 | 479 |
| Mortality rate (%) | 0.57 | 0.79 | 0.56 | 0.55 | 0.19 | 0.23 | 0.21 |
| Standard deviation | 0.25 | 0.48 | 0.18 | 0.29 | 0.05 | 0.04 | 0.07 |
| Number of voyages (n) | 10 | 7 | 7 | 4 | 5 | 3 | 6 |

Figure 35 shows the mortality rates following regulatory changes since 2018. Mortality rates during the Northern Hemisphere summer are now as low or lower than the mortality rates reported during the NHW.

**Figure 35 Sheep mortality rates associated with regulated condition changes introduced since 2018**




## 6.2 Reported causes of mortalities

Under the ASEL, for voyages over 10 days the causes of mortality must be reported to the department in daily reports, including the number of sheep euthanased. The introduction of standardised reporting through LIVEXCollect is likely to improve the consistency of mortality reporting.

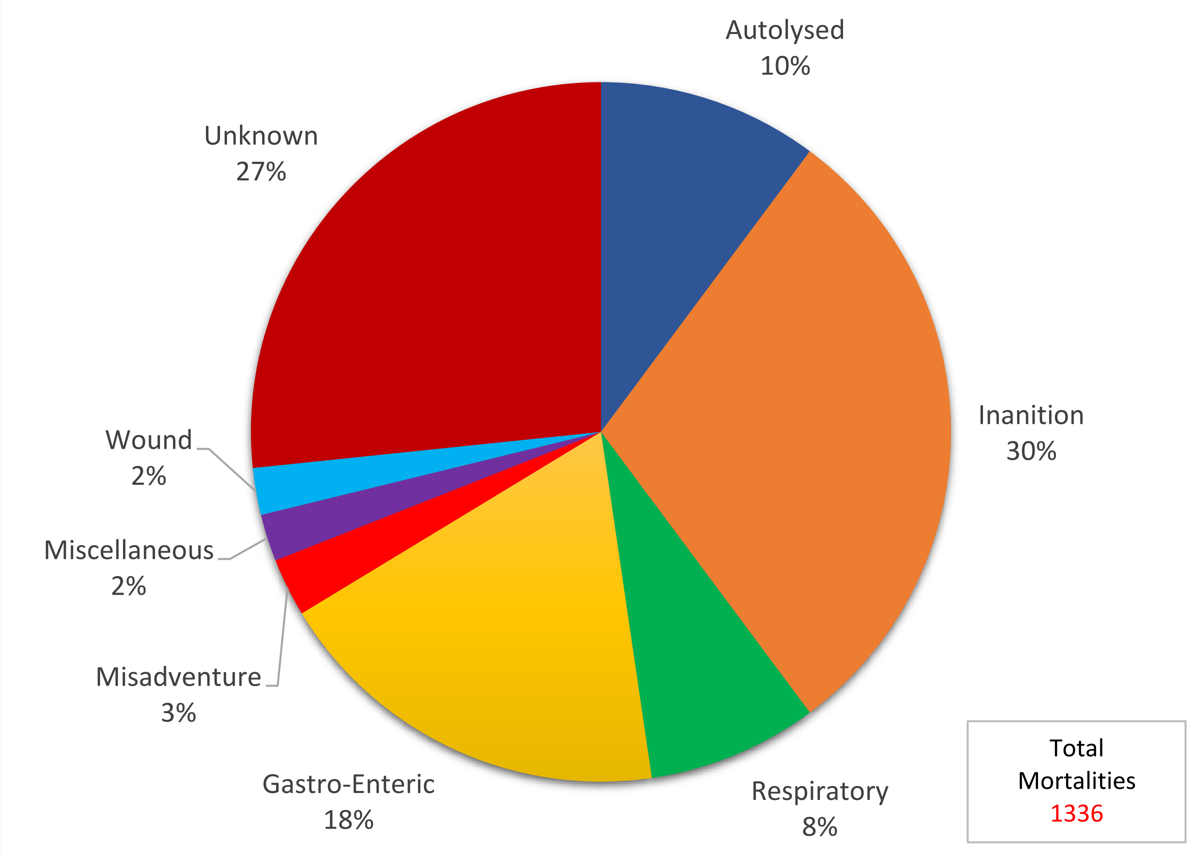
The department's and industry's understanding of risk factors for sheep mortalities would be improved if a greater proportion of the causes of sheep mortalities were able to be accurately reported. For example, 27% of sheep died without a cause of death listed in the respective daily reports (Figure 36). While there may be reasons for not reporting a cause of death, such as inability to perform a post-mortem due to proximity to a coastline, the absence of even a syndromic cause of death reduces the value of reporting in identifying manageable health issues and prevention strategies. Of the reported mortalities, inanition is the major cause of death reported on sheep vessels, making up 30% of all mortalities. Other reported causes include gastro-enteric diseases (18%) and respiratory diseases (8%) (Figure 36).

