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A review of Shipboard Mortality Data 1988–2017

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Abstract

The livestock export industry has collected daily mortality summaries of livestock export voyages since 1988 and produced an annual report for industry based on recent data. This review is the first attempt to collate and analyse all data collected since 1988, to better understand changes in industry performance (mortality) over this time.

This work has been made possible by the aggregation of all prior data into the new live export database. Data on cattle, sheep and goat voyages were described. In addition, cattle and sheep voyages were analysed using statistical models to investigate predictors of mortality. Data on environmental conditions were included in these analyses. For the first time, these data were analysed on a daily mortality basis, rather than only a voyage basis, to allow better understanding of predictors of mortality.

These investigations have shown that mortality rates have declined steadily over the past 30 years. These improvements may have been driven by long-term economic and technological factors, including improvements in pre-export preparation and vessel design and management, underpinned by a substantial continuous investment in research. Future work should further explore predictors that can also be measured on a daily basis or incorporated from other data sources for use in real-time monitoring at individual animal level during livestock voyages to improve voyage outcomes.

Executive summary

Background and Objective

Since 1988, the livestock export industry has collated data on the welfare performance of livestock loaded in Australian ports for long-haul (and some short-haul) voyages. In 2016, the shipboard mortality database application was updated from a 1980s-style dedicated application to a modern, secure, web-based system. As a result, nearly thirty years' worth of live export data are now available in a single database, including the number of animals loaded on voyages and daily mortality.

In this review, a number of analyses were undertaken on data held within this database. In reviewing long-haul (voyage duration ≥10 days) live export of sheep, cattle and goats from Australia, 1988 to 2017, the objectives were to

- summarise and describe voyages, considering year, route (origin and discharge ports), animal class, vessel and time of year
- describe mortality across years (particularly in consideration of timing of introduction of industry strategies to reduce mortality), routes (origin and discharge ports), animal classes, vessels and time of year
- identify risk factors for mortality.

Methodology

Descriptive statistics

An exploratory data analysis was conducted to summarise long-haul voyages between 1988 and 2017. Variables described in the analysis included number of animals loaded, origin and destination ports, year and month of departure, vessel, voyage duration, number of load and discharge days, animal species, animal class and age and voyage mortality rate (VMR). Numeric variables were described using means, medians and ranges, and variables were cross-tabulated and plotted across time to explore potential relationships. Mean and median VMR were calculated across voyages.

Mapping

Ship routes were mapped to understand the spatial and temporal trends of daily mortality rate (DMR) on different voyages and to generalise risk factors across all voyages. Spatial coordinates were assigned to each day of a voyage by segmenting shipping routes for each voyage into equal lengths, with segments equivalent to the number of voyage days. Sea surface temperatures and distance to nearest land mass were then assigned to each DMR observation. From these data, heat maps were generated to illustrate shipping routes and locations with elevated DMR.

Exploratory modelling

Risk factors were included within a generalised additive mixed modelling approach (GAMM). These risk factors included season (as day of year), animal class (sex, age and breed of animal were combined to circumnavigate issues associated with unbalanced data impacting on model estimation and interpretability[*]), sea surface temperatures, voyage duration and destination region. Many of the events recorded (e.g. daily sea surface temperature sourced from spatially coarse satellite sensors) might be seen to be a proxy for conditions on the boat (e.g. daily ambient temperatures on board were not recorded as part of the data set). Vessel courses were also approximate, have been acquired from linear daily

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[*] With multiple sex, age and breed combinations some of the combinations of these factors were poorly represented. For example, there were 3,720 Karakal wether lambs and no Karakal wether adults transported over the period of the database record, compared to 97,718,488 Merinos. Moreover, when treated singly estimates of sex, age or breed in the modelling were not consistent, likely because of the strong clustering of each class among the voyages.

approximations from great circle shipping routes that assume a constant vessel speed throughout a voyage. These data were then compared with historical records of sea surface temperature dating back to 1998, to provide a daily environmental temperature for the vessel.

Results

Descriptive statistics

A total of 2,240 long-haul voyages transporting sheep, cattle and/or goats were recorded between November 1988 and November 2017. More than 100 million sheep, 3 million cattle and almost 180,000 goats were exported during this time, with overall VMRs of 1.3%, 0.4% and 2.2%, respectively.

Voyages in this study departed from 13 different origin ports in Australia, most frequently Fremantle, Portland and Adelaide. Animals were exported to five different ‘regions’: Middle East/North Africa, Southeast Asia, South-eastern Europe, Northeast Asia and Miscellaneous. Most voyages went to the Middle East/North Africa (MENA) region. Mina Qaboos (Muscat) in Oman was the most frequent discharge port, with 592 recorded discharges of livestock. South-eastern Europe was the destination region with the longest mean voyage duration, at 25.5 days (excluding load and discharge days).

The number of departing voyages peaked between 1998 and 2002. Oman received the highest proportion of sheep exports (40%, just over 40 million head); Egypt received the highest proportion of cattle exports (25%, just over 750,000 head); and Saudi Arabia received the highest proportion of goat exports (46%, just over 83,000 head).

Fifty-four vessels were involved in exporting sheep, cattle and/or goats between 1988 and 2017. A large proportion carried two or more animal classes during a single voyage (70.2%).

A general downward trend was observed in VMRs across the three species, with decreasing fluctuation with time. VMRs were elevated for sheep during the northern summer period for voyages to the MENA region.

Mapping

Cattle mortality was concentrated in a small handful of large-scale, reportable mortality events. These events occurred before 2002 and were clearly featured in the mapping of shipping routes to the Persian Gulf. In comparison, sheep mortality was of larger scale and distributed across voyages. Again, large-scale reportable mortality events were clearly visible in the mapping of shipboard mortality, principally along the Persian Gulf route.

Exploratory Modelling

Exploratory modelling highlighted the importance of temperature as a risk factor in shipboard mortality of sheep, and that elevated mortality occurred during the northern summer months when sea surface temperatures were greater than 25°C on average. Similarly, sea surface temperatures above 25°C on average were also associated with higher levels of cattle mortality. However, the scale of this mortality response was much lower for cattle than it was for sheep, and mortality among cattle was largely independent of season. When other risk factors such as temperature were included in the cattle model, there was some evidence for higher mortality in the northern winter months.

Persian Gulf routes exhibited higher DMRs than Red Sea routes for both sheep and cattle. Moreover, elevated mortality was sustained for a longer proportion of the voyage duration for the Persian Gulf routes.

Discussion and Conclusions

The key conclusion of this report is that shipboard mortality for sheep, cattle and goats has steadily decreased across the 30-year data record now captured by the shipboard mortality database. Although not fully explored, there is no apparent link between regulator initiatives and the reduction in shipboard mortality— the reduction in mortality may have been driven by long-term economic and technological factors.

Analysis of the data is consistent with previous findings on causative risk factors of shipboard mortality. In particular, the exploratory modelling identifies that as sea surface temperature rises above 25°C there is an increase in the risk of elevated levels of mortality (we note that an increase in the risk of elevated mortality is not the same as an increase in mortality). This appears to peak around 29˚C. No data on wet bulb temperature were available for these voyages; however under still-air conditions, wet bulb temperature experienced on a livestock vessel with the agreed minimum pen air turnover would be expected to be a few degrees higher than the sea surface temperature. This would be consistent with reports of a 28°C wet bulb temperature threshold for increasing mortality, across both sheep and cattle reported in the existing literature. It would also be consistent with anecdotal reports that wet bulb temperatures exceeding 32˚C are associated with elevated mortality rates. Understanding the physiological response of livestock to these conditions was outside the scope of this report. The adoption of penside logging of the environment will provide a massive benefit to understanding this relationship.

The introduction of a ban on northern summer live exports needs to be carefully considered. Firstly, cattle mortality was relatively constant through the year, and if anything was slightly elevated prior to this period. It is then expected that a ban will not realise a benefit in terms of improved animal welfare outcomes for cattle, while incurring significant cost in terms of lost trade in cattle.

For sheep, elevated DMRs during the northern summer months may be observed when considering background, attritional mortality (mortality that does not exceed the threshold for mortality event reporting). In contrast, the three most recent reportable mortality events attributable to heat stress occurred in a cluster over 2016–2017 during the northern summer period.

Making inferences about the causes of reportable mortality events was beyond the scope of this project. We note that the number of reportable mortality events has continued to decline (consistent with the general improvement in survival) since records began. The small number of recent reportable mortality events precludes useful statistical analysis. The next previous heat stress related reportable event was recorded in 2013. Combined with a possible shift of reportable mortality events to the shoulder periods of the northern summer that may follow a live export ban, the intent of the regulatory initiative to improve animal welfare outcomes may not be fully realised, at considerable cost to trade and market share, in turn contributing to a disincentive to invest in technological improvements to the livestock export process.

The shipboard mortality database will likely become more federated in future with the possible inclusion of: 1) weather forecasts; 2) on-board climate monitoring; 3) animal welfare measures such as panting and feed intake that are precursors to mortality; 4) daily performance reporting; and 5) animal specific data via RFID devices. Each of these data sources is both technically feasible and should be relatively cost-effective to implement.

Incorporating other data sources will provide two benefits. The most important benefit will be the improved capacity of shipboard managers to pre-emptively respond to changing ambient conditions, such that the worst of each mortality event may be largely avoided. Secondary benefits of maintaining the database will be the capacity to: 1) utilise these data so as to learn and improve the outcomes of stress mitigating activities; 2) integration of monitoring data with automation of on-board systems within an IoT framework; 3) auto-generation of industry annual reports; and 4) provide an evidence-based approach to supporting regulatory and operational management innovations and initiatives, and avoid the risk of implementing potentially costly but ineffective — or worse, counterproductive — interventions.

Table of contents

1 Background

Live animal exports are a valuable industry in Australia, worth over $800 million annually (DAWR, 2015). Livestock are exported to a large number of countries throughout the Middle East, Southeast Asia, northern Asia and parts of Europe (ALEC 2017). The lack of cold chain facilities and cultural preferences for freshly slaughtered meat in many of these countries maintains high demand for live animal exports (DAWR, 2015; Farmer, 2011).

The Australian government and the livestock export industry are working collaboratively to improve animal welfare (DAWR, 2015). Over the last three decades, there have been voyages with high mortality events. To address this, industry initiatives have been implemented, including the:

1. Livestock Export Accreditation Program in 1998;
2. HotStuff (Heat Stress Risk Assessment Model), introduced in 2003;
3. Australian Standards for the Export of Livestock (ASEL), following an independent review (Keniry Review) in 2004; and the
4. Exporter Supply Chain Assurance System, following a live export ban between 8th June and 6th July 2011 and an independent review (the Farmer Review) (Farmer, 2011).

ASEL defines the levels of mortality that are reportable for each animal class during a voyage. Reportable mortality levels are: >0.5% for cattle on short-haul voyages (<10 days); >1% for cattle on long-haul voyages (≥10 days); and >2% for sheep and goats[1] (all voyage durations).

Performance data on livestock export voyages departing from Australian ports have been collated by the livestock export industry since 1988 for sheep and goats, and since 1995 for cattle. However, only recently have data from the last 29 years became available in a single database: the 'Yellow Book' Shipboard Mortality Database (SMDB), funded by Meat & Livestock Australia and LiveCorp. This database contains daily voyage-level data, inclusive of mortality, to enable the analysis of livestock export performance. These analyses provide an evidenced-based approach towards supporting industry-level strategies that reduce mortality risk on long-haul livestock export voyages.

The objectives of this report were to conduct a number of analyses related to industry performance, with a focus on long-haul voyages. This involved:

- exploratory data analysis, with reporting of animal performance summaries by year, month, route (origin and destination ports), animal class and vessel,
- mortality analysis, with development of a model to assess variables that may be predictors of mortality on long-haul livestock export voyages; and
- generation of maps to visualise mortality along shipping routes.

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[1] We note that the reportable mortality threshold for sheep was subsequently adjusted to 1% by regulation, but 2% was the defined level for the date range covered in the data.

2 Project objectives

2.1 Full data set analysis

A number of analyses were undertaken. These analyses were focussed on industry performance over the full 28 years of data collection, incorporating additional related data where available. The analyses attempt to take into account previously inaccessible predictor data (such as environmental conditions based on spatial location), and combine them with suspected risk factors such as season / time of year, animal class and vessel.

The key metrics for this work are focussed on a range of analyses. These include

- animal performance (mortality) summaries, by year, route and animal class,
- visualisation of mortality by geographic location at time of death,
- construction of a predictive model including all parameters included in the reporting, plus any other covariates that might be significant predictors of animal performance (e.g. HotStuff model vs pre-HotStuff model analyses, introduction of ASEL) - validated model (based on bootstrapping existing data set).

3 Methodology

3.1 Data Cleaning

Data of sea voyages transporting livestock between March 1988 and November 2017 were obtained from the SMDB database (Appendix 1).

The analysis focussed on long-haul voyages (defined as ≥10 days). Exclusion criteria were

- short-haul voyages (voyages that were fewer than ten days in duration),
- species other than cattle, sheep and goats, and
- voyages with Australian discharge ports.

As described by Norris et al. (2003), load regions[*] from Australia were classified as either:

1) Northern ports: ports located north of 20° latitude south: Port Hedland, Broome, Wyndham, Darwin, Karumba, Weipa, Mourilyan and Townsville.
2) Southern ports: ports located south of 31° latitude south: Fremantle, Bunbury, Esperance, Thevenard, Adelaide, Portland, Geelong, Devonport, Port Kembla, Sydney and Newcastle.
3) Other ports: located between 20° and 31° latitude south: Geraldton, Denham, Carnarvon, Dampier, Mackay, Gladstone and Brisbane.

Discharge ports were categorised into five different regions:

1) Middle East and North Africa (MENA: Bahrain, Egypt, Israel, Jordan, Kuwait, Libya, Oman, Pakistan, Qatar, Saudi Arabia, Sudan and United Arab Emirates)
2) Southeast Asia (SE Asia: Brunei, Indonesia, Malaysia, Philippines, Singapore and Vietnam)
3) Northeast Asia (NE Asia: China, Japan, Russian ports on the Pacific facing coast of Russia and South Korea)
4) South-eastern Europe (SE Europe: Turkey and Russian ports on the Black Sea)
5) Miscellaneous (Sri Lanka, Madagascar, Russian ports on the west coast (near Finland) and Mexico)

The recording of Turkey and the Black Sea in the new discharge region 'South-eastern Europe' was introduced in 2012.

A voyage is defined by a single pair of loading and discharge port. Split-load voyages were considered as separate voyages. To maintain confidentiality, individual ships are identified by codes.

3.2 Descriptive Statistics

Descriptive statistics were obtained using R v3.5.3 (R Core Team, 2019) and EpiTools (Sergeant, 2019). Data were reviewed for missing data and outliers. Voyages that did not meet inclusion criteria or were missing data and thus removed included

- 3 voyages, where destination was listed as 'Australia',
- 5 voyages, where animal class type was absent,
- 63 voyages, where discharge days was '0',
- 148 voyages, where voyage length was <10 days (based on the definition of long-haul voyage), and
- 2 voyages, where mortality data were absent.

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[*] Not all of these load ports or discharge ports were used by long haul voyages.

Voyages with high mortality rates (exceptional voyages) were included, to present an overall view of the industry spanning the last 30 years.

Variables described included:

- the number of animals loaded on livestock export voyages,
- origin port of voyage and origin port region (northern ports/ southern ports/ other ports),
- discharge port and discharge port region (Middle East and North Africa/ Southeast Asia, Northeast Asia, South-eastern Europe and Miscellaneous),
- year and month of voyage departure,
- vessel,
- species (cattle / sheep / goat),
- class and age group of animal
  - cattle: beef cow, beef heifer, bull adult, dairy cow, dairy heifer, steer adult, steer calf, cattle
  - sheep: Merino / Crossbreed / Awassi / Damara / Karakul / Other; lamb / hogget / adult
  - goats: agricultural buck large / agricultural doe large / agricultural doe small / agricultural wether large / feral buck large / feral buck small / feral wether small / goats,
- voyage duration,
- number of load and discharge days, and
- voyage mortality rate (VMR), a percentage calculated with a numerator as total number of animals that died on the voyage and a denominator of total animals loaded on that voyage.

Numeric variables were described using means, medians and ranges, and variables were cross-tabulated and plotted to explore potential interrelationships. Mean and median mortality rates were calculated across voyages.

3.3 Exploratory Mortality Analysis

The ‘mortality rate’ value, though commonly used in the livestock export industry, may not accurately represent mortality risk across voyages of different lengths. For example, where daily mortalities are similar, shorter voyages will have fewer mortalities than longer voyages, and therefore a lower ‘mortality rate’. This may result in bias when assessing variables that predict higher mortality in livestock export. To avoid this bias, the daily mortality rate (DMR) was calculated, as the number of mortalities per day divided by the number of alive sheep on each day. This was modelled as a binomial generalised additive mixed effects model (GAMM). Generalised additive models (GAM) extend generalised linear models by replacing linear regression terms with smoothed non-linear terms. GAMMs extend the GAM framework by allowing for random effect terms in addition to smoothed non-linear terms (Wood, 2006).

Data were extracted from the Shipboard Mortality Database as panel data (a format where each record represented aggregated results of mortality amongst a particular class of animal on one day of a particular voyage). Variables extracted included: a voyage identification number; the start date of the voyage; the vessel name; the origin port of the voyage; the voyage discharge region (Middle East/North Africa, Southeast Asia, Northeast Asia, or Miscellaneous; Southeast Europe was aggregated with Miscellaneous due to the low number of voyages); the day of the voyage that the record related to (day 1, day 2, etc.); the class of animal that the record related to (for example, Merino ram lambs, crossbreed ewe adults, dairy heifers, adult steers); the number of animals of that class loaded per deck at the start of the voyage; and the number of mortalities of animals of that class on that deck on that day of the voyage.

Variables created from these data included:

- a unique identifier for data relating to a particular class of animal on a particular voyage;
- cumulative mortality across days of a voyage, relating to the particular voyage and class of animal;
- the number of animals of that class on that voyage alive at the start of each day;
- the days since departure (excluding loading and discharging days);
- the 'agricultural', 'feral', 'other' and 'unspecified' classes of sheep were grouped into a category named 'other';
- the start date of the voyage was used to group data into time categories:
    - for sheep, data were grouped into: 1996 and prior; 1997 – 2003 (pre-Keniry report); 2004 – 2011 (post Keniry report); and 2012 to 2017,
    - for cattle, data were grouped into: 1995 – 2001 (pre-HotStuff model); 2002 – 2011 (post-HotStuff model); and 2012 to 2017;
- the start date of the voyage was used to identify possible seasonal effects related to day length, by assigning the start date a 'day of year' variable.
- for later modelling of the data, the origin region of the voyage was used to create a variable of departure from southern Australia (all ports south of Geraldton) or northern Australia (Geraldton and all ports north of Geraldton); and
- the 67 destination ports were regrouped into 14 destination regions chosen in an ad hoc fashion to simplify the modelling (Table 27). In particular, MENA was divided into Persian Gulf and Red Sea destination regions, allowing for a viable comparison between regions given the number of voyages to other destination regions was small.

3.3.1 Mapping

To appropriately understand when and where mortality occurred on different voyages, and to generalise risk factors across all voyages, the daily shipboard mortality data were assigned geospatial coordinates. Assigning spatial coordinates required shipping routes for each voyage to be interpolated to daily locations. The shipping routes were approximated through an in-house algorithm that generated 'likely' shipping routes, by identifying a minimum set of graph edges linking ports with other ports while taking into account a buffered distance from known land masses. Each shipping route for each voyage was then segmented into equal lengths, with the number of segments equal to the trip length of the voyage in days, given no other daily positional data were available. The point of intersection between segments provided the daily longitude and latitude coordinates of the coordinates. These spatial coordinates are therefore coarse approximations, in lieu of more precise shipboard global navigation satellite system (GNSS) records acquired through services such as MarineTraffic (www.marinetraffic.com).

Sea surface temperatures and distance to nearest land mass were then assigned to each daily mortality observation. Daily sea surface temperatures were sourced from the National Oceanic and Atmospheric Administration's National Centers for Environmental Information repository of global environmental data (National Centers for Environmental Information, 2019). The sea surface temperature data were captured by the AVHRR sensor and provided as 0.25° resolution global daily imagery (longitude and latitude coordinates; equating to ~27-28 km pixels at the equator). These data were available from 1st September 1981, providing complete temporal and spatial coverage of the shipboard mortality data. It was hypothesised that higher sea surface temperatures have been correlated with higher shipboard mortality rates.

The distance to nearest land mass predictor required a mask of the sea surface temperature imagery to be created. The rationale for including the distance to nearest land mass as a predictor variable was to account for any localised albedic impact on air temperature, over and above sea surface temperature.

These albedic effects may potentially be observed in the Persian Gulf and Red Sea ports, where significant land mass surrounds the water body in a region characterised by hot desert temperatures.

A global map of where mortality is geographically higher was also produced. This map averages the mortality rate for all data observations within each map grid cell sourced from the daily sea surface temperature maps. This global map was smoothed through kernel density estimation (Bowman and Azzalini, 1997), so as to avoid in part the small area estimation problem that is common to disease mapping (Moraga, 2018). However, such smoothing should ideally possess soap film properties (Wood et al., 2008), due to the presence of coastline barriers such as the Indonesian archipelago. However, soap film operators are generally computationally prohibitive to implement where there are many data and complex geographies.

3.3.2 Modelling

Daily mortality data were treated as a binomial variable, defined by the daily total deaths on a voyage and the number of animals alive at the start of the day set as the number of binomial trials. To account in part for correlations among daily observations within each voyage and for each vessel, the voyage identifier was nested within the vessel identifier as random effects. Results for the linear fixed effects (class and origin port) were reported as exponentiated coefficients (i.e. odds ratios), with 95% confidence intervals. Smoothed non-linear (fixed) terms were reported as marginal predictions.

The number of knots allowed for each non-linear term was fixed at five, to reduce computation and to provide interpretable marginal predictions. The 'day of year' variable was fitted as a cubic cyclic spline, whereas the other terms were fitted through thin plate regression splines (Wood, 2006). Pairwise interactions between regression terms were not considered as smooth non-linear terms pairwise interactions were both computationally impractical given the large data set and difficult to interpret. The only interaction permitted was between destination region and the non-linear term for day-since-departure, as it was hypothesised that these different destination regions may have different length of voyage mortality responses, given voyages reaching each destination region spent differing amounts of time in the tropics. Competing models arrived at through further exploration of the model space may be considered under a model averaging framework (for example, Burnham and Anderson, 2002). However, the model specification presented here is sufficient for investigating the possible explanatory power of a GAMMs modelling approach. As it stands, all variables and functional expressions included in the model were statistically significant when model terms are dropped one-at-a-time and a likelihood ratio test applied ($\alpha = 0.05$ significance level). The model formula applied may be specified as:

$$\begin{aligned}(total\ deaths, number\ of\ animals) \sim & f_1(day\ since\ departure | destination\ region) \\ & + f_2(sea\ surface\ temperature) + f_3(day\ of\ year) + f_4(distance\ to\ land) + class \\ & + departure\ port + \varepsilon_{vessel} + \varepsilon_{voyage|vessel} + \varepsilon_{residual}\end{aligned}$$

where ε_* is a random effect term, $f(*)$ is smoothed non-linear function, and $f(* \mid *)$ refers to a conditional interaction (e.g. the functional response to day since departure given a destination region). Note, the nested random effect is also conditional $\varepsilon_{voyage|vessel}$ and specifies voyage specific effects over and above vessel specific effects.

The covariates in the above model were highly correlated (i.e. multicollinearity was present). Multicollinearity has an impact on trying to understand the individual components of the model, as having multiple variables that can represent the same causal phenomenon leads to increased uncertainty in the coefficient estimates (i.e. model parameters have lower identifiability), reducing the statistical power of the analysis. This also means that model estimates can be highly sensitive to small changes in the model or data. However, for predicting daily risk the issue is not as pronounced. To illustrate this point the marginal predictions of the cattle and sheep models of shipboard mortality were produced along two axes: day of year and sea surface temperature. These marginal predictions were constructed by generating model predictions for each data point (i.e. they are standardised marginal predictions; Muller and MacLehose, 2014). For visual purposes, these predictions were then smoothed by applying kernel smoothing regression, with mortality rate regressed on latitude and sea surface temperature (Bowman and Azzalini, 1997). Without the smoothing the marginal predictions would be relatively noisy, given the predictions were applied to the data which can vary quite widely, and for which there are multiple terms in the model. Overlain on the 2D plot of these predictions is a kernel regression of day of voyage on day of year and sea surface temperature, as represented by contours. This gives an approximate idea of the average number of days into the voyage of where elevated mortality may occur.

Survival analysis may also be considered for these data as the probability of an animal surviving for more than a specified period of time at sea. Survival analysis accounts both for the lack of independence among observations taken over time for the same subject, and for right censoring of the data (i.e. the mortality of animals remaining alive at the end of a voyage is not observed). Survival analysis, however, applies only to individual level data. For the current application survival analysis is computationally impractical to implement, given the number of animals (more than 804 million sheep and 24.8 million cattle). Age-Period-Cohort (APC) models may be seen as a generalisation of survival analysis to large data sets (Yang and Land, 2013; Keyes and Li, 2012). However, these models are essentially generalised linear models with constraints imposed due to collinearity among the APC factors. Given the large numbers of animals, a binomial generalised additive model suffices.

4 Results

4.1 Sheep, Cattle and Goat Voyages

This section summarises livestock export voyages from November 1988 to November 2017, exporting cattle, sheep and goats, on voyages of ≥10 days.

4.1.1 Overview

There were 2,240 long-haul voyages (≥10 days) carrying cattle, sheep and/or goats recorded in the SMDB from November 1988 to November 2017. These voyages went to five different regions globally. Sheep live export records were from November 1988 to November 2017; goat records were from November 1988 to December 2007; and cattle records were from June 1995 to November 2017 (Fig. 1).

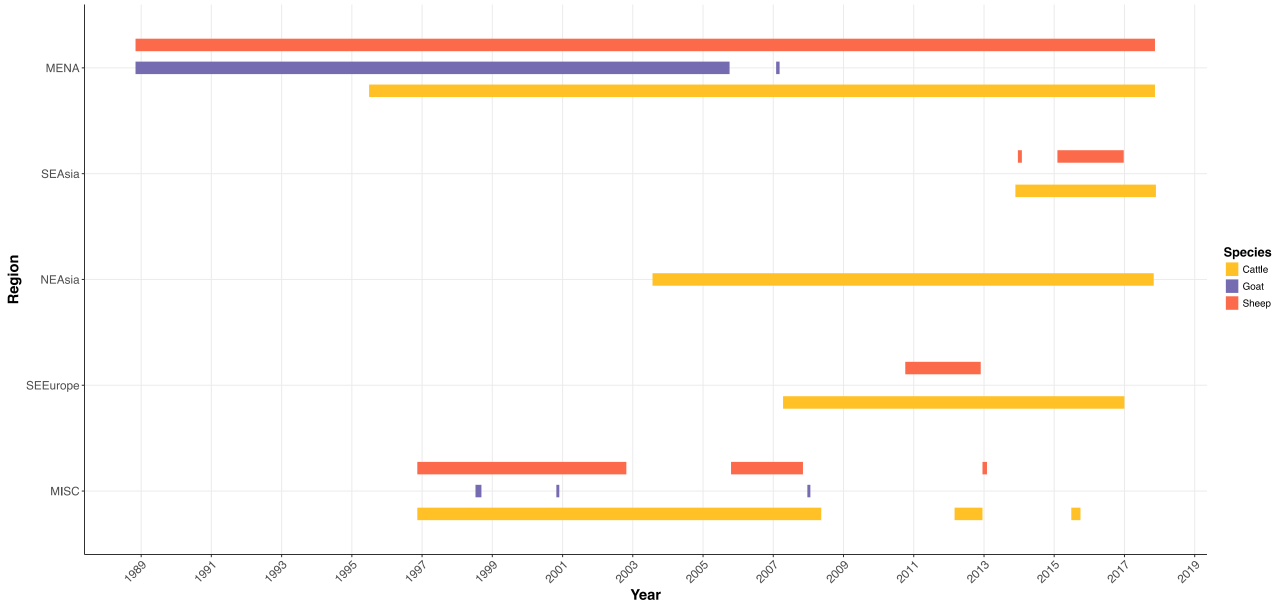

Fig. 1: Time periods across which livestock export from Australia occurred (November 1988 – November 2017), by species and discharge region (MENA: Middle East/North Africa, SEAsia: Southeast Asia, NEAsia: Northeast Asia, SEEurope: South-eastern Europe, MISC: Miscellaneous.

By discharge region, the largest number of voyages exporting livestock were to the Middle East/North Africa region (Fig. 2). As this analysis included only long-haul voyages, there are relatively few records of voyages to closer regions, such as Southeast Asia.

