live export

# Upgrade of biological assumptions and parameters used in the HS risk management model

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## Abstract

The animal parameters in the HS risk management model are critical to the assessment of voyage risk and hence also critical to the regulatory approval of live export voyages from Australia to the Middle East.

A review has shown the few recent heat stress data sets available to be consistent with the original heat stress data applied in the HS software. In general, the efficacy of the original figures is reaffirmed. A slight change is recommended to the heat stress threshold, mortality limit and coat factor for *Bos taurus* dairy (Friesian) cattle.

Two methods are given for accepting minor loading variations without having to rework and resubmit the HS file. This will save time and complication during the loading process, without significantly increasing voyage heat stress risk.

# Executive Summary

The HS risk management model was released for use in 2001. Because of the diversity of livestock types and conditions, there will always be room for more data on heat stress susceptibility. This report surveys recent literature and analyses recent experimental data to see whether the animal parameter database can be extended or revised. Those data which were well documented and relevant were found to support the heat stress threshold values used to build the original model. As in the original analysis, a number of data sources which initially looked promising were found to be unusable for this purpose.

Specific outcomes were:

- The data for *Bos taurus* steers and Merino wethers were consistent with previous data.
- Previous anecdotal evidence of the susceptibility of heavy rams were not supported by the limited new data. Future work such as data logging or hot room experiments should look for opportunities to collect further data on heavy rams.
- The heat stress threshold (HST) for *Bos taurus* dairy cattle should be revised upwards from 28.2°C to 28.4°C, with mortality limit increased from 32.9°C to 33.1°C.
- *Bos taurus* dairy cattle, such as Friesians, without strong coat changes in winter should be assessed using a mid-season coat factor through winter.

By noting that the available data are generally consistent with HS and making adjustments where justified by data, the efficacy of the HS assumptions is confirmed. It is expected that further livestock type-specific investigations will occur in the future, driven by industry need.

# Contents

# 1 Background

HS is both a model and a software tool for evaluating the risk of heat stress on live export voyages from Australia to the Middle East.

While HS has been central to heat stress related welfare improvements and has a sound scientific basis, it is recognised that the animal parameters were necessarily based on limited reliable data. Recognising that there will never be the ideal complete data set, this review aims to assess the HS model in the context of new data which have become available since the model was established. By doing so, confidence in the efficacy of the model is further improved.

Practical difficulties have been encountered with HS during vessel loading. It is inevitable that the livestock finally on board will differ in some way from the planned loading which was approved by AQIS in the form of an HS printout. A legalistic approach could insist that the HS file be revised for the actual loading to demonstrate that the risk is still under control. For most practical loading variations, the risk will be minimally affected. This report arrives at methods to assess loading variations as being within the spirit of HS, and suggests that these methods be given regulatory sanction such that the loading operation is facilitated without significant change in risk.

# 2 Project objectives

The overall objective was to update and validate the animal parameters in the HS model using recent data. The specific objectives, taken from the contract schedule were:

1. Review data and results from heat stress related research involving sheep, goats and cattle completed since the HS model was developed and make recommendations for changes to model parameters where appropriate. This includes research funded by MLA and others in Australia and overseas.
2. Analyse and where appropriate factor into the HS model the results available from exporters shipping livestock to the Middle East and involved with the use of HS.
3. Investigate and amend where necessary the risk calculations as they apply to:
   - A probable underestimate of risk with heavy rams,
   - The comparative mortality between hoggets and lambs,
   - A probable overestimate of risk with heavy wethers on enclosed decks,
   - The comparative mortality risk between hoggets and wethers.

4. Investigate the sensitivity of mortality risk to minor variations in deck and livestock lines as-loaded, to recommend a procedure based on total ship cargo weight which would formally permit sailing when used in conjunction with the HS plan.

# 3 Heat stress data analysis

This section discusses the new data sets which have become available since the HS animal parameters were initially set up. In reviewing the data, the aim is to arrive at values for the heat stress threshold (HST) which can be compared with the original HS data.

## 3.1 University of Queensland - Angus

The University of Queensland, Gatton Angus experiment (Gaughan, not yet published) was run in four repetitions, each with 4 animals in the hot rooms for six days. The dates of the start of each trial were:

| | |
|---|---|
| Trial 1 | 21 July 2004 |
| Trial 2 | 31 July 2004 |
| Trial 3 | 9 August 2004 |
| Trial 4 | 26 August 2004 |

The heating was turned off overnight, with the wet bulb falling and giving some respite. Conditions were made gradually hotter over the first four days. During the hottest part of the test, wet bulb temperatures overnight fell to between 22°C and 25°C and climbed in the morning to between 26°C and 32°C. The record of wet bulb temperature for the four trials is given in Figure 3.1. The animals in these tests were all black Angus steers, with a liveweight of 425 to 450kg, 0 to 2 tooth and body condition score 4 (on a 1-5 scale). They had been on feedlot rations for 75 days prior to the experiment.