No heat stress mortalities were reported in any of the 15 voyages analysed for this review.

Inanition and gastro-enteric diseases are strongly associated with dietary and other management factors (MLA 2008). This reinforces the importance of minimising the incidence of 'shy feeders' during preparation in the RE, the benefit of appropriately transitioning sheep to onboard diets and the benefit of ensuring adequate access to fodder on vessels.

Investigating potential changes to the LIVEXCollect format, AAV training and other measures to improve the quality of reporting on causes of sheep mortality during export could assist in assessing any potential animal welfare issues onboard vessels.

**Figure 36 Reported causes of mortality 2019-2021**




## 6.3 Summary of mortality data findings

- No mortalities due to heat stress were reported on the 15 voyages.
- The most frequently reported causes of mortality during 2019-2021 were inanition and gastro-enteric diseases.
- There has been a 77.5% reduction in sheep mortality rates during the Northern Hemisphere summer (1 May to 31 October inclusive) after specific regulatory changes to mitigate heat stress and improve animal welfare were introduced over the period 2018 to 2020. Voyage mortality rates for Northern Hemisphere summer voyages have now stabilised within a narrow range, averaging 0.2%. This strongly indicates that regulatory changes have been effective in reducing the risk of heat stress and associated mortalities.
- In May, September and October (Northern Hemisphere summer months outside the prohibition period) there has been a 67% reduction in sheep mortality rates. This indicates that, independent to a prohibition, regulatory changes, including allometric pen space allowances, body condition score limits, and automated watering systems, have been effective in reducing the risk of heat stress and heat stress mortalities.
- In 2015-17, the highest mortality rates occurred during June, July and August. The prohibition has prevented exports departing Australia during these high-risk months.

# 7 Stakeholder feedback

On 17 December 2021 the department released a draft report for public consultation. Based on an initial assessment of the updated climatology data from the BOM and other data, the draft report proposed that, to maintain or improve the welfare of exported sheep, an absolute prohibition period during the hottest, most humid part of the Northern Hemisphere summer should remain and that conditional prohibition periods for various destinations should be introduced. The draft report received over 700 written submissions when consultation closed on 28 January 2022. Nearly 600 of these submissions were campaign-style templated submissions opposing live animal exports.

Due to high levels of interest, the complexity of the issues, the important implications for animal welfare and the practical requirements of any change to export processes the department advised it would undertake additional stakeholder engagement on 28 February 2022. From then to 29 March 2022 departmental officers engaged with animal welfare organisations, exporters, industry representatives and livestock producers and their representatives, in face-to-face and virtual meetings, including visiting stakeholders in Western Australia.

Following public consultation on the draft report, additional engagement in early 2022 and further consideration of the available data and reports, the department announced that, to mitigate the risk of heat stress on sheep, a conditional prohibition period for Persian Gulf destinations (other than Kuwait and Oman) would be implemented for voyages departing Australia from 22 to 31 May. The data indicated that risks for Qatar were similar to those for these Persian Gulf destinations, so Qatar was included with these. The data also indicated that heat stress risks for voyages to or through the Red Sea were not as high in June as previously understood and the prohibition start date was moved to 15 June.