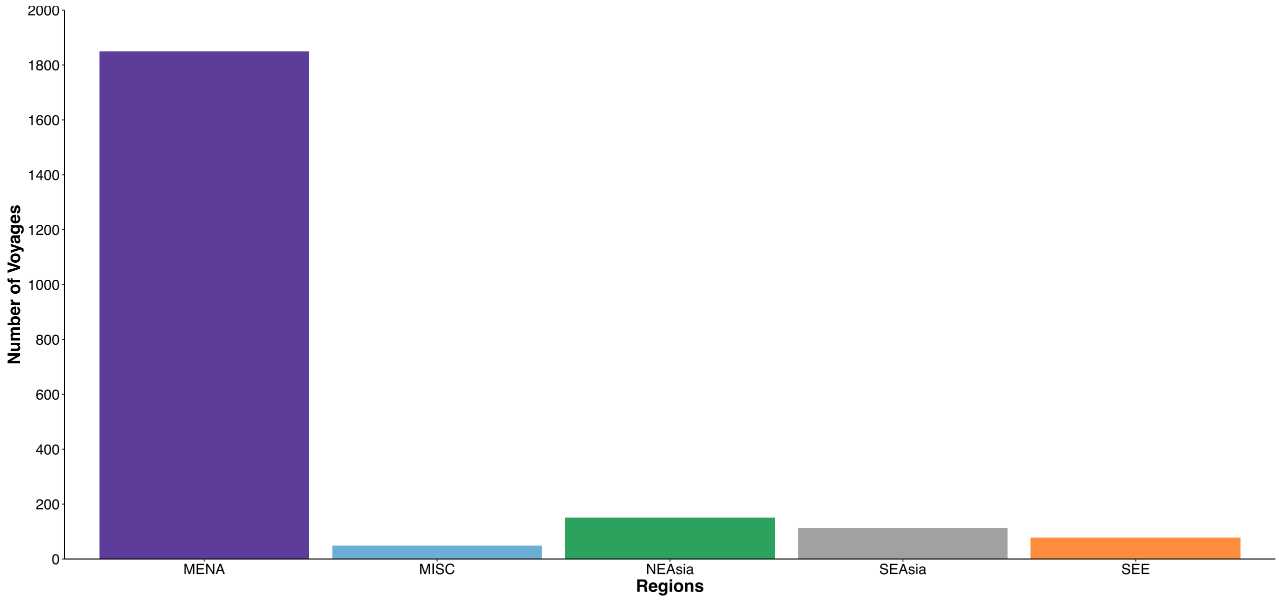

Fig. 2: Number of livestock export voyages that transported cattle, sheep and/or goats from Australia on long-haul voyages (November 1988 – November 2017), by discharge region.
MENA: Middle East/North Africa, MISC: Miscellaneous, NEAsia: Northeast Asia, SEAsia: Southeast Asia, SEEurope: South-eastern Europe.

Sheep were the most common type of animal exported: 100,126,920 sheep were exported across 1,810 voyages, to all regions except Northeast Asia. Cattle were exported to all five regions, with 3,098,252 cattle exported across 1,136 voyages. Relatively few exports of goats occurred — 179,277 head across 150 voyages, to two regions (Middle East/North Africa and Miscellaneous).

The annual number of long-haul voyages peaked in the 1998 – 2002 time period (Fig. 3), and more specifically in 2001 and 2002 (107 and 150 voyages, respectively). Long-haul voyage data suggest that demand for different animal classes varies by region (Sections 4.2, 4.3 and 4.4). The majority of long-haul voyages exported animals to the Middle East/North Africa market (Fig. 3). In recent years, the number of long-haul voyages to the Southeast Asia market has increased (Fig. 3).

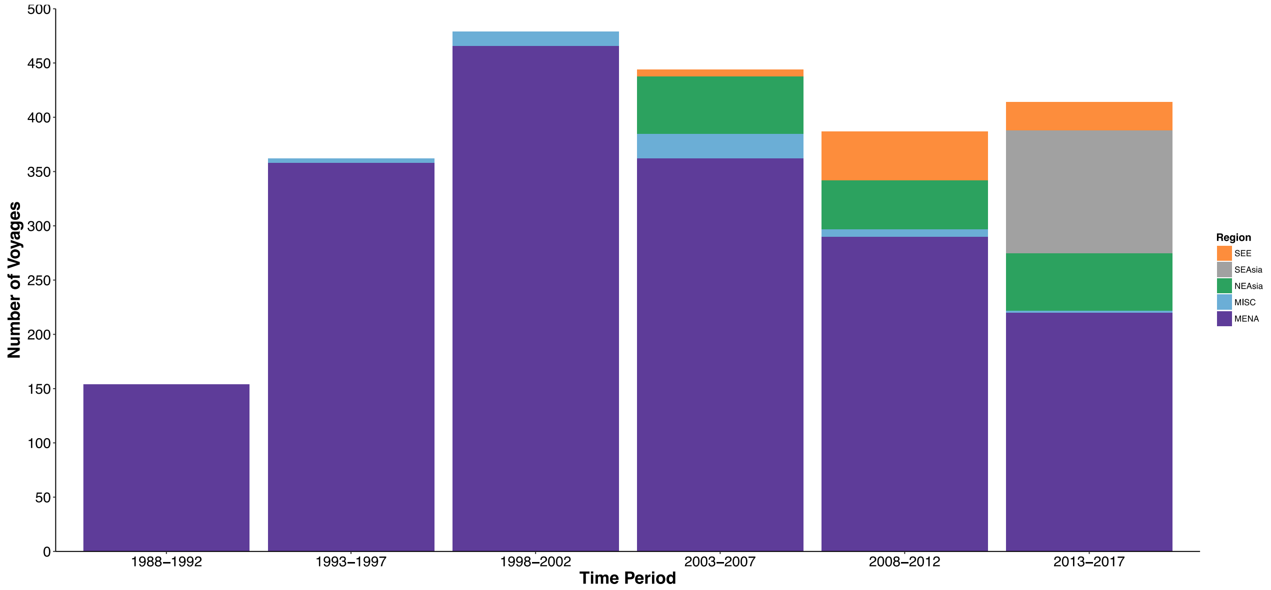

Fig. 3: Number of livestock export voyages that transported cattle, sheep and/or goats from Australia (November 1988 – November 2017), by time period and discharge region
(SEE: South-eastern Europe, SEAsia: Southeast Asia, NEAsia: Northeast Asia, MISC: miscellaneous discharge locations, MENA: Middle East/North Africa).

The Middle East/North Africa market has consistently received sheep exports since 1988 and cattle exports since 1995 (Fig. 1). Considering long-haul voyages, the Southeast Asia market has developed in more recent years, with the first recorded long-haul export in 2013 (Fig. 1). The reduced presence of voyages to Southeast Asia in these data is due to the selection of voyages of ≥10 days duration (an additional 144 voyages of <10 days duration to Southeast Asia, from 2005 on, are present in the SMDB database). Fig. 1 highlights some differences in species demand across regions — for example, Northeast Asia has only imported cattle.

Mortalities were recorded across all three animal classes on long-haul voyages.

- Sheep mortality across voyages was 1.3% of sheep exported (1,334,611 deaths from 100,126,920 loaded).
- Cattle mortality across voyages was 0.4% (11,861 deaths from 3,097,669 loaded).
- Goat mortality across voyages was 2.2% (3,932 deaths from 179,277 loaded).

4.1.2 Origin Ports

Between 1988 and 2017, 13 Australian ports were utilised for long-haul livestock exports (Fig. 4). The most frequently used ports for long-haul voyages were Fremantle, Portland and Adelaide (Table 1).

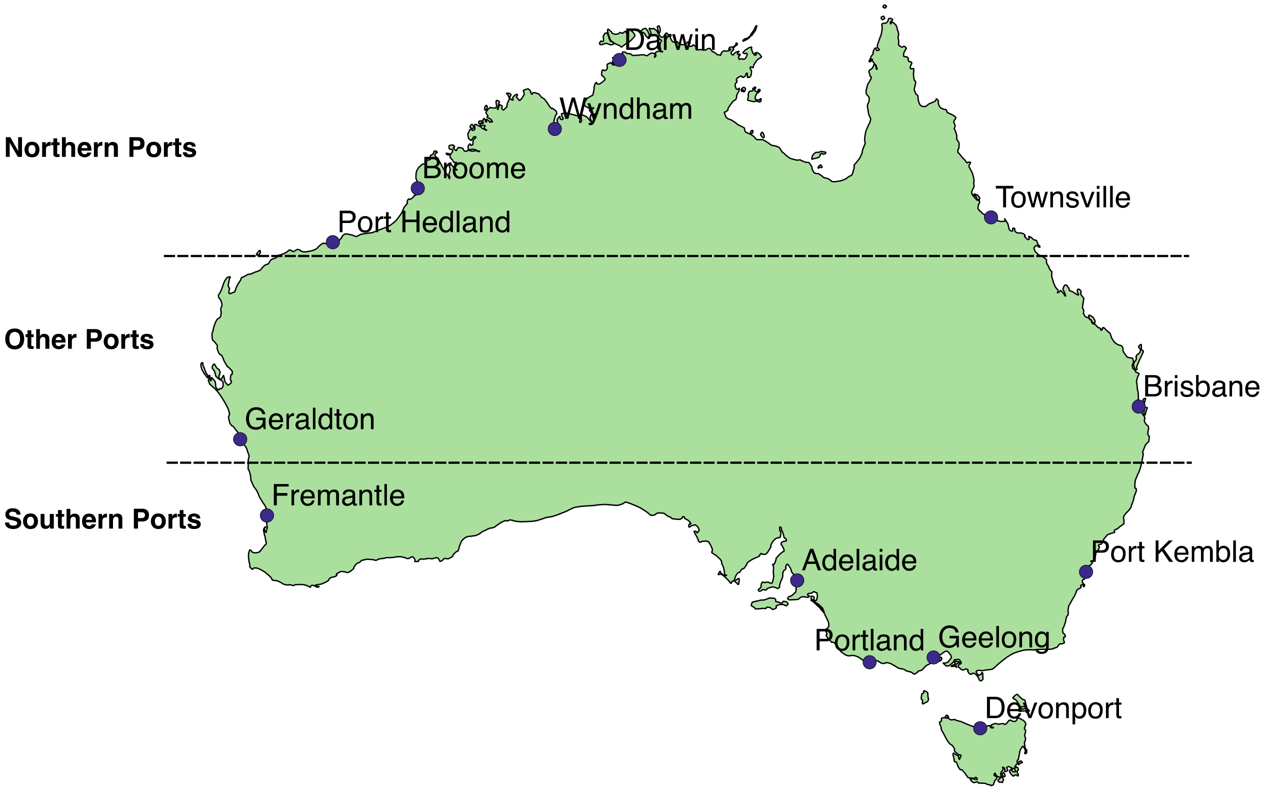

Fig. 4: Origin ports used for long-haul livestock exports from Australia between November 1988 and November 2017, grouped by origin port regions.
'Northern ports' are defined as ports located north of 20° latitude south; 'southern ports' are defined as ports location south of 31° latitude south; 'other ports' are defined as ports located between 20° and 31° latitude south.

Table 1: Summary figures for voyages recorded in the SMDB transporting livestock (sheep, cattle and goats) from Australia, November 1988 – November 2017. Discharge regions: MENA (Middle East/North Africa), SEA (Southeast Asia), NEA (Northeast Asia), SEE (South-eastern Europe) and MISC (Miscellaneous).

Origin port region	**Origin port**	**No. voyages (%)**	**Mean loading days (range)**	**Mean voyage days (range)**	**Mean discharge days (range)**	**No. voyages (%), by discharge region:**					**No. animals (%), by species**		
						MENA	**SEA**	**NEA**	**SEE**	**MISC**	**Sheep**	**Cattle**	**Goats**
Southern	Adelaide	219 (10%)	1.22 (1–3)	20.5 (12–33)	5.32 (1–22)	200 (91%)	2 (1%)	1 (<1%)	15 (7%)	1 (<1%)	9,856,924 (96%)	317,257 (3%)	40,250 (<1%)
	Devonport	11 (<1%)	1.18 (1–2)	18.8 (16–23)	6.36 (2–10)	11 (100%)	0	0	0	0	558,300 (99%)	6,924 (1%)	0
	Fremantle	1465 (65%)	1.34 (1–10)	15.0 (10–40)	5.27 (1–71^{A})	1 336 (91%)	38 (3%)	32 (2%)	40 (3%)	19 (1%)	73,145,127 (98%)	1,697,088 (2%)	83,563 (<1%)
	Geelong	13 (<1%)	1.00 (1–1)	17.6 (14–21)	1.08 (1–2)	0	0	13 (100%)	0	0	0	38,067 (100%)	0
	Port Kembla	1 (<1%)	1.00	21.0	2.00	0	0	0	0	1 (100%)	0	0	2,124 (100%)
	Portland	414 (19%)	1.20 (1–6)	18.1 (12–41)	5.38 (1–20)	269 (65%)	1 (<1%)	95 (23%)	22 (5%)	27 (7%)	16,334,524 (96%)	612,605 (4%)	51,487 (<1%)
Northern	Broome	19 (<1%)	1.37 (1–5)	16.2 (10–26)	2.63 (1–7)	10 (53%)	9 (47%)	0	0	0	0	80,800 (100%)	0
	Darwin	15 (<1%)	1.00 (1–1)	13.9 (10–24)	2.53 (1–5)	4 (33%)	8 (67%)	0	0	0	65,462 (59%)	43,780 (39%)	1,963 (2%)
	Port Hedland	13 (<1%)	1.23 (1–2)	20.0 (16–26)	3.69 (1–8)	12 (92%)	0	0	0	1 (8%)	86,480 (48%)	94,298 (52%)	12 (<1%)
	Townsville	56 (2.5)	1.20 (1–3)	12.7 (10–23)	2.50 (1–6)	5 (9%)	51 (91%)	0	0	0	0	182,133 (100%)	0
	Wyndham	3 (<1%)	1.33 (1–2)	20.3 (14–24)	3.67 (1–6)	2 (67%	1 (33%)	0	0	0	102,534 (91%)	9,499 (9%)	0
Other	Brisbane	10 (<1%)	1.00 (1–1)	16.4 (15–18)	1.30 (1–3)	0	0	10 (100%)	0	0	0	12,867 (100%)	0
	Geraldton	1 (<1%)	1.00	17.0	2.00	1 (100%)	0	0	0	0	1,412 (33%)	2,934 (67%)	0

^{A} Exceptional voyage— this was independently investigated.

As expected, voyage duration varied with origin and discharge ports. Vessels departing from Port Kembla recorded the longest mean voyage duration (21.0 days). The longest voyage durations recorded (excluding load and discharge days) were 41 days from Portland to Novorossiysk port (Russia) and 40 days from Fremantle to Adabiya port (Egypt). The average number of voyage days for voyages originating from southern ports was 16.2 (range 10–41) days, while the average for voyages originating from northern ports was 14.6 (range 10–26) days.

Total voyage duration (load days + voyage days + discharge days) reached a maximum of 87 days for a voyage carrying sheep from Fremantle to Jeddah in August 2003. This was recorded on the database as a 15-day voyage, with one day for loading and 71 days for discharge. It was considered an exceptional voyage and was independently investigated.

Mean loading days were similar across Australian ports (Table 1), with a mean across ports of 1.29 days. The highest recorded loading time was a voyage departing from Fremantle (10 days) — this was an exceptional voyage, which was investigated independently.

Discharge days ranged from one to 71 days, with a mean across voyages of 5.13 days. Vessels that departed from Devonport recorded the highest average number of discharge days (6.36 days) (Table 1).

4.1.3 Discharge Ports

From 1988 to 2017, 74 discharge ports across 28 countries were utilised for delivery of livestock from Australia (Table 2). The Middle East/North Africa region had the highest number of discharge ports, and received the largest number of animals from long-haul voyages: 98,603,708 sheep (98.5% of total sheep exports), 2,330,260 cattle (75.2% of total cattle exports) and 177,024 goats (98.7% of total goat exports) were transported to this region between 1988 and 2017. Oman received the highest number of sheep, Egypt received the highest number of cattle, and Saudi Arabia received the highest number of goats (Table 2).

The mean long-haul voyage duration from Australia was 16.1 days (not including loading and discharge days). Mean voyage length to South-eastern Europe was longest (25.5 days), followed by Miscellaneous (21.6 days), Northeast Asia (17.6 days), Middle East/North Africa (15.7 days) and Southeast Asia (13.0 days).

The most frequently utilised discharge ports were in Middle East/North Africa, and the top 5 were:

1. Mina Qaboos (Muscat) in Oman (592 voyages)
2. Kuwait (179 voyages)
3. Jeddah in Saudi Arabia (155 voyages)
4. Bahrain (153 voyages)
5. Aqaba in Jordan (151 voyages)

Table 2: Number of sheep, cattle and goats exported by sea from Australia, November 1988 – November 2017, by discharge region and country.
MENA: Middle East/North Africa, SEAsia: Southeast Asia, NEAsia: Northeast Asia, SEEurope: South-eastern Europe, MISC: Miscellaneous.

Discharge region	No. ports	No. countries	Country	No. sheep (%)	No. cattle (%)	No. goats (%)
MENA	26	13	Algeria	81,930 (<1%)	0	0
			Bahrain	8,703,656 (9%)	18,769 (1%)	162 (<1%)
			Egypt	3,790,084 (4%)	759,299 (25%)	15,839 (9%)
			Israel	3,104,524 (3%)	573,064 (18%)	0
			Jordan	8,564,651 (9%)	360,368 (12%)	13,350 (7%)
			Kuwait	8,420,705 (8%)	4,983 (<1%)	9,099 (5%)
			Lebanon	272,982 (<1%)	0	0
			Libya	389,660 (<1%)	156,738 (5%)	5 (<1%)
			Oman	40,103,878 (40%)	52,150 (2%)	29,839 (17%)
			Qatar	4,846,647 (5%)	12,385 (<1%)	0
			Saudi Arabia	11,421,950 (11%)	224,725 (7%)	83,140 (46%)
			UAE	8,292,821 (8%)	12,982 (<1%)	25,468 (14%)
			Yemen	586,377 (<1%)	0	0
SEAsia	13	5	Brunei Darussalam	0	9,410 (<1%)	0
			Indonesia	0	15,081 (<1%)	0
			Malaysia	7,194 (<1%)	8,331 (<1%)	0
			Philippines	0	2,431 (<1%)	0
			Vietnam	0	120,805 (4%)	0
NEAsia	23	4	Japan	0	12,867 (<1%)	0
			Pakistan	0	7,061 (<1%)	0
			China	0	270,847 (9%)	0
			Russia (Vanino)	0	7,156 (<1%)	0
SEEurope	7	2	Turkey	752,891 (1%)	180,252 (6%)	0
			Russia (Novorossiysk)	0	154,214 (5%)	0
MISC	5	4	Madagascar	0	0	2,124 (1%)
			Mexico	727,946 (1%)	128,293 (4%)	251 (<1%)
			Sri Lanka	59,024 (<1%)	2,003 (<1%)	0
			Russia (Ust Luga)	0	3,455 (<1%)	0
TOTAL	74	28	–	100,126,920	3,097,669	179,277

The most frequently utilised discharge port for each of the other regions were

- Southeast Asia: Cua Lo in Vietnam (22 voyages)
- Northeast Asia: Tianjin in China (44 voyages)

- South-eastern Europe: Novorossiysk in Russia (32 voyages)
- Miscellaneous: Manzanillo in Mexico (42 voyages)

4.1.4 Vessels

Fifty-four vessels were involved in long-haul transportation of livestock between 1988 and 2017. Forty-seven vessels transported animals to the Middle East/North Africa region. Of these, 44.7% (21/47) went to Middle East/North Africa alone; they did not transport animals to other regions. Thirteen vessels transported livestock to Southeast Asia, 24 vessels transported livestock to Northeast Asia, nine vessels transported livestock to South-eastern Europe and 13 vessels transported livestock to Miscellaneous.

Fig. 5 illustrates the time periods over which different vessels were active on long-haul voyages between 1988 and 2017. The livestock export market was dominated by vessels departing to Middle East/North Africa; other markets such as Southeast Asia, Northeast Asia and South-eastern Europe became more frequent routes in the most recent 10–15 years.

A large number of voyages carried two or more animal classes during export (70.2%; 1,572/2,240), including across species.

Forty-eight vessels involved in long-haul transportation of livestock from Australia were built prior to 2004; 6 vessels were built post 2004. The oldest ship present in the dataset was built in 1960. Improved design and ventilation features were implemented in ships built after 2004 to comply with the requirements of Marine Orders 43 (AMSA 2006).

As new regulations were introduced, or vessels experienced notable mortality events, vessels' names were often changed. In Fig. 5, some of these renaming events can be followed — for example, vessel code 30 underwent a refit and was renamed and subsequently recorded as vessel code 32.

Fig. 5 also highlights the decommissioning of old boats and the introduction of new boats. Ten vessels (code 1 and codes 45–54) can be seen to be active variably between 1988 and 1999, then decommissioned. The common characteristic of these vessels is that they were manufactured in the 1960s. The introduction of three new vessels since 2016 can be seen with vessel codes 55, 56 and 57. This relatively simple convention of reusing the vessel record causes difficulty in assessing vessel performance as two radically different vessels may be treated as the same. This would mask improvement associated with new vessel design and investment.

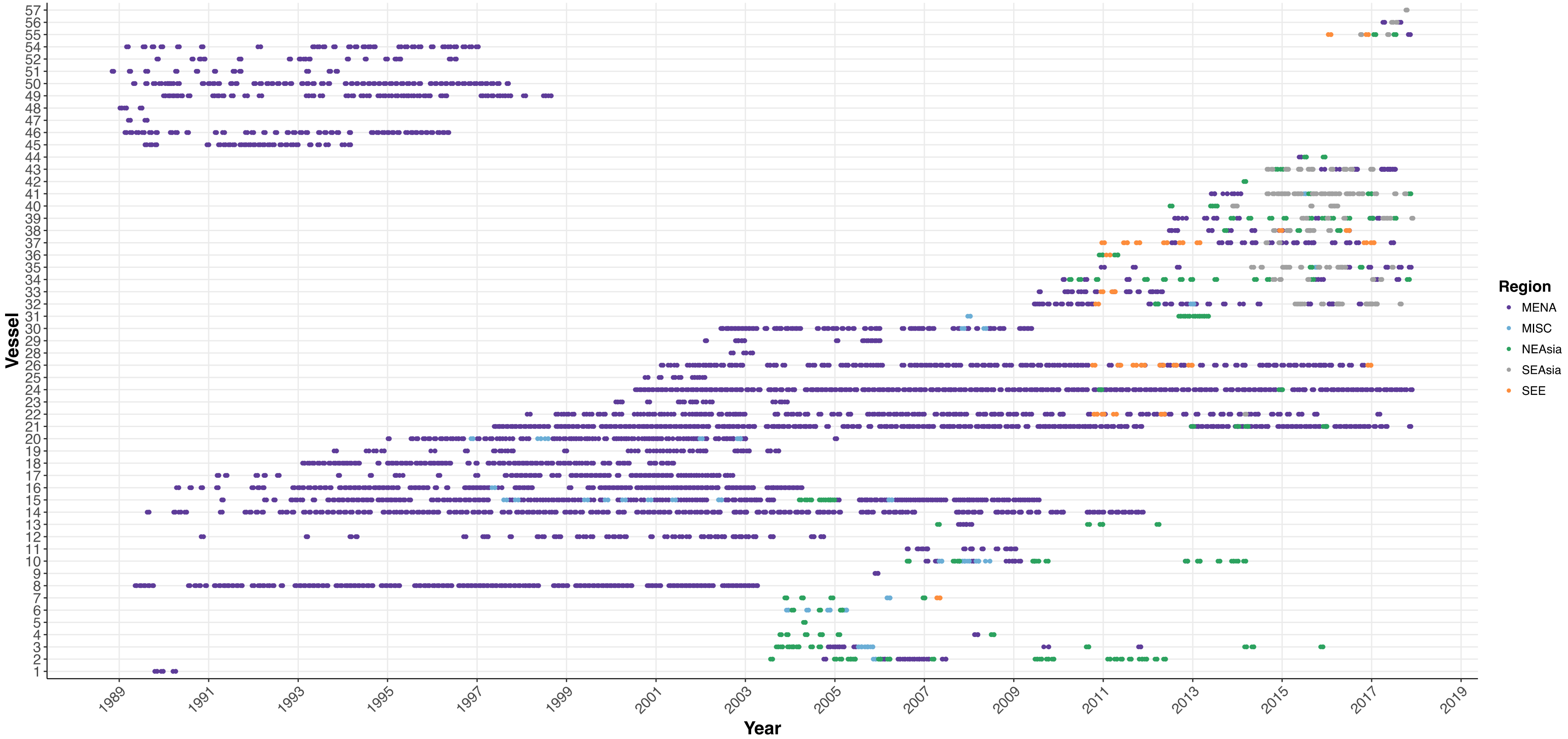

Fig. 5: Time periods of activity for individual vessels involved in livestock export from Australia, November 1988 – November 2017, by discharge region. MENA: Middle East/North Africa, MISC: Miscellaneous, NEAsia: Northeast Asia, SEAsia: Southeast Asia, SEE: South-eastern Europe.

4.1.5 Time of Year

Of voyages to the Middle East/North Africa, 98.2% (1,816/1,850) departed from southern ports. Of voyages departing from southern ports, 49.1% (892/1,816) departed Australia during the northern summer (May to October), a potential risk period for mortality events for livestock exports (Moore et al. 2015; Phillips 2016). The most common departure month for voyages to Middle East/North Africa was July (175 voyages) (Fig. 6).

There was a more variable pattern in the number of long-haul voyages departing to other livestock export discharge regions by month of departure (Fig. 6). December was the most common month of departure for voyages to Northeast Asia (Fig. 6).

It must be reemphasised that this report focussed on long-haul voyages (≥10 days duration): these patterns cannot be considered representative of livestock export voyages of shorter duration.

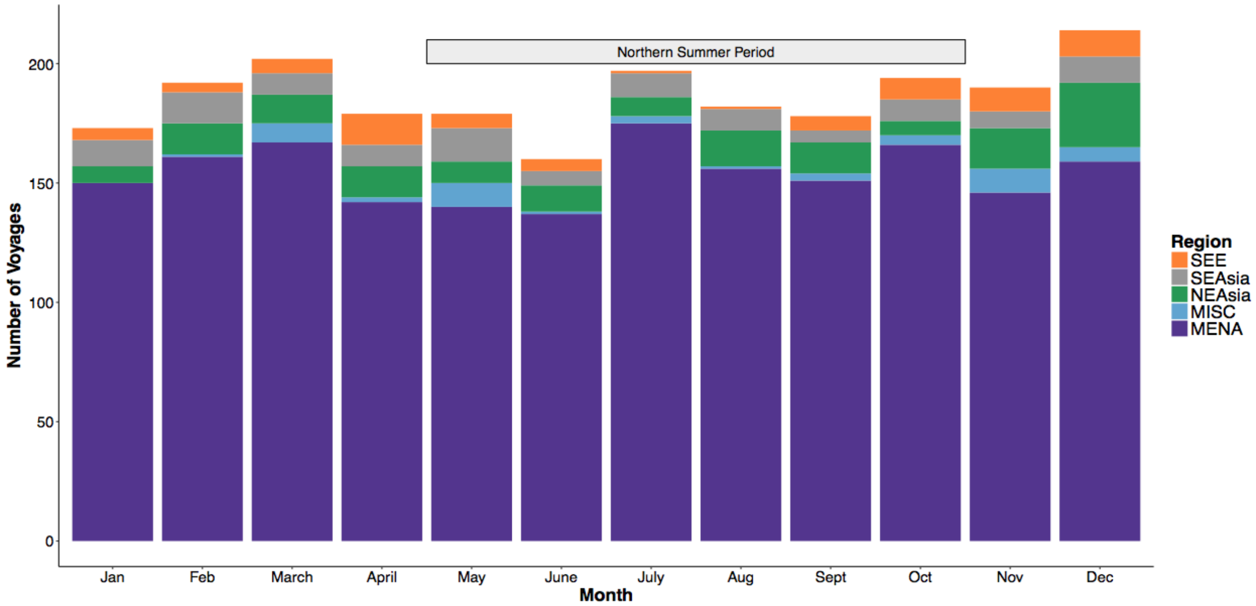

Fig. 6: Number of livestock export voyages transporting cattle, sheep and/or goats from Australia, November 1988 – November 2017, by month of departure and discharge region
SEE: South-eastern Europe; SEAsia: Southeast Asia; NEAsia: Northeast Asia; MISC: Miscellaneous; MENA: Middle East/North Africa. The northern summer period is indicated on the graph by the grey box (May to October, inclusive).

4.2 Sheep Voyages

4.2.1 Overview

Between November 1988 and November 2017, just over 100 million sheep were exported on long-haul voyages from Australia. The majority were to the Middle East/North Africa discharge region (98,579,865 head), followed by Miscellaneous (786,970 head), South-eastern Europe (752,891 head) and Southeast Asia (7,194 head). No sheep were exported to Northeast Asia.

