Final report

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Cattle Heat Load Toolbox 2021-2023

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Abstract

The Cattle Heat Load Toolbox (CHLT), developed by Katestone and now operated by Weather Intelligence (a Katestone Company), alerts feedlot operators of impending adverse weather conditions that could lead to excessive heat load in feedlot cattle.

The toolbox is web based and provides access to weather and heat load forecasts out one week as well as risk assessment programs. The service is underpinned by 20 years of research into cattle heat load funded by Meat and Livestock Australia (MLA). This service provides useful and practical information to help feedlot operators manage heat stress in cattle through advanced warning of adverse conditions thus allowing operators time to undertake appropriate actions to mitigate the risk of heat stress.

The CHLT service has become an integral part of heat load management at Australian feedlots. The number of subscribers and feedlots that are registering for the service continues to grow every year with a significant increase since the new website was launched in October 2019. The service now has over 1000 users and services 370 sites.

Executive summary

Background

The Cattle Heat Load Toolbox (CHLT), developed by Katestone and now operated by Weather Intelligence (a Katestone Company), alerts feedlot operators of impending adverse weather conditions that could lead to excessive heat load in feedlot cattle.

The service is underpinned by over 20 years of research into cattle heat load funded by Meat and Livestock Australia (MLA). The CHLT service brings all this research together with a world class weather forecasting system to generate accurate and site-specific forecasts across Australia. This service provides useful and practical information to help feedlot operators manage heat stress in cattle through advanced warning of adverse conditions thus allowing operators time to undertake appropriate actions to mitigate the risk of heat stress.

Objectives

The key objectives for the 2022-2023 season were to:

- Provide daily updates of CHLT website with a seven-day forecast for all parameters
- Daily issue of alerts during the season
- Provide a newsletter and training webinars (pre season)
- Undertake a survey of users (end of season)
- Deliver a Final Milestone report (end of season)

The above objectives were achieved.

Methodology

The toolbox is web based and provides access to weather and heat load forecasts out one week as well as risk assessment programs. Feedlot operators subscribe to the service free of charge and request a forecast for their feedlot. Subscribers also define risk alert levels suitable to their feedlot management and cattle type and condition through the Risk Assessment Program. Alerts are sent daily by email or SMS to designated recipients (e.g. site managers, veterinarians).

Results/key findings

The key achievements for the 2022-2023 season include:

- Reached the milestones of over 1000 users and 370 sites
- Delivered over 18,000 alerts via sms and e-mail during the heat season
- Preseason newsletter, training webinars and end of season survey.

Benefits to industry

The CHLT service has become an integral part of heat load management at Australian feedlots. The number of subscribers and feedlots that are registering for the service continues to grow every year with a significant increase since the new website was launched in October 2019. Overall, the user base is satisfied with the delivery and performance of the service and see it as an integral part of their strategy to manage heat at their feedlot.

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1 Project objectives

The Cattle Heat Load Toolbox was developed to assist in warning feedlot operators of impending adverse weather conditions that could lead to excessive heat loads for feedlot cattle. The objectives of the project are to:

1. Provide a daily forecast of heat load to the Australian feedlot sector, incorporating:
   a. Continuous monitoring of infrastructure to ensure the security and continued provision of the service.
   b. Timely update of the forecasts, plus review of forecast delivery and performance on a daily basis.
   c. Ongoing integration of new subscribers into the Heat Load Data Network (HLDN), plus regular checks with existing users to ensure everything is functioning correctly.

2 Service Use

A total of 1015 subscribers, 370 user sites (367 feedlots and 3 abattoirs) are currently registered for the CHLT (Fig. 1).

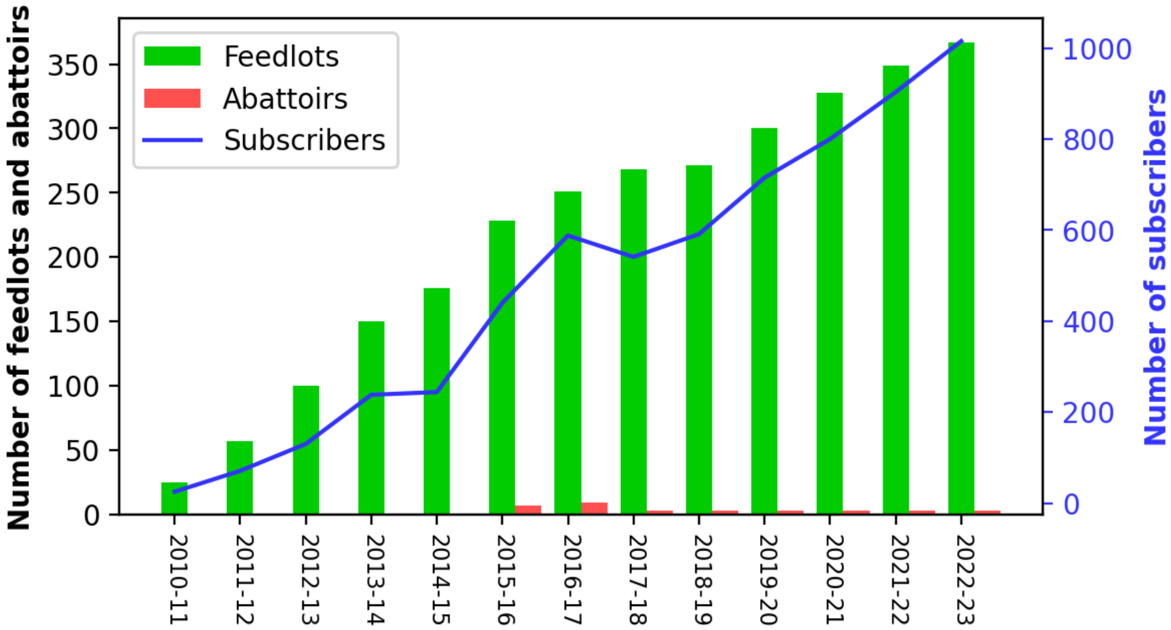

Fig. 1 Uptake of the CHLT service since its launch in 2010-2011

There are now 83 feedlots participating in the Heat Load Data Network (HLDN). The HLDN integrates the onsite weather station data into the CHLT system every hour (if the data is available), initialising the predicted AHLU from the measured data. However, most sites upload the weather data every 4, 6 or 24 hours. HLDN data is also displayed on the feedlots CHLT My Site page. The observations of the current day are proceeded by the forecast for the balance of the day. The user can also check the observations for the last 7 days and the forecast for the next 7 days (including the current day). The facility to download all observations as a file is also available.

3 Methodology

3.1 Forecasting Service

3.1.1 Overview

There are three parts to a successful early warning system:

1. Accurate weather forecast
2. Appropriate triggers that are relevant to the local climate and represent conditions that are conducive to heat stress in lot fed cattle
3. Communication of the warnings via an appropriate media

The following schematic presents an overview of the CHLT system (Fig. 2). The blue areas represent the global input from weather stations and models. These data are not gathered or generated directly by Weather Intelligence. The purple represents the local weather forecast, generated by Weather Intelligence every day. The red box indicates the areas of research that need to go into developing a robust system. The grey box represents the input from feedlot weather stations (HLDN). And finally, the delivery of the information is represented in green and shows the web site and alerts.

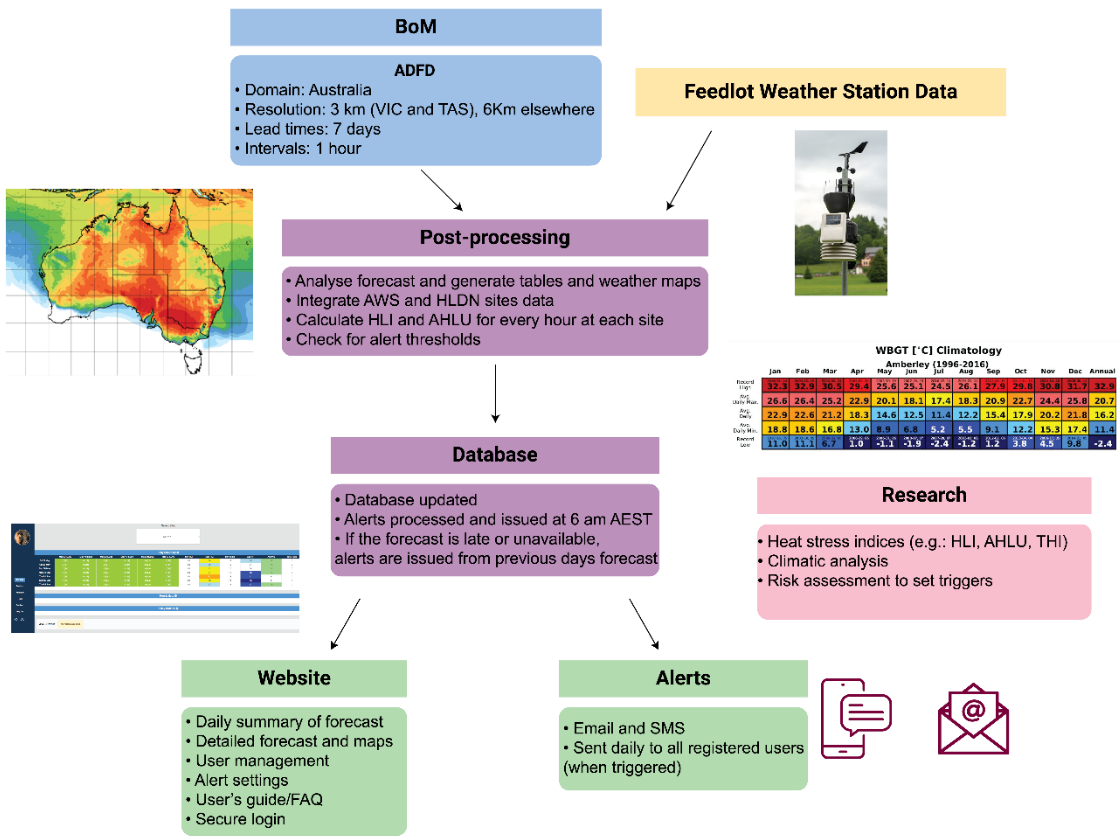

Fig. 2 Overview of the current process to deliver a forecast to CHLT

3.1.2 The Weather Models

The weather forecasting model utilised by Weather Intelligence is the Australian Digital Forecast Database (ADFD) provided by the Bureau of Meteorology.

The ADFD operates continuously and contains the official BOM weather forecast elements produced from multiple models controlled by the Bureau's operational meteorologists. ADFD covers a 7-day period and provides hourly data. The ADFD has a horizontal grid resolution of 3 km for Victoria and Tasmania, and 6 km for the remainder of Australia. ADFD does not make solar radiation data available to the public, therefore a clear-day assumption is considered to estimate solar radiation.

3.1.3 Heat Load

There are many climatic conditions that may predispose feedlot cattle to high body heat loads, including:

- A recent rain event
- A high ongoing minimum and maximum ambient temperature
- A high ongoing relative humidity
- An absence of cloud cover with a high solar radiation level
- Minimal air movement over an extended period (4-5 days)
- A sudden change to adverse climatic conditions

It is usually a combination of some of these conditions that leads to an excessive heat load event, which may result in cattle deaths if conditions persist for a few days.

The calculation of HLI requires Relative Humidity (RH) expressed as a percentage, Wind Speed (WS) in m/s and Black Globe Temperature (BGT) in °C. HLI is calculated as a composite of HLI_{low} and HLI_{high}, with a weighting factor determined as a function of the difference in the calculated BGT and a threshold of 25°C (Gaughan et. Al 2002). A blending function was introduced as a result of an analysis of data over time, wherein it was evident that large jumps in HLI could occur under some circumstances when the BGT passes through 25°C – for example from 24.9°C to 25.1°C (B.FLT.0357).

In equation form, HLI_{LOW} and HLI_{HIGH} are calculated as follows, noting that exp is the exponentiation function:

$$HLI_{low} = 1.3 * BGT + 0.28 * RH - WS + 10.66$$

$$HLI_{high} = 1.55 * BGT + 0.38 * RH - 0.5 * WS + \exp(2.4 - WS) + 8.62$$

The weighting factor is calculated and used as:

$$FRAC_{high} = \frac{1.0}{\left(1.0 + e^{-\frac{BGT - 25.0}{2.25}}\right)}$$

$$HLI = \left(FRAC_{high} * HLI_{high}\right) + \left(\left(1 - FRAC_{high}\right) * HLI_{low}\right)$$

It is also worth noting that if any calculation of HLI yields a value less than 50, this value must be set to 50, as the dissipation of heat does not increase below this point.

The use of BGT in calculating the HLI, rather than ambient temperature, takes into account radiation effects as well as air temperature. Although sensors for measuring BGT exist, these are not included as part of the standard weather station and must be ordered from a suitable supplier. In the absence of measured BGT, a quantified relationship between BGT, ambient temperature (T) and solar radiation (SR) can be used. Here solar radiation can either be a measured value or a calculated value.

BGT can be calculated from T and SR using the following equation (noting that log is the logarithm function using base-10):

$$BGT = 1.33 * T - 2.65 * \sqrt{T} + 3.21 * \log(SR + 1) + 3.5$$

Accumulated Heat Load Units (AHLU) has been developed to give some indication of the amount of heat that is accumulated by an animal when it is exposed to environmental conditions that are above its ability to maintain thermo-neutral conditions.

For every hour that an animal is above its threshold HLI value, it will gain heat. This additional heat load accumulates over time and is reflected as an increase in body temperature. It is a normal physiological response for animals to gain heat during the day and dissipate this accumulated heat to the environment at night. If the animal cannot dissipate this accumulated heat overnight, the animal carries a heat load into the following day.

This makes the animal more susceptible to the effects of subsequent heat load. The three aspects that determine the potential for excessive heat load in feedlot cattle include time, intensity, and the opportunity to dissipate heat.

The following variables are required to calculate the AHLU:

- the HLI,
- upper (UL) and lower (LL) limit of the thermal neutral zones, and
- interval (in hours) between successive HLI estimates (Δt).

LL is fixed at 77, while UL is a variable dependent on the HLI value at which stock begins to accumulate heat. This depends on the stock characteristics, location, and management practices including mitigation measures.

The equation for calculating AHLU is as follows:

$$AHLU_{current} = AHLU_{previous} + BALANCE$$

If the HLI is less than LL ($HLI \leq 77$), then the heat is dissipated at half the rate of accumulation (the difference between HLI and LL). If the HLI falls between the LL and UL, then heat is neither dissipated nor accumulated. If the HLI is greater than UL, heat is accumulated.

In equation form, the $AHLU_{current}$ is calculated as:

$$HLI \leq 77 \; yields \rightarrow \; AHLU_{current} = AHLU_{previous} - \Delta t * \frac{77 - HLI}{2}$$

$$77 < HLI < UL \; yields \rightarrow \; AHLU_{current} = AHLU_{previous}$$

$$HLI \geq UL \; yields \rightarrow \; AHLU_{current} = AHLU_{previous} + \Delta t * (HLI - UL)$$

AHLU values do not go below zero. If any calculation results in an AHLU value below zero, it is set to zero.

Sites connected to the HLDN are initialised from AHLU calculated from data collected at local AWS, which theoretically would result in a more accurate AHLU forecast. The same holds true for BOM sites. Sites which do not have an integrated AWS are initialised from the previous day’s AHLU forecast.

3.1.4 Delivery

3.1.4.1 Forecast Generation

The sequence of steps that must be completed for the forecast to be delivered (as outlined in Fig. 2) is monitored between the hours of 6 am and 9 pm, 7 days a week (during the season).

Once the forecast is generated a daily checklist is completed. These checks include but are not limited to:

- Successful processing of site data
- Alerts triggered successfully and delivered
- Website updated with most recent forecast.

3.1.4.2 Website and database administration

The CHLT system is administered and maintained by a system administrator. The system administrator maintains the integrity and security of the cloud-based infrastructure. There are three nodes within the HPC facility that require administration and maintenance:

1. Computational node - Core activities are data retrieval and forecast computation
2. Database node - Core activities are post processing, data storage and data availability to the web server
3. Web node - Core activities are website delivery, user information management, web security

The system administrator also maintains the CHLT website including:

- Registering new subscribers
- Checking their coordinates are valid
- Configuring site specific forecasts in the model
- Maintaining the CHLT web site and associated databases
- Maintaining e-mail and SMS alert functions
- Daily monitoring and maintenance of computer systems including weekends and holidays (during the season)
- Online and phone support for registered users during regular office hours (8 am to 5 pm)
- Maintaining and updating the FAQ page.