The department considered all feedback received during the consultation process, when finalising the review. Any additional science or evidence presented during public consultation was incorporated into this report where appropriate. Submissions to the draft report (where permission was given) will be published on the department's "Review of live sheep exports by sea, to or through, the Middle East during the Northern Hemisphere summer" Have Your Say web page here.

The department has summarised key issues raised in submissions and during the additional consultation.

## 7.1 Key issues raised during public consultation

Common themes were raised in both written submissions and during face-to-face stakeholder engagement. Core concerns included:

- presence of IOs on voyages
- data reporting and reliability
- heat stress thresholds and WBT thresholds
- length of prohibition periods
- the impact of climate change

- mortality rates
- the range and practicality of additional heat stress mitigation conditions (pen space allowances, body weight and wool length limits)
- regulatory approach
- commercial competition
- longevity of the trade
- conditions in the importing country.

These issues have been considered in greater detail in this section.

### 7.1.1 Presence of independent observers on voyages

Submissions raised concerns that IOs were present on only 6 of the 15 voyages. Submitters often stated the presence of IOs onboard vessels increased public trust in the live export sector and provided an independent 'voice' when addressing any potential inconsistencies in heat stress reporting by AAVs. The department notes that while there was a pause in the deployment of IOs on all livestock vessels from March 2020 in response to the COVID-19 pandemic, extra reporting requirements were put in place for some voyages during this period. Additional reporting elements included information regarding the daily livestock husbandry routine, feeding, water provision and treatment of sick livestock.

The IO program recommenced from 1 May 2022.

### 7.1.2 Data reporting and reliability

Feedback generally commented that logger data was very useful in demonstrating actual conditions on deck and that the analysis of logger data presented in the draft report was thorough and informative.

Many submissions raised concerns that the limited number of voyages in the review, and the resulting insufficient quantity of data or evidence, would not be sufficient to support recommendations to change regulatory settings. The department notes that the review addresses the commitment made in 2020 to analyse the effectiveness of the regulatory settings implemented for sheep exports by sea to, or through, the Middle East during the Northern Hemisphere summer. The outcomes of live sheep voyages to, or through, the Middle East will continue to be monitored by the department.

### 7.1.3 Heat stress thresholds and wet bulb temperature thresholds

Concerns about the current HSRA model were raised with suggestions that the current model should be improved in order to support the proposed regulatory changes. The department notes that the ASEL sea review (2019) recommended the HotStuff model be updated. This work is currently being undertaken by LiveCorp.

One submission stated that additional heat-mitigating conditions in the draft report achieved an increase of 2.6°C in sheep HST, which was substantially greater than the expected ambient WBT differential of 1.5°C during conditional prohibition periods. Another submission stated that high heat cannot be effectively mitigated even with the application of additional conditions.

The 29°C degree WBT threshold for heat stress management was debated amongst stakeholders. It was suggested that the threshold should be adjusted against real-world voyage outcomes, after low mortality voyages have occurred during times where WBTs have exceeded the threshold. By contrast, other feedback questioning the scientific rigour of the threshold, stating it should be reduced to 26°C to improve animal welfare outcomes.

One submission referred to a study by Carnovale and Phillips (2020), that concluded heat stress in sheep on decks did not start to become evident until the bridge (ambient) WBT reached approximately 27.5°C. This study was based on reporting from voyages that occurred between 2016-2018 under ASEL 2.3 conditions when stocking densities were 25-39% higher than current levels, and before increases in minimum ventilation rates were implemented by AMSA in Marine Order 43. Under these conditions, deck WBT rises for the voyages analysed in the study would likely have been 1-2°C higher than seen with current voyages, and in total, up to 5°C higher than the bridge WBT. When changes to stocking density and ventilation are factored in, this study indicates heat stress under current voyage conditions is unlikely to be seen until a WBT of 28.5°C -29.5°C is reached on the bridge.

This provides evidence that a bridge WBT of 29°C appears to be effective as a threshold for limiting the risk of heat stress in sheep and should continue to be used until a more suitable and validated science-based alternative is identified.