The number of sheep exported overseas from Australia peaked in 2001, at 6,474,692 head (Fig. 7). This was followed by a steep decline between 2002 and 2004, in a longer-term largely downward trend in the number of sheep exported overseas from Australia (Fig. 7). A temporary live export ban in 2011 was an additional contributing factor.

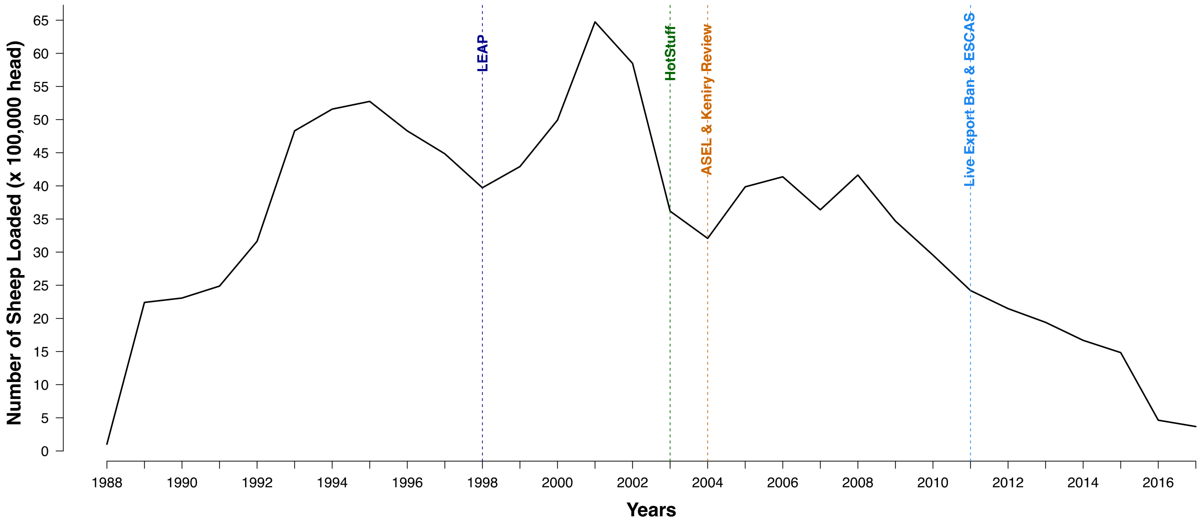

Fig. 7: Total number of sheep loaded for live export from Australia, November 1988 – November 2017, by year. The years of implementation of industry initiatives aimed at reducing mortality are included in the map as vertical lines (LEAP: Livestock Export Accreditation Program, HotStuff: Heat Stress Risk Assessment Model, ASEL: Australian Standards for the Export of Livestock and ESCAS: Exporter Supply Chain Assurance System), as is the 2011 live export ban.

All voyages transporting sheep recorded mortalities, except for two transporting sheep to Miscellaneous ports. The mean VMR for sheep across all voyages was 1.24% (range 0–13.2%) (Table 3).

Exceptional voyages, in terms of VMR, identified in the data set and that underwent independent investigation included:

1. Corriedale Express: from Portland to Fujairah (UAE) in 2002, with the highest sheep VMR (13.2%; 5,644 deaths recorded from 42,666 loaded).
2. Becrux: sheep loaded in Portland and Fremantle in June 2002 for discharge in Saudi Arabia, with 2.24% VMR (1,419 deaths from 63,434 loaded).

Table 3: Summary statistics for live sheep exports from Australia, November 1988– November 2017, by discharge region. MENA: Middle East/North Africa.

	Voyage discharge region:				
Sheep parameters	**MENA** [A]	**Southeast Asia**[B]	**South-eastern Europe**[C]	**Miscellaneous**[D]	**TOTAL**
No. voyages (%)	1,694 (97%)	3 (<1%)	20 (1%)	22 (1%)	1,739 (100%)
Total sheep loaded (%)	98,579,865 (98%)	7,194 (<1%)	752,891 (1%)	786,970 (1%)	100,126,920 (100%)
Mean VMR (%)	1.3	0.7	0.9	0.9	1.2
Median VMR (%)	1.0	0.7	0.9	0.6	1.0
VMR range (%)	0.1–13.2	0.4–1.1	0.3–1.4	0–6.7	0–13.2
Mean voyage duration (days)	15.4	14.3	25.6	23.4	15.6
Mean discharge (days)	6.0	1.0	5.3	3.5	5.9
Voyages with zero mortality	0	0	0	2	2

[A] Voyages occurred 1988–2017

[B] Voyages occurred 2013 and 2015

[C] Voyages occurred 2010–2012

[D] Voyages occurred 1996–2002, 2005–2007, 2012

The largest number of voyages exporting sheep from Australia occurred in 2002 (133 voyages). The largest number of sheep loaded for export occurred in 2001 (Table 4).

Amongst sheep exported to Middle East/North Africa, mean VMRs across voyages were highest in 1988 (3.08%) and 1993 (2.90%), with a subsequent downward trend (Fig. 8). During this time, new legislation and other mitigation strategies were introduced, including the Livestock Export Accreditation Program (LEAP) and the Heat Stress Risk Assessment Model (HotStuff) in 1998 and 2003, respectively.

Subsequent to 1988, a peak in mean VMR occurred in 1992 and 1993 (Fig. 8). In these years, 23 (52.3%) and 44 (63.8%) voyages had VMRs >2% (the reportable level for mortality in sheep), respectively. The highest VMR during this period was 7.61%, for a 12-day voyage from Fremantle to Mina Qaboos (Muscat) in November.

From 2012 to 2017 the lowest annual mean VMR was in 2015 (0.6%).

Table 4: Summary of VMRs, voyage days, loading days and discharge days across live export voyages of sheep from Australia, November 1988 – November 2017, by year.

Year	No. voyages (%)	No. sheep (%)	Mean VMR (%)	Median VMR (%)	VMR range (%)	Mean voyage days	Mean loading days	Mean discharge days	No. nil mortality voyages
1988	1 (<1%)	10,128 (<1%)	2.9	2.9	-	13.0	3.0	8.0	0
1989	34 (2%)	2,240,970 (2%)	1.7	1.4	0.7–7.6	14.9	1.0	6.1	0
1990	34 (2%)	2,307,697 (2%)	1.7	1.5	0.4–4.5	14.2	1.0	5.4	0
1991	41 (2%)	2,487,561 (2%)	1.2	1.1	0.2–3.2	13.9	1.0	6.6	0
1992	44 (3%)	3,164,389 (3%)	2.4	2.1	0.6–7.6	14.3	1.9	7.0	0
1993	69 (4%)	4,831,246 (5%)	2.4	2.3	0.9–5.8	14.0	1.9	7.1	0
1994	74 (4%)	5,158,456 (5%)	2.0	1.7	0.4–4.4	13.8	1.9	6.7	0
1995	75 (4%)	5,274,133 (5%)	1.9	1.6	0.3–6.6	14.5	1.9	6.2	0
1996	70 (4%)	4,830,129 (5%)	1.4	1.4	0.4–2.8	13.9	2.1	6.1	0
1997	72 (4%)	4,483,932 (5%)	1.2	1.0	0.2–4.3	14.9	1.7	5.5	0
1998	65 (4%)	3,971,452 (4%)	1.5	1.3	0.3–6.6	15.7	1.6	6.0	0
1999	71 (4%)	4,291,113 (4%)	1.3	1.3	0.5–3.2	15.7	1.3	5.6	0
2000	85 (5%)	4,993,024 (5%)	1.2	1.0	0.2–5.0	16.1	1.3	4.9	0
2001	106 (6%)	6,474,692 (6%)	1.2	1.0	0.1–4.2	17.1	1.0	4.5	0
2002	137 (8%)	5,848,163 (6%)	1.1	0.9	0.1–13.2	16.7	1.1	5.1	0
2003	86 (5%)	3,618,238 (4%)	1.1	0.9	0.2–9.8	15.7	1.0	6.5	0
2004	60 (3%)	3,207,510 (3%)	0.8	0.7	0.2–2.0	14.9	1.1	6.8	0
2005	64 (4%)	3,985,218 (4%)	0.9	0.9	0.0–2.0	14.7	1.2	5.8	2
2006	66 (4%)	4,137,584 (4%)	0.9	0.8	0.3–2.4	15.5	1.1	5.9	0
2007	66 (4%)	3,638,632 (4%)	1.0	0.7	0.3–6.7	15.5	1.1	6.2	0
2008	73 (4%)	4,163,612 (4%)	0.8	0.7	0.2–2.2	15.3	1.0	7.1	0
2009	64 (4%)	3,468,993 (3%)	0.9	0.8	0.3–2.2	15.9	1.0	5.6	0
2010	53 (3%)	2,955,392 (3%)	1.0	0.8	0.3–3.6	16.6	1.2	5.7	0
2011	55 (3%)	2,420,220 (2%)	0.8	0.7	0.2–2.4	18.4	1.0	6.5	0

Year	No. voyages (%)	No. sheep (%)	Mean VMR (%)	Median VMR (%)	VMR range (%)	Mean voyage days	Mean loading days	Mean discharge days	No. nil mortality voyages
2012	42 (2%)	2,148,171 (2%)	0.8	0.7	0.2–1.8	18.5	1.1	4.4	0
2013	38 (2%)	1,940,337 (2%)	0.7	0.5	0.2–7.3	15.8	1.2	6.1	0
2014	36 (2%)	1,668,728 (2%)	0.7	0.6	0.2–3.9	16.9	1.3	6.4	0
2015	34 (2%)	2,483,438 (2%)	0.6	0.6	0.1–1.7	16.6	1.3	5.8	0
2016	15 (1%)	464,628 (<1%)	0.6	0.5	0.2–1.5	16.0	1.4	6.7	0
2017	9 (%)	367,981 (<1%)	0.7	0.7	0.3–1.3	17.1	1.4	8.6	0
Total	1,739 (100%)	100,126,920 (100%)	1.2	1.0	0.0-13.2	15.6	1.3	5.9	2

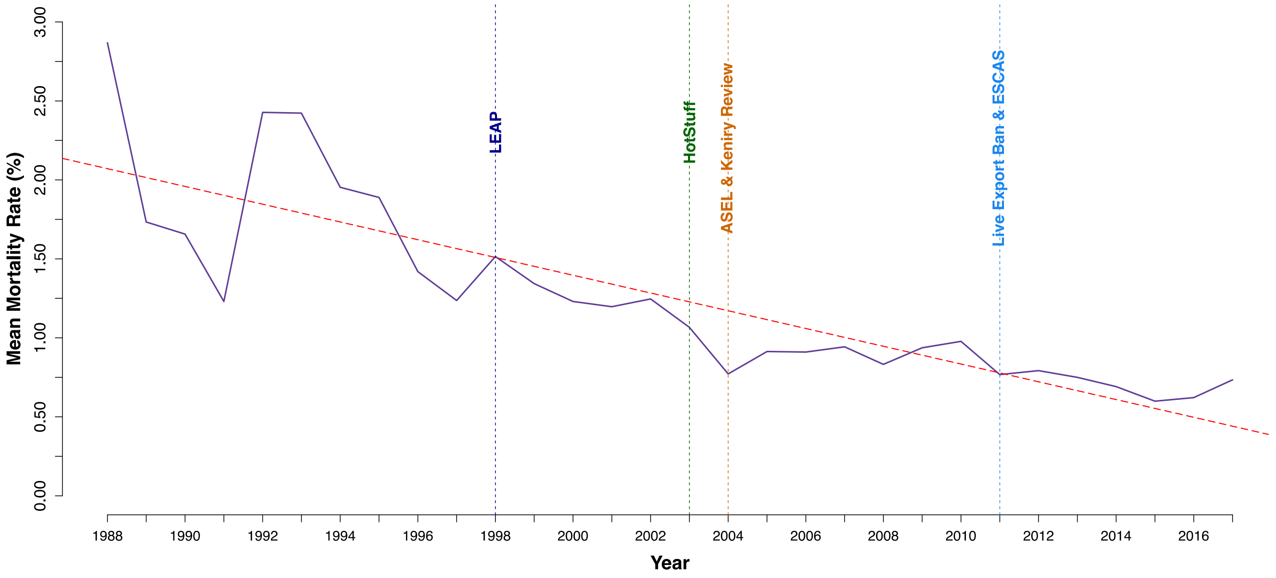

Fig. 8: Mean voyage mortality rate (%) for sheep exported from Australia on voyages to the Middle East/North Africa (MENA) discharge region, November 1988 – December 2017.
The years of implementation of key industry initiatives aimed at reducing mortality are included in the map as vertical lines (LEAP: Livestock Export Accreditation Program; HotStuff: Heat Stress Risk Assessment Model; ASEL: Australian Standards for the Export of Livestock; ESCAS: Exporter Supply Chain Assurance System), as is the 2011 live export ban.

4.2.2 Origin Ports

Eight Australian ports were used for live export of sheep on long-haul voyages between 1988 and 2017 (Table 5 and Table 6). Fremantle was used most frequently, with a total of 73,121,284 sheep loaded across 1,268 voyages, followed by Portland (16,334,524 head across 262 voyages) and Adelaide (9,856,924 head across 191 voyages) (Table 5).

Middle East/North Africa was the only region to receive sheep from all eight origin ports (Table 5). The majority of voyages to this region departed from southern ports (99.7%; 1,688/1,694), with 49.1% (829/1,688) departing during the northern summer period (May to October).

4.2.3 Discharge Ports

Sheep were exported to 17 countries, primarily within the Middle East/North Africa region. Oman and Saudi Arabia were the two most common countries of discharge (Table 7). Sheep were exported from Fremantle to the majority of countries of discharge (16 out of 17). Discharge ports in Algeria and Sri Lanka were the most infrequently used, only receiving one voyage each between 1988 and 2017.

The dominant market for live export sheep was the Middle East/North Africa region. More recently, there was an increase in the South-eastern Europe region market, with the number of voyages peaking in 2011 (10 voyages). Only three long-haul voyages exported sheep to Southeast Asia: all were from Fremantle to ports in Malaysia. The two Miscellaneous ports to which sheep were exported, were Manzanillo (Mexico) and Colombo (Sri Lanka).

Table 5: Number of voyages transporting sheep from Australia, by origin port, VMR mortality and discharge region. MENA: Middle East/North Africa, SEA: Southeast Asia, SEE: South-eastern Europe, MISC: Miscellaneous.

Origin port region	**Origin port**	**No. voyages by VMR percentage (%)**				**No. voyages by discharge region**			
		0%	**<1%**	**1.0 – 2.0%**	**>2%**	**MENA**	**SEA**	**SEE**	**MISC**
Southern	Adelaide	0	97	77	17	187	0	4	0
	Devonport	0	0	8	3	11	0	0	0
	Fremantle	1	644	432	191	1,238	3	13	14
	Portland	1	120	104	37	252	0	3	7
Northern	Darwin	0	1	0	0	1	0	0	0
	Port Hedland	0	2	1	0	2	0	0	1
	Wyndham	0	0	0	2	2	0	0	0
Other	Geraldton	0	1	0	0	1	0	0	0
TOTAL		2	865	622	250	1,694	3	20	22

Table 6: Summary statistics for live sheep exports from Australia between November 1988 and November 2017, grouped by origin port.

Origin port region	**Origin port**	**No. voyages**	**Mean loading days (range)**	**Mean voyage days (range)**	**Mean discharge days (range)**	**Mean VMR (range)**	**No. sheep loaded by discharge region:**				**Total loaded**
							MENA	**SEA**	**SEE**	**MISC**	
Southern	Adelaide	191	1.2 (1–3)	19.9 (12–30)	5.6 (1–22)	1.1 (0.1–7.3)	9,757,227	0	99,697	0	9,856,924
	Devonport	11	1.2 (1–2)	18.8 (16–23)	6.4 (2–10)	1.8 (1.1–2.8)	558,300	0	0	0	558,300
	Fremantle	1,268	1.3 (1–10)	14.5 (10–40)	5.7 (1–71)	1.2 (0.0–9.8)	72 ,006,209	7,194	621,232	486,649	73,121,284
	Portland	262	1.2 (1–3)	17.6 (12–31)	7.4 (2–20)	1.3 (0.0–13.2)	16,044,992	0	31,962	257,570	16,334,524
Northern	Darwin	1	1.0	24.0	5.0	1.0	65,462	0	0	0	65,462
	Port Hedland	3	1.7 (1–2)	21.3 (18–26)	5.3 (3–8)	1.0 (0.3–1.6)	43,729	0	0	42,751	86,480
	Wyndham	2	1.5 (1–2)	23.5 (23–24)	5.0 (4–6)	2.3 (2.1–2.5)	102,534	0	0	0	102,534
Other	Geraldton	1	1.0	17.0	2.0	0.4	1,412	0	0	0	1,412

Discharge regions: MENA (Middle East/North Africa), SEA (Southeast Asia), SEE (South-eastern Europe), MISC (Miscellaneous).

Table 7: Mean sheep VMR on live export voyages from Australia, November 1988 – November 2017, by discharge country; and number of sheep loaded for live export across Australian (origin) ports across the same time period, by discharge country.
Discharge regions: MENA (Middle East/North Africa), SEAsia: (Southeast Asia), SEE (South-eastern Europe), MISC (Miscellaneous).

Discharge region	**Discharge country**	**No. voyages**	**No. discharge ports**	**Mean VMR (%)**	**No. sheep loaded by origin port (%):**								**Total loaded**
					Fremantle	**Adelaide**	**Portland**	**Devonport**	**Geraldton**	**Port Hedland**	**Wyndham**	**Darwin**	
MENA	Algeria	1	1	3.0	81,930 (100%)	0	0	0	0	0	0	0	81,930
	Bahrain	151	1	1.2	5,489,624 (63%)	968,480 (11%)	2,245,552 (26%)	0	0	0	0	0	8,703,656
	Egypt	85	1	1.2	2,856,247 (75%)	505,589 (13%)	162,163 (4%)	54,360 (1%)	0	43,729 (1%)	102,534 (3%)	65,462 (2%)	3,790,084
	Israel	70	1	0.9	2,709,299 (87%)	352,727 (12%)	41,086 (1%)	0	1,412 (<1%)	0	0	0	3,104,524
	Jordon	144	1	1.2	7,057,997 (82%)	875,696 (10%)	578,735 (7%)	52,223 (1%)	0	0	0	0	8,564,651
	Kuwait	158	1	1.3	5,834,070 (69%)	583,336 (7%)	1,964,406 (24%)	38,893 (<1%)	0	0	0	0	8,420,705
	Lebanon	7	1	2.0	272,982 (100%)	0	0	0	0	0	0	0	272,982
	Libya	13	3	1.6	369,676 (95%)	9,922 (3%)	10,062 (3%)	0	0	0	0	0	389,660
	Oman	588	2	1.4	28,253,034 (70%)	2,517,337 (6%)	9,065,409 (23%)	268,098 (1%)	0	0	0	0	40,103,878
	Qatar	110	2	1.0	3,892,414 (81%)	571,212 (10%)	383,021 (9%)	0	0	0	0	0	4,846,647
	Saudi Arabia	198	2	0.8	8,950,304 (78%)	2,141,304 (6%)	256,925 (2%)	73,417 (1%)	0	0	0	0	11,421,950
	United Arab Emirates	159	5	1.6	5,652,255 (69%)	1,231,624 (15%)	1,337,633 (16%)	71,309 (<1%)	0	0	0	0	8,292,821
	Yemen	10	2	1.64	586,377 (100%)	0	0	0	0	0	0	0	586,377
SEAsia	Malaysia	3	2	0.7	7,194 (100%)	0	0	0	0	0	0	0	7,194

Discharge region	Discharge country	No. voyages	No. discharge ports	Mean VMR (%)	No. sheep loaded by origin port (%): Fremantle	Adelaide	Portland	Devonport	Geraldton	Port Hedland	Wyndham	Darwin	Total loaded
SEE	Turkey	20	5	0.9	621,232 (83%)	99,697 (13%)	31,962 (4%)	0	0	0	0	0	752,891
MISC	Sri Lanka	1	1	0.3	0	0	59,024 (100%)	0	0	0	0	0	59,024
	Mexico	21	1	1.0	486,649 (67%)	0	198,546 (27%)	0	0	42,751 (6%)	0	0	727,946

4.2.4 Vessels

Thirty-nine vessels exported sheep between November 1988 and November 2017. The most frequently used vessel was ID 21 (Table 8). The majority of vessels only travelled to one discharge region; seven vessels undertook voyages to two or more discharge regions.

Out of 1,739 voyages, 867 voyages had mean mortality rates <1%, 622 voyages reported mortality rates between 1 and 2% and 250 voyages recorded mortality rates >2% (the reportable level of mortality for live export sheep. The vessel with the highest mean mortality rate was vessel code 10 (3.58%); this vessel only recorded 2 voyages in 2007 from Fremantle to Manzanillo (Table 8). The vessel with the second highest mean mortality rate was vessel code 46, which made 40 voyages to the Middle East/North Africa region.

Table 8: Number of voyages for each vessel involved in live export of sheep from Australia November 1988 – November 2017, by discharge region; mean mortality rates across voyages for each vessel; and no. voyages by mortality rate (MR) for each vessel. Discharge regions are Middle East/North Africa (MENA), Southeast Asia (SEA), South-eastern Europe (SEE) and miscellaneous category (MISC).

Vessel code	**No. voyages, by discharge region:**				**Mean VMR (%)**	**No. voyages (%), by VMR:**		
	MENA	**SEA**	**SEE**	**MISC**		**<1%**	**1.0 – 2.0%**	**>2%**
14	160	0	0	0	1.3	76 (48%)	57 (36%)	27 (17%)
21	185	0	0	0	1.1	104 (56%)	64 (35%)	17 (9%)
24	189	0	0	0	1.0	130 (69%)	45 (24%)	14 (7%)
8	115	0	0	0	1.5	41 (36%)	45 (39%)	29 (25%)
50	54	0	0	0	2.3	5 (9%)	22 (41%)	27 (50%)
45	25	0	0	0	1.6	4 (16%)	14 (56%)	7 (28%)
46	39	0	0	0	2.5	4 (10%)	13 (33%)	22 (56%)
9	2	0	0	0	0.4	2 (100%)	0	0
1	3	0	0	0	2.2	0	2 (67%)	1 (33%)
43	0	1	0	0	0.4	1 (100%)	0	0
22	105	0	4	0	1.0	63 (58%)	42 (39%)	4 (4%)
35	1	0	0	0	0.4	1 (100%)	0	0
30	55	0	0	0	0.7	47 (85%)	7 (13%)	1 (2%)
25	7	0	0	0	1.1	4 (57%)	3 (43%)	0
53	1	0	0	2	0.1	3 (100%)	0	0
16	99	0	0	1	1.5	41 (41%)	37 (37%)	22 (21%)
51	11	0	0	0	1.5	5 (45%)	4 (36%)	2 (18%)

Vessel code	**No. voyages, by discharge region:**				**Mean VMR (%)**	**No. voyages (%), by VMR:**		
	MENA	**SEA**	**SEE**	**MISC**		**<1%**	**1.0 – 2.0%**	**>2%**
20	48	0	0	5	0.9	31 (58%)	21 (40%)	1 (2%)
11	13	0	0	0	0.9	7 (54%)	6 (46%)	0
49	40	0	0	0	1.6	4 (10%)	28 (70%)	8 (20%)
48	3	0	0	0	1.4	0	3 (100%)	0
28	3	0	0	0	1.4	1 (33%)	1 (33%)	1 (33%)
54	27	0	0	0	1.8	6 (22%)	10 (37%)	11 (41%)
37	9	0	7	0	0.8	10 (63%)	6 (38%)	0
40	0	2	0	0	0.9	1 (50%)	1 (50%)	0
18	62	0	0	0	1.3	33 (53%)	18 (29%)	11 (18%)
12	46	0	0	0	1.2	18 (39%)	26 (57%)	2 (4%)
17	54	0	0	0	1.4	25 (46%)	20 (37%)	9 (17%)
26	110	0	9	0	0.9	76 (64%)	41 (34%)	2 (2%)
15	120	0	0	11	1.4	59 (45%)	44 (34%)	28 (21%)
19	33	0	0	0	0.8	23 (70%)	9 (27%)	1 (3%)
38	2	0	0	0	0.4	2 (100%)	0	0
32	23	0	0	1	0.9	18 (75%)	5 (21%)	1 (4%)
33	12	0	0	0	1.0	7 (58%)	5 (42%)	0
34	2	0	0	0	1.0	1 (50%)	1 (50%)	0
23	11	0	0	0	1.2	4 (36%)	7 (64%)	0
29	9	0	0	0	1.0	6 (67%)	3 (33%)	0
10	0	0	0	2	3.6	1 (50%)	0	1 (50%)
52	16	0	0	0	1.4	3 (19%)	12 (75%)	1 (6%)

4.2.5 Time of Year

The largest number of voyages transporting sheep to Middle East/North Africa departed in July (161 voyages). There appears to be a seasonal trend, consistent across time periods, of relatively increased VMRs during the time of year roughly corresponding to the northern summer (Fig. 9: northern summer period is highlighted in grey). For the most recent time period (2013–2017), VMRs peaked in August, reaching levels similar those in 2003–2012.

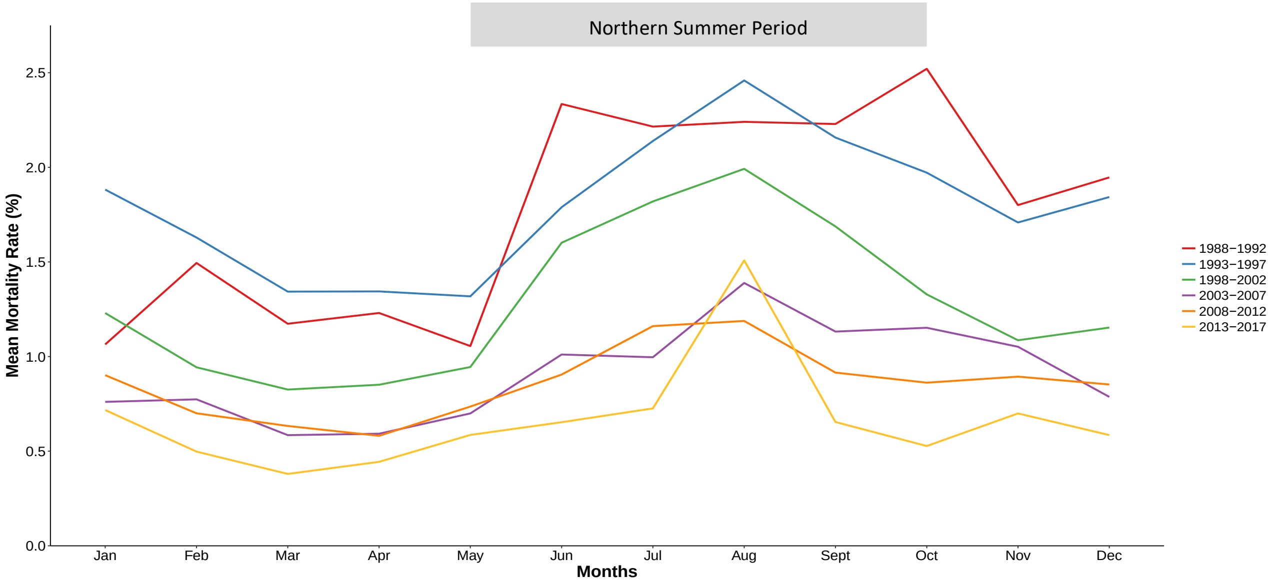

Fig. 9: Mean VMR of sheep live export voyages departing Australia to the Middle East/North Africa discharge region, November 1988 – December 2017, by month of voyage departure.
Data are stratified into 4–5 year periods. May to October represents the northern summer period.

4.2.6 Animal Class and Breed

The wether sheep class dominated the live export market — 86,316,062 were exported between November 1988 and November 2017 (Table 9). The remainder made up of 8,589,830 rams and 4,728958 ewes. The most common age group within the wether class included adults, followed by lambs, with hoggets the least common (Table 10). Wethers and rams were the mostly commonly exported sheep classes to the Middle East/North Africa region (Table 9). Merinos were the most common breed exported for all age groups.

Rams exported to South-eastern Europe recorded the highest mean and median VMR (Table 9). Merinos had the highest mean VMR across voyages (1.2%, range 0–40.6), followed by Damara (1.2%, range 0–25.0), crossbreeds (1.1%, range 0–16.6), 'other' (0.9%, range 0–7.54), Karakul (0.8%, range 0–8.5) and Awassi (0.5%, range 0–13.6).

Table 9: Descriptive statistics of mortality in different sheep classes exported by sea, November 1988 – November 2017, by discharge region
MENA: Middle East/North Africa, SEA: Southeast Asia, SEE: South-eastern Europe and MISC: Miscellaneous.