3.1.4.3 Onsite AWS Integration

The Heat Load Data Network (HLDN) allows feedlots to send their weather station data to our servers and include these data in their site-specific forecast for the AHLU. To date, 83 sites are operational.

The AWS integration requires continuous monitoring of data quality, as spurious data entering the system can adversely impact the prediction of risk and degrade confidence in the system. The integration step involves calculating the AHLU for all thresholds from the onsite data and initialising the predicted AHLU from the last available time step in the observations.

An automated data quality check is initiated at the integration step that flags spurious data and issues an internal alert to manually quality assure the offending dataset. Our experience indicates that the spurious data is either due to damage to the sensor, i.e. lightning strike, or changes to the data format following a system update by the AWS provider.

3.1.4.4 Alerts

The alerts, for a user selected HLI Threshold value, used in the system are:

- AHLU event today: AHLU > 50 units for today
- AHLU event tomorrow: AHLU > 50 for tomorrow and AHLU = 0 for less than 6 hours
- Extended AHLU event: AHLU > 50 units for more than 3 consecutive days
- Incomplete night time recovery: AHLU = 0 for less than 6 hours for more than 3 consecutive days in 7 day forecast period
- Rapid HLI change: change in HLI > 40 units over 4 hours

Alerts are processed every morning during the period 1 October – 31 March and issued around 6.30 am AEST.

3.2 RAP

The Risk Analysis Program (RAP) was developed in 2005 for the purpose of obtaining the risk profile of a heat event for the Australian Feedlot industry. The risk that is calculated by the RAP consists of the probability of occurrence of specific heat events at the specified site (All BOM weather station sites). These heat events are classified in terms of their duration (in days) and the daily maximum AHLU value. The classifications are: High Risk (AHLU between 51 and 100) and Extreme Risk (AHLU greater than 100). For example, the probability of Extreme Risk events of three-day duration is one event in two years. The output is displayed to the user with no interpretation of the acceptability of the predicted risk level.

The RAP is available for anyone to use on the Cattle Heat Load Toolbox website.

No changes have been made to the RAP in the 2022-2023 season.

4 Success in meeting the project objectives

The CHLT was operational for the full season with alerts sent out daily from 1 October 2021 to 31 March 2023. In terms of the most recent 2022-2023 season, achievements include:

- Daily update of website with new seven day forecast for all parameters
- Daily delivery of alerts via sms and e-mail during the heat season
- Preseason newsletter
- Delivery of a series of training webinars
- Delivery of end of season survey

The following sections present a summary of the season including:

- General climatic conditions and heat load
- Delivery of alerts
- Web site statistics
- An overview of the performance of the forecasts, and
- Feedback from the users via the end of season survey.

4.1 Season Overview

4.1.1 Weather and Climate Review

4.1.1.1 Temperature and Rainfall 2022-2023

Australia's area-averaged mean temperature for 2022 was 0.50˚C above the 1961-1990 average, which made it the coolest year since 2012 though still the equal-22nd warmest year on record. Maximum temperatures were above average in some parts of the country, particularly northern Australia, Tasmania, and parts of the west coast, and cooler than average in other parts, such as New South Wales, southern Queensland, parts of northern Victoria and parts of South Australia. Minimum temperatures were above average for the majority of Australia. Regarding rainfall, nationally averaged rainfall for 2022 was 587.8 mm, 26% above the 1961-1990 average.

Focusing on the 2022-2023 heat season (from October 2022 to March 2023), temperatures were within 1°C of the average for the majority of Australia (Fig. 4). Minimum temperatures were below average in central New South Wales, while being above average on Queensland's Carpentaria coast, in east-central Western Australia and around the north-eastern border of South Australia, including parts of the Northern Territory and Queensland. Maximum temperatures were below average in central New South Wales, parts of inland Western Australia, Queensland and the Northern Territory as well as some coastal areas of Western Australia around Port Hedland and Esperance.

Rainfall during the 2022-2023 season was average or well above average across most of Australia, particularly in northern Australia, Victoria, inland New South Wales, and northern Tasmania, where rainfalls were significantly above average (Fig. 3 left). However, rainfalls in south-east Queensland and along much of the New South Wales and southern Queensland east coast were significantly below average and rainfalls in some coastal parts of Western Australia and south-western Tasmania were also below average.

Comparing rainfall of the 2022-2023 season the previous season (2021-2022), a dramatic increase is observed across northern Australia and much of Victoria and Tasmania, whereas a significant decrease occurred along the east coast from southern Queensland to Victoria (Fig. 3 right).

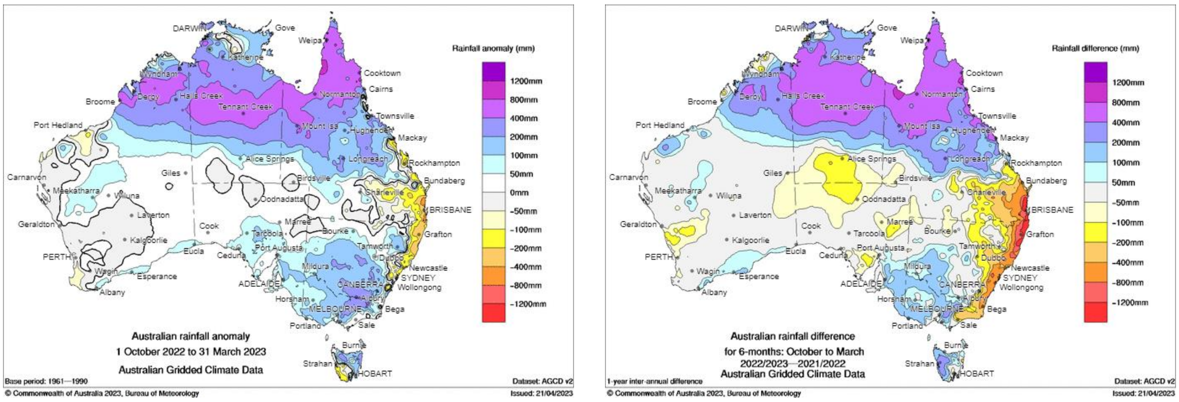

Fig. 3 Rainfall anomalies during the 2022-2023 season (left) and the difference between rainfall during the October 2022 - March 2023 season and October 2021 – March 2022 (right)

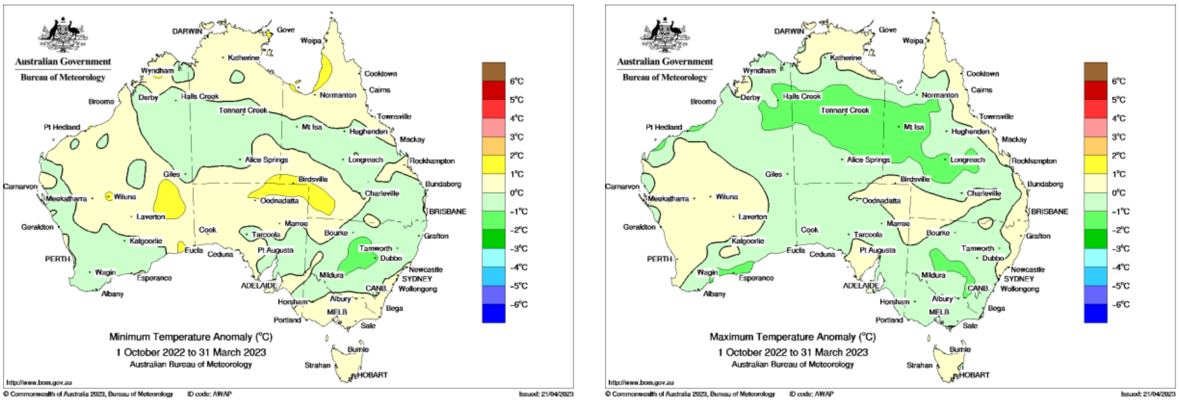

Fig. 4 Minimum (left) and maximum (right) temperature anomaly during the 2022-23 season

4.1.1.2 Climate Drivers

Australia's weather is influenced by many climate drivers. A brief description and their impacts on the 2022-2023 season are given here.

El Niño-Southern Oscillation

El Niño-Southern Oscillation (ENSO) is arguably the most important global climate pattern affecting extreme weather conditions. It is characterized by two phases: warm phase (El Niño) and cold phase (La Niña). An El Niño event occurs when sea surface temperatures in the central and eastern tropical Pacific Ocean become substantially warmer than average, and this causes a shift in atmospheric circulation. As a result, the heavy rainfall that usually occurs to the north of Australia moves to the central and eastern parts of the Pacific basin. Therefore, an El Niño event is usually associated with drier conditions over eastern parts of Australia. Conversely, the enhanced trade winds during La Niña events lead to cooling of the central and eastern tropical Pacific Ocean and heavy rainfall can occur to the north of Australia.

In order to monitor ENSO events, two main indices are utilized: Niño-3.4 and SOI, measuring changes in the ocean and the atmosphere, respectively. The Niño-3.4 index refers to the observed sea surface temperatures within a region of the central and eastern equatorial Pacific, whereas SOI takes the difference of atmospheric pressure between Darwin and Tahiti.

SOI values remained high throughout 2022 but declined at the start of 2023, resulting in a La Niña phase for the start of the 2022-2023 summer which eased to neutral by the end of the season (March 2023) (Fig. 5).

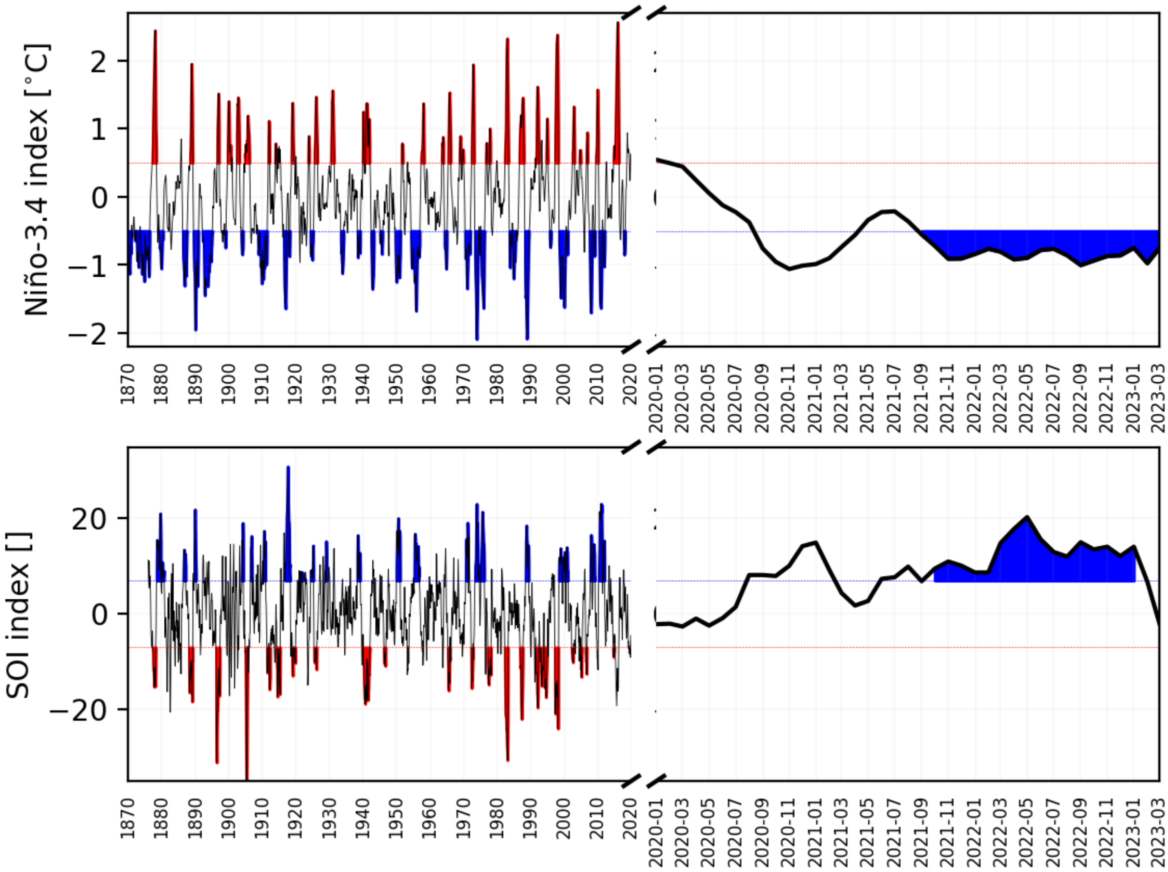

Fig. 5 Time series of Niño-3.4 index and SOI. Red shaded areas indicate El Niño and blue indicated La Niña events. Data source: NOAA and BOM

Indian Ocean Dipole

Indian Ocean sea surface temperatures impact rainfall and temperature patterns over Australia. Sustained changes in the difference between sea surface temperatures of the tropical western and eastern Indian Ocean are known as the Indian Ocean Dipole (IOD). Being one of the key drivers of Australia's climate, IOD can have a significant impact on agriculture since the events generally coincide with the winter crop growing season. Neutral IOD phase means that water from the Pacific flows between the islands of Indonesia, keeping seas to Australia's northwest warm. Positive IOD phase, i.e. with cooler than normal water in the east and warmer than normal in the west, implies less moisture than normal in the atmosphere to the northwest of Australia, resulting in less rainfall and higher than normal temperatures over parts of the country during winter and spring. However, negative IOD phase, i.e. with warmer than normal water in the east and cooler than normal in the west, leads to above-average winter-spring rainfall over parts of southern Australia.

The Dipole Mode Index (DMI) declined in mid-2022 and remained negative until the end of the year. It was then neutral for the remainder of the 2022-2023 season (Fig. 6).

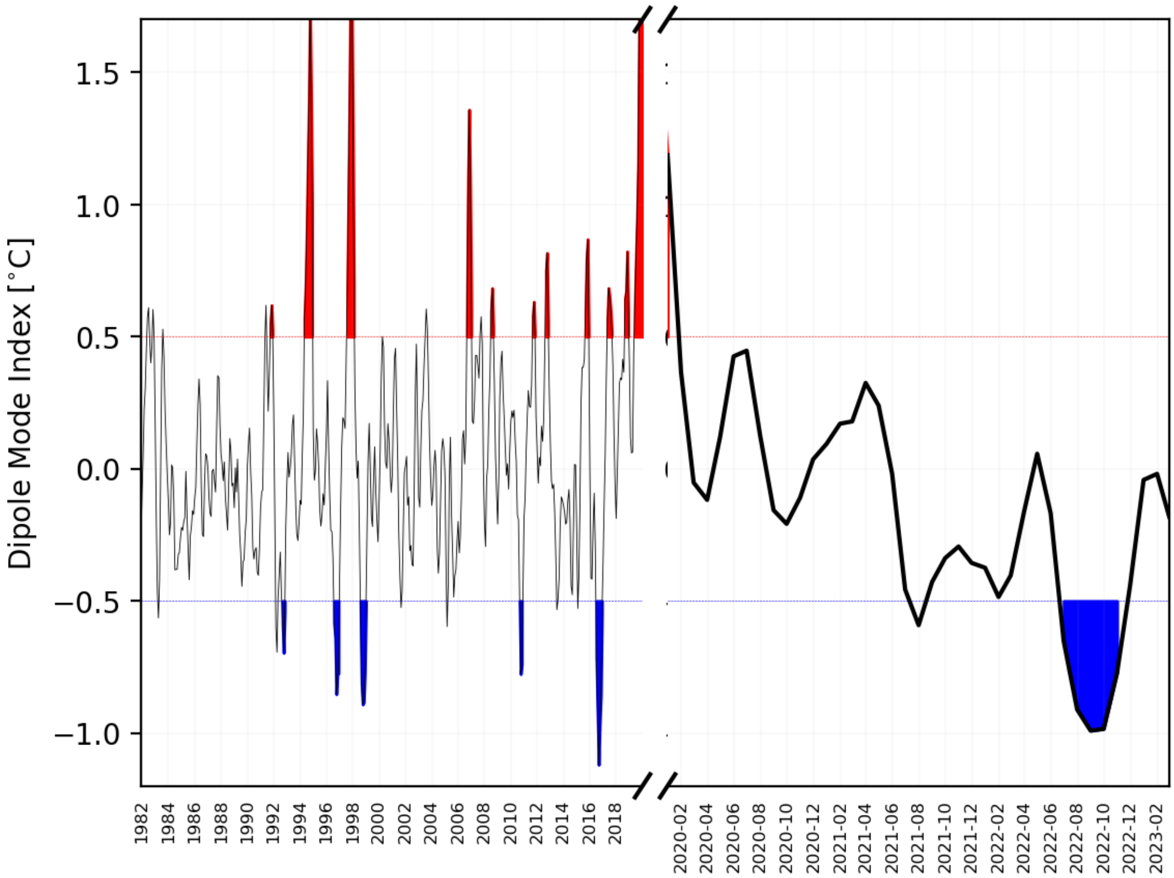

Fig. 6 Time series of Dipole Mode Index. Red shaded areas indicate positive IOD events and blue areas indicated negative events. Data Source: NOAA

Southern Annular Mode

The Southern Annular Mode (SAM) describes the north-south movement of the westerly wind belt that circles Antarctica, dominating the middle to higher latitudes of the southern hemisphere (Ho et al. 2012). The changing position of the westerly wind belt influences the strength and position of cold fronts and mid-latitude storm systems, and it is an important driver of rainfall variability in southern Australia. In a positive SAM event, the band of westerly winds contracts towards Antarctic. This results in weaker than normal westerly winds and higher pressures over southern Australia, restricting the penetration of cold fronts inland. Conversely, a negative SAM indicates that the band of westerly winds expands towards the equator. This shift in the westerly winds leads to more low-pressure systems over southern Australia.