### 7.1.4 Length of prohibition periods

A number of submissions advocated for either an expansion of the Northern Hemisphere summer prohibition period or for a reduction in absolute prohibition periods. These submissions were typically not supported by scientific data or evidence.

Some submissions suggested the deployment of trial voyages in periods within the existing prohibition for the purpose of collection of additional scientific information around heat tolerance and methods for ameliorating high WBTs. Such trial voyages, in the hottest most humid part of the Northern Hemisphere summer, are not in line with the current risk settings implemented by the department.

### 7.1.5 The impact of climate change

Some submitters were concerned that climate change was not addressed in its own section in the draft report and that the 2021 BOM analysis of 42 years of accumulated data would fail to adequately account for the impact of climate change. Concerns were also raised that the potential for hotter weather would increase animal welfare issues during voyages to the Middle East. Some submissions quoted predictions that temperatures in the Middle East would be much higher by 2050, stating this was justification for ending live sheep exports immediately.

In response to feedback, the final report includes a section discussing some recent literature on the effects of climate change and how BOM includes the influence of climate change in its analysis.

### 7.1.6 Mortality rates

The draft report identified a significant decrease in mortality rates since 2018, following the introduction of new regulations, including prohibition periods introduced in 2019. However, the department notes mortality rates are only one of several quantitative and qualitative measurements that can be linked to animal welfare outcomes. Since 2018, the prohibition settings for the export of sheep to the Middle East during the Northern Hemisphere summer have been based on the risk of heat stress rather than mortalities. Some submissions restated the need to shift focus to animal welfare outcomes rather than mortality outcomes, usually without acknowledging sheep export regulation has already moved in that direction. Some submissions questioned the magnitude ate of the improvement on the basis of pre-prohibition mortality rates being relatively high.

Another view was that as mortality rates during the Northern Hemisphere summer are now lower than during the Northern Hemisphere winter, this implies over-regulation. Conversely, some animal welfare organisations suggested that Northern Hemisphere summer conditions should be applied all year.

### 7.1.7 Pen space allowances and ventilation

Some feedback suggested that pen space allowances should be increased using an allometric equation where the $k$-value is 0.047. Petherick and Phillips (2009) used an allometric equation with a $k$-value of 0.047 to estimate the space occupied by pigs when lying laterally with legs extended. They stated, however, that it may not be necessary to provide all group members with this space allowance as all would not show 'lying down behaviours' simultaneously.

The current allometric spacing for Northern Hemisphere summer periods is set at $k$-value=0.033. Petherick and Phillips (2009) state that for long-term confinement (weeks to months), a minimum allowance per head using a $k$-value of 0.033 appears to reduce risks to welfare and productivity. This space allowance appears to permit all animals to lie simultaneously in a normal lying posture. The department has not received any other scientific evidence to dispute the approach of using an allometric equation with a $k$-value of 0.033.

Some submissions stated the minimum PAT score suggested in the draft report of 200 $m^3$/h was inflexible, unachievable and did not account for other heat-mitigating factors. In response to this feedback, the department incorporated a number of different ways to achieve lower deck WBT rises, to account for vessels that have lower PAT scores. These are outlined in the additional conditions section.

### 7.1.8 Body weight and age

Concerns were raised about young sheep potentially increasing in number as a percentage of overall shipments. It was stated that this trend is expected to continue into the future and that young sheep can exhibit heavy weights (50-60kg).

Feedback from industry consultation identified that young sheep, typically between 38-48kg and at least 12 months old, make up the greatest proportion sourced for live export. In addition, voyage reporting from the 15 voyages during the 2019-2021 Northern Hemisphere summer consistently indicated younger sheep were less heat affected than older sheep.

Under the ASEL, there are no minimum age restrictions for the export of sheep, however sheep must have a minimum individual liveweight of 32kg to be sourced for export by sea. This prevents the export of very young lambs that are more susceptible to heat stress.