Region	Class	No. voyages (%)	Total loaded (%)	Mean VMR (%)	Median VMR (%)	VMR range (%)
MENA	Wether	1682 (44%)	85,488,329 (87%)	1.1	0.8	0–16.6
	Ram	1392 (37%)	8,464,799 (9%)	1.4	0.9	0–40.6
	Ewe	706 (19%)	4,134,667 (4%)	1.0	0.6	0–10.8
SEA	Wether	2 (50%)	1,363 (19%)	0.1	0.0	0–0.38
	Ram	2 (50%)	5,831 (81%)	1.6	0.9	0.31–6.5
	Ewe	0	0	–	–	–
SEE	Wether	19 (49%)	642,019 (85%)	1.1	0.8	0.26–6.3
	Ram	19 (49%)	108,608 (14%)	2.0	1.3	0–12.7
	Ewe	1 (2%)	2,264 (<1%)	0	0	0–0
MISC	Wether	10 (20%)	184,351 (23%)	0.9	0.8	0.05–1.9
	Ram	19 (38%)	10,592 (1%)	0.5	0.4	0–2.0
	Ewe	21 (42%)	592,027 (75%)	1.1	0.7	0–25.0

Table 10: Animal class and breed characteristics for live sheep exports departing Australian ports for long-haul voyages between November 1988 and November 2017, and associated VMR.

Class	Age	Breed	No. voyages	Total loaded	Mean VMR (%)	No. loaded	Mean VMR (%)	VMR range (%)
Wethers	Adults	Merino	1597	60,289,114	1.4	61,415,851	1.4	0–8.5
		Crossbreed	31	1,079,619	1.4			
		Awassi	1	1,050	0.1			
		Damara	14	21,379	0.7			
		Karakul	0	0	–			
		Other	10	24,689	1.7			
	Hoggets	Merino	588	7,461,942	0.8	7,770,569	0.8	0–4.1
		Crossbreed	18	256,322	0.9			
		Awassi	0	0	–			
		Damara	0	0	–			
		Karakul	0	0	–			
		Other	9	52,305	0.8			
	Lambs	Merino	1111	12,067,534	1.0	16,408,114	1.0	0–16.6
		Crossbreed	654	4,082,505	1.0			
		Awassi	0	0	–			
		Damara	35	60,917	0.7			
		Karakul	1	465	0			
		Other	68	196,949	0.9			
Rams	Adults	Merino	1118	1,796,979	1.5	1,950,075	1.5	0–27.8
		Crossbreed	30	45,327	1.8			
		Awassi	51	44,418	0.8			
		Damara	42	45,714	1.1			
		Karakul	6	6,890	0.4			
		Other	26	15,618	0.8			

Class	Age	Breed	No. voyages	Total loaded	Mean VMR (%)	No. loaded	Mean VMR (%)	VMR range (%)
	Hoggets	Merino	418	843,849	1.2	967,882	1.2	0–10.7
		Crossbreed	15	32,468	1.2			
		Awassi	6	7,665	0.4			
		Damara	61	72,879	1.4			
		Karakul	1	490	0.4			
		Other	11	15,145	1.5			
	Lambs	Merino	599	2,648,420	1.3	5,659,387	1.2	0–40.6
		Crossbreed	155	728,015	1.5			
		Awassi	200	964,611	0.6			
		Damara	292	796,369	1.3			
		Karakul	54	368,514	0.9			
		Other	85	166,779	1.0			
Ewes	Adults	Merino	500	2,027,120	1.2	2,363,143	1.1	0–25.0
		Crossbreed	17	90,286	1.1			
		Awassi	48	116,619	0.4			
		Damara	73	74,124	1.1			
		Karakul	6	22,971	0.5			
		Other	23	20,878	0.7			
	Hoggets	Merino	29	73,885	1.1	125,230	1.0	0–10.8
		Crossbreed	6	32,783	1.1			
		Awassi	2	733	0.1			
		Damara	2	1,398	2.7			
		Karakul	0	0	–			
		Other	4	16,431	0.5			

Class	Age	Breed	No. voyages	Total loaded	Mean VMR (%)	No. loaded	Mean VMR (%)	VMR range (%)
	Lambs	Merino	92	597,066	0.8	2,231,517	0.7	0–9.5
		Crossbreed	94	648,647	0.8			
		Awassi	127	529,342	0.3			
		Damara	83	185,991	0.9			
		Karakul	20	143,203	1.0			
		Other	23	127,268	0.8			

Mean VMR across time varied between sheep classes (Fig. 10). Seasonal trends in mean mortality rates roughly corresponding with the northern summer period, as per Fig. 9, are common across sheep class types (Fig. 10).

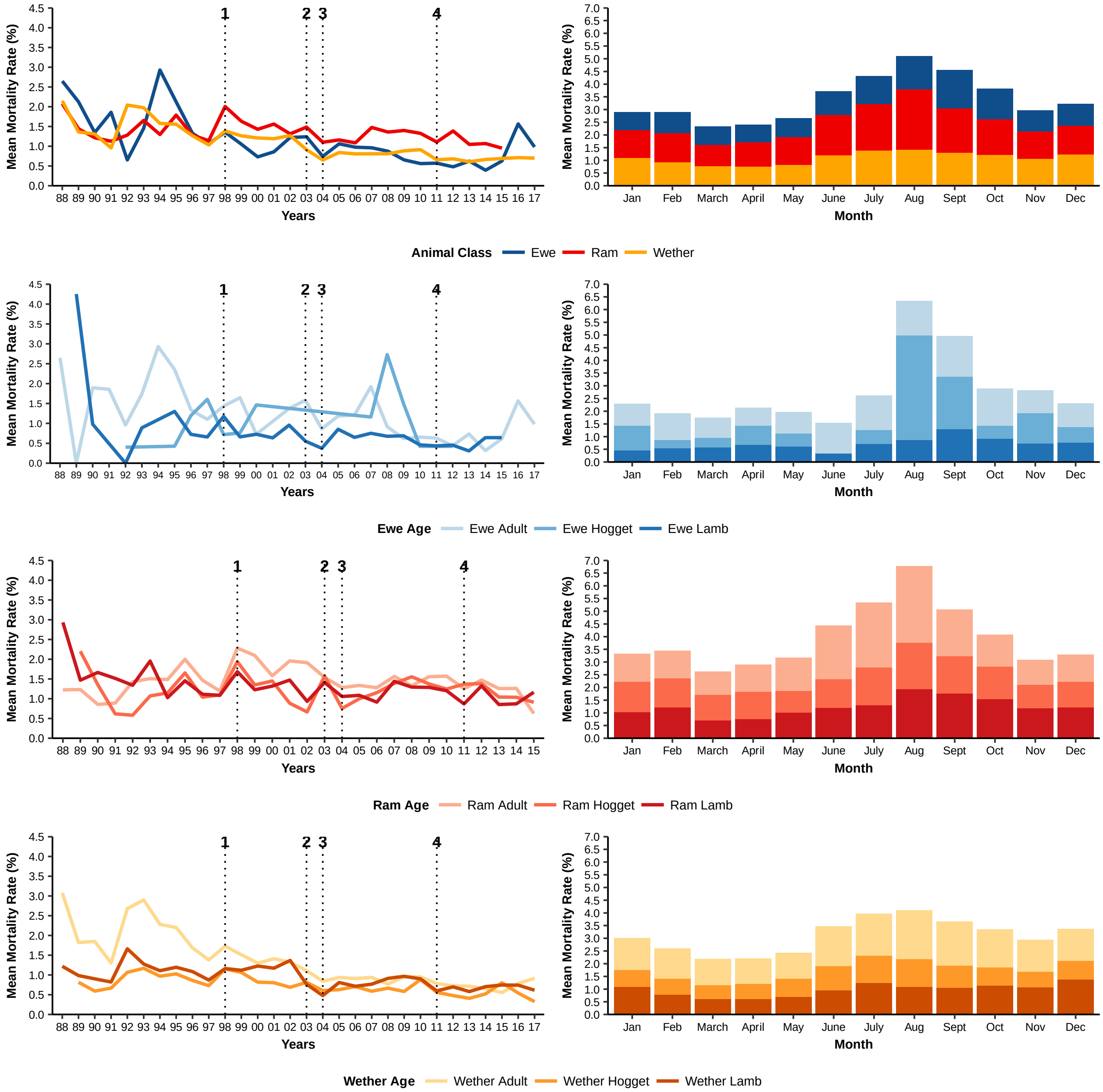

Fig. 10: Mean VMR for different sheep types transported by sea from Australia to Middle East/North Africa (MENA), by year (left) and month (right) of departure.
In the mean-mortality-rate-by-year graphs (left), the years of implementation of industry initiatives are indicated with dotted lines (1: LEAP (Livestock Export Accreditation Program), 2: HotStuff (Heat Stress Risk Assessment Model), 3: ASEL (Australian Standards for the Export of Livestock), 4: Exporter Supply Chain Assurance System (ESCAS); 4 also represents the live export ban of 2011). In the mean-mortality-rate-by-month graphs (right), the May to October represents the northern summer period.

4.2.7 Daily Sheep Deaths

For voyages to MENA, mean mortality rate per day across voyages peaked at day 10 and was lowest towards the end of the voyage (Fig. 11). Fig. 11 is inclusive of voyage days plus discharge days. For voyages to SEE, mean sheep deaths per day of voyage were variable, which may reflect fewer data points. Data for SE Asia and MISC were not included in Fig. 11, as there were too few data records for comparison. More in-depth analysis regarding deaths per day is presented in Section 4.5.1.

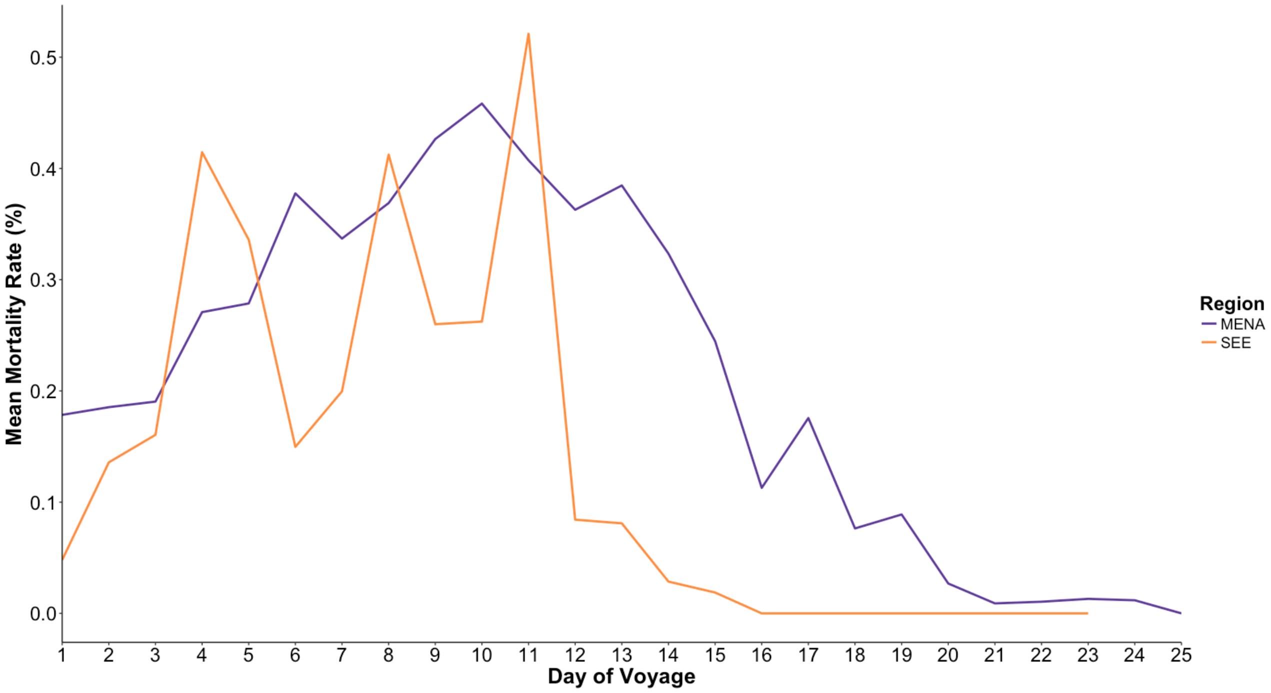

Fig. 11: Mean number of sheep deaths per voyage day comparing countries located in Middle East/North Africa (MENA) and South-eastern Europe (SEE) between 1988 and 2017.
Displayed data are only for voyages up to 25 days.

4.3 Cattle Voyages

4.3.1 Overview

A total of 3,097,669 cattle were exported from Australian ports on long-haul voyages between 1995 and 2017. The most common discharge region, in terms of number of cattle, was the Middle East/North Africa (2,175,011 head across 705 voyages), followed by South-eastern Europe (334,466 head across 55 voyages). In contrast to live export of sheep from Australia, a large number of loading ports and loading port regions were used for live export of cattle (Section 4.3.2), and cattle were exported to all five discharge regions (Table 11).

Table 11: Summary statistics for long-haul live cattle export voyages from Australia between 1995–2017, by discharge region. MENA: Middle East/North Africa, Miscellaneous: Mexico, Russia (Ust Luga) and Sri Lanka; VMR = voyage mortality rate.

Parameters	**MENA**[A]	**Southeast Asia**[B]	**Northeast Asia**[C]	**South-eastern Europe**[D]	**Miscellaneous** [E]	**TOTAL**
No. voyages	705 (73%)	35 (4%)	123 (13%)	55 (6%)	44 (5%)	962 (100%)
Total cattle loaded	2,175,463 (70%)	156,058 (5%)	297,931 (10%)	334,466 (11%)	133,751 (4%)	3,097,669 (100%)
Mean VMR (%)	0.4	0.2	0.2	0.3	0.4	0.4
Median VMR (%)	0.2	0.1	0.1	0.3	0.3	0.2
VMR range (%)	0–35.1	0–0.5	0–2.0	0–1.4	0–3.0	0–35.0
Mean voyage duration (days)	16.5	13.9	17.1	25.8	22.0	17.3
Mean discharge (days)	5.2	2.6	1.3	4.4	2.4	4.4
Voyages with nil mortality	237	3	24	3	7	274

[A] Voyages occurred 1995–2017

[B] Voyages occurred 2013–2015

[C] Voyages occurred 2003–2015

[D] Voyages occurred 2007 and 2010–2013

[E] Voyages occurred 1996–2008 and 2012

The trend of increasing numbers of cattle exported from Australia on long-haul voyages from 1995 peaked in 2002, with 251,755 head exported that year (Fig. 12). This was followed by a steep decline, coinciding with the notable voyages of exceptional mortality in July 2002 and August 2003. The number of cattle exported generally increased from 2003, to peak again in 2010 (228,644 head) and 2015 (243,625 head) (Fig. 12). Export numbers in 2015 were just short of those of 2002. The key industry initiative HotStuff was introduced in 2003 (Fig. 12).

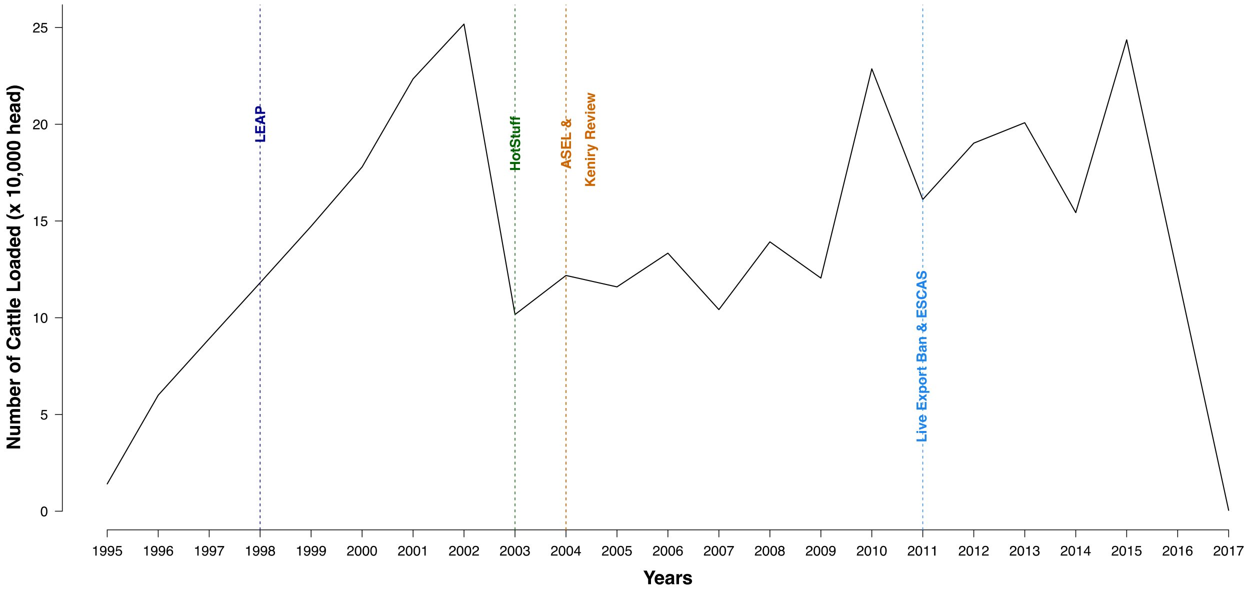

Fig. 12: Number of cattle loaded for live export from Australia, 1995–2017, by year.
The years of implementation of key industry initiatives aimed at reducing mortality are included in the map as vertical lines (LEAP: Livestock Export Accreditation Program, HotStuff: Heat Stress Risk Assessment Model, ASEL: Australian Standards for the Export of Livestock and ESCAS: Exporter Supply Chain Assurance System), as is the 2011 live export ban.

The total number of cattle deaths recorded was 11,861 (0.38% of those loaded; 11,861/3,097,669). The mean VMR across voyages was 0.4% (range 0–35.1%), with mean VMRs across voyages peaking in 1998 (Fig. 13). Three exceptional voyages, in terms of mortality, were identified in the data:

1. Fremantle to Mina Qaboos aboard vessel ID 17 in 1998 with a VMR of 11.1% (6 deaths from 54 loaded).
2. Fremantle to Mina Qaboos aboard vessel ID 21 in 2000 with a VMR of 8.00% (8 deaths from 100 loaded).
3. Portland to Dammam aboard vessel ID 30 in 2002 with a VMR of 35.1% (614 deaths from 1,752 loaded).

A general downward trend in VMRs amongst cattle exported to Middle East/North Africa occurred after 1998, with intermittent upward fluctuations (Fig. 13). Mean VMRs amongst cattle exported to Miscellaneous were substantially reduced from 2002 on, compared to earlier years (Fig. 14).

There were 274 voyages that recorded zero mortality for cattle: 237 to Middle East/North Africa, 3 to Southeast Asia, 24 to Northeast Asia, 3 to South-eastern Europe and 7 to Miscellaneous.

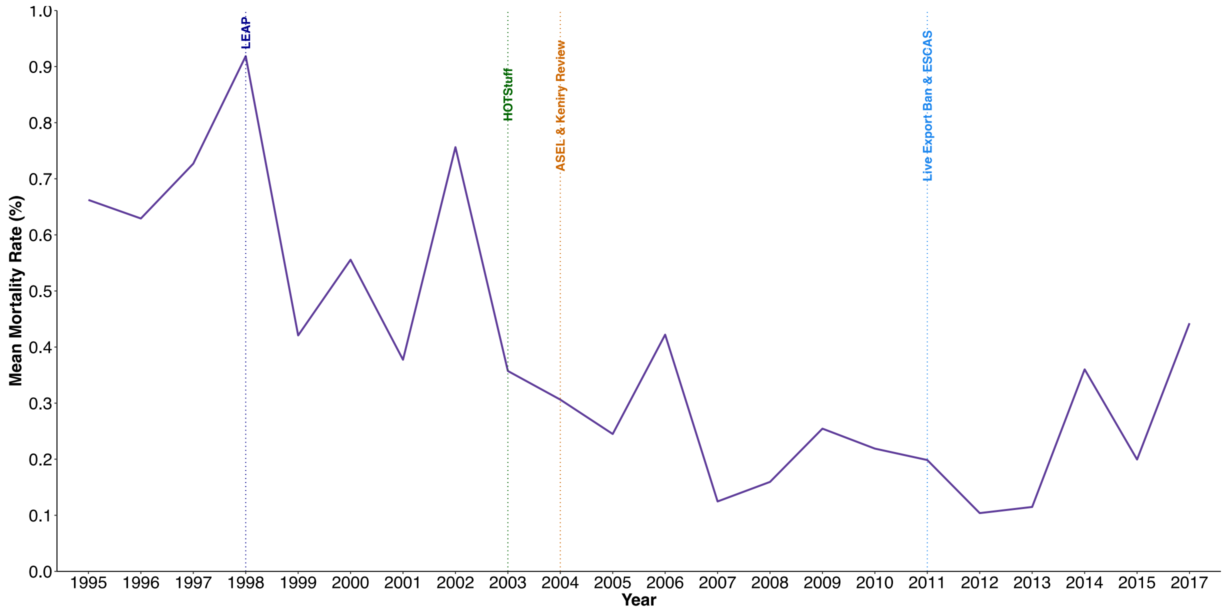

Fig. 13: Mean VMR for cattle exported from Australia by sea to Middle East/North Africa from 1995–2017.
The years of implementation of key industry initiatives aimed at reducing mortality are included in the map as vertical lines (LEAP: Livestock Export Accreditation Program, HotStuff: Heat Stress Risk Assessment Model, ASEL: Australian Standards for the Export of Livestock and ESCAS: Exporter Supply Chain Assurance System), as is the 2011 live export ban.

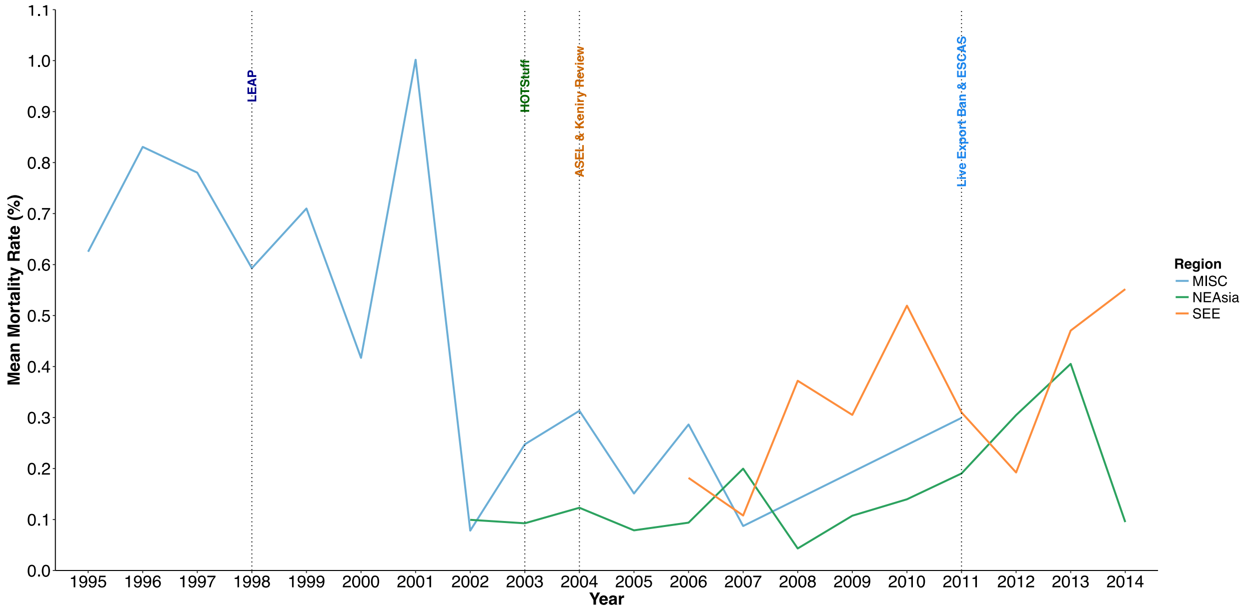

Fig. 14: Mean VMRs for cattle exported by sea from Australia for three regions (Miscellaneous (MISC), Northeast Asia (NEAsia) and South-eastern Europe (SEE) between 1995 and 2017, by year.
The years of implementation of key industry initiatives aimed at reducing mortality are included in the map as vertical lines (LEAP: Livestock Export Accreditation Program, HotStuff: Heat Stress Risk Assessment Model, ASEL: Australian Standards for the Export of Livestock and ESCAS: Exporter Supply Chain Assurance System), as is the 2011 live export ban. Voyages to Southeast Asia have been omitted, due to limited data.

4.3.2 Origin Ports

Twelve Australian ports were used to export cattle on long-haul voyages between 1995 and 2017. The majority of these voyages (92.8%; 893/962) departed from southern ports; Fremantle was the most frequently used port. Cattle were exported from Fremantle and Portland to all discharge regions (Table 12).

The highest maximum recorded loading days occurred in Fremantle and Portland (Table 13). Voyage duration ranged from 10 to 41 days. Voyages departing from Wyndham had the highest mean voyage duration of all departure ports (23.5 days) (Table 13). Total voyage duration, with the inclusion of load and discharge days, ranged between 12 and 47 days. Mean VMR was highest for those departing from Brisbane (0.46%), but this was based on relatively few voyages; of the more frequently utilised ports, mean VMRs across voyages were highest across those departing from Adelaide (Table 13).

4.3.3 Discharge Ports

Between 1995 and 2017, cattle were exported on long-haul voyages to 22 different countries across all discharge regions. The highest number of voyages were to Oman, Saudi Arabia and China — more than 100 voyages occurred to each of these countries (Table 14). The mean VMR across voyages for cattle exported to the Middle East/North Africa region was 0.41%, compared to 0.15% for Northeast Asia, 0.20% for Southeast Asia, 0.33% for South-eastern Europe and 0.43% for Miscellaneous (Mexico, Ust Luga in Russia, and Sri Lanka).

Table 12: Number of voyages transporting cattle from Australia, by origin port, VMR (%) and discharge region. MENA: Middle East/North Africa, SEA: Southeast Asia, SEE: South-eastern Europe, MISC: Miscellaneous, VMR: voyage mortality rate.

Port Location	**Origin**	**No. voyages, by VMR:**				**No. voyages, by discharge region**				
		0% (%)	**<1% (%)**	**1.0–2.0% (%)**	**>2% (%)**	**MENA (%)**	**SEA (%)**	**NEA (%)**	**SEE (%)**	**MISC (%)**
Southern	Adelaide	14 (17%)	64 (76%)	2 (3%)	1 (1%)	67 (83%)	1 (1%)	0	12 (15%)	1 (1%)
	Devonport	1 (33%)	2 (67%)	0	0	3 (100%)	0	0	0	0
	Fremantle	220 (38%)	326 (56%)	27 (5%)	12 (2%)	505 (86%)	9 (2%)	26 (4%)	27 (5%)	18 (3%)
	Geelong	1 (10%)	9 (90%)	0	0	0	0	10 (100%)	0	0
	Portland	36 (17%)	165 (77%)	8 (4%)	5 (2%)	96 (45%)	1 (<1%)	77 (36%)	16 (8%)	24 (11%)
Other	Brisbane	1 (10%)	8 (80%)	1 (10%)	0	0	0	10 (100%)	0	0
	Geraldton	0	1 (100%)	0	0	1 (100%)	0	0	0	0
Northern	Broome	0	11 (100%)	0	0	10 (91%)	1 (9%)	0	0	0
	Darwin	1 (13%)	7 (88%)	0	0	4 (50%)	4 (50%)	0	0	0
	Port Hedland	0	13 (100%)	0	0	12 (92%)	1 (8%)	0	0	0
	Townsville	0	24 (100%)	0	0	5 (21%)	19 (79%)	0	0	0
	Wyndham	0	2 (100%)	0	0	2 (100%)	0	0	0	0

Table 13: Port origin summary statistics for cattle exports from Australia to five different regions between 1995 and 2017.
MENA: Middle East/North Africa, SEA: Southeast Asia, SEE: South-eastern Europe, MISC: Miscellaneous, VMR: voyage mortality rate.