A high positive SAM has dominated during the 2022-2023 season. (Fig. 7).

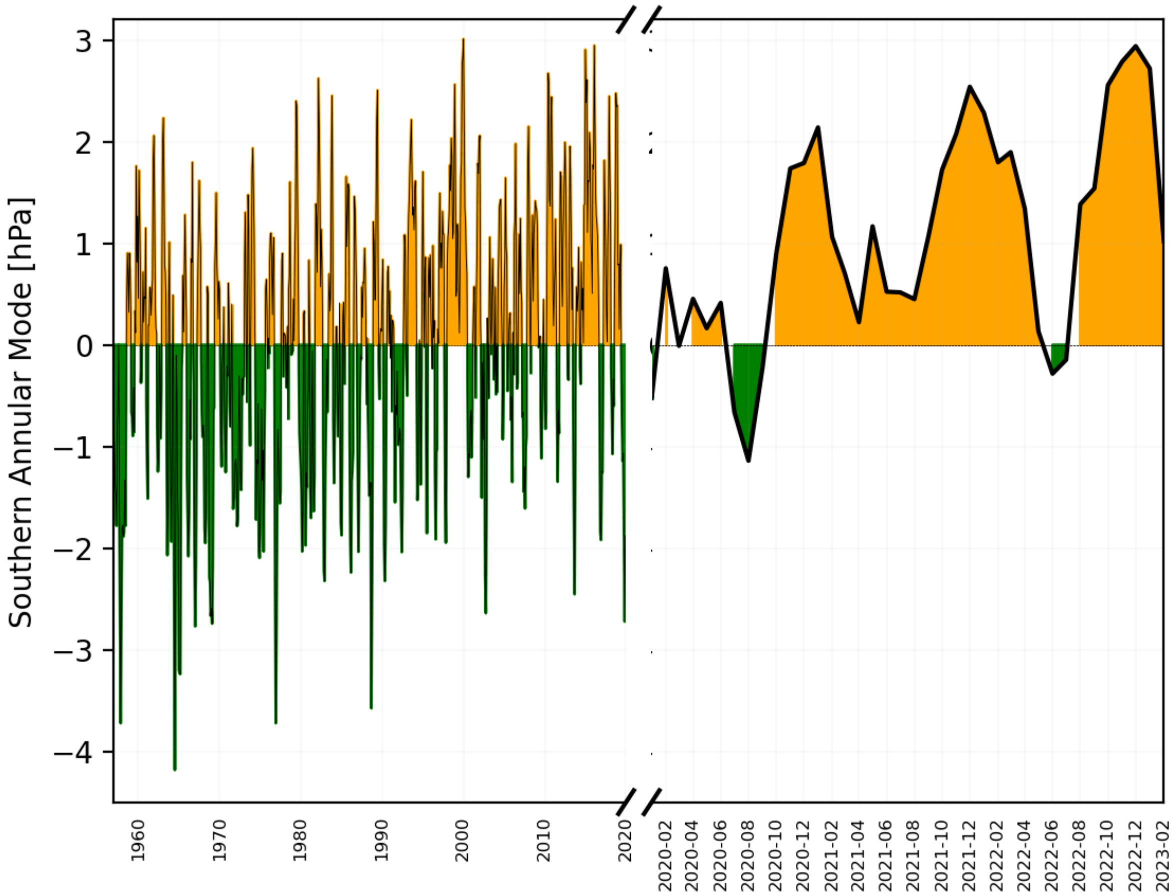

Fig. 7 Time series of Southern Annular Mode

4.1.1.3 Tropical Cyclones 2022-2023

There were 5 Tropical Cyclones (TC) during the forecast period within the Australia region, which is below the long-term average (11 TCs), although only one crossed the Australian mainland (Table 1).

Table 1 Tropical cyclones in the Australian region between October 2022 and March 2023

Date	Name	Category	Region
21 Dec 2022 - 8 Jan 2023	Ellie	1	NT, WA

4.1.1.4 Heat Load

The daily average HLI anomaly[1] derived from observations at the 17 benchmark locations (Section 4.1.4.1) for the 2022-2023 season is shown in Fig. 8. Most of the sites exhibit, as expected, some fluctuations of HLI between above and below average throughout the 6-month period. However, several sites show consistently below average HLI values in the summer months, such as Moree, Tamworth, Armidale, Roma, Oakey, Warwick, RAAF Amberley, Miles, Clare High School, and Katanning, whilst Albury Airport was more frequently above average throughout the season.

[1] The HLI anomalous values are calculated by subtracting the monthly climatology to the actual value. In order to smooth the data, 6-day moving averages are shown.

The weekly average of the daily maximum HLI derived from observations for all sites is presented in Fig. 9. HLI peaks anywhere between late December and mid-March and, as expected, follows trends based on location. QLD sites reached a peak in HLI in mid-March while NSW sites reached their peak HLI at various points in January. Not surprisingly, Yanco, Hay, and Griffith had similar maximum HLIs due to their proximity.

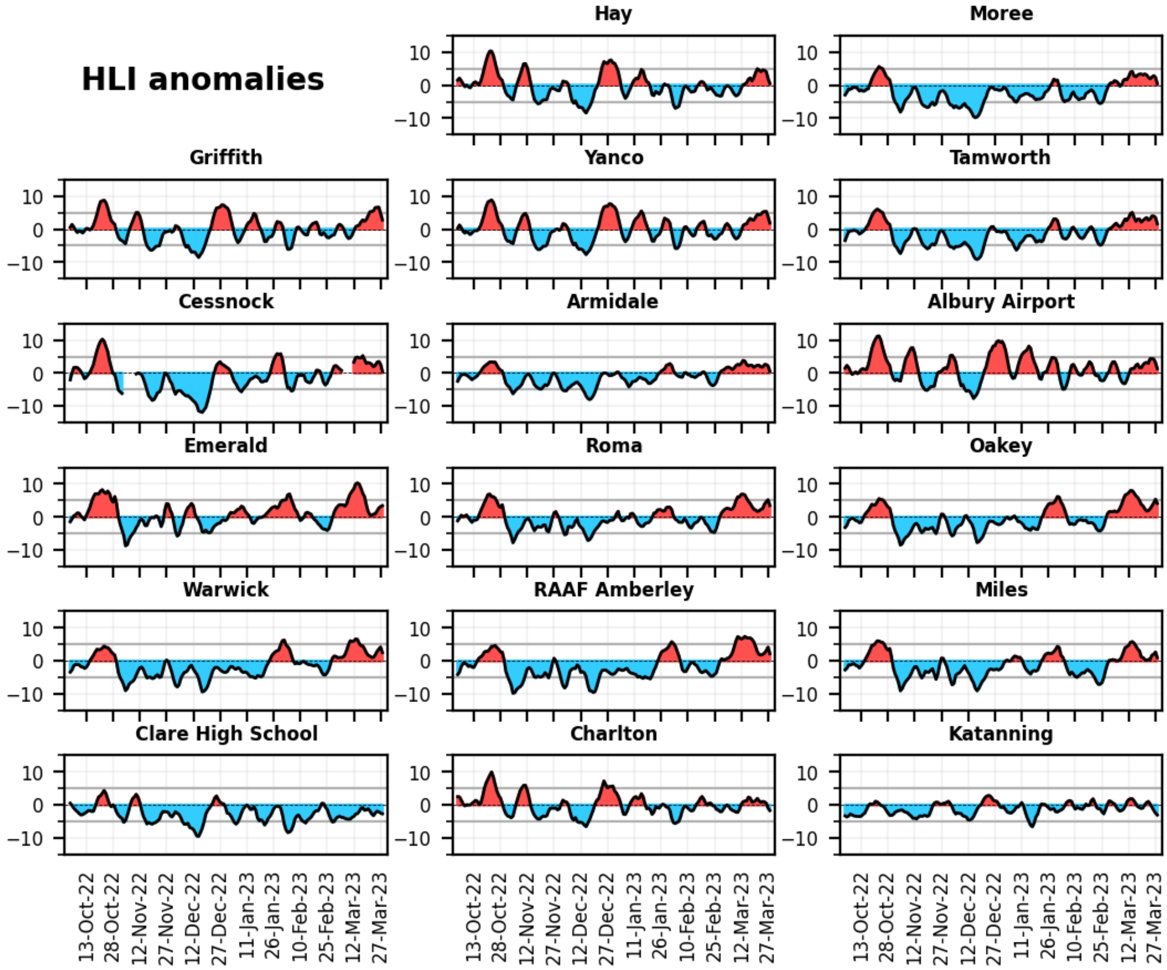

Fig. 8 Daily average HLI anomaly for the 17 benchmark locations during the 2022-2023 season. Note that red (blue) shades are used to denote higher (lower) HLIs values than usual

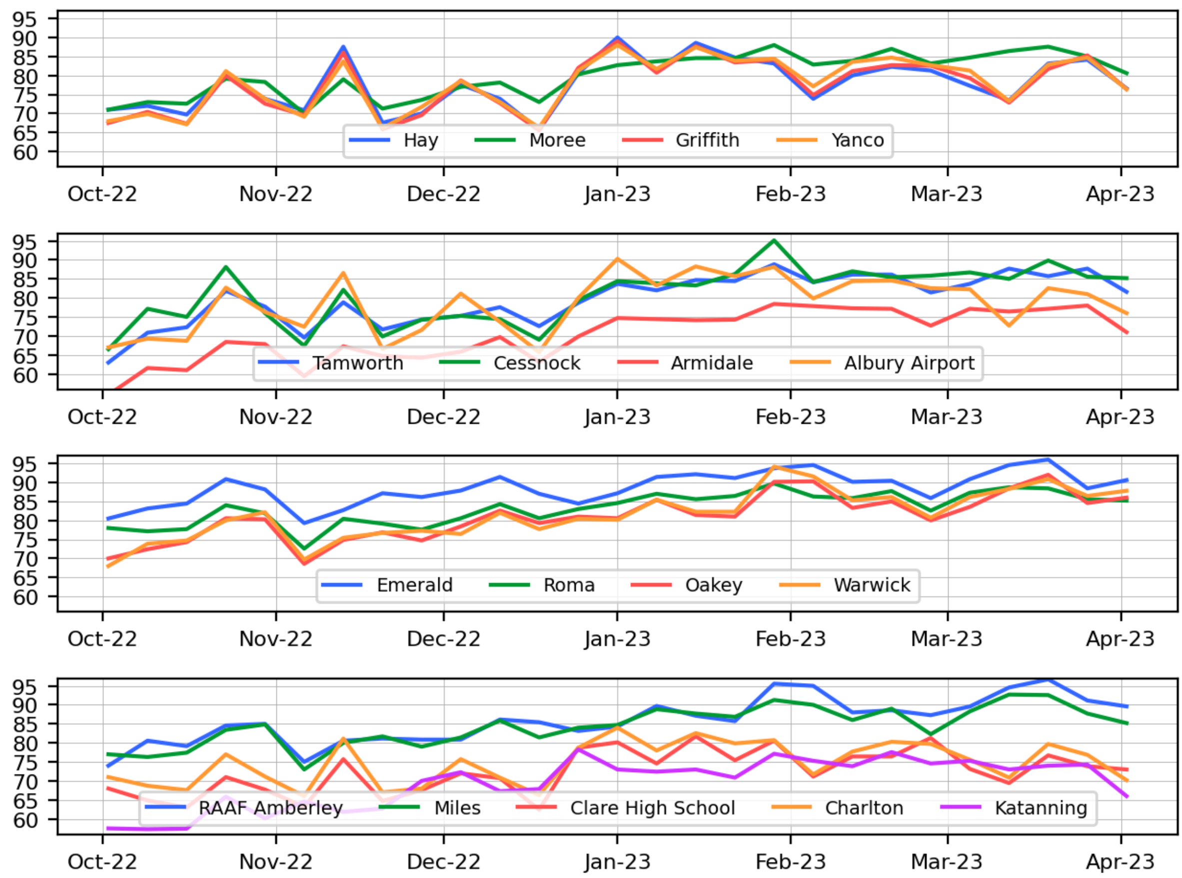

Fig. 9 Weekly average of daily maximum HLI for the 17 benchmark locations during the 2022-2023 season

4.1.2 Automated alerts

A total of 12,181 emails and 6,137 SMS alert messages were issued during the 2022-2023 summer forecast period, with a peak number of email and SMS alerts sent in January (Fig. 10). The breakdown of alerts by type for each month is shown in this figure. Alerts for extended AHLU event and for today-tomorrow comprise most of the alerts. There were no alerts for Rapid HLI change. The incomplete night-time recovery alerts were triggered 3,102 times in the 2022-2023 season.