### 7.1.9 Wool length

Concerns were raised regarding the practicality and welfare implications of the draft report proposal that less heat-tolerant sheep must be off-shears (shorn within 14 days of loading for export). Advice received during additional stakeholder engagement indicated an RE may have the capacity to shear up to 10,000 sheep per week, limiting the ability to meet the proposed requirement. Feedback also indicated that re-shearing a short-wool sheep (fleece 20mm or less) was impractical and raised welfare concerns as the shears can pull and cut the skin rather than shear the fleece. In response to this feedback and recognising the practicalities of shearing sheep prior to export, the department determined that setting the wool length requirement of no longer than 20 millimetres for less heat tolerant breeds of sheep would mitigate the risk of heat stress for sheep being exported during the conditional prohibition period.

The department also considered a number of options regarding pen space allowances, weight limits, wool length limits and minimum PAT scores for sheep exported in late May destined for Persian Gulf ports (other than Kuwait and Oman) where WBTs are hotter and more humid. A range of requirements were included in the amendments to the Animal Rules made on 6 April 2022. These requirements are considered to provide appropriate additional heat stress mitigation for the sheep being exported during the conditional prohibition period and are recommended to be retained.

Heat tolerant breeds must be shorn to the ASEL requirement (all sheep must have wool or hair no longer than 25mm in length at the time of loading for transport to the port of embarkation).

### 7.1.10 Regulatory approach

Submissions conveyed a wide range of views on the department's regulatory approach to live sheep exports.

One submission praised the current risk-based approach, other submissions called for refinement of the current regulatory approach to allow for flexibility and to reduce regulatory burden and still others called for the department to apply 'precautionary principles' in considering any changes to existing prohibition periods.

### 7.1.11 Commercial competition

Feedback was received on the department's regulatory approach and its impact on commercial competition. It was suggested that the current approach is too prescriptive and inflexible to sustain a financially viable trade. Potential damage to economies of scale and impediments to shipping logistics were cited as barriers to the commercial viability of the live sheep export trade.

Multi-port voyages were noted as critical to the underlying economics of the trade. Some submissions stated that single port voyages were not considered economically viable.

### 7.1.12 Longevity of the trade

Feedback in relation to the industry as a whole was received across both written submissions and in-person stakeholder meetings. It was also suggested that government should co-design an industry exit plan to facilitate a five-year phase out of live sheep export.

### 7.1.13 Conditions in the importing country

Exposure to high heat periods for up to 6 weeks after arrival and before slaughter was raised as an issue to be considered. The department acknowledges the issue raised and notes that heat conditions in the importing country are beyond the scope of the review.

# 8 Conclusion

After examining data and reports for the 15 voyages that travelled during the Northern Hemisphere summers of 2019, 2020 and 2021, and considering the 2021 BOM report, the review concluded that use of prohibition periods to reduce the risk of heat stress in sheep during export to, or through, the Middle East by sea during the hottest part of the Northern Hemisphere summer, remains appropriate.

The updated climate data presented in the 2021 BOM report shows that the prohibition dates can be more precisely delineated, based on 95$^{th}$ percentile maximum WBTs and other observations, for particular destinations. The result is a number of recommendations to change absolute prohibition periods and to introduce a conditional prohibition period to ensure the regulatory settings for live sheep exports to the Middle East during the Northern Hemisphere summer continue to be evidence-based and mitigate the risk of heat stress.

While an analysis of the overall impact of regulatory changes could be assessed, the available voyage data and reports did not enable statistical evaluation of the effect of specific regulatory changes (such as pen space allowances).

The implementation of the LIVEXCollect platform in late 2020 is likely to improve the consistency of data provided to the department. High quality, consistent and complete data will assist the department to effectively regulate whilst promoting animal welfare outcomes.

The department's analysis of voyage data showed a 77.5% reduction in mortality rates for Northern Hemisphere summer voyages after regulatory changes to mitigate heat stress were introduced since 2018. The voyage reports, WBT readings and mortality outcomes validated that the regulatory parameters introduced in 2020 have been effective in minimising the risk of heat stress and heat stress mortalities for sheep exported to the Middle East during the Northern Hemisphere summer. These parameters were used to inform the proposed changes to prohibition dates and the introduction of a conditional prohibition period.