Region of origin	**Port of origin**	**No. voyages**	**Mean loading days (range)**	**Mean voyage days (range)**	**Mean discharge days (range)**	**Mean VMR (range)**	**Total cattle loaded (%), by discharge region:**				
							MENA	**SEA**	**NEA**	**SEE**	**MISC**
Southern	Adelaide	81	1.2 (1–3)	21.7 (13–33)	4.7 (1–10)	0.42 (0–2.9)	215,827 (68%)	4,164 (1%)	0	96,796 (31%)	470 (<1%)
	Devonport	3	1.3 (1– 2)	20.0 (16–23)	7.7 (4–10)	0.43 (0–0.9)	6,924 (100%)	0	0	0	0
	Fremantle	585	1.2 (1–6)	16.3 (10–40)	4.8 (1–20)	0.3 (0–11.1)	1,480,493 (87%)	15,393 (<1%)	12,323 (<1%)	154,046 (9%)	32,519 (2%)
	Geelong	10	1.0 (1–1)	17.7 (14–21)	1.0 (1–1)	0.2 (0–0.4)	0	0	38,067 (100%)	0	0
	Portland	214	1.1 (1– 6)	18.1 (12–41)	3.8 (1–16)	0.3 (0–4.3)	196,254 (33%)	4,902 (<1%)	227,518 (38%)	84,483 (14%)	87,944 (15%)
Other	Brisbane	10	1.0 (1–1)	16.4 (15–18)	1.3 (1–3)	0.5 (0–1.2)	0	0	12,867 (100%)	0	0
	Geraldton	1	1.0	17.0	2.0	0.1	2,934 (100%)	0	0	0	0
Northern	Broome	11	1.2 (1–2)	19.8 (12–26)	2.8 (1–7)	0.2 (0.1–0.7)	77,612 (96%)	3,188 (4%)	0	0	0
	Darwin	8	1.0 (1–1)	14.9 (10–24)	3.4 (2–5)	0.2 (0–0.5)	25,348 (58%)	18,432 (42%)	0	0	0

	Port Hedland	13	1.2 (1–2)	20.0 (16–26)	3.8 (1–8)	0.2 (0–4.3)	84,935 (90%)	0	0	0	9,363 (10%)
	Townsville	24	1.4 (1–3)	14.4 (10–23)	2.7 (1–6)	0.2 (0.02–0.3)	72,154 (40%)	109,979 (60%)	0	0	0
	Wyndham	2	1.5 (1–2)	23.5 (23–24)	5.0 (4–6)	0.2 (0.1–0.3)	9,499 (100%)	0	0	0	0

Table 14: Mean cattle VMRs (%) on live export voyages from Australia, 1995–2017, by discharge country; and number of cattle loaded for live export across Australian (origin) ports during the same time period, by discharge country.
Discharge regions: MENA: Middle East/North Africa, SEA: Southeast Asia, NEA: Northeast Asia, SEE: South-eastern Europe, MISC: Miscellaneous; VMR = voyage mortality rate.

Region	**Country**	**No. voyages**	**Mean VMR (%)**	**No. cattle loaded (%)**											
				Adelaide	**Fremantle**	**Portland**	**Geelong**	**Devonport**	**Brisbane**	**Geraldton**	**Broome**	**Darwin**	**Port Hedland**	**Townsville**	**Wyndham**
MENA	Bahrain	51	0.1	1,421 (8%)	6,023 (32%)	5,071 (27%)	0	0	0	0	891 (5%)	5,363 (29%)	0	0	0
	Egypt	98	0.4	105,231 (14%)	357,366 (47%)	71,232 (9%)	0	2,972 (<1%)	0	0	72,694 (10%)	19,985 (3%)	48,166 (6%)	72,154 (10%)	9,499 (1%)
	Israel	93	0.3	37,125 (7%)	506,948 (88%)	4,657 (<1%)	0	0	0	2,934 (<1%)	0	0	21,824 (4%)	0	0
	Jordon	93	0.6	32,090 (9%)	278,537 (77%)	35,156 (19%)	0	3,901 (1%)	0	0	4,027 (1%)	0	6,657 (2%)	0	0
	Kuwait	22	0.4	0	4,408 (86%)	734 (14%)	0	0	0	0	0	0	0	0	0
	Libya	18	0.4	10,984 (7%)	104,335 (67%)	35,740 (23%)	0	0	0	0	0	0	5,679 (4%)	0	0
	Oman	152	0.4	3,958 (8%)	21,755 (42%)	26,386 (51%)	0	51 (<1%)	0	0	0	0	0	0	0
	Qatar	32	0.1	420 (3%)	9,564 (77%)	2,401 (19%)	0	0	0	0	0	0	0	0	0
	Saudi Arabia	114	0.5	23,393 (11%)	188,297 (84%)	8,674 (4%)	0	0	0	0	0	0	2,609 (1%)	0	0
	United Arab Emirates	32	0.5	1,205 (9%)	5,574 (43%)	6,203 (48%)	0	0	0	0	0	0	0	0	0
SEA	Brunei Darussalam	1	<1%	0	0	0	0	0	0	0	0	9,410 (100%)	0	0	0
	Indonesia	4	0.2	0	570 (4%)	0	0	0	0	0	0	0	0	14,511 (96%)	0
	Malaysia	6	0.2	0	5,143 (62%)	0	0	0	0	0	3,188 (38%)	0	0	0	0

	Philippines	1	0.4	0	0	0	0	0	0	0	0	2,431 (100%)	0	0	0
	Vietnam	23	0.2	4,164 (3%)	9,680 (8%)	4,902 (4%)	0	0	0	0	0	6,591 (6%)	0	95,468 (79%)	0
NEA	China	102	0.1	0	8,257 (3%)	224,523 (83%)	38,067 (14%)	0	0	0	0	0	0	0	0
	Japan	10	0.5	0	0	0	0	0	12,867 (100%)	0	0	0	0	0	0
	Pakistan	7	0.3	0	4,066 (58%)	2,995 (42%)	0	0	0	0	0	0	0	0	0
	Russia (Vanino)	4	0.1	0	553 (15%)	3,143 (85%)	0	0	0	0	0	0	0	0	0
SEE	Turkey	28	0.4	29,599 (16%)	133,537 (74%)	17,116 (10%)	0	0	0	0	0	0	0	0	0
	Russia (Novorossiysk)	27	<1%	67,197 (44%)	19,650 (13%)	67,367 (44%)	0	0	0	0	0	0	0	0	0
MISC	Mexico	41	0.4	470 (<1%)	32,519 (25%)	85,941 (67%)	0	0	0	0	0	0	9,363 (7%)	0	0
	Russia (Ust Luga)	1	0.1			3,455 (100%)									
	Sri Lanka	2	0.3	0	0	2,003 (100%)	0	0	0	0	0	0	0	0	0

Records of cattle exports on long-haul voyages to Middle East/North Africa were available from 1995. For the Middle East/ North Africa market, both the number of live export voyages containing cattle and the number of cattle exported peaked in 2002 (Table 15).

Table 15: Summary statistics for cattle exported by sea on long-haul voyages to discharge ports in the Middle East/North Africa region, by year (VMR= voyage mortality rate).

Year	No. voyages (%)	No. cattle (%)	Mean VMR (%)	Median VMR (%)	VMR range (%)	Mean voyage days	Mean loading days	Mean discharge days	No. nil mortality voyages
1995	9 (1%)	14,103 (1%)	0.7	0.4	0.0–2.1	13.9	2.3	7.3	2
1996	28 (4%)	56,142 (3%)	0.6	0.4	0.0–5.0	15.5	2.3	6.0	10
1997	24 (3%)	82,190 (4%)	0.7	0.5	0.0–4.2	16.3	1.7	5.9	9
1998	35 (5%)	96,915 (5%)	0.9	0.5	0.0–11.1	16.5	1.6	6.3	11
1999	33 (5%)	139,559 (6%)	0.4	0.2	0.0–2.1	16.9	1.4	5.9	11
2000	38 (5%)	169,902 (8%)	0.6	0.2	0.0–8.0	17.6	1.3	5.0	11
2001	55 (8%)	214,854 (10%)	0.4	0.3	0.0–3.4	17.7	1.2	4.3	17
2002	83 (12%)	236,184 (11%)	0.8	0.3	0.0–35.1	16.6	1.4	4.5	25
2003	37 (5%)	78,598 (4%)	0.4	0.1	0.0–2.0	15.2	1.0	6.3	13
2004	31 (4%)	61,679 (3%)	0.3	0.2	0.0–1.3	15.8	1.3	5.7	9
2005	34 (5%)	84,666 (4%)	0.2	0.2	0.0–1.0	15.2	1.3	5.4	10
2006	43 (6%)	119,297 (6%)	0.4	0.2	0.0–4.3	15.8	1.1	4.7	13
2007	37 (5%)	68,612 (3%)	0.1	0.1	0.0–0.5	15.5	1.1	4.8	14
2008	43 (6%)	113,175 (5%)	0.3	0.1	0.0–0.8	16.1	1.0	6.1	18
2009	39 (5%)	96,387 (4%)	0.3	0.1	0.0–1.8	15.1	1.0	4.9	12
2010	27 (4%)	124,214 (6%)	0.2	0.1	0.0–1.6	16.0	1.1	5.1	12
2011	25 (4%)	75,255 (4%)	0.1	0.1	0.0–0.7	16.3	1.0	5.4	8
2012	23 (3%)	89,436 (4%)	0.1	0.1	0.0–0.3	18.3	1.2	3.6	9
2013	28 (4%)	112,192 (5%)	0.1	0.1	0.0–0.4	18.9	1.1	4.9	10
2014	15 (2%)	60,406 (3%)	0.4	0.2	0.0–2.8	19.6	1.3	5.7	6
2015	17 (2%)	81,245 (4%)	0.2	0.2	0.0–0.8	18.5	1.3	4.5	7
2016	0	–	–	–	–	–	–	–	–
2017	1 (<1%)	452 (<1%)	0.4	0.4	0.4	18.0	3.0	3.0	0

Long-haul voyages exporting cattle to Southeast Asia were recorded from 2013 (Table 16). As previously mentioned, cattle were exported to this region prior to 2013 on short-haul voyages, but short-haul voyages are not within the scope of this report.

Table 16: Summary statistics for cattle exported by sea on long-haul voyages to discharge ports in the Southeast Asia region, by year (VMR = voyage mortality rate).

Year	No. voyages (%)	No. cattle (%)	Mean MR (%)	Median MR (%)	MR range (%)	Mean voyage days	Mean loading days	Mean discharge days	No. nil mortality voyages
2013	2 (6%)	2,852 (2%)	0.5	0.5	0.5	11.5	1.0	1.5	0
2014	4 (11%)	34,274 (22%)	0.2	0.2	<0.1%–0.5	13.0	1.3	3.5	0
2015	29 (83%)	118,932 (76%)	0.2	0.1	0.0–0.5	14.2	0.1	2.6	3

Records of cattle exported to Northeast Asia on long-haul voyages were available from 2003 (Table 17). The greatest number of cattle were exported to Northeast Asia during 2004, across 23 voyages. The highest annual mean mortality rate across voyages was in 2014.

Table 17: Summary statistics for cattle exported by sea on long-haul voyages to discharge ports in the Northeast Asia region, by year (VMR = voyage mortality rate).

Year	**No. voyages (%)**	**No. cattle (%)**	**Mean VMR (%)**	**Median VMR (%)**	**VMR range (%)**	**Mean voyage days**	**Mean loading days**	**Mean discharge days**	**No. nil mortality voyages**
2003	8 (7%)	20,507 (7%)	0.1	0.1	0.0–0.3	14.8	1.0	1.3	2
2004	23 (19%)	54,538 (18%)	0.1	0.1	0.0–0.5	15.6	1.0	1.2	4
2005	10 (8%)	16,840 (6%)	0.1	0.1	0.0–0.4	16.3	1.0	1.5	3
2006	6 (5%)	8,807 (3%)	0.1	0.1	0.0–0.2	15.5	1.0	1.0	2
2007	5 (4%)	10,636 (4%)	0.1	1.1	0.0–0.2	15.2	1.0	1.3	0
2008	2 (2%)	2,873 (1%)	0.2	0.2	<0.1–0.4	20.5	1.0	1.0	0
2009	8 (7%)	20,616 (7%)	<1%	<1%	0.0–0.1	16.4	1.0	1.1	2
2010	11 (9%)	19,871 (7%)	0.1	0.1	0.0–0.6	19.4	1.0	1.5	4
2011	10 (8%)	25,125 (8%)	0.1	0.1	0.0–0.4	20.1	1.0	1.0	2
2012	14 (11%)	33,273 (11%)	0.2	0.1	0.0–0.6	17.6	1.0	1.4	2
2013	15 (12%)	41,191 (14%)	0.3	0.1	0.0–1.2	17.7	1.0	1.1	1
2014	7 (6%)	23,720 (8%)	0.4	0.1	<0.1–2.0	17.4	1.0	1.1	0
2015	4 (3%)	19,934 (7%)	0.1	0.1	0.1–0.2	18.5	1.0	1.0	0

Cattle were exported to South-eastern Europe from 2006 (Table 18). The highest frequency of voyages occurred during 2010–2012, with the largest number of cattle exported during 2010. The longest voyage duration recorded was 41 days, for a voyage from Portland to Novorossiysk (Russia) in 2009. The VMR on this voyage was 0.37%.

Table 18: Summary statistics for cattle exported by sea on long-haul voyages to discharge ports in the South-eastern Europe region, by year (VMR = voyage mortality rate).

Year	No. voyages (%)	No. cattle (%)	Mean VMR (%)	Median VMR (%)	VMR range (%)	Mean voyage days	Mean loading days	Mean discharge days	No. nil mortality voyages
2007	6 (11%)	6,544 (2%)	0.2	0.2	0.0–0.3	22.6	1.0	2.8	2
2008	5 (9%)	9,615 (3%)	0.1	0.1	0.0–0.3	25.8	1.0	2.0	1
2009	1 (2%)	3,493 (1%)	0.4	0.4	0.4	41.0	1.0	1.0	0
2010	10 (18%)	84,559 (25%)	0.3	0.2	0.0–0.7	22.1	1.4	6.0	1
2011	11 (20%)	60,745 (18%)	0.5	0.4	0.2–1.4	26.7	1.0	5.9	0
2012	11 (20%)	65,513 (20%)	0.3	0.3	0.1–0.5	27.6	1.1	4.2	0
2013	5 (9%)	44,560 (13%)	0.2	0.2	0.1–0.3	24.2	1.4	4.2	0
2014	3 (6%)	35,923 (11%)	0.5	0.5	0.3–0.6	26.3	1.3	5.3	0
2015	3 (6%)	23,514 (7%)	0.6	0.6	0.2–0.8	29.3	1.3	3.0	0

Exports of cattle from Australia to discharge ports grouped into “Miscellaneous” (Mexico, Ust Luga (Russia) and Sri Lanka) occurred across 1996 to 2012 (Table 19).

Table 19: Summary statistics for cattle exported by sea on long-haul voyages to discharge ports in the Miscellaneous region, by year (VMR = voyage mortality rate).

Year	No. voyages (%)	No. cattle (%)	Mean VMR (%)	Median VMR (%)	VMR range (%)	Mean voyage days	Mean loading days	Mean discharge days	No. nil mortality voyages
1996	1 (2%)	3,839 (3%)	0.6	0.6	0.6	17.0	2.0	8.0	0
1997	2 (5%)	6,960 (5%)	0.8	0.8	0.6–1.1	25.0	1.5	4.0	0
1998	2 (5%)	21,163 (16%)	0.8	0.8	0.4–1.1	26.5	1.0	7.0	0
1999	2 (5%)	7,701 (6%)	0.6	0.6	0.5–0.7	26.0	1.0	3.5	0
2000	2 (5%)	8,005 (6%)	0.7	0.7	0.4–1.1	25.5	1.0	5.0	0
2001	2 (5%)	8,606 (6%)	0.4	0.4	0.2–0.6	23.0	1.0	3.0	0
2002	5 (11%)	15,571 (12%)	1.0	0.7	0.0–3.0	22.2	2.0	2.8	1
2003	1 (2%)	2,558 (2%)	0.1	0.1	0.1	16.0	1.0	1.0	0
2004	3 (7%)	5,633 (4%)	0.3	0.1	0.0–0.7	17.7	1.0	1.7	1
2005	8 (18%)	14,450 (11%)	0.3	0.3	0.0–0.8	21.0	1.0	1.1	1
2006	4 (9%)	5,271 (4%)	0.2	0.1	0.0–0.5	22.8	1.0	1.5	2
2007	6 (14%)	18,414 (14%)	0.3	0.3	0.2–0.4	18.8	1.2	1.3	0
2008	4 (9%)	13,577 (10%)	0.1	0.1	0.0–0.1	19.3	1.0	1.3	1
2012	2 (5%)	2,003 (1%)	0.3	0.3	0.0–0.6	26.5	1.0	1.0	1

4.3.4 Vessels

Forty-four vessels were used to export cattle on long-haul voyages from Australia between 1995 and 2017. Fifteen vessels transported cattle exclusively to the Middle East/North Africa region (Table 20). The majority of voyages had a VMR of <1% (94.3%; 906/961 voyages). The vessel that recorded the highest mean VMR only had one recorded voyage (vessel code 52).

Table 20: Number of voyages for each vessel involved in long-haul live export of cattle from Australia 1995–2017, by discharge region; mean VMRs (MR) across voyages for each vessel; and no. voyages by VMR for each vessel.
Discharge regions are Middle East/North Africa (MENA), Southeast Asia (SEA), Northeast Asia (NEA), South-eastern Europe (SEE) and miscellaneous category (MISC); VMR = voyage mortality rate.

Vessel code	No. voyages, by discharge region:					Mean VMR (%)	No. voyages (%), by VMR:		
	MENA	SEA	NEA	SEE	MISC		<1%	1.0–2.0%	>2%
21	85	0	3	0	0	0.4	81 (92%)	3 (3%)	4 (5%)
24	81	0	1	0	0	0.2	80 (98%)	2 (2%)	0
8	13	0	0	0	0	0.3	12 (92%)	1 (8%)	0
46	2	0	0	0	0	0.0	2 (100%)	0	0
9	1	0	0	0	0	0.4	1 (100%)	0	0
7	0	0	7	2	2	0.1	11 (100%)	0	0
43	0	5	0	0	0	0.1	5 (100%)	0	0
22	91	1	0	6	0	0.4	94 (96%)	3 (3%)	1 (1%)
30	27	0	0	0	2	0.2	27 (93%)	2 (7%)	0
25	3	0	0	0	0	0.5	3 (100%)	0	0
2	9	0	24	2	1	0.2	35 (97%)	1 (3%)	0
3	6	0	13	1	5	0.2	25 (100%)	0	0
16	6	0	0	0	0	0.0	6 (100%)	0	0
20	53	0	0	0	7	0.6	54 (90%)	4 (7%)	2 (3%)
39	7	1	4	1	0	0.1	13 (100%)	0	0
11	8	0	0	0	0	0.1	8 (100%)	0	0
13	2	0	5	2	0	0.1	9 (100%)	0	0
49	6	0	0	0	0	0.4	5 (83%)	1 (17%)	0
28	1	0	0	0	0	0.0	1 (100%)	0	0
6	0	0	4	0	6	0.1	10 (100%)	0	0
54	7	0	0	0	0	0.7	5 (71%)	2 (29%)	0

Vessel code	**No. voyages, by discharge region:**					**Mean VMR (%)**	**No. voyages (%), by VMR:**		
	MENA	**SEA**	**NEA**	**SEE**	**MISC**		**<1%**	**1.0–2.0%**	**>2%**
36	0	0	4	1	0	0.1	5 (100%)	0	0
5	0	0	1	0	0	0.3	1 (100%)	0	0
42	0	0	1	0	0	<1%	1 (100%)	0	0
44	1	0	0	0	0	0.2	1 (100%)	0	0
37	11	1	0	15	0	0.3	26 (96%)	1 (4%)	0
40	0	3	3	0	0	0.5	5 (83%)	1 (17%)	0
18	11	0	0	0	0	0.5	8 (73%)	3 (27%)	0
12	20	0	0	0	0	0.3	19 (95%)	0	1 (5%)
17	35	0	0	0	0	0.8	26 (74%)	4 (11%)	5 (14%)
26	78	0	0	8	0	0.3	84 (98%)	1 (1%)	1 (1%)
15	77	0	8	0	11	0.3	90 (94%)	6 (6%)	0
31	0	0	7	0	0	0.4	7 (100%)	0	0
38	3	7	1	5	0	0.3	16 (100%)	0	0
32	23	3	0	3	2	0.2	30 (97%)	0	1 (3%)
35	2	6	0	1	0	0.1	9 (100%)	0	0
33	12	0	0	3	0	0.3	14 (93%)	1 (7%)	0
34	3	1	11	0	0	0.1	15 (100%)	0	0
41	5	7	1	0	0	0.1	13 (100%)	0	0
23	2	0	0	0	0	0.9	2 (100%)	0	0
29	8	0	0	0	0	0.6	6 (75%)	2 (25%)	0
4	0	0	8	2	0	0.2	10 (100%)	0	0
10	5	0	16	8	3	0.2	31 (97%)	0	1 (3%)
52	1	0	0	0	0	5.0	0	0	1 (100%)

4.3.5 Time of Year

Four hundred and sixty (47.8%) voyages departed during the northern summer period. For voyages to the Middle East/North Africa discharge region, 44.5% (314/705) departed from southern Australian ports during the northern summer period.

Mean VMR fluctuated across departure months for long-haul voyages to the Middle East/North Africa (Fig. 15). Prominent peaks occurred in May for the 1995–1998 time period, and in June for the 1999–2002 time period. Such pronounced peaks did not occur from 2003 onwards.

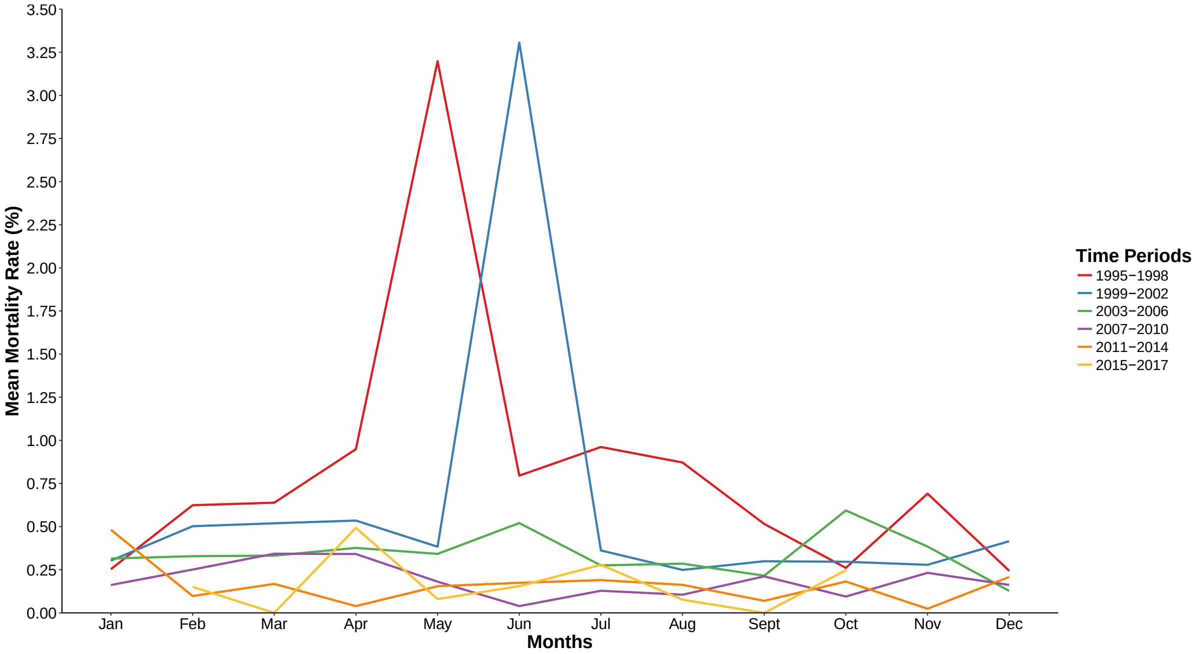

Fig. 15: Mean VMRs (%) of cattle live export voyages departing Australia to the Middle East/North Africa discharge region, 1995–2017, by month of voyage departure.
Data are stratified into 3–4 year periods. The May-Oct represents the northern summer period.

4.3.6 Animal Class and Breed

Classification of cattle into different sub-categories began in mid-2002. Prior to then, classification was limited to 'cattle'. The generic category 'cattle' (1995 — 2002, also used in 13 voyages in 2015) made up 32.5% (899,582/2,771,107 head) of exported cattle. Of the sub-categorised animal classes, bull adults, adult steers, dairy heifers were predominant on long-haul voyages, comprising 24.7% (684,219/2,771,107), 20.4% (565,281/2,771,107) and 15.0% (415,220/2,771,107) of the total number of cattle exported, respectively.

Discharge ports in the Middle East/ North Africa region received the highest number of bull and steer adults. The highest number of dairy cattle were exported to Northeast Asia. This is likely to be associated with the increasing demand and consumption of dairy products in China, which has been occurring over the past decade (Zhou et al., 2012).

The highest mean VMR across cattle classes was the 'cattle' category (0.6%) — this may be associated with this class being used from 1995 to 2002, when VMRs were generally higher. The higher VMRs in the VMR ranges (Table 21) were often associated with cattle classes on voyages where there were small numbers of the respective class loaded.

Table 21: Descriptive statistics of mortality (VMR = voyage mortality rate) in different cattle classes exported by sea, 1995–2017, by discharge region.
MENA: Middle East/North Africa, SEA: Southeast Asia, NEA: Northeast Asia, SEE: South-eastern Europe and MISC: Miscellaneous.

Discharge region	Class	No. voyages (%)	Total loaded (%)	Mean VMR (%)	Median VMR (%)	VMR range (%)
MENA	Beef cow	7 (<1%)	4,090 (<1%)	0.3	<0.1	0.0–0.9
	Beef heifer	73 (7%)	90,783 (5%)	0.3	0.1	0.0–3.2
	Bull adult	353 (34%	643,525 (32%)	0.4	0.1	0.0–32.6
	Dairy cow	53 (5%)	17,989 (<1%)	0.5	0.2	0.0–4.1
	Dairy heifer	81 (8%)	72,123 (4%)	0.2	0.1	0.0–0.9
	Steer adult	205 (20%)	340,734 (17%)	0.5	0.1	0–40.9
	Steer calf	26 (3%)	23,912 (1%)	0.3	0.0	0.0–3.2
	Cattle[A]	254 (24%)	839,662 (41%)	0.6	0.3	0.0–11.1
SEA	Beef cow	9 (9%)	2,606 (2%)	0.6	0.0	0.0–2.4
	Beef heifer	24 (25%)	18,418 (12%)	0.1	0.0	0.0–0.5
	Bull adult	28 (29%)	11,875 (8%)	0.3	0.0	0.0–2.7
	Steer adult	33 (34%)	119,278 (77%)	0.2	0.1	0.0–0.5
	Steer calf	2 (2%)	3,506 (2%)	0.1	0.1	0.0–0.3
NEA	Beef heifer	8 (6%)	12,976 (4%)	0.1	<0.1	0.0–0.2
	Bull adult	8 (6%)	145 (<1%)	0.0	0.0	0.0–0.0
	Dairy cow	5 (4%)	5,123 (2%)	0.1	0.0	0.0–0.2
	Dairy heifer	106 (77%)	267,273 (90%)	0.1	0.1	0.0–2.0
	Steer adult	10 (7%)	12,414 (4%)	0.5	0.5	0.0–1.2
SEE	Beef heifer	4 (6%)	6,630 (4%)	0.6	0.3	0.3–1.3
	Bull adult	23 (36%)	28,479 (19%)	0.4	0.2	0.0–1.7
	Dairy heifer	3 (5%)	6,911 (5%)	0.3	0.3	0.2–0.5
	Steer adult	24 (38%)	92,855 (61%)	0.5	0.3	0.0–2.1
	Steer calf	10 (16%)	16,049 (11%)	0.5	0.4	0.0–1.1

MISC	Beef cow	1 (2%)	600 (<1%)	0.2	0.2	–
	Beef heifer	5 (9%)	4,123 (3%)	0.1	0.0	0.0–0.2
	Bull adult	9 (15%)	195 (<1%)	0.7	0.0	0.0–5.0
	Dairy heifer	31 (53%)	59,920 (45%)	0.4	0.2	0.0–3.0
	Cattle[A]	13 (22%)	68,913 (52%)	0.6	0.6	0.0–1.1

[A] Subcategories of cattle type not introduced until 2002.

4.3.7 Daily Cattle Deaths

Fig. 16 illustrates a comparison of mean mortality rate per voyage day for cattle exported from Australia, stratified by different destination regions. Mean mortality rate per day for voyages to MENA peaked at day 15 at 2.9%. For long-haul voyages to other discharge regions, the peak mean MR was less distinct with fewer voyages and data points for analysis (Fig. 16). More in-depth analysis regarding deaths per day can be seen in Section 4.5.2.