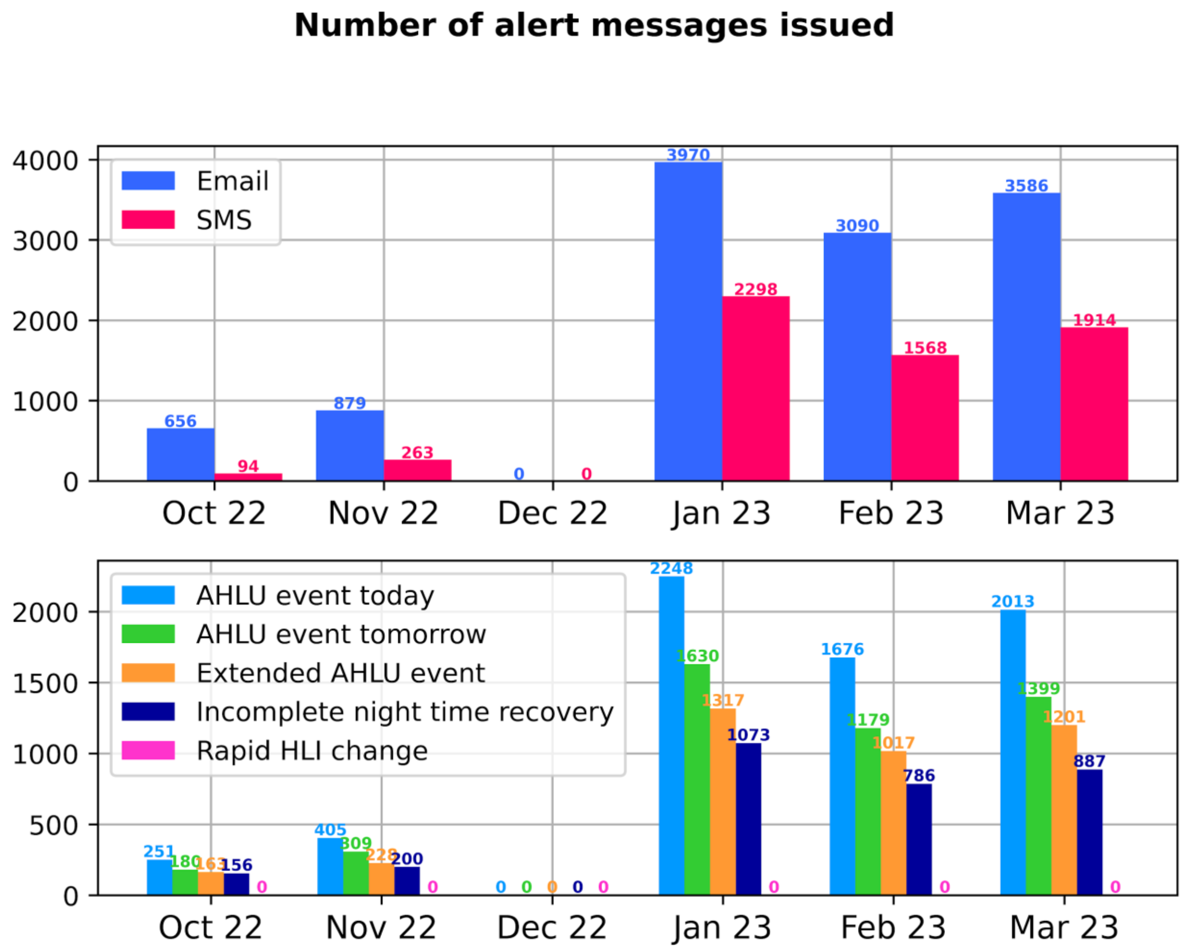

Fig. 10 Number of alerts sent by alert and notification types during the 2022-2023 season

4.1.3 Web site statistics

The distribution of the CHLT Australian website traffic by state is shown in Fig. 11 for 2022-2023. New South Wales accounts for 37% of the site overall traffic, followed by QLD (33%) and VIC (15%). The remaining 15% is made from the other states and territories. Note that this is only domestic site traffic from within Australia; site traffic from overseas has been excluded.

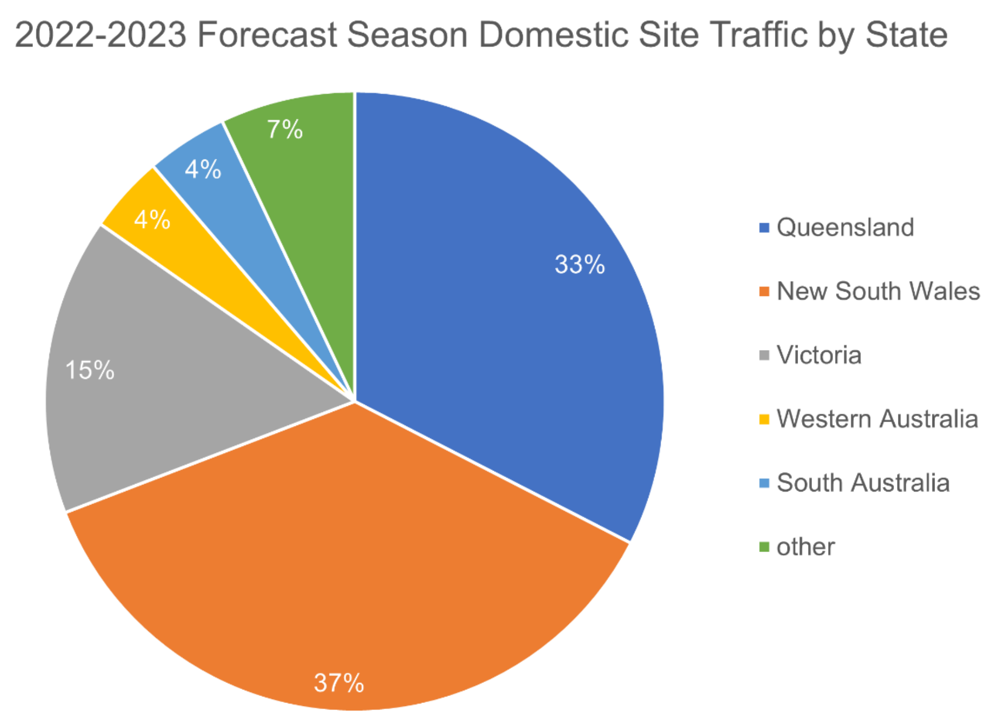

Fig. 11 CHLT Domestic website traffic by state during 2022-2023 season

The top 10 webpages for 2022-2023 are shown in Table 2. The "My Site" and "Homepage" are the top two web pages. This is to be expected as they are the landing pages for the public and subscribers accessing the http://chlt.katestone.com.au/. The "RAP calculator" in the "Toolbox" is the next most visited page.

Table 2 Top 10 webpages as percentage of site traffic

Web page	% Site Traffic 2021-2022
/my-site/	26.46
/	13.48
/toolbox/rap-calculator/	5.78
/toolbox/	3.91
/manage/	2.19
/weather/	1.58
/hrf_faq/what-is-the-hli-and-how-is-it-calculated/	1.31
/toolbox/hli-calculator/	0.99
/my-site/?site=602d78bd63d94243a6fd300f401690f7	0.95
/help/	0.88

Fig. 12 shows the distribution of devices accessing the CHLT website. Most users (80.7%) access the service from a desktop computer. The remainder of users access from mobile phones (18.8%) and very few from tablets (0.5%).

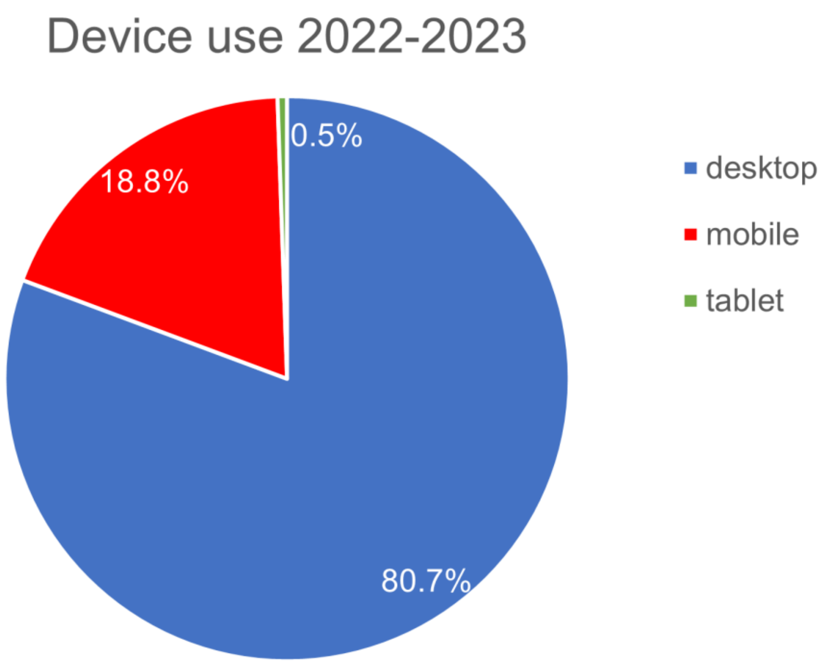

Fig. 12 Distribution of devices accessing the website

4.1.4 Service performance

4.1.4.1 Benchmark locations

The performance of the forecasting service has been assessed each season against 17 benchmark locations. Most of these sites have been included in the forecast service since its inception and provide a good measure of the forecast's performance over the years. Fig. 13 and Table 3 describe the benchmark locations.

Table 3 Geographical information and WMO code of the benchmark locations analysed

Site Name	Lat	Lon	WMO code	State
Hay	-34.54	144.83	94702	NSW
Moree	-29.48	149.84	95527	NSW
Griffith	-34.24	146.06	95704	NSW
Yanco	-34.62	146.43	95705	NSW
Tamworth	-31.07	150.83	95762	NSW
Cessnock	-32.78	151.33	95771	NSW
Armidale	-30.52	151.61	95773	NSW
Albury Airport	-36.07	146.95	95896	NSW
Emerald	-23.56	148.17	94363	QLD
Roma	-26.54	148.77	94515	QLD
Oakey	-27.4	151.74	94552	QLD
Warwick	-28.2	152.1	94555	QLD
RAAF Amberley	-27.62	152.71	94568	QLD
Miles	-26.65	150.18	95529	QLD
Clare High School	-33.82	138.59	95667	SA
Charlton	-36.28	143.33	94839	VIC
Katanning	-33.68	117.6	94641	WA

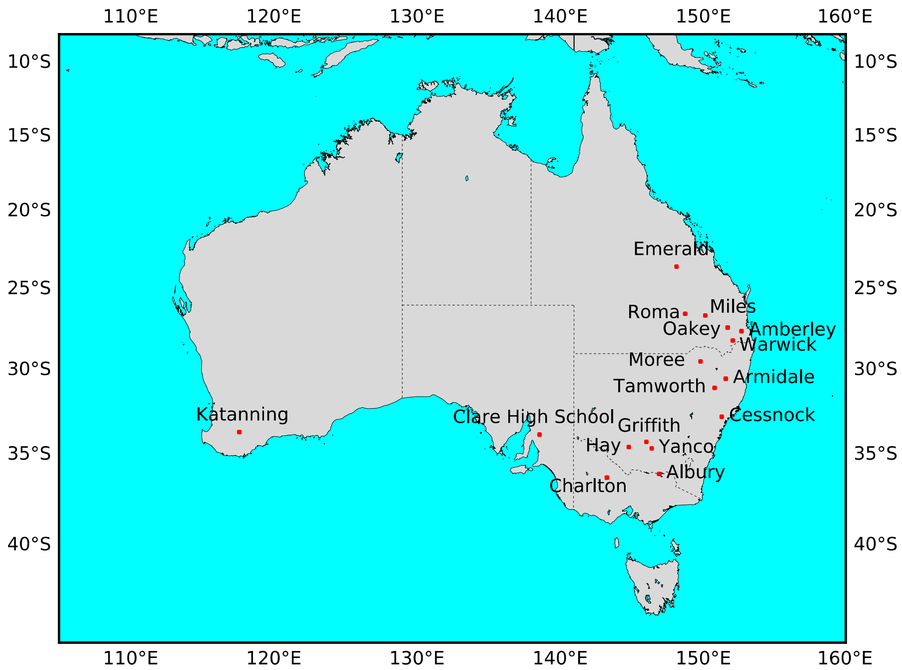

Fig. 13 Map of the 17 benchmark sites

4.1.4.2 Results

The HLI and AHLU performance analysis is presented in the following sections. A description of the statistical measured used to assess the performance of the system are in Appendix A1.

Heat Load Index

Fig. 14 shows the progression of the forecast performance since the 2005-06 season for the 17 benchmark locations. In particular, it represents the Root Mean Square Error (RMSE), which is the average magnitude of the forecast error with zero being the perfect score. As expected, the 1-day lead time RMSE has always been lower than that for the 3-day lead time although their difference was much higher during the first years in contrast to more recent years.

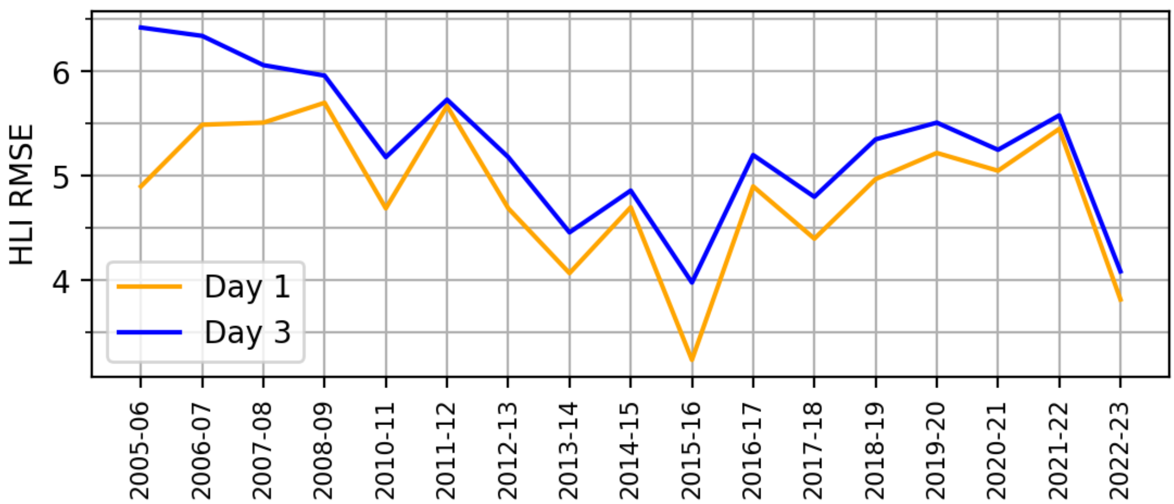

Fig. 14 HLI RMSE averaged seasonally (from 1-Oct to 31-Mar) and across the 17 benchmark sites

To further verify the model performance, the following continuous scores have been considered:

- Mean Absolute Error (MAE): measures the average magnitude of the errors without considering their direction, as RMSE, but it is not a quadratic scoring rule. Rather, MAE is a linear score, which means that all the individual differences are weighted equally in the average. Both the MAE and RMSE can range from 0 to ∞, and they are negatively-orientated scores (i.e., the lower values, the better).
- Mean Error (ME): indicates the average direction of error. It is not a measure of the correspondence between forecasts and observations, as such it is possible to get a perfect score (0) for a bad forecast if there are compensating errors.
- Bias (BIAS): compares the average forecast magnitude to the average observed magnitude. As ME, it does not measure the correspondence between forecasts and observations, and therefore errors can cancel out.
- Correlation Coefficient (CC): measures the linear association between forecast and observation. Visually, the correlation measures how close the points of a scatter plot are to a straight line. Ranging from -1 to 1, the CC is positive when higher forecast values tend to be associated with higher observed values whereas CC is negative when higher forecast values tend to be associated with lower observed values.
- Refined Index of Agreement (rIOA): this index, developed by Willmott et al. (2011), indicates the sum of the magnitudes of the differences between the model-predicted and observed deviations about the observed mean relative to the sum of the magnitudes of the perfect-forecast and observed deviations about the observed mean. A value of rIOA of 0.5, for example, indicates that the sum of the error-magnitudes is one half of the sum of the perfect-model-deviation and observed-deviation magnitudes. Thus, rIOA is a measure of how well each time step (hour) performance is compared to the average of the observations.

In the most recent year, the first 4 days of the forecast exhibit similar values of RMSE followed by a gradual increase to 7-day lead time (Fig. 15a). This decrease in model efficiency with increase in lead time can be explained by increase in uncertainty. We point out that RMSE puts greater influence on large errors than smaller errors, but it does not indicate the direction of the deviations.

The MAE indicates that the average difference between the forecast and the observed HLI is from roughly 2 units for 1-day lead time to 4 units for 7-day lead time (Fig. 15b). Furthermore, the fact that RMSE indexes are not much larger than MAE indexes (approximately 2 HLI units), suggests a similar magnitude error in the forecast. In other words, very large errors are unlikely to have occurred. The overall positive values of ME (Fig. 15c) along with a general BIAS > 1 (Fig. 15d) imply that HLI tends to be over-forecast.

Consistent with the results described above, the very high CCs represent positive and very strong correlation between forecast and observed values, with decreasing, although still strong, performance as lead times increase (Fig. 15e). Finally, the close values of rIOA to 1 indicate a very good agreement between the variation of predicted and observed values at different time steps (Fig. 15f).

Overall, the performance of the operational forecasts in predicting the HLI on an hour-by-hour basis is good. We found that forecast skill is good out to 4 days.

It is also worth noting that as the data is paired in time the forecast can be an hour or two behind or ahead of the environment, causing a disparity in the dataset where the observed HLI is higher than predicted at any given hour. This can be caused by the movement of weather features, such as a trough, across the monitoring point. For instance, the model may move the trough over a region at

7 am, whereas in reality the trough crossed that point at 9 am. These small variations at the hourly scale can cause large variations in the HLI. In this aspect, a review of daily AHLU via the contingency tables (as presented in the following section) overcomes some of the minor discrepancies by interpreting hourly data.