# Glossary

| Term | Definition |
|---|---|
| Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) | The science and economics research division of the Department of Agriculture, Fisheries and Forestry |
| Accredited veterinarian (AAV) | A veterinarian who is accredited under the Export Control (Animals) Rules 2021 to carry out duties in relation to the export of livestock |
| allometry | The relationship of body size to shape, anatomy, physiology and behaviour |
| Australian Maritime Safety Authority (AMSA) | Australia's national agency responsible for maritime safety, protection of the marine environment, and maritime aviation search and rescue |
| Australian Standards for the Export of Livestock (ASEL) | The set of requirements and minimum animal health and welfare conditions exporters must meet when exporting livestock from Australia by sea and air<br><br>Note: 'the ASEL' referrers to ASEL version 3.2, the current version. Historic versions will be referred to individually within the text of the report |
| Body condition score (BCS) | Visual assessment of an animals' weight based on relative proportions of muscle and fat |
| Consignment | A group of sheep that are under export preparation by one exporter and are destined for export or have been exported from a single seaport or airport |
| Daily mortality rate | The rate (%) that is calculated by dividing the mortality rate by the number of voyage days |
| Deck wet bulb temperature rise | The temperature rise resulting from the volumetric air flow of a pen absorbing the heat generated by animals within the pen |
| Exporter Supply Chain Assurance System (ESCAS) | The set of regulatory requirements placed on exporters to have arrangements in place for the humane handling and slaughter of livestock in the importing country. |
| Excessive heat load (EHL) | The increase of temperature above normal due to lack of ability to dissipate body heat effectively (MLA 2021) |
| Feeder sheep | Sheep that are exported to be fattened prior to slaughter |
| Heat load | An animal's thermal balance incorporating the cumulative effects of animal factors and environmental conditions on thermal comfort |
| Heat stress | Excessive heat load. Occurs when an animal's normal biological responses to hot conditions can no longer maintain body temperature. |
| Heat stress risk assessment (HSRA) | An assessment performed using a heat stress model that combines weather statistics, vessel parameters and animal heat tolerance factors to determine the pen space allocation for the livestock for an intended voyage to predict the risk of mortality or heat stress |
| Heat stress threshold (HST) | The wet bulb temperature when the animal's core temperature is 0.5°C above when it would otherwise have been (Maunsell 2003) |
| Hotspots | Discrete areas on vessel decks with higher WBTs than surrounding areas, often due to proximity to the engine room |
| HotStuff | Software program for the assessment of heat stress risk for live export voyages |
| Independent observer (IO) | Authorised officer under the live animal exports legislation, acting in a regulatory capacity to undertake specific regulatory monitoring activities aimed at ensuring compliance |
| *k* value | *K* values are used in allometric calculations for pen space allowances as a determinant of the threshold for all sheep to be able to either stand, sit or lie down at the same time |

| Term | Definition |
|---|---|
| LIVEXCollect | A data collection, management, reporting and analysis platform for the livestock export industry |
| Middle East area of interest (MEAI) | Middle East area of interest |
| Mortality limit (ML) | The wet bulb temperature (WBT) at which the animal will die |
| Northern Hemisphere summer | Northern Hemisphere summer (1 May to 31 October) |
| Pen air turnover (PAT) | A measure of a vessel's ventilation efficiency, measured in $m^3$/hour per square metre of pen space. |
| Percentile | Thresholds or boundary values in frequency distributions. Thus the 5$^{th}$ percentile is that value which marks off the lowest 5% of the observations from the rest and the 95$^{th}$ percentile exceeds all but 5% of the values |
| Technical Advisory Committee (TAC) | The technical group that reviewed the Australian Standards for the Export of Livestock (ASEL) (ASEL sea review) and in Independent Observer (IO) voyage reports |
| Thermoneutral zone (TNZ) | The range of environmental temperatures at which metabolic rate is basal, with no requirement to either increase heat production or use additional processes to lose heat (HSRA final report) |
| Wet bulb temperature (WBT) | The temperature read by a thermometer with the bulb covered by a water-soaked cloth other which air is passed, or by an automated data logger. Wet bulb temperature takes into account air temperature and humidity and may also vary with are pressure and elevation. |

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