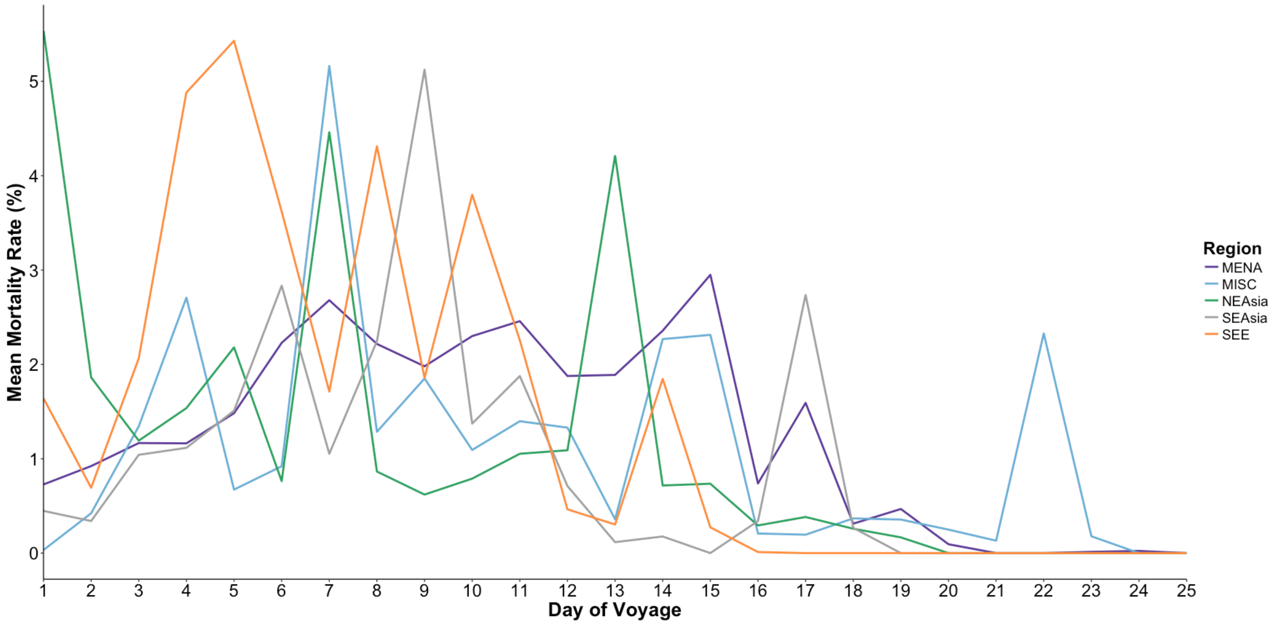

Fig. 16: Mean number of deaths per day of voyage for cattle exported from Australia between 1995 and 2017. MENA: Middle East/North Africa; SEAsia: Southeast Asia; NEAsia: Northeast Asia; SEE: South-eastern Europe; MISC: Miscellaneous.

4.4 Goat Voyages

4.4.1 Overview

One hundred and fifty long-haul voyages exported goats from Australia between 1988 and 2007, with 179,277 goats exported across these voyages (Table 22). These were predominantly to the Middle East/North Africa (147 voyages), with a small number to Miscellaneous ports (two voyages to Manzanillo (Mexico) and one voyage to Tamatave (Madagascar). Live export of goats peaked in 2002 (Fig. 17).

Table 22: Summary statistics for long-haul live goat export voyages from Australia between 1988 and 2007, by discharge region. MENA: Middle East/North Africa, Miscellaneous: Madagascar and Mexico.

Parameters	**MENA**[A]	**Miscellaneous**[B]	**TOTAL**
No. voyages	147 (98%)	3 (2%)	150 (100%)
Total goats loaded	176,902 (99%)	2,375 (1%)	179,277 (100%)
Mean MR (%)	2.0	0.8	2.0
Median MR (%)	1.5	0.00	1.5
Mortality range (%)	0–10.4	0–2.5	0–10.4
Mean voyage duration (days)	16.4	24.0	16.5
Mean discharge (days)	5.6	5.3	5.5
Voyages with zero mortality	21	2	23

[A] Voyages occurred 1988–2005, 2007

[B] Voyages occurred 1998, 2000, 2007

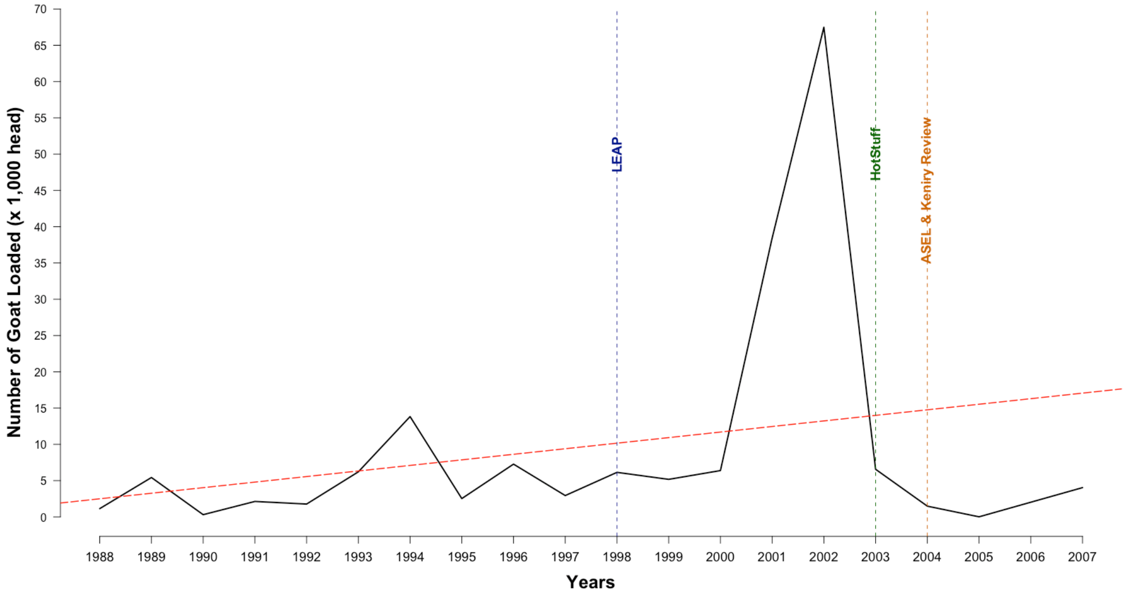

Fig. 17: Number of goats loaded for live export from Australia, 1988–2007, by year.
The years of implementation of industry initiatives aimed at reducing mortality are included in the map as vertical lines (LEAP: Livestock Export Accreditation Program, HotStuff: Heat Stress Risk Assessment Model, ASEL: Australian Standards for the Export of Livestock, and the Keniry review).

Mean VMRs were higher in goats than in cattle and sheep. A general downward trend in mean VMR occurred in goats exported on long-haul voyages from Australia to the Middle East/North Africa region from 1988 (Fig. 18).

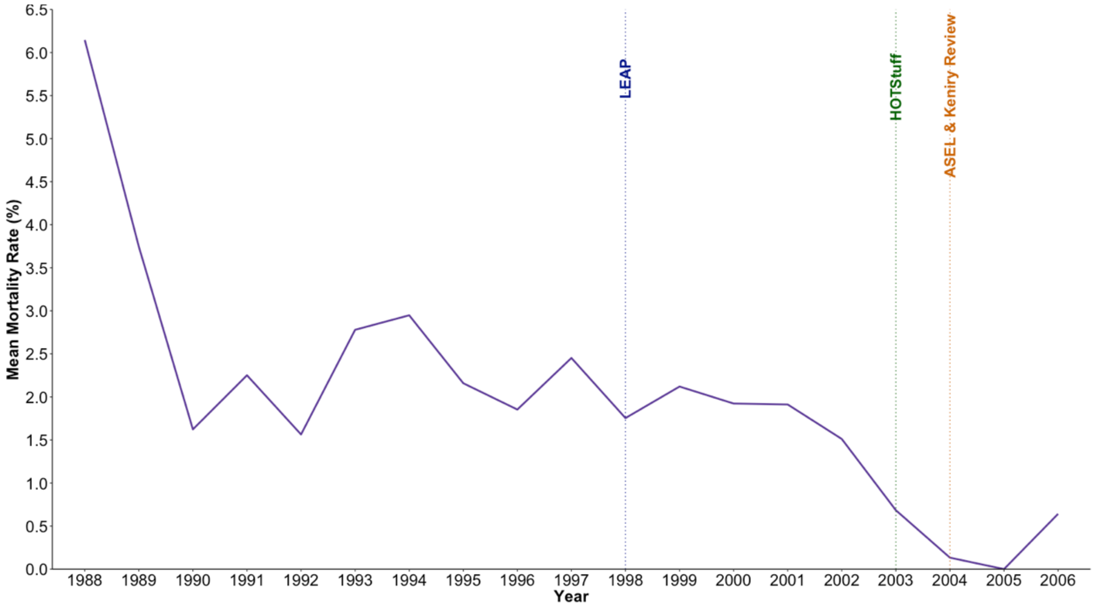

Fig. 18: VMR for goats transported by sea from Australia to the Middle East/North Africa between 1988 and 2007.
The years of implementation of key industry initiatives aimed at reducing mortality are included in the map as vertical lines (LEAP (Livestock Export Accreditation Program), HotStuff (Heat Stress Risk Assessment Model), ASEL (Australian Standards for the Export of Livestock) and the Keniry review).

4.4.2 Origin Ports

Six ports across Australia were used for the export of live goats on long-haul voyages between 1988 and 2007. The majority of voyages departed from southern ports, with the exception of two (one from Darwin and one from Port Hedland). The most frequently used ports were Fremantle and Adelaide (Table 23).

Table 23: Port origin summary statistics for goat exports from Australia to two regions (MENA (Middle East/North Africa) and MISC (Miscellaneous)), 1988–2007. VMR = voyage mortality rate.

Origin port region	**Origin Port**	**No. voyages**	**VMR rate (range)**	**Median VMR (range)**	**Mean loading days (range)**	**Mean voyage days (range)**	**Mean discharge days (range)**	**Total goats loaded (%), by discharge region:**	
								MENA	**MISC**
Southern	Adelaide	35	0.9 (0–3.4)	1.23 (0–3.4)	1.23 (1.0–2.0)	20.8 (13.0–27.0)	4.7 (1.0–10.0)	40,250 (100%)	-
	Fremantle	92	2.5 (0–10.4)	1.5 (0–10.4)	1.5 (1.0–4.0)	14.4 (10.0–29.0)	5.6 (1.0–14.0)	83,324 (99%)	239 (<1%)
	Port Kembla	1	2.5	1.0	1.0	21.0	2.0	-	2,124 (100%)
	Portland	20	1.5 (0–5.1)	1.5 (0–5.1)	1.5 (1.0–2.0)	17.5 (14.0–24.0)	7.1 (0.00–11.0)	51,365 (100%)	-
Northern	Darwin	1	1.7	1.00	1.0	24.0	5.0	1,963 (100%)	-
	Port Hedland	1	0.0	1.0	1.0	26.0	8.0	-	12 (100%)

4.4.3 Discharge Ports

Goats were exported from Australia to ten countries on long-haul voyages between 1988 and 2007. These were primarily to countries in the Middle East/North Africa region, including Oman, Saudi Arabia and the United Arab Emirates (Table 24). The voyage that recorded the highest VMR was from Port Kembla to Madagascar (2.5%, 54 deaths from 2,124 loaded).

Table 24: Mean goat VMRs (%) on live export voyages from Australia, 1988–2007, by discharge country; and number of goats loaded for live export across Australian (origin) ports during the same time period, by discharge country.
Discharge regions: MENA (Middle East/North Africa) and MISC (Miscellaneous); VMR = voyage mortality rate.

Discharge region	**Discharge country**	**No. voyages**	**Mean VMR (%)**	**No. goats loaded (%)**					
				Adelaide	**Fremantle**	**Port Kembla**	**Portland**	**Darwin**	**Port Hedland**
MENA	Bahrain	2	0.3	–	150 (93%)	–	12 (7%)	–	–
	Egypt	13	1.6	2,997 (19%)	8,943 (57%)	–	1,936 (12%)	1,963 (12%)	–
	Jordan	17	2.0	851 (6%)	9,533 (71%)	–	2,966 (22%)	–	–
	Kuwait	7	1.8	325 (4%)	8,288 (91%)	–	486 (5%)	–	–
	Libya	1	0.0	–	5 (100%)	–	-	–	–
	Oman	55	2.3	5,306 (18%)	21,253 (71%)	–	3,280 (11%)	–	–
	Saudi Arabia	29	1.6	25,182 (30%)	16,718 (20%)	–	41,240 (50%)	–	–
	United Arab Emirates	27	2.4	5,589 (22%)	18,462 (72%)	–	1,445 (6%)	–	–
MISC	Madagascar	1	2.5	–	–	2,124 (100%)	–	–	–
	Mexico	2	0.0	–	239 (95%)	–	–	–	12 (5%)

4.4.4 Vessels

Between 1988 and 2007, 23 vessels transported goats on long-haul voyages from Australia. Two of these vessels transported goats to both the Middle East/North Africa and Miscellaneous discharge regions (Table 25).

Table 25: Number of voyages for each vessel involved in live export of goats from Australia, 1988–2007, by discharge region; mean VMR across voyages for each vessel; and no. voyages by mortality rate for each vessel.
Discharge regions: Middle East/North Africa (MENA) and miscellaneous category (MISC); VMR = voyage mortality rate.

Vessel ID	**No. voyages, by VMR**			**Mean VMR (%)**	**No. voyages, by discharge region**	
	<1%	**1.0–2.0%**	**>2%**		**MENA**	**MISC**
14	6 (55%)	3 (27%)	2 (18%)	1.6	11	0
21	4 (44%)	2 (22%)	3 (33%)	2.3	9	0
24	2 (67%)	0	1 (33%)	1.8	3	0
8	1 (25%)	0	3 (75%)	2.2	4	0
50	3 (33%)	2 (22%)	4 (44%)	2.3	9	0
46	0	2 (50%)	2 (50%)	3.5	4	0
22	6 (40%)	8 (53%)	1 (7%)	1.5	15	0
30	3 (100%)	0	0	0.7	3	0
25	1 (100%)	0	0	0.9	1	0
16	2 (33%)	2 (33%)	2 (33%)	3.0	6	0
51	0	1 (50%)	1 (50%)	3.7	2	0
20	4 (80%)	0	1 (20%)	0.5	4	1
48	0	0	1 (100%)	5.1	1	0
54	0	0	6 (100%)	5.5	6	0
18	3 (19%)	4 (25%)	9 (56%)	2.6	16	0
12	4 (31%)	7 (54%)	2 (15%)	1.2	13	0
17	3 (27%)	6 (55%)	2 (18%)	1.5	11	0
26	4 (44%)	3 (33%)	2 (22%)	1.4	9	0
15	1 (33%)	2 (67%)	0	1.2	2	1
19	8 (57%)	3 (21%)	3 (21%)	1.0	14	0

31	0	0	1 (100%)	2.5	0	1
23	0	0	1 (100%)	3.4	1	0
52	1 (33%)	1 (33%)	1 (33%)	1.7	3	0
TOTAL	56 (37%)	46 (31%)	48 (32%)	2.0	147	3

4.4.5 Time of Year

Mean goat VMRs varied depending on the time of year (Fig. 19). However, the limited number of goat voyages limits the validity of inferences of trends in VMR patterns.

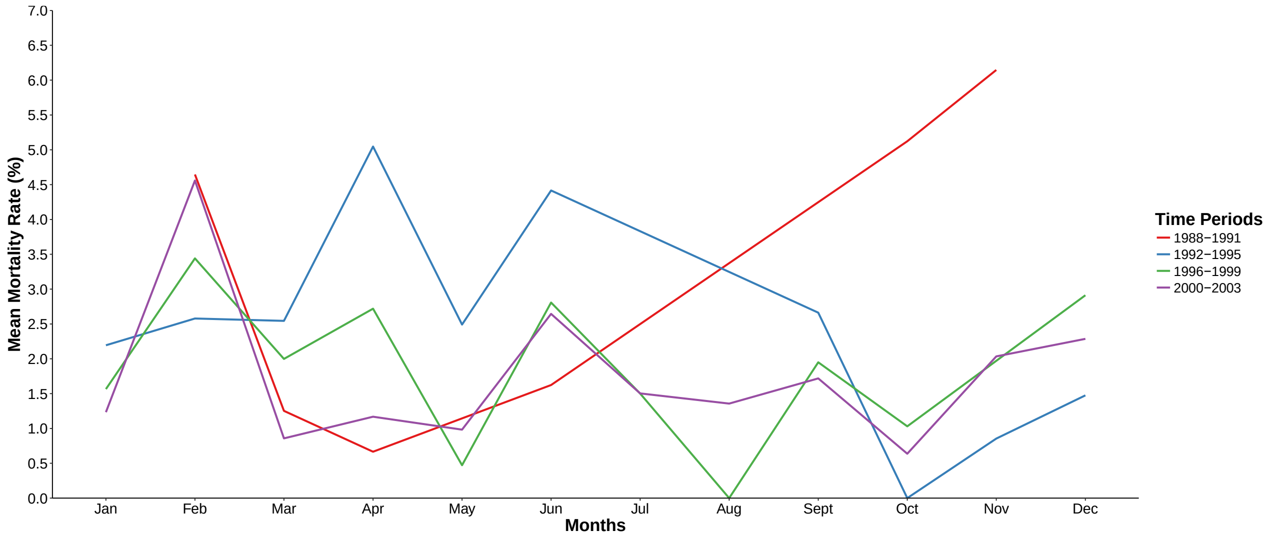

Fig. 19: Mean VMRs (%) of goat live export voyages departing Australia to the Middle East/North Africa discharge region, 1988–2007, by month of voyage departure.
Data are stratified into 4 year periods. The May to Oct represents the northern summer period.

4.4.6 Animal Class and Breed

The majority of exported goats (157,240 head) were not classified into subcategories indicating details of type or sex — classification was restricted to “goats”. The remaining goats (1,747 head) were subclassified (Table 26).

Table 26: Descriptive statistics of mortality in different goat classes exported by sea, Nov 1988 – Dec 2007, by discharge region. MENA: Middle East/North Africa, MISC: Miscellaneous; VMR = voyage mortality rate.
*** The findings of this table should be read carefully due to the small number of data available **.*

Discharge region	Class	No. voyages (%)	Total loaded (%)	Mean VMR (%)	Median VMR (%)	VMR range (%)
MENA	Agricultural Buck Large	5 (3%)	561 (<1%)	2.0	0.0	0–5.8
	Agricultural Doe Large	4 (3%)	775 (<1%)	1.4	1.2	0–3.0
	Agricultural Wether Large	4 (3%)	2,792 (2%)	2.1	1.9	0.1–4.7
	Feral Buck Large	10 (7%)	9,224 (5%)	3.1	2.6	0–7.3
	Feral Buck Small	5 (3%)	4,870 (3%)	2.1	1.9	1.3–3.0
	Feral Wether Small	2 (1%)	1,574 (1%)	2.2	2.2	2.2–2.3
	Goats	122 (80%)	157,228 (89%)	1.9	1.3	0–10.4
MISC	Agricultural Buck Large	1 (20%)	366 (15%)	0.8	0.8	–
	Agricultural Doe Large	1 (20%)	45 (2%)	0.0	0.0	–
	Agricultural Doe Small	2 (40%)	1,952 (82%)	1.5	1.5	0–3.0
	Goats	1 (20%)	12 (<1%)	0.0	0.0	–

4.4.7 Daily Goat Deaths

The mean VMR per day for voyages to MENA peaked at day five for long-haul voyages between 1988 and 2007 (Fig. 20).

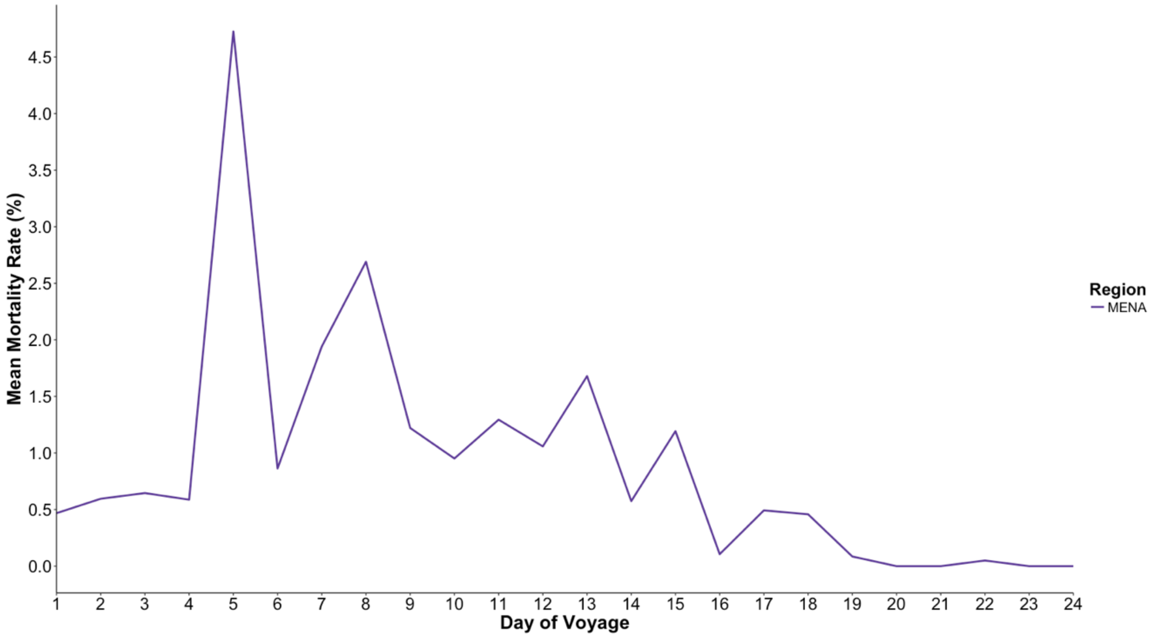

Fig. 20: Mean number of deaths per day of voyage for goats exported from Australia to MENA (Middle East/North Africa), 1988-2007.

4.5 Mortality Modelling

The MENA region accounts for 97% of sheep voyage days, and 72% of cattle voyage days available in the shipboard mortality database. To facilitate a valid modelling comparison, the regions applied in the descriptive statistics (which were as previously reported upon in industry reports), were reclassified into 14 modelling regions (Table 27). Of these regions, the Persian Gulf and Red Sea destinations represent the greatest proportion voyage days across the data record. Hence, the exploratory modelling of daily mortality was restricted these two modelling regions.

Table 27. Number of voyage days across all (fully recorded) voyages departing from Australian ports to the destination regions reclassed for the exploratory modelling of mortality.
These numbers exclude any missing data observations that could not be included within the GAMM analysis.

Destination Region	**Sheep**		**Cattle**	
	Total voyage days	**% of all voyage days**	**Total voyage days**	**% of all voyage days**
Baltic Sea	217	0.1	105	0.3
Bay of Bengal	0	0.0	55	0.2
Black sea	40	0.0	1,460	4.5
Central America	810	0.4	335	1.0
Eastern Mediterranean	3,322	1.8	2,306	7.0
Java Sea	137	0.1	443	1.4
North Africa	925	0.5	893	2.7
Persian Gulf	117,618	65.1	8,827	26.9
Red Sea	57,262	31.7	14,723	44.9
Sea of Japan	0	0.0	319	1.0
South China Sea	0	0.0	1,350	4.1
West India	408	0.2	269	0.8
Yellow Sea	0	0.0	1,718	5.2
Total	180,739	100.0	32,803	100.0

4.5.1 Sheep

The highest DMR across all sheep classes were observed on voyages from southern Australia to the Persian Gulf, followed by the voyages transiting through and/or arriving in the Red Sea (Fig. 21). Mortality on the Persian Gulf route increased from the Tropic of Capricorn, with peaks off the south to south-western coast of India and off the coast of Oman.

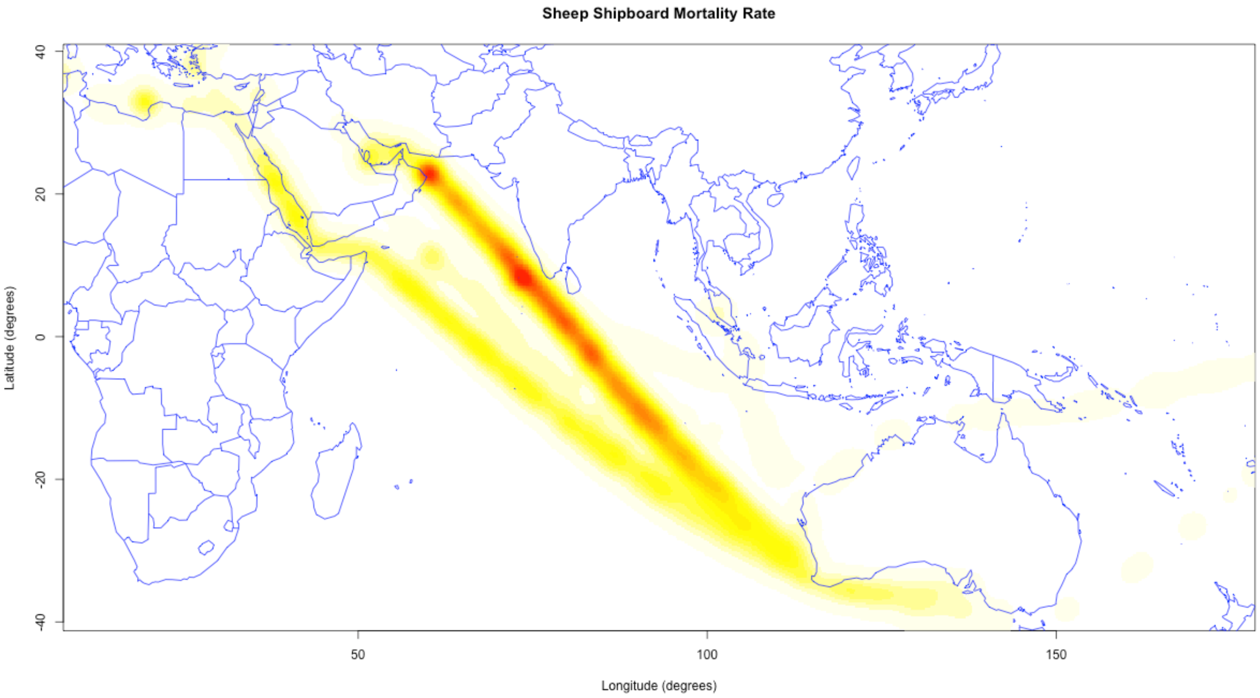

Fig. 21. Heatmap of shipboard DMRs of sheep originating from Australian ports, November 1988 to November 2017. Increasing DMR is represented on a colour scale from light yellow through to red. Data were smoothed through kernel regression to demonstrate where hotspots in shipboard mortality occur. As the data were sparse, with geolocations assigned based on the segmentation of single origin-to-destination routes, the smoothed DMR estimate was impacted by the smoothing process itself. Hence, the DMR scale has not been reported.

Sheep class and departure origin

The parametric components of the mortality model identify both sheep class (age by sex by breed) and port of origin as key predictors of mortality. When compared to adult Merino wethers, only Damara and other rams (all ages) and Awassi ram hoggets have higher odds of mortality (
Table 28). Other animal classes, particularly ewes and lambs, have lower or equivalent odds of mortality.

There were higher odds of mortality amongst sheep on voyages departing from Portland and Devonport, compared to sheep on voyages departing from Fremantle (
Table 28). The discrepancies in odds of mortality between ports of origin are on the whole larger than those between different classes of sheep, indicating that the port of origin is a better predictor of mortality than sheep class.

The estimated standard deviation among different voyages by the one vessel (1.17) was almost four times that than inter-vessel differences (0.33), with autocorrelation accounted for in the GAMM modelling through the smoothing across the day since departure. This suggests that voyage-specific factors influence mortality in sheep more than vessel-specific design factors.