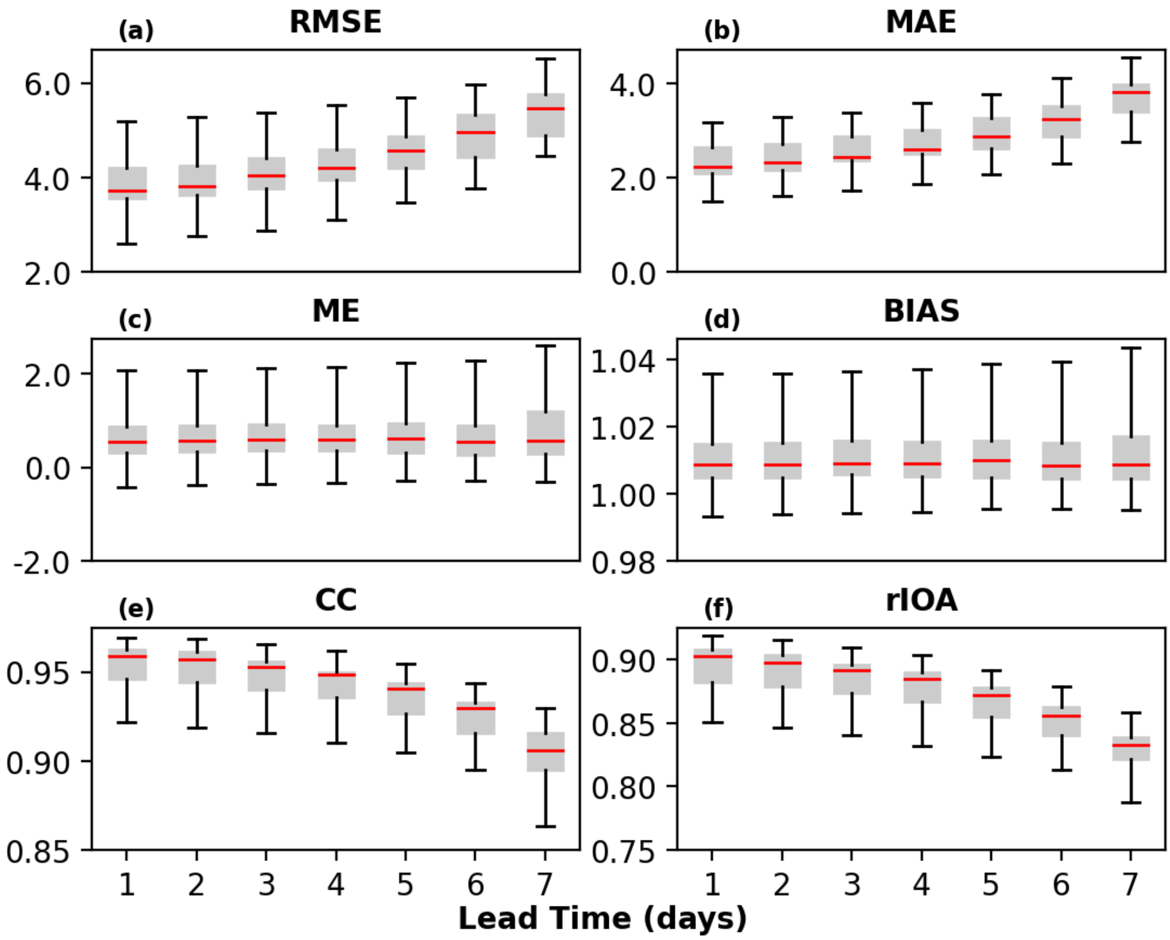

Fig. 15 Box plots comparing several continuous verification methods and statistics of HLI forecast averaged across the 17 benchmark sites for the 2022-2023 season. The bottom and top of the box show the 25th and 75th percentiles, respectively; the red line represents the median and the lower and upper whiskers are the minimum and maximum, respectively.

Accumulated Heat Load Units

A number of categorical statistics of AHLU contingency tables are analysed in this section. Among the metrics, the contingency table (Wilks, 2006) is extensively used in evaluation studies. The contingency table metrics describe whether forecast AHLU hits or misses the observed AHLU and leads to false forecasts relative to observations.

Table 4 Contingency table. A perfect forecast system would produce only "hits" and "correct negatives", and no "misses" or "false alarms"

	Observed: YES	**Observed: NO**
Forecast: YES	hits	false alarms
Forecast: NO	misses	correct negatives

Based on the contingency table (Table 4), several metrics are defined as follows:

- Accuracy: gives an indication of what fraction of the forecasts were correct. Ranging from 0 to 1, 0 means no skill and 1 is the perfect score.
- Bias (or frequency bias): measures the ratio of frequency of forecast events to the frequency of observed events. Therefore, it indicates whether the forecast system has a tendency to under-forecast (BIAS<1) or over-forecast (BIAS>1) events. The bias ranges from 0 to infinite, with 1 being the perfect score.
- Probability of Detection (POD) or hit rate: answers the question what fraction of the observed "yes" events were correctly forecast? The POD is very sensitive to the climatological frequency of the events and it is a good measure for rare events. The POD ranges from 0 to 1; 0 indicates no skill and 1 is a perfect score.
- Probability of false detection (POFD) or false alarm rate: answers the question what fraction of the observed "no" events were incorrectly forecast as "yes". The FAR ranges from 0 to 1 where 0 is a perfect score.
- False Alarm Ratio (FAR): indicates what fraction of the predicted "yes" events did not occur (i.e., were false alarms). As for POD, FAR is very sensitive to the climatological frequency of the event. FAR ranges from 0 to 1, where 0 is a perfect score.
- Threat Score (TS) or critical success index: indicates how well the forecast "yes" events correspond to the observed "yes" events. Thus, it can be thought of as the accuracy when correct negatives have been removed from consideration. It depends on climatological frequency of events, with poorer scores for rarer events.

Fig. 16 to Fig. 19 show the above metrics including all benchmark locations for the forecast season for 1-day through to 6-day forecast AHLU. Above each figure is displayed the number of correct forecasts (hits and correct negatives) followed by the number of incorrect forecasts (misses and false alarms) for each lead time and risk level. The data is not presented for AHLU92 and AHLU95 due to the lack of events.

The results for each AHLU threshold and category show a varied range of forecasting accuracy and reliability in predicting the correct category. Because of the nature of the derivation of the AHLU (with distinct cut offs) and the methods used to assess the categorical forecasts, it is difficult to draw many meaningful conclusions.

The following points can be made from review of Fig. 16 to Fig. 19:

- The accuracy for all categories and forecast lead times are high for the season (>90%) with minimal if any decrease as lead time increases.
- The AHLU89 threshold forecast has high accuracy (>97%) for all events whereas the bias, POD FAR and TS all significantly worsen with increasing lead time. There are insufficient High and Extreme events for the AHLU89 category to come to any further meaningful conclusions and therefore the remaining points concern the AHLU80, AHLU83 and AHLU86 threshold forecasts only.
- The accuracy reliability of most forecasts with thresholds of AHLU80-86 show a gradual decrease as lead times increase, with some forecasts showing no or minimal difference in reliability between 1- and 6-day lead times.

- The bias in the Medium and High forecasts is > 1 for all lead times for AHLU80-86, indicating that the forecasts for these thresholds overpredict the frequency of these events. The bias in the forecasting of Low and Extreme events is generally closer to 1 and often < 1. It is therefore likely that the missed Low and Extreme events were incorrectly forecast as Medium or High events. This pattern is also reflected in the false alarm ratio for the AHLU80-86 forecasts, which shows the FARs for Medium and High events are at least 10% above the FARs for Low and Extreme events.
- The probability of detection (POD) of an AHLU80-86 Extreme event shows little dependence on lead time, being above 80% for even up to 6 days for AHLU80 and 83, and above 60% for AHLU86.
- The probability of false detection (POFD) of an AHLU80-86 Extreme event gradually increases with lead time, but remains < 2% for AHLU80 and < 0.5% for AHLU83 and 86 at a 6-day lead time.
- The probability of detection (POD) of an event is >80% for AHLU80 Extreme event even for a 6-day lead time. Noting that the number of false alarms for Extreme events is less than 20% out to 5 days, this means that a feedlot manager can confidently make a decision up to 5 days ahead of an Extreme event forecast. However, the rate of overprediction means that at 5 days out there is a greater than 20% chance of an Extreme event being forecast but not actually occurring. Note that a High or Medium event will likely occur instead.

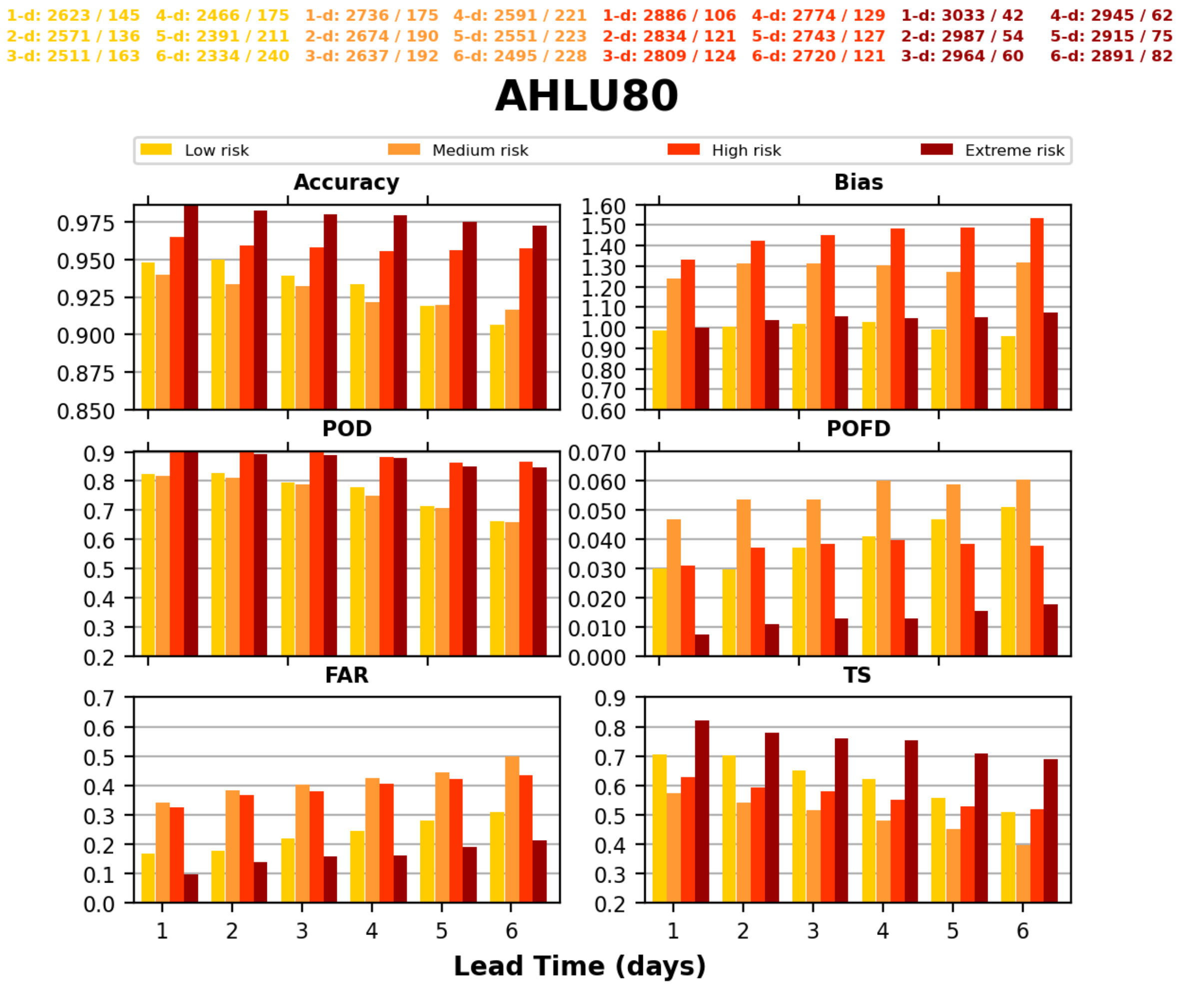

Fig. 16 Measures derived from the AHLU80 contingency table across the benchmark locations

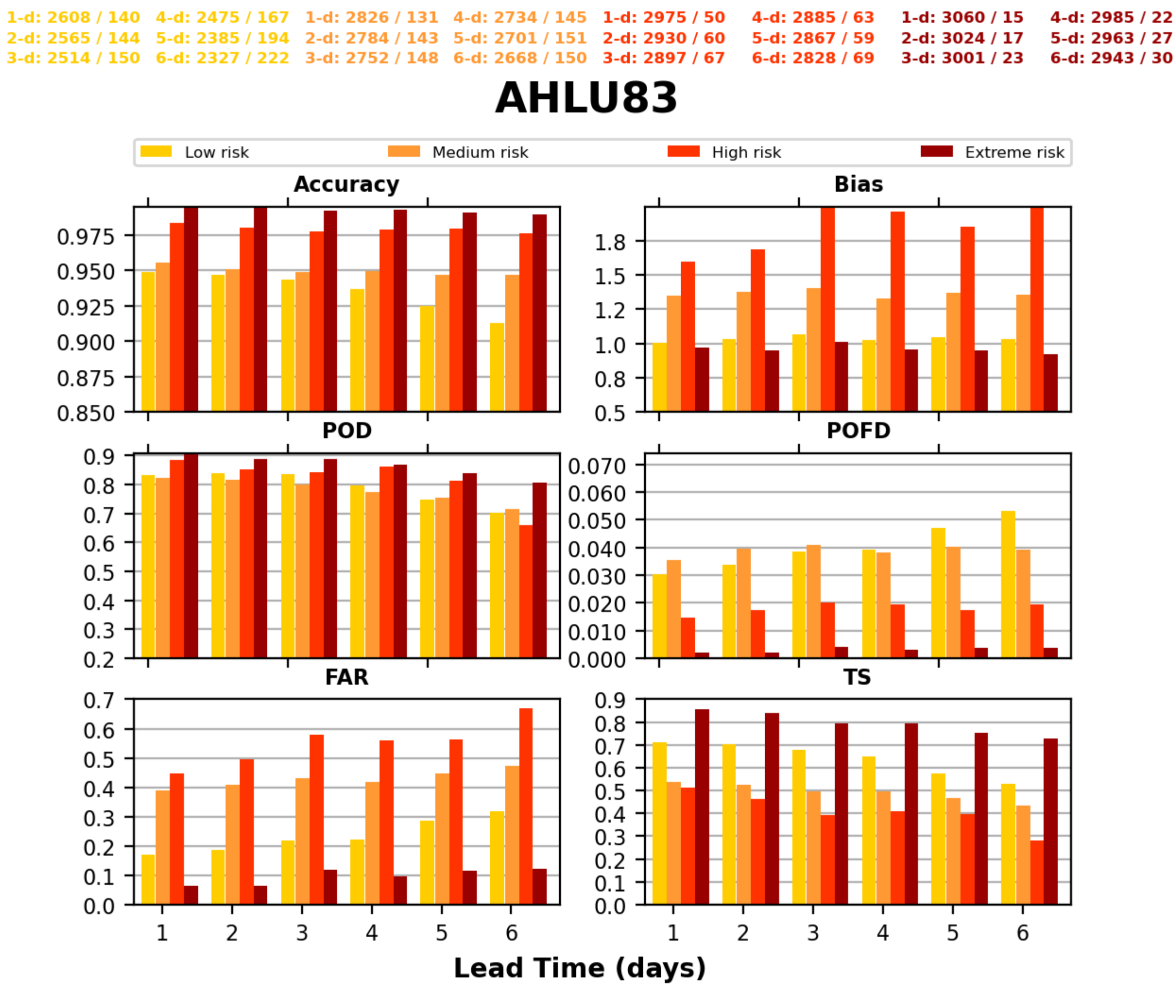

Fig. 17 Measures derived from the AHLU83 contingency table across the benchmark locations

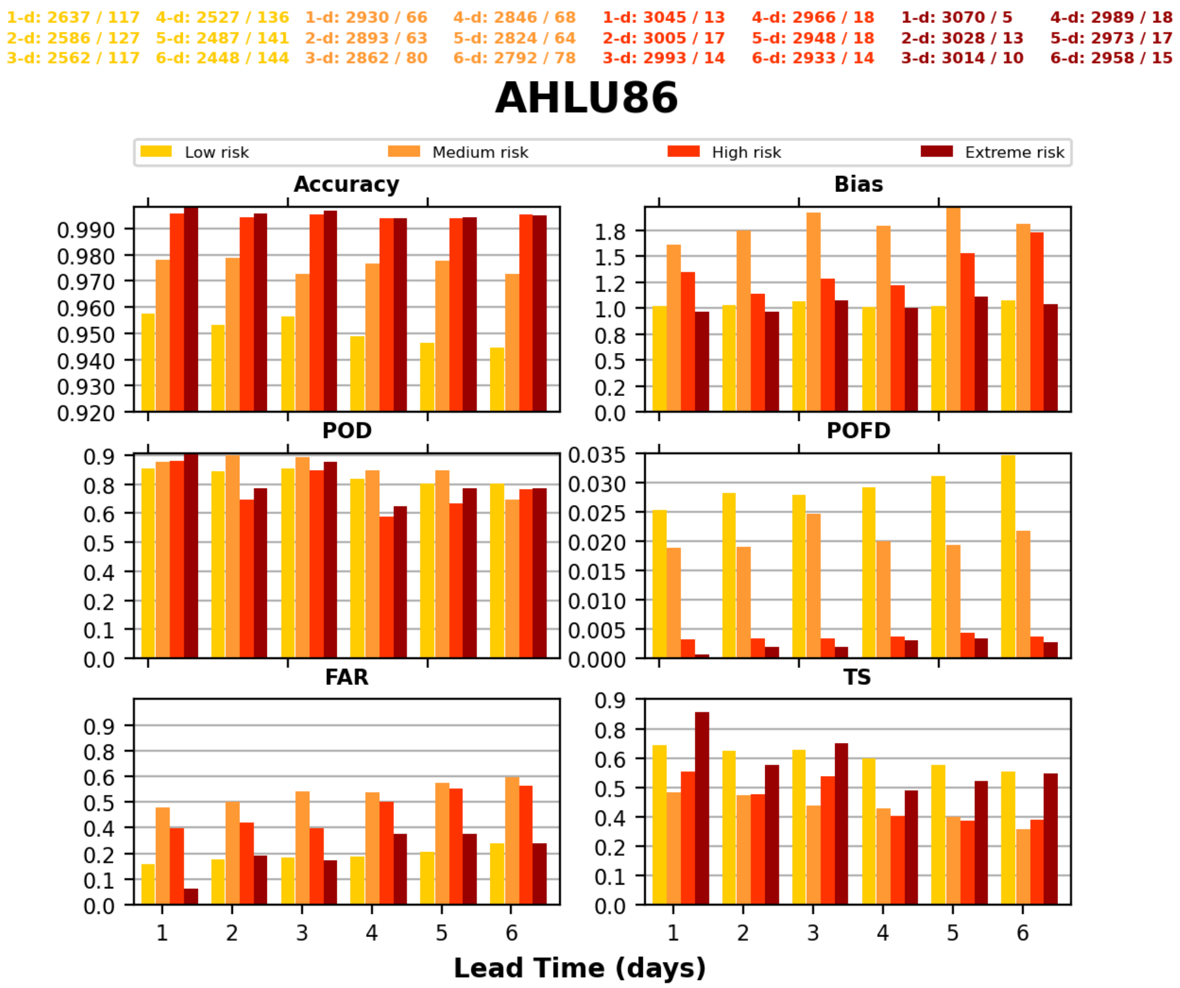

Fig. 18 Measures derived from the AHLU86 contingency table across the benchmark locations

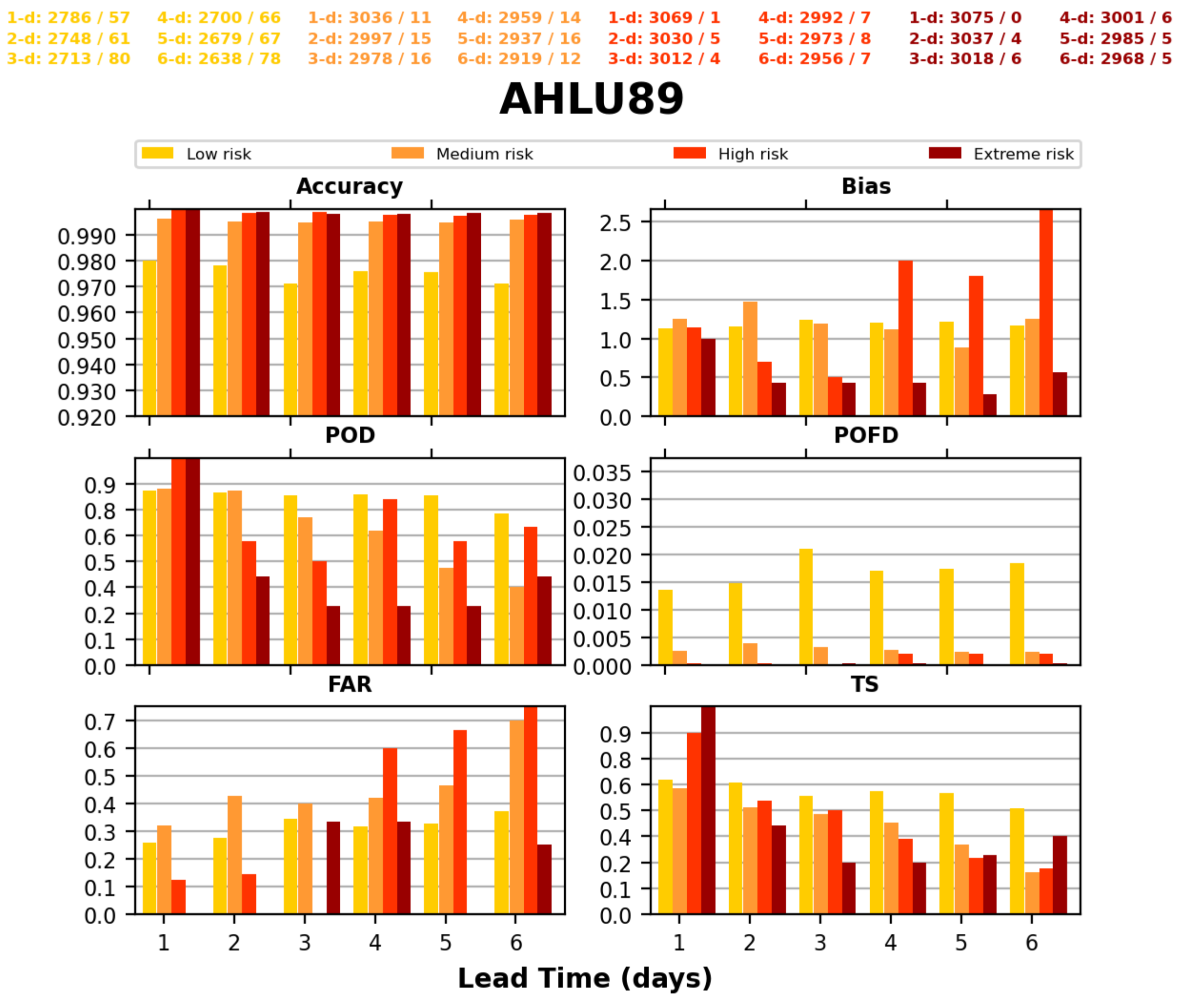

Fig. 19 Measures derived from the AHLU89 contingency table across the benchmark locations

4.1.5 User Survey

At the end of each season, a survey is sent out to all CHLT subscribers. The subscribers are usually invited to comment on the accuracy of the forecast and other aspects of the service.

The 2023 survey received 111 responses with the full detail of the survey results presented in Appendix A2. The key outcomes from the March 2023 survey are indicated below:

- 73% of participants perceived the heat load at their site as mostly low with a couple of moderate or high heat events.
- Three quarters of participants indicated that CHLT provided them with adequate pre-warning of heat events at their site. Of the remaining quarter of participants, 44% perceived the heat load at their site as “Low all season” and 92% felt like they were well prepared for a heat event this season. Almost half (48%) did not have alerts set for their highest risk cattle and 70% did not participate in heat load training nor watch any recorded webinars, possibly indicating that further training or changes to their use of CHLT could improve the pre-warning of heat events at these sites.
- Nearly all participants (97%) felt like they were well prepared for a heat event this summer. Of the three participants who answered “No” to this, one did not have any cattle on feed and

the others mentioned specific environmental factors such as “humidity after rain” and “a sudden increase in heat” as responsible for their lack of preparedness.

- Of the 21 participants whose sites have an automated weather station and are not already part of the HLDN, 13 expressed interest in joining the HLDN.
- Of the 40 participants whose sites have an automated weather station which is part of the HLDN, 71% stated that their access to the HLDN to obtain a site-specific Heat Load forecast affects their ability to effectively manage cattle heat load during the summer.
- Of the 34 participants who stated that they participated in the offered heat load training or watched the recorded webinars, 33 (97%) found these resources useful. The other participant undertook training with a nutritionist. Still, over two-thirds of these participants would like more training.
- Of the 77 participants who either stated that they did not participate in the offered heat load training or watched the recorded webinars or did not respond to this question, 19 stated that they did not know there was training offered and 28 stated that they would not like more training.
- Over half of the participants indicated that they would like more training. The most popular mode of delivery for this training was “a training kit with documentation, check lists, templates, worked examples and stories of how other feedlots manage heat” followed by “live webinar (with Q&A)” and then “YouTube videos”. It is clear that there is a strong desire for a combination of self-guided training resources in addition to interactive training through webinars. Face-to-face modes of delivery were the least popular, though there was some interest.

5 Conclusions

The CHLT service has become an integral part of heat load management at Australian Feedlots. The number of subscribers and feedlots that are registering for the service continues to grow every year with a significant increase. Overall, the user base is satisfied with the delivery and performance of the service and see it as an integral part of their strategy to manage heat at their feedlot.

The 2022-23 season saw generally average temperatures and abnormal rainfall totals across much of Australia, with large regions experiencing both significantly above and below average rainfall totals.

The forecast performance for prediction of HLI was slightly better than last year, with RMSE, MAE, ME, bias and rIOA all being generally closer to their respective “good” values. Correlation coefficient was comparable between the years. The volatility of the HLI algorithm has been shown in previous studies (B.FLT.0392), indicating that a near perfect forecast can still produce an error of 5 to 7 HLI units, which is similar to the RMSE for a 6-day forecast.

The reliability of the service to predict the correct risk category for different AHLU thresholds is mixed. The rarity of events also makes the ability to draw meaningful conclusions challenging. However, for an Extreme event forecast (AHLU80) a feedlot manager can confidently make a decision up to 5 days ahead of an Extreme event forecast, with a 20% chance of a false alarm.

User feedback identified a desire for further online training resources; particularly, a comprehensive training kit, live webinars with Q&A and YouTube videos.

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Appendix

A1 EVALUATION PARAMETERS

Methods for forecasts of continuous variables:

- Root mean square error: $RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)^2}$
- Mean absolute error: $MAE = \frac{1}{N}\sum_{i=1}^{N}|F_i - O_i|$
- Mean error: $ME = \frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)$
- (Multiplicative) bias: $Bias = \frac{\frac{1}{N}\sum_{i=1}^{N} F_i}{\frac{1}{N}\sum_{i=1}^{N} O_i}$
- Correlation coefficient: $r = \frac{\sum(F-\bar{F})(O-\bar{O})}{\sqrt{\sum(F-\bar{F})^2}\sqrt{\sum(O-\bar{O})^2}}$
- Refined index of agreement:

$$rIOA = \begin{cases} 1 - \dfrac{\sum|F_i - O_i|}{2\sum|O_i - \underline{O}|}, & when \sum|F_i - O_i| \leq 2\sum|O_i - \underline{O}| \\ \dfrac{2\sum|O_i - \underline{O}|}{\sum|F_i - O_i|} - 1, & when \sum|F_i - O_i| > 2\sum|O_i - \underline{O}| \end{cases}$$

Methods for dichotomous (yes/no) forecasts:

- Accuracy: $Accuracy = \frac{hits + correct\ negatives}{total}$
- Bias: $Bias = \frac{hits + false\ alarms}{hits + misses}$
- Probability of detection: $POD = \frac{hits}{hits + misses}$
- Probability of false detection: $POFD = \frac{false\ alarms}{correct\ negatives + false\ alarms}$
- False alarm ratio: $FAR = \frac{false\ alarms}{hits + false\ alarms}$
- Threat score: $TS = \frac{hits}{hits + misses + false\ alarms}$

A2 2023 CHLT SURVEY SUMMARY

At the end of the 2022-2023 season, a survey was sent out to all CHLT subscribers. The subscribers were invited to comment on the use of, and satisfaction with, the forecast and other aspects of the service. The survey included 17 questions and received a total of 111 responses. Fig. A2.1 to Fig. A2.15 and Table A2.1 to Table A2.6 present the results of the 2023 end of season survey.

Some of the survey questions were only asked if respondents submitted particular answers to previous questions:

- Questions 4-6 were only asked of respondents who answered “No” to question 3.
- Question 9 was only asked of respondents who answered “Yes” to question 8, and question 10 was only asked of respondents who answered “Yes” to question 9.
- Question 12 asked for the details of those respondents who answered “Yes” to question 11 – i.e. that they want to join the HLDN. Answers to question 12 are therefore not presented in this section.
- Question 14 was only asked of respondents who answered “Yes” to question 13.
- Question 15 was only asked of respondents who did not answer “Yes” to question 13.
- Question 17 was only asked of respondents who answered “Yes” to question 16.

Fig. A2.1 presents the responses to question 1 of the survey. All of the 111 participants responded to this question.

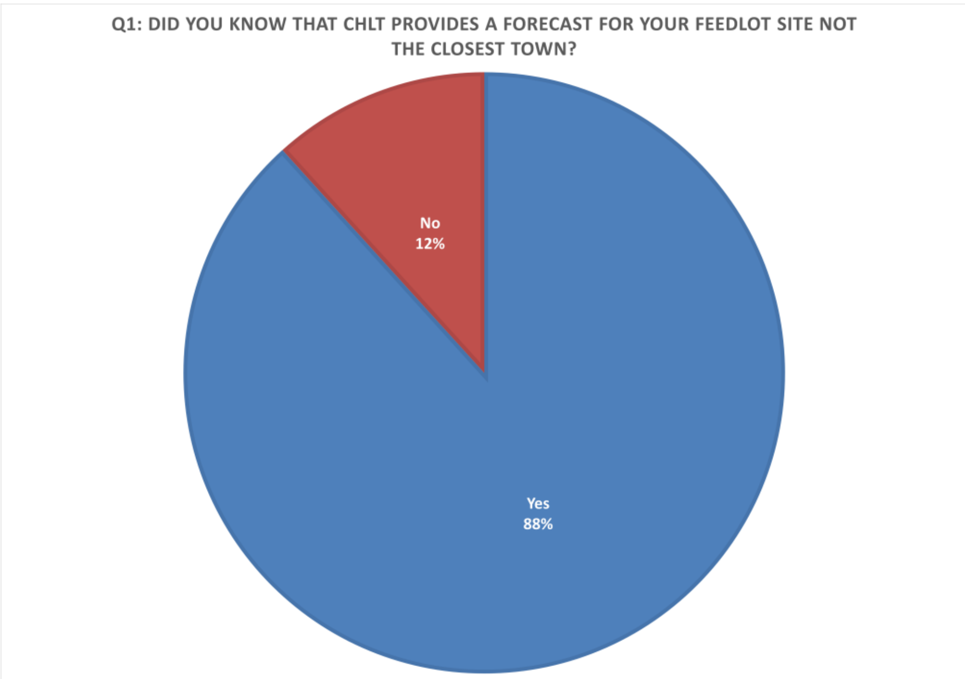

Fig. A2.1 Responses to question 1 of the end of season survey

Fig. A2.2 presents the responses to question 2 of the survey. 108 of the 111 participants responded to this question. Table A2.1 presents additional detail provided by those participants who answered “Other” to question 2.