*Table 28. Odds ratios for shipboard mortality of sheep across the class and origin categorical factors. Note that significance in the table does not consider any multiple test adjustment to the p-values, such as the Bonferroni correction (*** = p-value < 0.0001; ** = p-value < 0.01; * = p-value < 0.05; . = p-value < 0.10).*

Model term	Value	Odds Ratio	95% CI	p-value	Significance
Class	Merino Ram Adult Origin: Fremantle Destination: Red Sea	0.0004	0.0003 – 0.0004	<0.001	***
	Awassi Ewe Adult	0.61	0.56 – 0.65	<0.001	***
	Awassi Ewe Hogget	0.75	0.38 – 1.51	0.42	
	Awassi Ewe Lamb	0.34	0.33 – 0.35	<0.001	***
	Awassi Ram Adult	0.58	0.52 – 0.65	<0.001	***
	Awassi Ram Hogget	1.18	0.99 – 1.42	0.07	.
	Awassi Ram Lamb	0.43	0.42 – 0.44	<0.001	***
	Awassi Wether Adult	0.40	0.20 – 0.80	0.01	**
	Crossbreed Ewe Adult	0.79	0.74 – 0.85	<0.001	***
	Crossbreed Ewe Hogget	0.62	0.54 – 0.71	<0.001	***
	Crossbreed Ewe Lamb	0.81	0.78 – 0.83	<0.001	***
	Crossbreed Ram Adult	0.86	0.81 – 0.91	<0.001	***
	Crossbreed Ram Hogget	0.90	0.81 – 1.00	0.04	*
	Crossbreed Ram Lamb	0.99	0.97 – 1.02	0.54	
	Crossbreed Wether Adult	0.82	0.79 – 0.84	<0.001	***
	Crossbreed Wether Hogget	0.50	0.48 – 0.53	<0.001	***
	Crossbreed Wether Lamb	0.73	0.72 – 0.74	<0.001	***
	Damara Wether Lamb	0.73	0.66 – 0.80	<0.001	***
	Damara Ewe Adult	0.74	0.69 – 0.80	<0.001	***
	Damara Ewe Hogget	0.83	0.41 – 1.68	0.61	
	Damara Ewe Lamb	0.82	0.78 – 0.86	<0.001	***
	Damara Ram Adult	1.06	0.98 – 1.14	0.18	
	Damara Ram Hogget	1.29	1.23 – 1.37	<0.001	***
	Damara Ram Lamb	1.25	1.23 – 1.28	<0.001	***
	Damara Wether Adult	0.81	0.70 – 0.95	0.01	**
	Feral Wether Small	1.33	0.89 – 1.99	0.16	
Class	Karakul Ewe Adult	0.83	0.68 – 1.01	0.07	.
	Karakul Ewe Lamb	0.36	0.32 – 0.39	<0.001	***
	Karakul Ram Adult	0.22	0.11 – 0.45	<0.001	***
	Karakul Ram Hogget	0.0001	0.00 – ∞	0.89	
	Karakul Ram Lamb	0.52	0.50 – 0.55	<0.001	***

Model term	Value	Odds Ratio	95% CI	p-value	Significance
	Karakul Wether Lamb	0.0000	0.00 – ∞	0.98	
	Merino Ewe Adult	0.98	0.96 – 0.99	0.01	**
	Merino Ewe Hogget	0.64	0.59 – 0.70	<0.001	***
	Merino Ewe Lamb	0.77	0.74 – 0.79	<0.001	***
	Merino Ram Hogget	1.02	1.00 – 1.04	0.07	.
	Merino Ram Lamb	0.97	0.95 – 0.98	<0.001	***
	Merino Wether Adult	0.99	0.98 – 1.00	0.11	
	Merino Wether Hogget	0.52	0.52 – 0.53	<0.001	***
	Merino Wether Lamb	0.68	0.67 – 0.69	<0.001	***
	Other Ewe Adult	0.99	0.84 – 1.17	0.91	
	Other Ewe Hogget	1.06	0.81 – 1.38	0.69	
	Other Ewe Lamb	0.64	0.59 – 0.71	<0.001	***
	Other Ram Adult	2.52	2.27 – 2.79	<0.001	***
	Other Ram Hogget	1.35	1.19 – 1.52	<0.001	***
	Other Ram Lamb	1.50	1.43 – 1.56	<0.001	***
	Other Wether Adult	0.63	0.54– 0.74	<0.001	***
	Other Wether Hogget	0.28	0.24 – 0.32	<0.001	***
	Other Wether Lamb	1.42	1.35 – 1.49	<0.001	***
Origin	Adelaide	1.22	1.02 – 1.47	0.03	*
	Darwin	2.06	0.21 – 20.6	0.54	
	Devonport	6.12	3.05 – 12.27	<0.001	***
	Geraldton	0.00	0.00 – ∞	0.97	
	Port Hedland	0.38	0.097 – 1.50	0.17	
	Portland	1.76	1.49 – 2.08	<0.001	***
	Wyndham	0.52	0.10 – 2.67	0.44	

The GAMM model of the shipboard mortality of sheep replicates the key features of the global map. Significantly, DMR (per 100,000 animals) increases with increasing length of voyage (Fig. 22). Response curves for only the Red Sea and Persian Gulf destinations were reported here, as they represent the majority of voyages. Overall, the Red Sea voyages have lower odds of mortality than the Persian Gulf voyages. For the Red Sea voyages, the DMR peaks at 24 days and then declines; for the Persian Gulf voyages, daily mortality has an initial earlier peak (at close to 12 days), with a second peak near 30 days. These peaks in mortality roughly coincide with the elevated mortality observed off the southern coast of India, and again off the coast of Oman (Fig. 21). These peaks may result from either highly influential, one-off mortality events, or may be due to temporal factors undescribed by the other terms in the model.

Shipboard mortality of sheep peaked in September–October of each year (approximately day 280; Fig. 22), with an odds ratio (~ 5) that was much higher than for the other components in the model (< 1.6). Day of year, as a measure of seasonality, was not correlated with the other predictor variables (< 2% correlation).

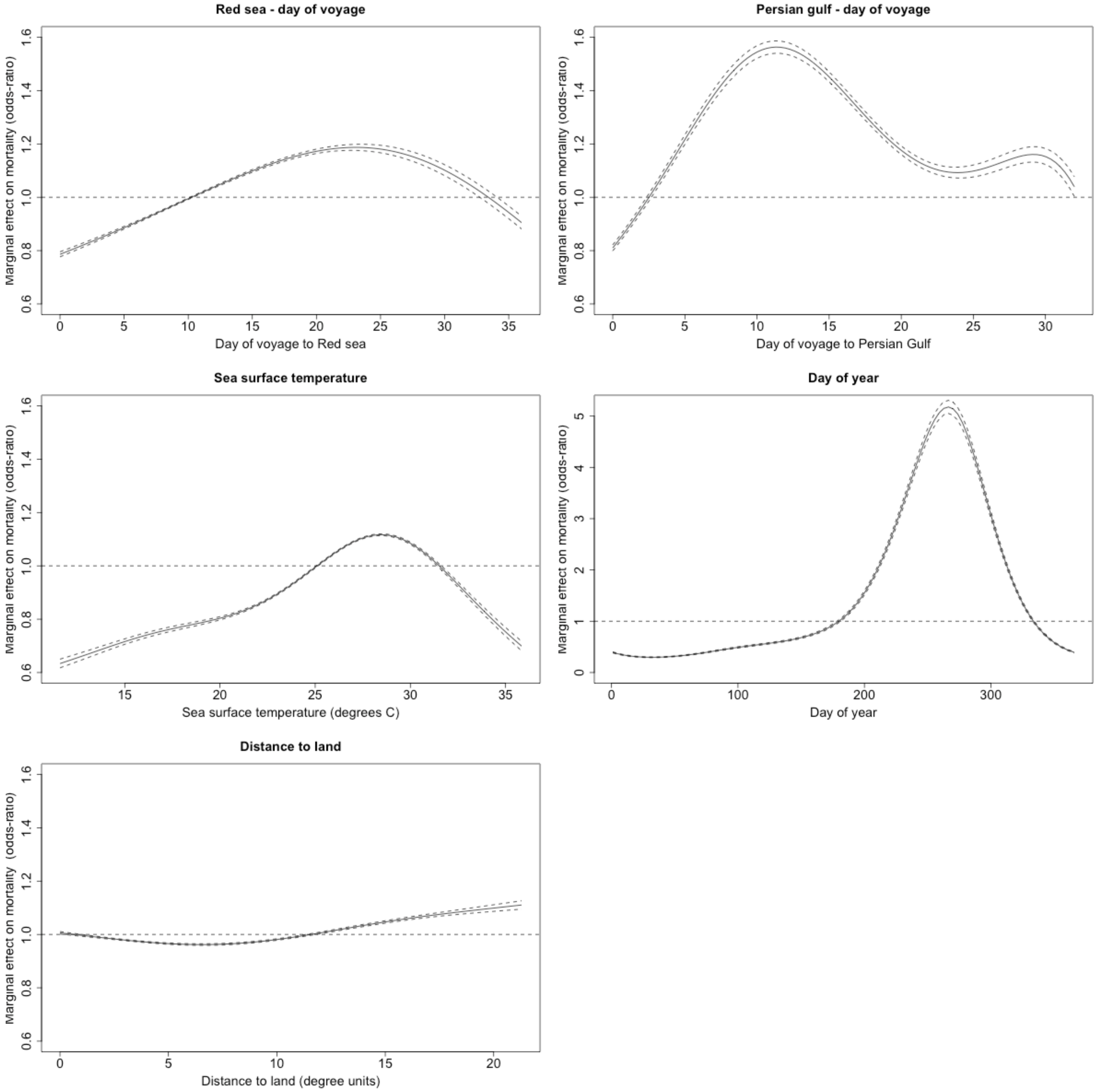

Fig. 22. Component smooth terms in the GAMM model of shipboard mortality for sheep.
Note that these component plots are presented on an odds ratio scale, and hence are centred on one. Distance to land is measured in degree units, with one degree unit approximating 100 km.

Shipboard mortality was seen to increase with increasing sea surface temperature, peaking at 25°C (Fig. 22). Though the modelled mortality declines after 25°C, a result that is counter-intuitive to an expectation that mortality would increase with increasing heat stress, it must be noted that day of voyage and sea surface temperatures are potentially confounder variables, with ~ 45% correlation between the variables. Hence, posterior model predictions need to be applied before the effect of sea surface temperature can be integrated over the response to day of voyage and distance to land. For illustration purposes, the joint posterior prediction over both day of year and sea surface temperature was constructed to examine if there were any seasonal variation in the effect of sea surface temperature (Fig. 23).

The model for voyages to the Persian Gulf (Fig. 23) reported that

- mortality was greatest between July (day 180) and October (day 300) across all sheep classes and sea surface temperatures.
- mortality on the Persian Gulf route was higher than for the Red Sea route, with elevated mortality of greater than 30 deaths per 100,000 sheep days for sea surface temperatures above 25°C. These temperatures equate to approximately 8 days since departure from Fremantle to the Persian Gulf, compared to 16 days (or sea surface temperatures above 27°C) for departures to the Red Sea for Merino adult wethers.
- mortality for Merino lamb wethers was lower than for Merino adult wethers, with elevated mortalities beginning at 16 days for the Persian Gulf voyage for lamb wethers, and after 20 days for the Red Sea voyage. For both voyage destinations, elevated mortality occurred at temperatures above 30°C.

These mortalities were risk-adjusted, by integrating out the effects of the other random effect and regressor terms included in the model. Extreme mortality events may be explained in part by random effect terms, and hence a generalised mortality response to the sea surface temperature and day of year risk factors emerges (Fig. 23). While the GAMM model generalises the mortality response to sea surface temperature and day of year across all destinations and sheep classes, the GAMM model is sensitive enough to identify differences between different destinations and sheep classes.

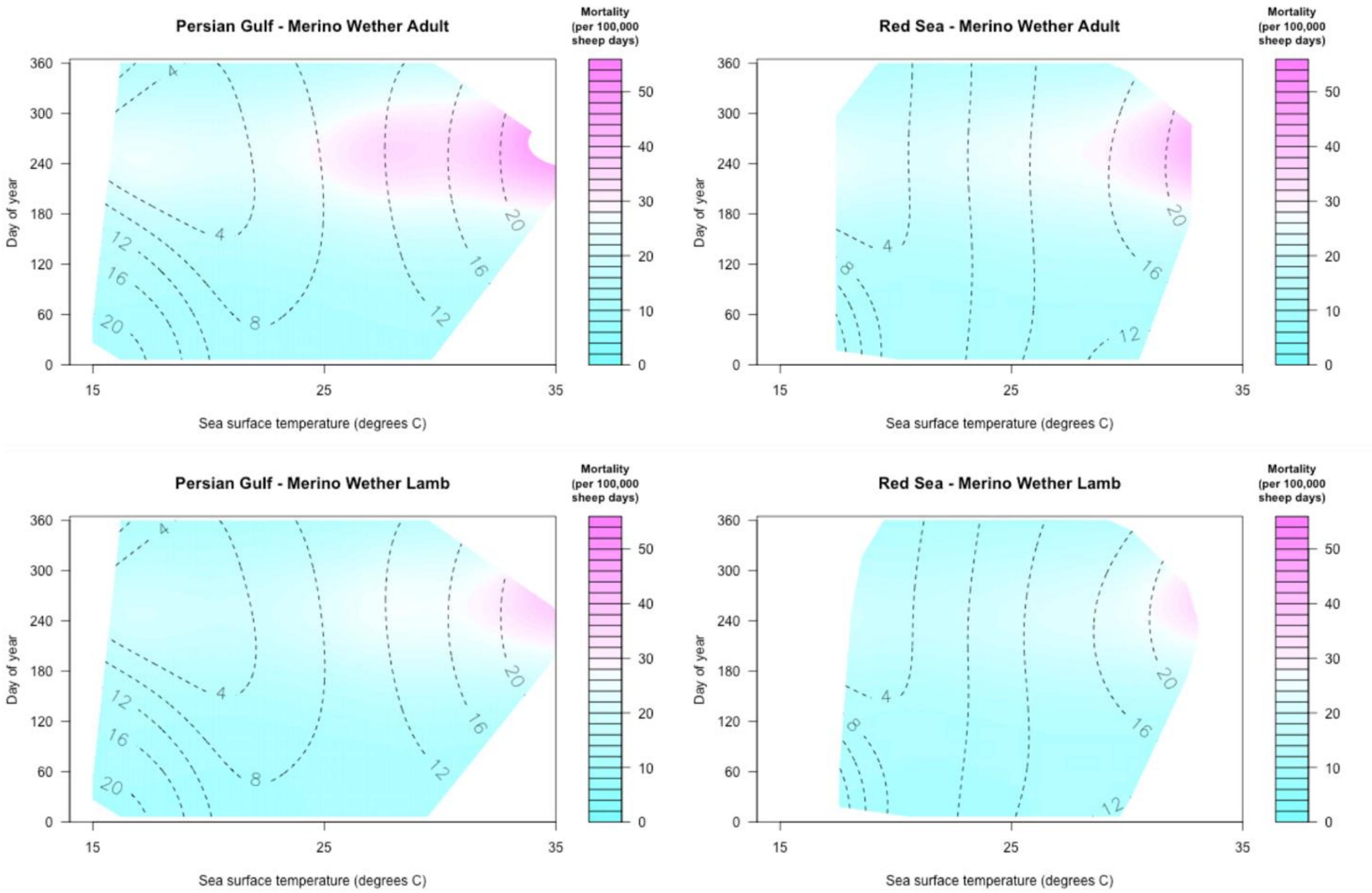

Fig. 23. GAMM modelling of the sheep DMR (per 100,000 sheep days) on sea surface temperature and day of year. Mortalities are for voyages originating from Fremantle port, with the class of sheep and destination region defined in the title of each plot. Superimposed on each plot is a contour representation of average day of voyage, to give an approximate reference as to when different mortality events were occurring given a sea surface temperature and day of year. These plots differ from the kernel regression plots insofar as posterior predictions from the GAMM modelling accounts for the other factors, thereby generalising the mortality response beyond singular events.

4.5.2 Cattle

DMRs across all cattle classes were observed to be greater on voyages to the Middle East than for voyages to south-east and east Asia (Fig. 24). While mortality was relatively constant for voyages to the Red Sea, two high mortality events may be observed on voyages to the Persian Gulf, with one located off the coast of Sumatra and the other off the coast of Bahrain in the Persian Gulf. A third, lower mortality event may be observed off the west coast of India.

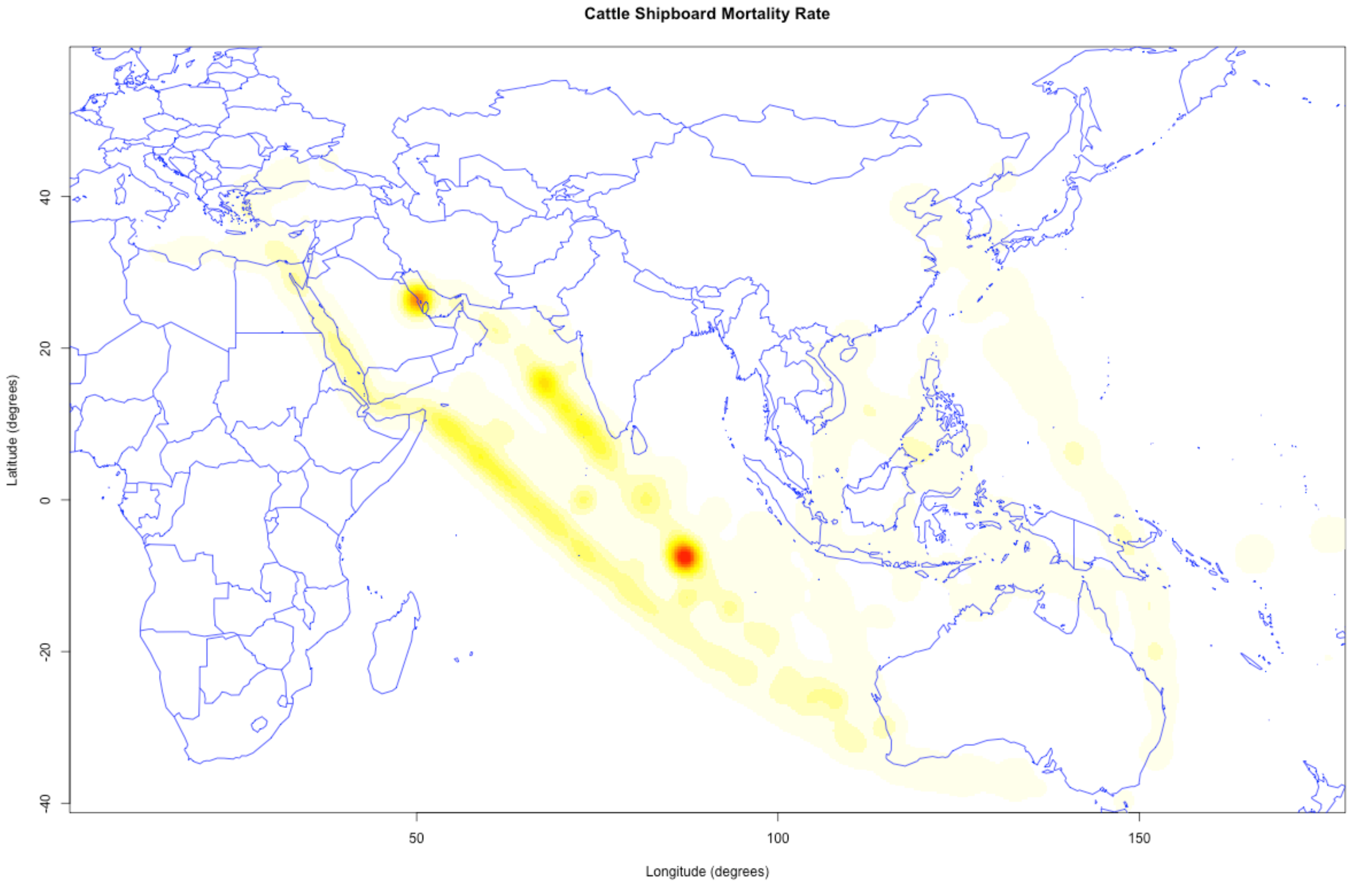

Fig. 24. Heatmap of shipboard DMRs of cattle originating from Australian ports, July 1995 to November 2017. Increasing DMR is represented on a colour scale from light yellow through to red. Data were smoothed through kernel regression to demonstrate where hotspots in shipboard mortality occur. As data were sparse, with geolocations assigned based on the segmentation of single origin to destination routes, then the smoothed DMR estimate was impacted by the smoothing process itself. Hence, the DMR scale has not been reported.

Of the different cattle classes (age by sex by production type; where production type is beef or dairy), only bull calves (odds ratio = 0.82) and dairy heifers (odds ratio = 0.68) had substantially lower odds of mortality than adult bulls (

Table 29). Meanwhile, beef heifers had similar mortality rates to adult beef bulls (p-value > 0.05), whilst the remaining classes, some of which were largely unspecified (e.g. the 'cattle' class), had substantially increased odds of mortality. Factor coefficients for different ports of origin variable were associated with large standard errors, with only Brisbane departures having a substantially lower DMR than Fremantle port. These port of origin effects may be confounded in part by cattle class and destination region effects, due to the imbalance in sample numbers across origins, classes and destination regions. For example, many of the dairy cattle (heifers and cows) departed from Portland to the Yellow Sea and Sea of Japan, whereas many of the beef cattle supplied to Red Sea ports originated from Fremantle.

The estimated standard deviation among different voyages by the one vessel (2.15) was almost three times that of inter-vessel differences (0.78). As with sheep transport, this suggests that voyage-specific factors influence mortality in cattle more so than vessel-specific (e.g. management and design) factors.

*Table 29. Odds ratios for shipboard mortality for cattle across the class and origin categorical factors. Note that significance in the table does not consider any multiple test adjustment to the p-values, such as the Bonferroni correction (*** = p-value < 0.0001; ** = p-value < 0.01; * = p-value < 0.05; . = p-value < 0.10).*

Model term	Value	Odds Ratio	95% CI	p-value	Significance
Class	Beef Bull Adult Origin: Fremantle Destination: Red Sea	0.00	0.00 – 0.00	<0.001	***
	Beef Cow	4.00	3.26 – 4.92	<0.001	***
	Beef Heifer	1.01	0.96 – 1.07	0.66	
	Bull Calf	0.82	0.79 – 0.85	<0.001	***
	Cattle	2.02	1.32 – 3.08	0.001	**
	Dairy Cow	1.45	1.25 – 1.67	<0.001	***
	Dairy Heifer	0.68	0.61 – 0.76	<0.001	***
	Steer Adult	1.11	1.07 – 1.14	<0.001	***
	Steer Calf	1.17	1.10 – 1.25	<0.001	***
Origin	Adelaide	1.34	0.77 – 2.34	0.30	
	Brisbane	0.03	0.00 – 0.39	0.01	**
	Broome	2.70	0.68 – 10.67	0.16	
	Darwin	1.37	0.26 – 7.11	0.71	
	Devonport	1.34	0.08 – 23.67	0.84	
	Geelong	1.05	0.23 – 4.89	0.95	
	Geraldton	1.25	0.01 – 117.27	0.92	
	Port Hedland	1.45	0.41 – 5.13	0.57	
	Portland	1.35	0.89 – 2.06	0.16	
	Townsville	2.41	0.89 – 6.49	0.08	.
	Wyndham	1.13	0.05 – 26.40	0.94	

Many of the marginal terms make intuitive sense in the GAMMS modelling for cattle (Fig. 25; Fig. 26), as there is

- a general increase in mortality with day of voyage to both the Red Sea and Persian Gulf. Elevated mortality generally occurs on day 12 onwards.
- daily mortality increases between a sea surface temperature of 15°C and 30°C, before plateauing beyond 30°C. The broader confidence band below 15°C implies less power to distinguish any change in daily mortality in response to sea surface temperature for that domain of values (Fig. 25).
- daily mortality is elevated for cattle between February (day 30) through to June (day 180) of each year.
- bull calves transported to the Red Sea had lower mortality than that of bull adults arriving at the same destination. Daily mortality for adult bulls on the Red Sea was elevated when sea surface temperatures were greater than 25°C, compared to 30°C on the Persian Gulf route for adult bulls (Fig. 26).

The estimated standard deviation explaining variation among different voyages by the one vessel (2.24) was three times the standard deviation of inter-vessel differences (0.68) on the linear predictor scale. These voyage and vessel specific factors explained proportionately more of the total variance in daily mortality than what these voyage and vessel specific factors did in the model for sheep.

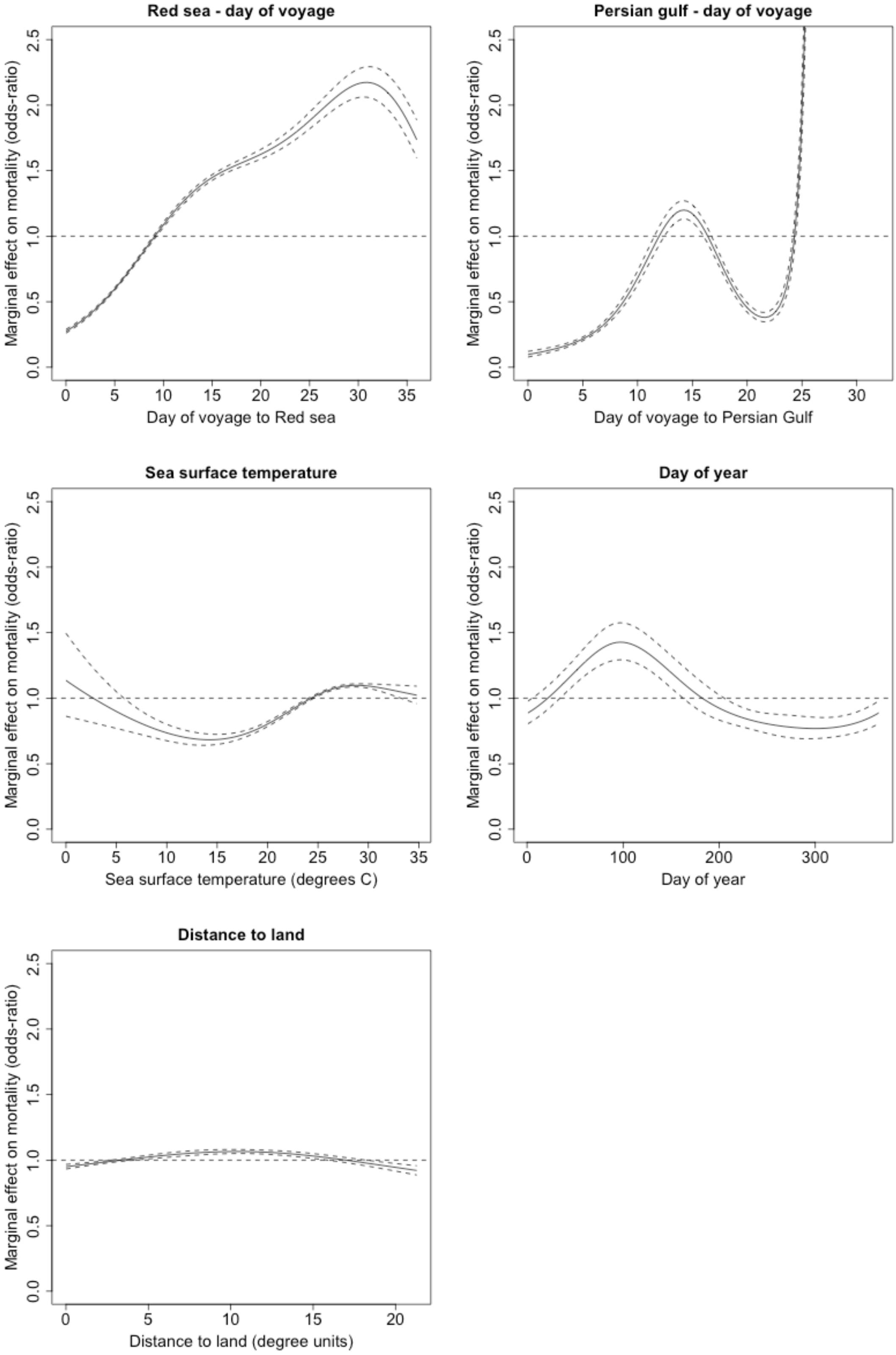

Fig. 25. Component smooth terms in the GAMM model of shipboard mortality for cattle.
Note that these component plots are presented on an odds ratio scale, hence are centred on one. Singular reportable mortality events and multicollinearity can influence the outcomes of the component-wise marginal predictions considerably, as may be the case for the day-of-voyage trend above.