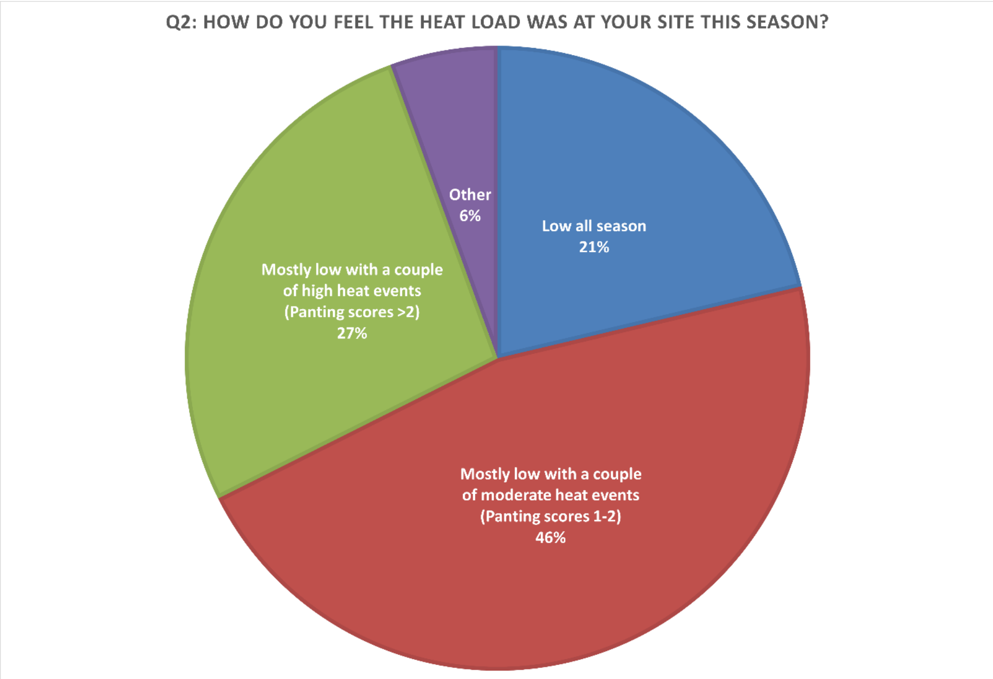

Fig. A2.2 Responses to question 2 of the end of season survey

Table A2.1 Additional comments on question 2 of the end of season survey

Q2. How do you feel the heat load was at your site this season?	
Answer options: Open-ended	**Response count: 6**
Comments: These comments are from those respondents who responded "Other" to question 2	
Number:	**Comments:**
1	Imminent was are large factor this year due to high humidity
2	no cattle on feed
3	We had a hotter and more humid year than usual but our cattle did not show this. I would call them moderate heat events for our feedlot.
4	Most sites only had imminent events (nutritionist)
5	No cattle on feed this season, but noting conditions we would have expected a number of high heat events
6	3 heat events 3+ panting

Fig. A2.3 presents the responses to question 3 of the survey. 106 of the 111 participants responded to this question.

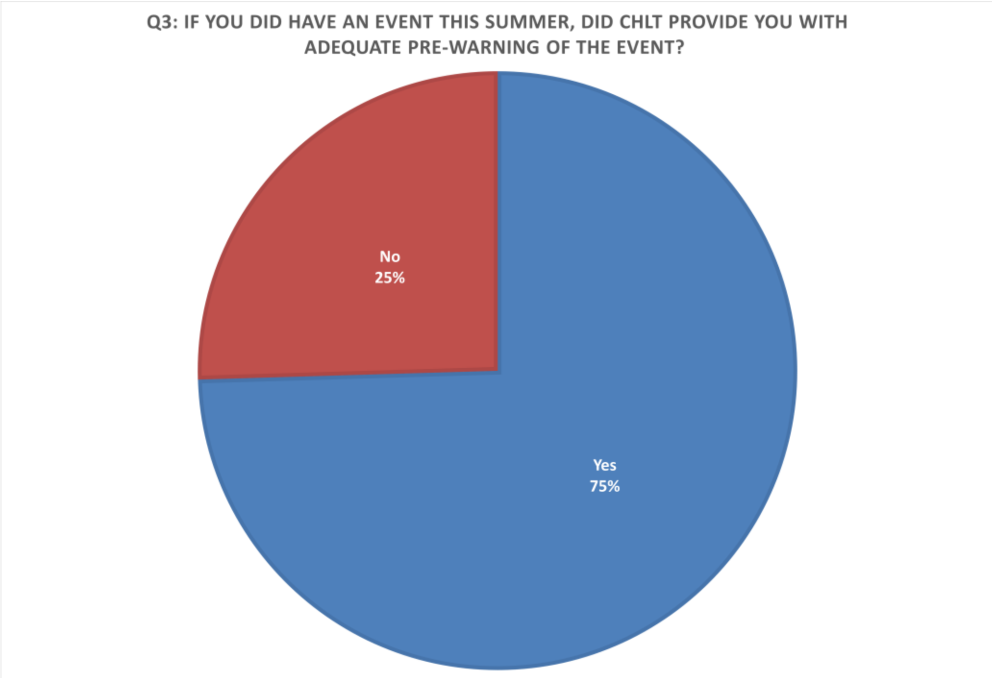

Fig. A2.3 Responses to question 3 of the end of season survey

Fig. A2.4 presents the responses to question 4 of the survey. Question 4 was only asked of the 27 participants who responded "No" to question 3. All 27 participants asked responded to this question.

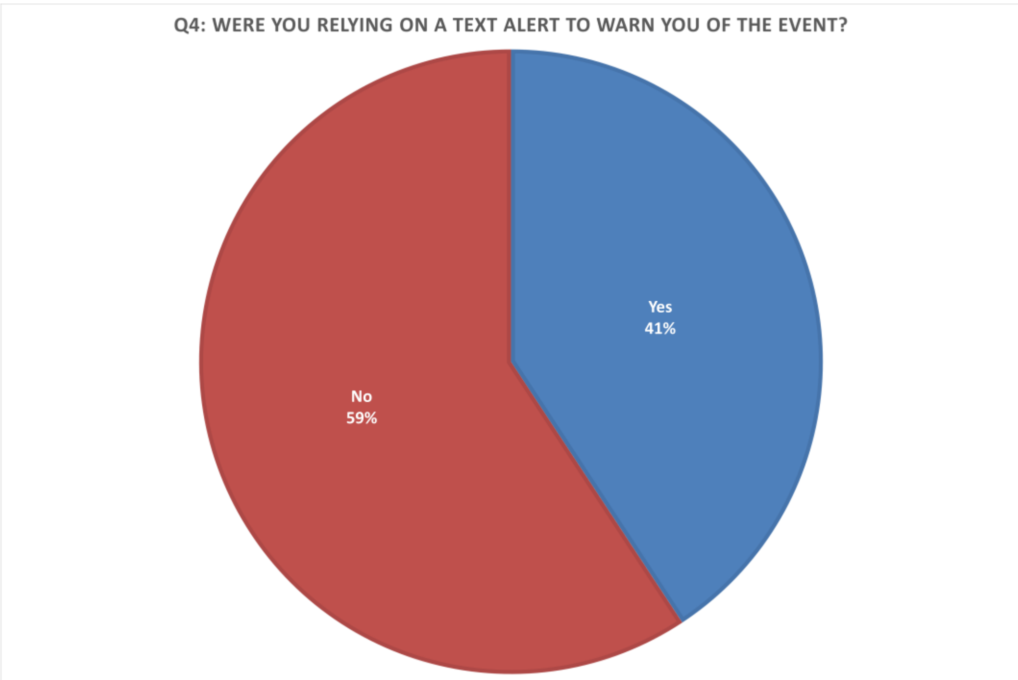

Fig. A2.4 Responses to question 4 of the end of season survey

Fig. A2.5 presents the responses to question 5 of the survey. Question 5 was only asked of the 27 participants who responded "No" to question 3. All 27 participants asked responded to this question.

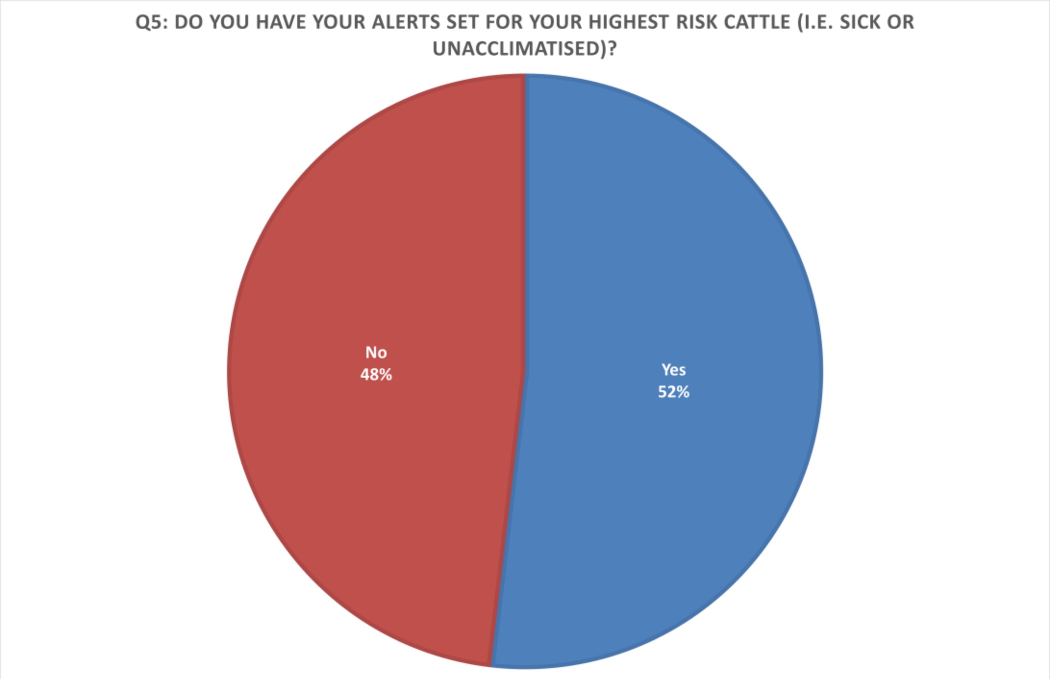

Fig. A2.5 Responses to question 5 of the end of season survey

Fig. A2.6 presents the responses to question 6 of the survey. Question 6 was only asked of the 27 participants who responded "Yes" to question 3. 24 of the 27 participants asked responded to this question.

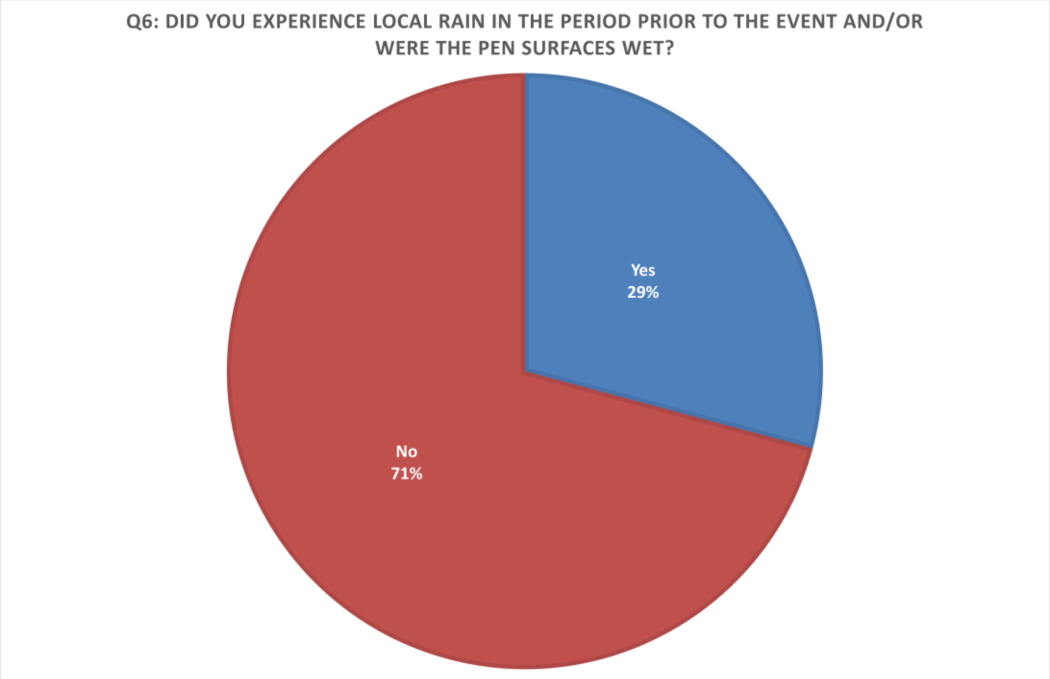

Fig. A2.6 Responses to question 6 of the end of season survey

Fig. A2.7 presents the responses to question 7 of the survey. 103 of the 111 participants responded to this question. Table A2.2 presents additional detail provided by those participants who answered "Other" to question 7.

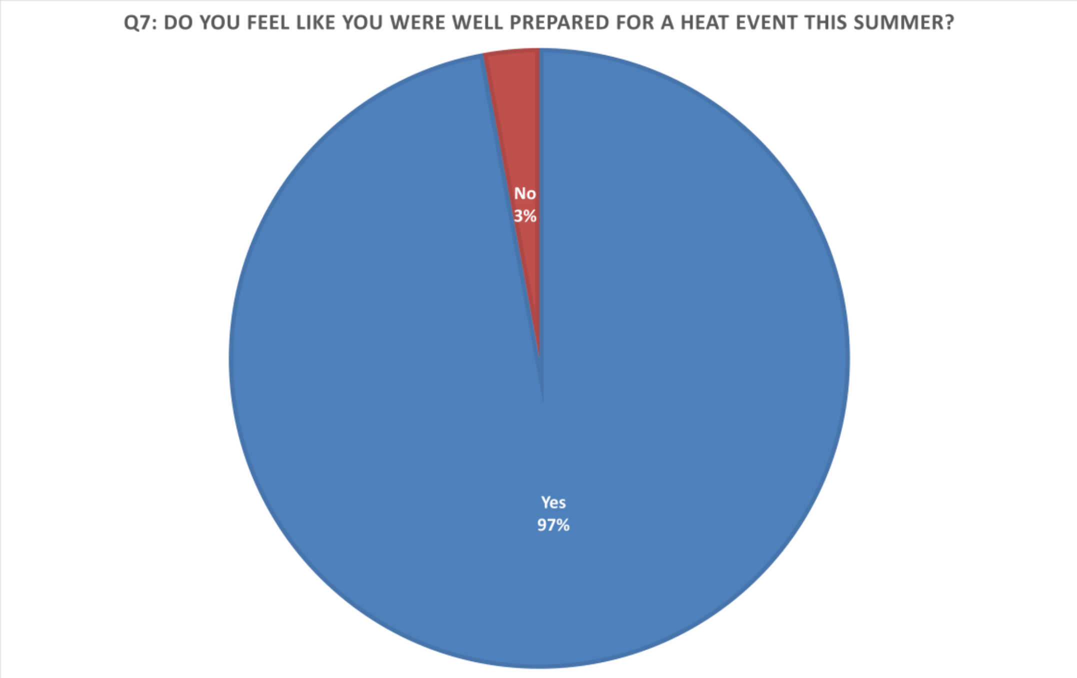

Fig. A2.7 Responses to question 7 of the end of season survey

Table A2.2 Additional comments on question 7 of the end of season survey

Q7. Do you feel like you were well prepared for a heat event this summer? If No, why?	
Answer options: Open-ended	**Response count: 3**
Comments: These comments are from those respondents who responded "No" to question 7	
Number:	**Comments:**
1	Humidity after rain event has us a little behind.
2	Didn't have any cattle on feed
3	There was a sudden increase in heat instead of freshly getting hotter so the first heat event we were unprepared for

Fig. A2.8 presents the responses to question 8 of the survey. 101 of the 111 participants responded to this question.