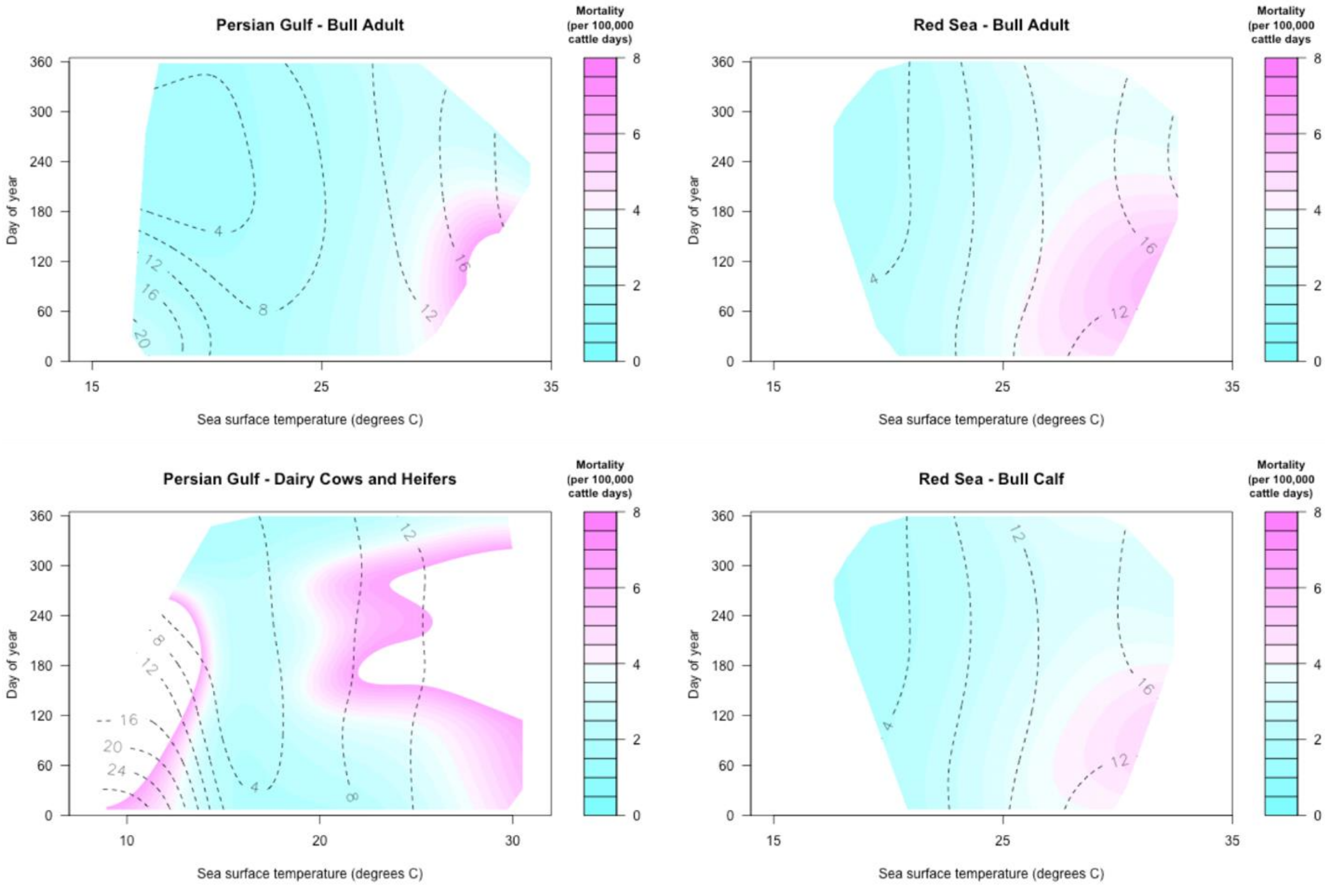

Fig. 26. GAMM modelling of the cattle DMR (per 100,000 cattle days) on sea surface temperature and day of year.
DMRs are for voyages originating from Fremantle port, with the class of cattle and destination region defined in the title of each plot. Superimposed on each plot is a contour representation of average day of voyage, to give an approximate reference as to when different mortality events were occurring given a sea surface temperature and day of year. Note that there were few exports from Fremantle port of bull calves to the Persian Gulf, and similarly, few exports of dairy cattle to the Red Sea, and so two different cattle classes have been presented on the bottom row. Moreover, as the data are relatively sparse there is sometimes misbehaviour of the fitted surface at the boundary regions of a plot, especially where data are sparse (as is the case in particular for the dairy cattle). This is a known limitation of the GAMM methodology. As a consequence, the plots have been truncated at the maximum scale for the Red Sea mortalities of eight deaths per 100,000 cattle days.

5 Discussion

5.1 Descriptive statistics

This report aimed to understand 30 years of the industry's historical shipboard mortality performance in terms of voyage and DMRs. The focus of the study was all long-haul voyages (≥ 10 days duration) recorded between 1988 and 2017. This analysis was made possible by the recent integration of previously omitted data into the shipboard mortality database (https://smdb.livexdb.com). The analysis of shipboard mortality comprised of

- exploratory data analyses, with reporting of animal performance (mortality) segmented by key variables such as year, month, route (origin and destination ports), animal class and vessel
- a mortality analysis with the development of a predictive model to investigate mortality risk factors
- generation of maps to visualise mortality along shipping routes, while controlling for seasonal, spatial and voyage-specific factors.

The pattern of livestock transport has varied over the past 30 years. Sheep exports plateaued in the early-to-mid 1990s, then peaked in 2001, before slowly declining since the adoption of the HotStuff model of heat stress risk assessment in 2003, and the introduction of the ASEL standards in 2004. These exports have been predominantly Merino wethers (adult and hogget) and Merino lambs (ram and ewe), totalling more than 100,000,000 animals across the 30-year period. Exports of other sheep breeds (Awassi, Damara and Karakul) were predominantly of ram and ewe lambs. The MENA region accounted for 98% of all sheep exports as a destination over this period. Oman received the highest proportion of sheep exports (40%, just over 40 million head).

Long-haul cattle exports commenced in 1995, with over 3,000,000 animals having since been transported. Approximately 75% of these long-haul voyages were discharged to the MENA region, with steers and bulls the major animal types. Recent years have seen considerable numbers of dairy heifers transported to the Northeast Asia region. Overall, cattle exports peaked in 2002, before a sudden drop coincident with the 2003 Keniry review, followed by a slow increase before another sharp drop across 2016 and 2017. Egypt received the highest proportion of cattle exports (25%, just over 750,000 head).

Close to 300,000 goats have been exported since 1988, with numbers exported peaking in 2002, and finishing in 2007. Saudi Arabia received the highest proportion of goat exports (46%, just over 83,000 head). While the goat VMR exceeded 2% to MENA destinations, the VMR had steadily declined during the two decades of goat exports.

VMRs on long-haul voyages have steadily declined for all species over their respective recording periods. Sheep VMR has declined from approximately 2.5% to 1% per voyage on average (Fig. 8), cattle VMR from approximately 0.7% to 0.3% on average (Fig. 13, Fig. 14), and goat VMR from above 2% to approximately 0.5% (Fig. 18). Similarly, year-to-year variability in VMRs appear also to have declined, with high year-to-year variability a characteristic of VMRs at the start of the study period. The implementation of various industry initiatives and structural changes to vessels to meet improved industry standards may have influenced this trend. A further characteristic of shipboard mortality is that high VMRs are concentrated to sporadic reportable mortality events. Reportable mortality events can highly influence the annual mortality figures.

Analyses indicate that sheep tend to experience higher average VMRs during the northern summer period on voyages to Middle East/North Africa. This corresponded well to the modelling of DMRs that identified seasonal variation in DMRS, with elevated mortality observed for sheep exported between June and

October/November (Fig. 9). The movement of livestock on voyages from southern ports in Australia during winter months to the northern hemisphere summer (from May to October) has been associated with elevated DMRs due to heat stress, particularly in sheep (Phillips, 2016). The high demand for sheep during this time has been associated with religious holidays such as the Eid al-Fitr and Eid al-Adha feasts (Phillips 2016).

In contrast, cattle mortality was relatively consistent across the year, with peaks in May and June attributable to well documented random mortality events occurring in the period prior to 2003 (Fig. 15).

DMRs across all cattle classes were observed to be greater on voyages to the Middle East than for voyages to south-east and east Asia (Fig. 24). As the breed typically in demand in the Middle East/North Africa region is *Bos taurus,* this may have inflated mortality rate figures for voyages destined for the Middle East compared to other destinations. In comparison to *Bos indicus* cattle, *Bos taurus* have been demonstrated to have lower tolerance to heat, and experience more pronounced physiological changes during prolonged exposure to heat and humidity (Beatty et al., 2006).

The descriptive statistics were supported by the modelling of DMRs, which controlled for other mortality risk factors: the odds-ratio for the sheep DMR was of greater scale for sheep, occurring between August (approximately day 200 of the year) and November (approximately day 310) (Fig. 22); whereas cattle DMR was elevated between February (approximately day 40) and June (approximately day 180) (Fig. 25). However, this last result for cattle may be highly influenced by early reportable mortality events. Goat mortality was highly variable from month-to-month, without demonstrating any clear seasonal pattern (Fig. 19).

Using the outcome of DMR (rather than VMR) allowed daily risk factors (such as temperature) to be included in the model. The marginal odds-ratio for the DMR was elevated for sea surface temperatures above 25°C for both sheep and cattle. The marginal odds ratio was greater for sheep than it was for cattle, suggesting that they may be more susceptible to shipboard heat stress (Fig. 22, Fig. 25). If so, this may reflect physiological or management differences between the species. Some confounding in the model may be occurring, between the day of year marginal effect plot and the temperature marginal effect plot for sheep when temperature is high, with daily humidity data absent from the analysis. Importantly, a threshold sea surface temperature of 25°C likely correlates with a wet bulb temperature of 28°C for sheep, a threshold that results in the animal's core body temperature increasing by 0.5°C (Stockman, 2011). Beef cattle appear more tolerant to heat stress but can exhibit core body temperature increases when wet bulb temperatures rise beyond 26°C (Caulfield et al., 2014). Of note, the level of heat stress experienced by an animal is influenced by a number of factors additional to temperature and species— these include breed, ship structure and ventilation, stocking rate and where animals are loaded onto a vessel (Collins et al., 2018; Phillips, 2016; Stockman et al., 2011; Zhang and Phillips 2018). Heat stress results in both behavioural and physiological changes; these can impair welfare and lead to death (Caulfield et al. 2014; Moore et al. 2015). Elevated temperatures can also result in many suboptimal production parameters, with body condition declining with reduced feed intake (Marai et al. 2007).

The descriptive analyses provide some support for the existence of an adjustment period, where initial mortality may be elevated as animals acclimatise to the shipboard environment (Moore et al., 2015). A similar period of adjustment may also be found for land-based feedlots (Perkins, 2013). For sheep, the initial period of elevated mortality was 12 days for SEE discharges, and 20 days for MENA discharges (Fig. 11). For cattle, the initial period was 15–18 days, depending on the destination (Fig. 16). For goats, it was 15 days (Fig. 20). However, the exploratory GAMM models, which control for temperature and seasonal effects, highlights that the DMR may actually be increasing with length of voyage, given temperature effects may be confounded by day of voyage when vessels traverse the equator: sheep discharged at Red Sea ports have DMRs peaking between 20 and 25 days, whereas sheep discharged at Persian Gulf ports have DMRs peaking at close to 10 days (Fig. 21). Consequently, sheep DMRs on voyages to the Persian Gulf are more pronounced along the length of the voyage, than for voyages to the Red Sea (Fig. 22). Cattle DMRs peaked between 30 and 35 days for Red Sea ports, whilst cattle on voyages to Persian Gulf ports have DMRs initially peaking at 15 days (Fig. 25). Moreover, for cattle exported to the Persian Gulf, a small number of reportable mortality events that occurred on specific voyage days were identifiable over a low background DMR, and are considered likely to have influenced findings (Fig. 24). Comparatively, the background DMR for sheep was higher, with days of high mortality more evenly distributed across the voyage, with a lower scope for such influences (Fig. 21). However, it remains for both sheep and cattle that high DMRs are typically associated with a reportable mortality event of one to several days' duration.

Given the focus of these analyses on long-haul voyages, some specific considerations are needed around the context of the outputs generated. Firstly, there is currently substantial trade of live cattle to Southeast Asia — however, as the average voyage length to this region is around 5 days, trade along this route has not been analysed. Thus, this study's findings cannot be extrapolated to these live export circumstances. In addition, by considering only long-haul voyages, the voyages included in these analyses are more likely to have departed from southern ports as opposed to northern ports.

5.2 Exploratory modelling approaches

A key result of the modelling analysis was that shipboard mortality to the Persian Gulf region was greater than for other routes when voyage destinations were considered in more localised manner. For sheep, mortality increased steadily to peak in the tropics off the west coast of India, before decreasing in the Indian Ocean prior to another peak off the coast of Oman (Fig. 21). For cattle, two clear hotspots in mortality were identified— off the coast of India en-route to the Persian Gulf, and within the Persian Gulf itself (Fig. 24). For cattle, shipboard DMRs were not as severe for voyages to East Asian destinations as they were for Middle Eastern destinations. From these global maps a manager may surmise that further care of animals may need to be undertaken when in transit through these hot spot areas, or identify when and where exceptional events have occurred as a starting point for a root-cause analysis. However, the kernel regression methods employed to construct the global maps do not identify which risk factors were at play when shipboard DMRs were high.

In contrast, a GAMM approach to modelling shipboard mortality was able to account for multiple risk factors in the model specification, as well as weight the model more towards common events rather than towards the exceptional events that descriptive models (such as the global maps) highlight. Importantly, interactions between key risk factors may be explored through marginal predictions that are adjusted for the impacts of other candidate factors. For example, the smoothed models demonstrated that daily mortality for sheep was elevated from June to October, in contrast to cattle where daily mortality was elevated from February to June (Fig. 23; Fig. 26). Moreover, elevated mortality occurs during these higher risk periods when sea surface temperatures were above 25°C and 30°C, depending on livestock class and destination. However, the interaction between the day of year of the data record and sea surface temperature is but one risk-adjusted 'slice' of the data that can be constructed. Interactions between other risk-factors may be explored in a similar manner by applying marginal predictions of a GAMM model.

Importantly, the shipboard mortality data were characterised principally by:

- high variability, with extreme DMRs occurring on a small number of voyages and not on the bulk of others
- low spatial precision of spatial covariates such as sea surface temperatures
- minimal balance across different values of some of the predictor variables (e.g. the Awassi sheep breed was not as well represented across voyages as Merinos)
- the omission of candidate predictors that may have a strong influence in predicting shipboard mortality (e.g. mean daily wind speed, shipboard relative humidity).

Increasing the accuracy of the data will provide greater confidence in conclusions drawn from modelling mortality risk factors. In the first instance, Marine Traffic records wind direction, speed and temperature at high temporal resolution, and these data may be readily federated into the shipboard mortality database. These records are derived from shipboard instrumentation and would enable daily mortality or other animal welfare measures to be coupled with GNSS vessel locations and weather station data (wind direction, speed, relative humidity, ambient temperature, and an inertia unit to measure sea roughness). Furthermore, the inclusion of random effects in the GAMM modelling helps to identify which voyages and vessels had relatively high mortalities. This may support root cause analysis to understand where technological advances with greatest impact on reducing mortality can be made, in terms of voyage management, animal stocking patterns, ship design and engineered solutions to animal stress. For example, this report's findings suggested that voyage-specific factors explain more variation in daily mortalities than ship-specific factors for both sheep and cattle, and proportionately more so for cattle. These conclusions would support greater innovation around voyage management, particularly when sea surface temperatures begin to climb above 25°C during high risk periods of the year (i.e., June to October for sheep).

5.3 Effectiveness of regulatory initiatives

The performance of the industry, as measured by shipboard mortality, has been improving over time: as a general trend, animal mortality per voyage has steadily declined. However, from the descriptive statistics it is unclear if the different regulatory initiatives to improve animal welfare have had any significant impact on shipboard mortality, as there appears to be no systematic decrease in mortality, lagged or otherwise, following any of the regulatory initiatives beyond a more-or-less linearly decreasing trend (Fig. 8, Fig. 13). Further analysis may be required to examine the effect of regulatory initiatives on reducing DMRs, after seasonal, day of voyage and destination effects have been accounted for. Other incentives and solutions for reducing shipboard mortality are present in the market, and which may be more consistent in explaining a steady decline in mortality, including the perennial need to improve the gross margin, ongoing social pressure to improve animal welfare outcomes, and faster operating vessels and loading facilities continually entering the market.

The probability of a reportable mortality event occurring is low— 14.4% (250 of 1,739) sheep voyages had mortality that exceeded 2% (Table 5) and 5.8% (56 of 969) cattle voyages had mortality that exceeded 1% (Table 12). The incidence of these events is thus highly stochastic. As a result, most of these events are to be expected to occur on export pathways where there is a greater volume of voyages, such as to the Persian Gulf and Red Sea. There has been a historical spike in the number of voyages to MENA in July, coinciding with the end of the Ramadan fast (Fig. 6). Regulatory interventions, such as placing a seasonal ban of voyages undertaken during the northern summer, may thus result in an increase the number of reportable mortality events observed during the shoulder periods of the ban. Elevated mortalities may therefore occur during the pre-Ramadan period up to May of each year in particular, as the volume of trade to the MENA region will be expected to increase at this time of year under such a ban. This may offset, to an extent, any benefit in reducing sheep mortality through a ban of trade during the northern summer period. Importantly, such a ban will not be expected to have a tangible positive impact in generally reducing cattle mortality, as the evidence since 2003 suggests that cattle mortality is largely independent of seasonal climate conditions.

Moreover, a seasonal ban on trade during the northern summer may reduce the frequency, but is unlikely to eliminate, reportable mortality events during sheep voyages. This is because only extreme heat stress is addressed by such a ban, and not the other root causes of reportable mortality (such as respiratory illness, injury due to rough seas or other *force majeure* event, rumen acidosis, and failures in the management of heat stress arising from breaches of ASEL requirements; http://www.agriculture.gov.au/export/controlled-goods/live-animals/livestock/regulatory-framework/compliance-investigations/investigations-mortalities). A possible negative effect of an enduring ban on exports during the northern summer may be stifling of economic incentives for vessel operators to innovate and improve their strategies and infrastructure for managing heat stress (though such innovations will be required for sustainable long-term trade to continue). Year-round supply of animal protein to destination ports supports the competitiveness and desirability of Australian meat exports among international customers, and creates these economic incentives for innovation.

5.4 Improving responsiveness through higher resolution monitoring

In regulating the industry, moving towards more informative performance measures may well allow on-board management of livestock to become more responsive to changing conditions as they occur, such as increasing heat load and hence heat stress. Such measures include reporting:

- daily mortality rate (DMR)
- weather forecasts and on-board climate monitoring
- animal welfare measures.

Reporting a DMR would allow a vessel that experiences elevated mortality early on in its voyage to be subject to regulatory oversight and take additional actions to alleviate and evaluate animal stress in a timely and cost-effective manner. In effect, shipboard managers shouldn't wait until the voyage is over before taking action to address animal welfare issues. The need for responsive management is akin to feedlot situations, where there is a dollar value benefit in addressing animal welfare issues such as disease in a timely fashion.

Modern communication technologies mean daily reporting can be delivered at minimal cost, given that data are already being captured. A consequence of daily mortality reporting would be that voyages would no longer be evaluated on a per-voyage measurement. Use of a per-voyage measure results in longer voyages having a higher probability of exceeding a per-voyage reporting threshold, assuming a constant DMR. For example, animal stress leading to elevated DMR may be somewhat masked in a short-haul voyage to South East Asia (fewer than 10 days at sea) when looking at VMR, compared to a long-haul voyage to the Americas (40 days at sea) experiencing low DMRs over a longer timeframe. There may be a trade-off in terms of total animal welfare between singular extreme animal stress events and low-level attritional stress summed over a voyage. However, it may also be said that public reaction to the live export trade is accentuated by graphic depictions of extreme animal stress in the media, whereas economics may largely determine whether a long voyage should be undertaken given sum attritional mortality.

Incorporating weather forecasting and on-board climate monitoring into the management calculus may enhance responsiveness to animal issues, given that temperature and humidity are well known risk factors (e.g. Stacey and More, 2003). Forecasts of future high temperature would enable shipboard managers to undertake pre-emptive active action to alleviate heat stress— for example, replace bedding, move vulnerable stock, ensure working order of cooling and water supply systems, decide whether conditions are suitable for a scheduled unloading, and increase monitoring of animals for signs of stress (Collins et al., 2018). This may pre-empt not only potentially high mortality, but also body condition losses. The cost of incorporating weather forecasting is expected to be minimal, given global weather forecasts may be purchased commercially as a fee-for-service at a corporate level.

In contrast, on-board monitoring is an IoT (internet-of-things) solution that would allow different vessel compartments to be monitored for temperature and humidity, or provide a video feed. There are some technical issues in implementing an IoT solution, but these are not deemed insurmountable (for example, robustness and installation of sensor housing and wiring, or ensuring wireless connectivity throughout a vessel). The cost of an IoT solution, relative to both the vessel and cargo, would be relatively small—particularly if vessel compartments that were known structural heat islands, or that housed vulnerable stock, were targeted for monitoring first. Most of the cost of an IoT solution would be an initial capital cost, rather than ongoing or variable costs for the maintenance of the solution. Together with weather forecasting, the analysis of resulting real-time data flow can be used to improve the predictive accuracy of heat stress risk assessment models such as HotStuff.

The adoption of animal welfare performance measures in addition to DMR, such as panting rate, is also targeted at increasing management responsiveness to welfare risk factors to pre-empt excessive mortality. Animal welfare measures can be readily adopted, with relatively low ongoing cost beyond that for measuring daily mortality. By default, animal welfare measures imply daily or near-daily reporting so as to deliver a pre-emptive capacity. However, there is greater subjectivity associated with some of these measures, as well as variability in the accuracy at which they observed if they are being measured visually. For example, panting of an animal may indicate that ambient temperatures are relatively high, but it does not ensue that panting is representative of discomfort: it may simply be part of a healthy physiological response to allow the animal to tolerate high temperature conditions, without excessive stress. Consequently, a lower specificity in identifying when animals are truly experiencing discomfort would be expected with candidate welfare measures. The implication, if pre-emptive action to alleviate heat stress bears significant cost, is one of ‘the boy who cried wolf’: when a performance measure has low specificity it will trigger a greater proportion of false alarms, each of which accrues unnecessary cost. Moreover, low specificity also impacts on whether an improvement in animal welfare performance can been detected by statistical inference, when in truth such an improvement has been achieved.

The adoption of animal welfare measures, in addition to daily mortality, will eventually have to demonstrate competitiveness in terms of cost and specificity when compared to an IoT solution. Both approaches are aimed at improving the pre-emptive capability of shipboard managers to deal with animal welfare issues. Animal welfare measures seek to deliver this pre-emptive capability by informing the manager of a stressed state that may be a precursor of high mortality. An IoT solution seeks to do similarly but through predicting mortality through forecast weather conditions and other risk factors. Investment in an IoT solution may be more strategic and more encompassing. For example, a video feed may also be used to evaluating panting, while enabling higher resolution reporting (per second rather than per day). Moreover, IoT provides a capacity for coupling sensor information with automated systems of cooling and water supply to deliver cost efficiencies, and a capacity for improving animal welfare responses through machine learning as the IoT data stream grows.

For each monitoring solution, the intention would be that costs of implementation and maintenance are offset by the economic benefit of reducing mortality rate and body condition loss by increasing management responsiveness. These benefits would be compounded if they led to avoidance of reportable mortality events, which impact export licencing, market share and/or the trade itself. In summary, there are both economic and animal welfare benefits to be gained by higher resolution monitoring.

5.5 Implications for the shipboard mortality database

The above presents the first time that all 30 years of data have been analysed, following the integration of data sourced between 1988 and 2017. The main constraint to such analyses previously was technological: at one stage, shipboard mortality data needed to be recovered from floppy disks. With today’s technology, such data loss is unlikely to occur. Instead, the shipboard mortality database has capacity to be rapidly and regularly updated, and to provide, in the interim, at least near-real-time data flows and reporting. This allows for tables, figures and maps to be autogenerated and embedded in web portals for ready access by stakeholders.

With the shipboard mortality database revised, the possibility for construction of a federated data store that incorporates data from sources is now open. Many of these data sources are, in effect, ‘low-hanging fruit’. In particular, daily mortality reporting can feasibly be coupled with vessel GNSS tracking, on-board climate monitoring, and a record of other animal health activities undertaken such as antibiotic treatments or euthanasia. While it will be infeasible to correct many historical errors in the data, either because of cost or that data are effectively missing, modern technologies provide high levels of data quality assurance enforced at the point-of-capture. Issues such as the recording of multiple vessels as one based on the name could likely be improved at relatively low cost.

A case in point is the increasingly ubiquitous use of radio-frequency identification device (RFID) stock tagging. RFIDs provide the capacity to record welfare outcomes at the level of the individual animal, enabling tracking of life history effectively from ‘paddock-to-plate’. Many life history attributes may inform risk factors associated with shipboard mortality. For example, RFIDs may allow for clearer knowledge of how previous timing and duration of land transport impacts shipboard mortality. An objection around incorporating RFID-level reporting has been that many animals would be missing RFIDs (a rule-of-thumb is ≈ 0.25% loss per month). However, one would have to weigh the benefits of RFID-level reporting and the accuracy of the RFID count against the weaknesses of current methods of counting animals that risk being highly inaccurate. Moreover, incorporating missing animals is relatively straightforward, either through latent variable analysis (similar to that applied in diagnostic testing) or through the flexible imputation of missing data. From an academic perspective, a statistical solution to the missing RFID problem will likely be preferable to the lower data quality of manual counting. Other objections, such as a significant scaling up in database size, have readily available solutions with cloud computing.

The foresight of those who set up the shipboard mortality database during the 1980s should be acknowledged for the impact it has had on measuring performance and allowing for reporting on the industry since that time. Moving forward, the shipboard mortality database is a rich source of information that can be used to support an evidence-based approach to setting industry performance targets. Due to this richness, the database has not been fully mined for insights. For instance, the drivers of reportable mortality events compared to the drivers of the background attritional mortality are likely different, highlighting a possible need for more targeted analyses, especially as the reportable mortality events have a large influence on overall mortality. Moreover, the seasonal pattern of voyages of each species has not been accounted for in the exploratory modelling undertaken here, as this may confound our understanding of the risks of reportable mortality events if the majority of live sheep exports occur in the northern summer months. In all, an evidence-based approach will only be enhanced in the future by coupling the current shipboard mortality database with increasing data resolution and other readily available data sources.

6 Conclusions/recommendations

The key conclusion of this report is that shipboard mortality for sheep, cattle and goats has steadily decreased across the 30-year data record now captured by the shipboard mortality database. Although not fully explored, there is no apparent link between regulator initiatives and the reduction in shipboard mortality: root causes of the reduction in mortality may have been driven by long-term economic and technological factors. Results of these analyses are consistent with previous findings on causative risk factors of shipboard mortality. In particular, the exploratory modelling identifies a sea surface temperature threshold of above 25°C (consistent with ≈ 27–28°C threshold in wet bulb temperature) for single time point is associated with elevated levels of mortality, across both sheep and cattle.

The introduction of a ban on northern summer live exports requires careful considerations. Cattle mortality was relatively constant through the year, and if anything was slightly elevated prior to this period. It is thus expected that a ban will not realise a benefit in terms of improved mortality outcomes for cattle, while incurring significant cost in terms of lost trade in cattle.

For sheep, an elevated DMR during the summer months may be observed when considering background attritional mortality (i.e., mortality that does not exceed the threshold for mortality event reporting). In contrast, the three most recent reportable mortality events attributable to heat stress occurred in a cluster over 2016–2017 during the northern summer period. This cluster of reportable mortality events may be attributable to an extreme mix of circumstances, data on which are not available for this report. The next previous heat stress-related reportable mortality event was recorded in 2013. Combined with a possible shift of reportable mortality events to the shoulder periods of the northern summer that may follow a live export ban, the intent of the regulatory initiative to improve animal welfare outcomes may not be fully realised, at considerable cost to trade and market share.

The shipboard mortality database will likely become more federated in the future, with the possible inclusion of: 1) weather forecasts; 2) on-board climate monitoring; 3) animal welfare measures that are precursors to mortality, such as panting and feed intake; 4) daily performance reporting; and 5) animal-specific data via RFID devices. All of these data sources are technically feasible and are expected to be relatively cost-effective to implement. Incorporating other data sources will provide two benefits. The most important benefit will be the improved capacity of shipboard managers to pre-emptively respond to changing ambient conditions, to minimise shipboard mortality. The second benefit will be the capacity to: 1) mine these data to learn and improve the outcomes of stress-mitigating activities; 2) integrate monitoring data with automation of on-board systems within an IoT framework; 3) auto-generate industry annual reports; and 4) provide an evidence-based approach to supporting regulatory and operational management innovations and initiatives.

7 Key messages

7.1 Livestock export voyage mortality

- Shipboard mortality for sheep, cattle and goats has steadily decreased across the 30-year data record now captured by the shipboard mortality database.
- Reportable mortality events are infrequent.
- Less of the difference in outcome is explained by vessel than other predictors.
- Exploratory modelling identifies a sea surface temperature threshold of above 25°C (consistent with ≈ 27–28°C threshold in wet bulb temperature) for single time point is associated with elevated levels of mortality in sheep and cattle.
- Higher resolution capture of animal-level data into a consolidated database will allow for more accurate analyses and predictions of livestock performance.
- Better linkage of voyage data with weather forecasts, on-board climate monitoring, animal welfare measures and animal-specific data via RFID devices will provide industry with improved voyage delivery rates and better animal welfare outcomes.

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9 Appendix

9.1 Data sources

9.1.1 Primary voyage data

All voyage data is stored in the shipboard mortality database, a secure online Australian based customised service.

9.1.2 Additional environmental data

Daily sea surface temperature data were sourced from the National Oceanic and Atmospheric Administration’s National Centers for Environmental Information repository of global environmental data:

National Centers for Environmental Information 2019, Sea surface temperature optimum interpolation, electronic dataset, National Oceanic and Atmospheric Administration, https://www.ncei.noaa.gov/data/sea-surface-temperature-optimum-interpolation/access/

The sea surface temperature data were captured by the AVHRR sensor and provided as 0.25° resolution global daily imagery (longitude and latitude coordinates; equating to ~27-28 km pixels at the equator).