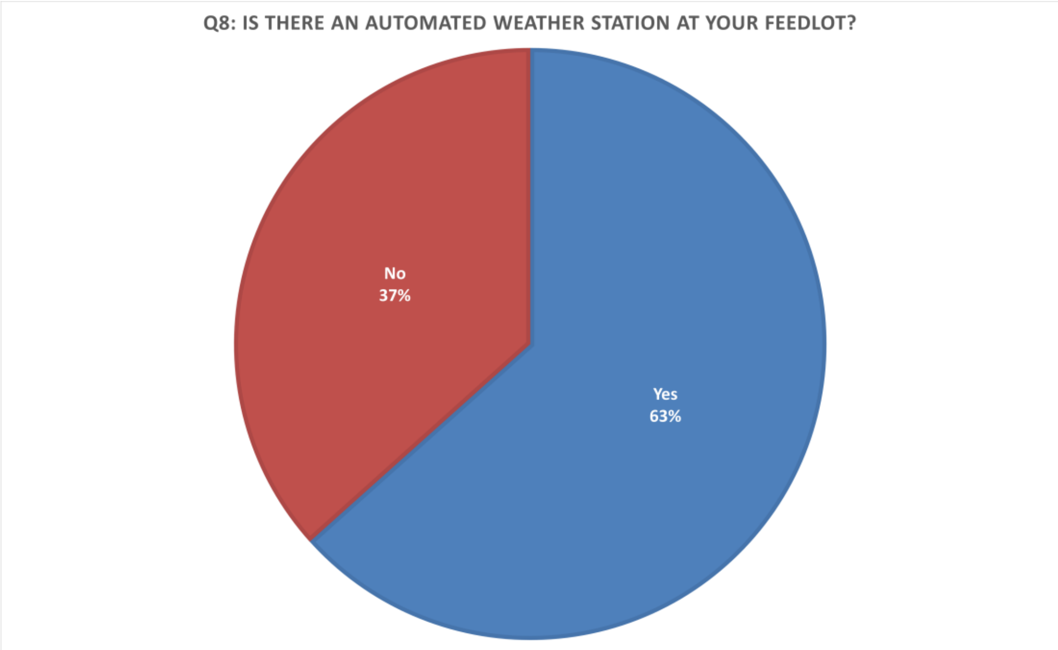

Fig. A2.8 Responses to question 8 of the end of season survey

Fig. A2.9 presents the responses to question 9 of the survey. Question 9 was only asked of the 64 participants who responded "Yes" to question 8. 61 of the 64 participants asked responded to this question.

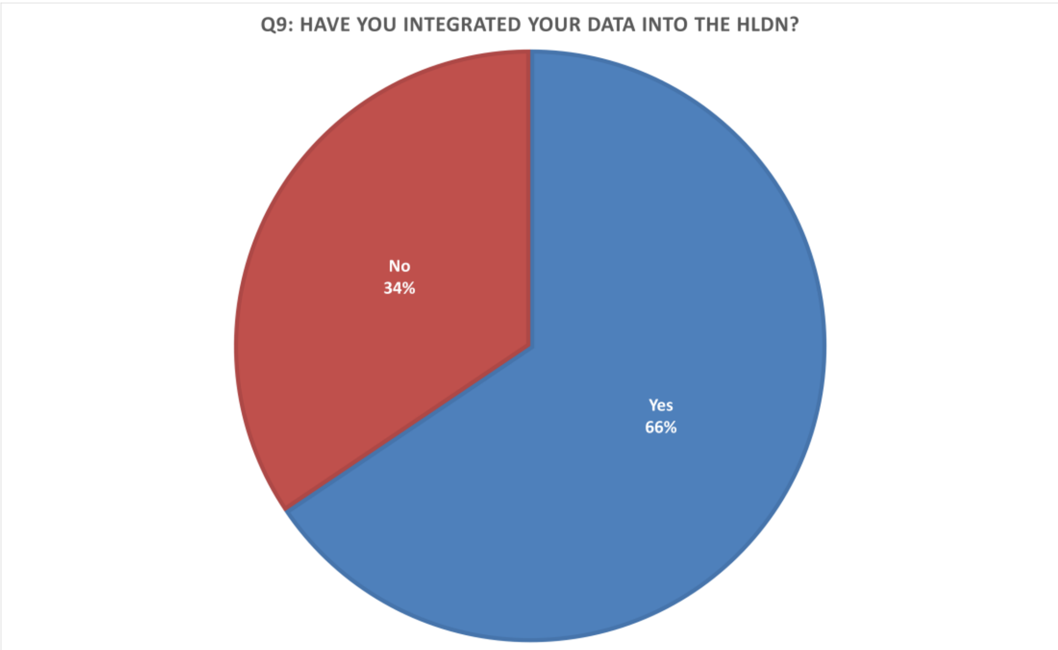

Fig. A2.9 Responses to question 9 of the end of season survey (for those who responded "Yes" to question 8)

Fig. A2.10 presents the responses to question 10 of the survey. Question 10 was only asked of the 40 participants who responded "Yes" to both question 8 and question 9. 39 of the 40 participants asked responded to this question. Table A2.3 presents additional detail provided by those participants who answered "Other" to question 10.

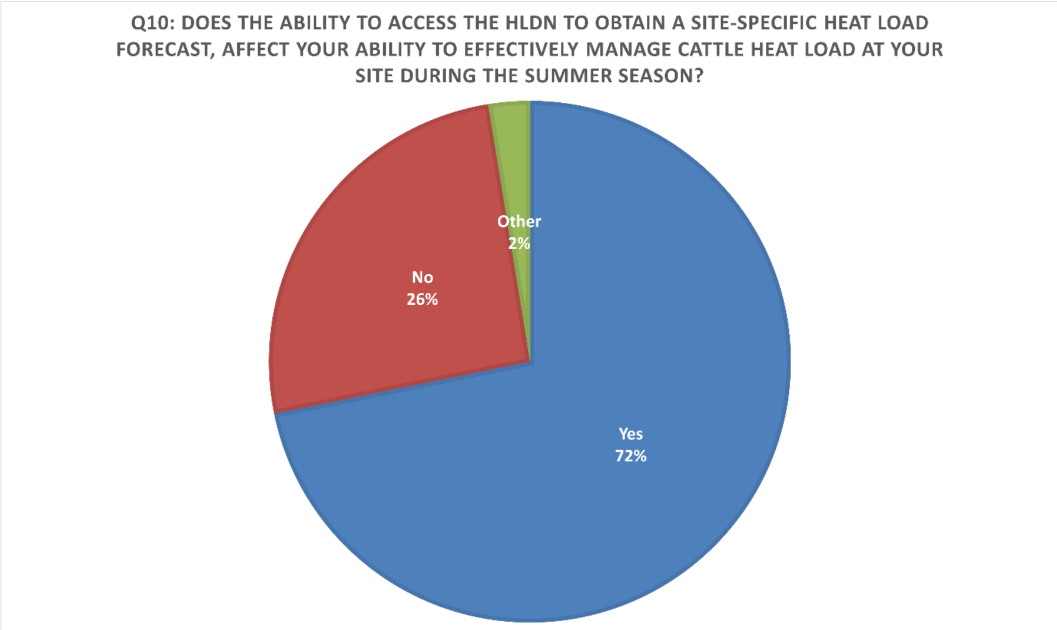

Fig. A2.10 Responses to question 10 of the end of season survey

Table A2.3 Additional comments on question 10 of the end of season survey

Q10. Does the ability to access the HLDN to obtain a site-specific heat load forecast, affect your ability to effectively manage cattle heat load at your site during the summer season?		
Answer options: Open-ended		**Response count: 1**
Comments: These comments are from those respondents who responded "Other" to question 10. Question 10 was only asked of respondents who answered "Yes" to questions 8 and 9.		
Number:	**Comments:**	
1	It needs to feed in as a continuous log so that at 6.05am we know what the load is at 6am	

Fig. A2.11presents the responses to question 11 of the survey. 58 of the 111 participants responded to this question.

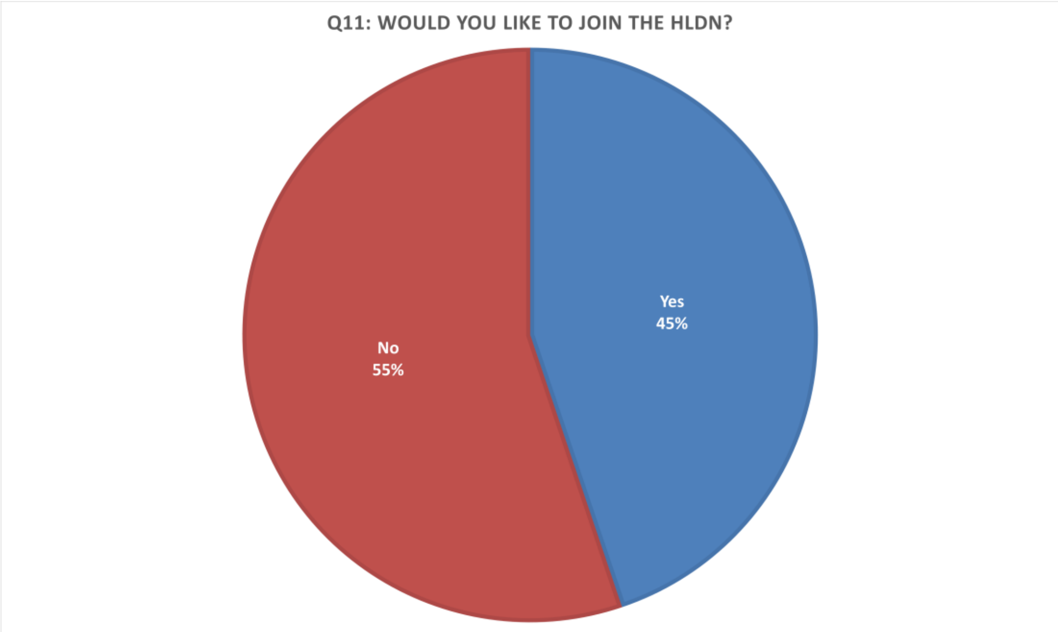

Fig. A2.11 Responses to question 11 of the end of season survey

Fig. A2.12 presents the responses to question 13 of the survey. 58 of the 111 participants responded to this question.

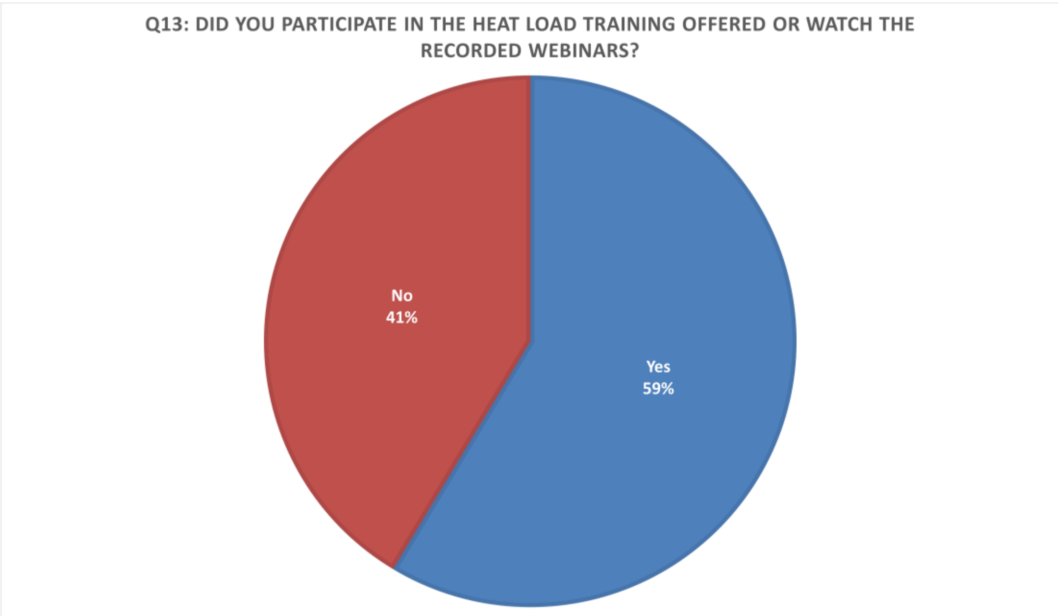

Fig. A2.12 Responses to question 13 of the end of season survey

Fig. A2.13 presents the responses to question 14 of the survey. Question 14 was only asked of the 34 participants who responded "Yes" to question 13. All of the 34 participants asked responded to this question. Table A2.4 presents additional detail provided by those participants who answered "Other" to question 14.

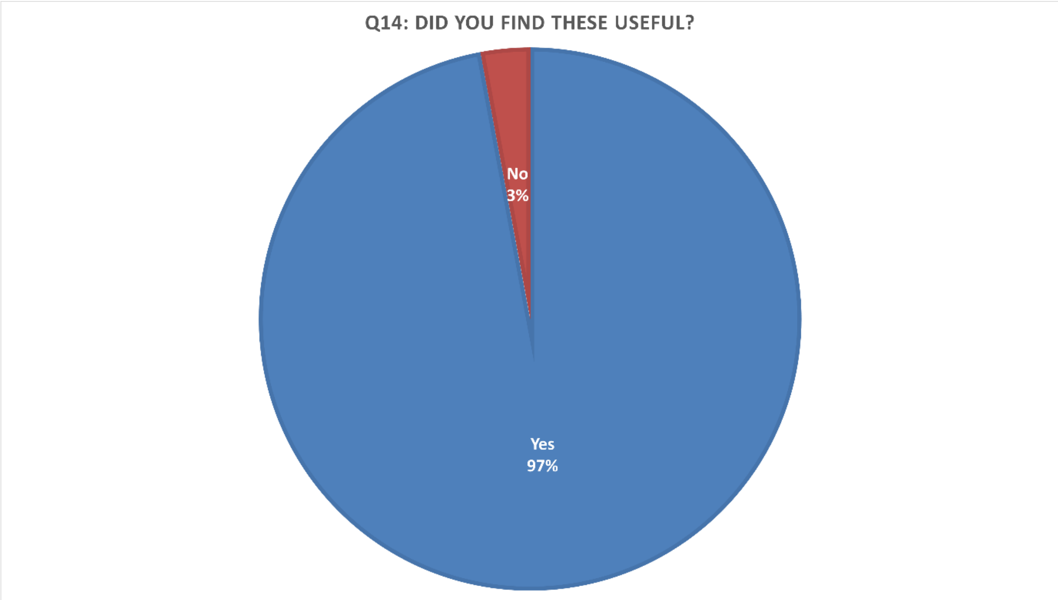

Fig. A2.13 Responses to question 14 of the end of season survey (for those who responded "Yes" to question 13)

Table A2.4 Additional comments on question 14 of the end of season survey

Q14. Did you find these useful?		
Answer options: Open-ended		**Response count: 1**
Comments: These comments are from those respondents who responded "No" to question 14. Question 14 was only asked of those respondents who answered "Yes" to question 13.		
Number:	**Comments:**	
1	Training with nutritionist	

Fig. A2.14 presents the responses to question 15 of the survey. Question 15 was only asked of the 77 participants who responded "No" or did not respond to question 13. 63 of the 77 participants asked responded to this question.

Fig. A2.14 Responses to question 15 of the end of season survey

Fig. A2.15 presents the responses to question 16 of the survey. 97 of the 111 participants responded to this question.

Fig. A2.15 Responses to question 16 of the end of season survey

Table A2.5 presents the responses to question 17 of the survey. Question 17 was only asked of the 58 participants who responded “Yes” to question 16. 57 of the 584 participants asked responded to this question. Table A2.6 presents additional detail provided by those participants who answered “Other” to question 17.

Table A2.5 Responses to question 17 of the end of season survey (for those who responded “Yes” to question 16)

Q17. What mode of delivery [of training] would you prefer?	
Answer options: Multiple choice, able to select multiple answers	**Response count: 57**
Answer:	**Count:**
Live webinar (with Q&A)	**30**
YouTube videos	**22**
A training kit with documentation, check lists, templates, worked examples and stories of how other feedlots manage heat	**39**
Face to face workshops (off-site)	**8**
Face to face inhouse training for my team	**10**
Other (please specify)	**1**

Table A2.6 Additional comments on question 17 of the end of season survey

Q17. What mode of delivery [of training] would you prefer?	
Answer options: Open-ended	**Response count: 1**
Comments: These comments are from those respondents who responded “Other” to question 17. Question 17 was only asked of those respondents who answered “Yes” to question 16.	
Number:	**Comments:**
1	we have training annually