The wet bulb acclimatisation of the animals was estimated by reviewing the meteorological data for Gatton. The relevant average was taken as being over the two week period prior to entering the test room. The results showed relatively even acclimatisation for the four experiments, with the Trial 1 animals acclimatised to 10°C wet bulb, and all others being acclimatised to around 12°C wet bulb. Given the variability typical in such experiments, the closeness of the acclimatisation figures allows all four trials to be assessed as one data set.

The diurnal variation in conditions during these tests is not typical of the shipboard environment, where the wet bulb temperature sees almost no systematic change with time of day. In order to isolate as far as possible the benefits of overnight respite, the data were separated into three time bands; morning from 8am to 12 noon, early afternoon (1pm to 3pm) and late afternoon (4pm to 6pm). The data in these bands are plotted in Figures 3.2 and 3.3 as respiration rates and rectal temperature against the room wet bulb temperature. It is not clear that there is any significant difference between the three time bands. It appears that the 4pm to 6pm temperatures are generally above the morning values, however the shift appears minor compared to the scatter of the data.

While no respite effect could be clearly seen in this way, it is still considered likely that the overnight respite made the animals better able to control their body temperature during the daily hot periods which lasted 10 hours (8am to 6pm). This needs to be considered when assessing heat stress thresholds relevant to shipboard conditions.

The data were plotted again in Figure 3.4 as respiration rate against wet bulb temperature, with each individual animal identified by a separate data series. Some interesting points can be noted from Figure 3.4. The first is that one animal (trial 1, animal 3, denoted '1-3') was breathing significantly faster than the others. There is no explanation for why that animal's ability to maintain homeostasis appears to have been compromised. It also appears that the trial 2 respiration rates are above those of the other trials, even at relatively low wet bulb temperatures. The same trend is not seen when rectal temperatures are compared as in Figure 3.5. In fact, the rectal temperature for one of the trial 2 animals is lower than the general range. It may be that there were differences in the assessment and recording of respiration rates for trial 2.

The effect matters little for our purpose as trial 2 was cooler than the other trials and the data do not show a heat stress threshold. Figure 3.5 also shows that the trial 1 animal with elevated respiration rate was not unusual in terms of rectal temperature rise. With animal 3 from trial 1 removed from the data set, the plot of respiration rate against temperature (Figure 3.6) has slightly less scatter than in Figure 3.5.

The afternoon (4pm to 6pm) data of Figures 3.2 and 3.3 are plotted again in Figures 3.7 and 3.8 without the morning and midday data. Rectal temperature data were also plotted for each trial individually to aid interpretation (Figures 3.9 to 3.12). Heat stress thresholds were assessed by inspection from all the plotted data. Table 3.1 gives the assessed values.

**Table 3.1 Heat stress thresholds interpreted from the Angus data from the University of Queensland, Gatton.**

| Data Type | Figure | HST (°C) |
|---|---|---|
| Respiration rate – All animals | 3.2 (&3.4) | 24 - 26 |
| Respiration rate – All time bands | 3.6 | 24 - 26 |
| Respiration rate – 4 to 6pm | 3.7 | 24 - 25 |
| Rectal temperature Trial 1 | 3.9 | 26 - 27 |
| Rectal temperature Trial 2 | 3.10 | Not hot enough |
| Rectal temperature Trial 3 | 3.11 | 29 |
| Rectal temperature Trial 4 | 3.12 | 27 - 29 |
| Rectal temperature 4 – 6pm | 3.8 | 26 |

It is noted that the heat stress threshold inferred from the 4 to 6 pm rectal temperature data is significantly lower than that inferred from all rectal temperature data aggregated together. Looking critically for a general 0.5°C rectal temperature rise has revealed a difference that was hidden by the general scatter of Figure 3.5. It seems likely that the heat stress threshold relevant to the shipboard conditions would be closer to 26°C or possibly lower, rather than the range up to 29°C which could be argued when including the morning data.

Looking at the respiration rate, the 4 to 6pm data also give a significantly lower HST estimate than that read from the whole data set. Using only the 4 to 6 pm data, if the threshold criterion is taken as 100 breaths per minute, the HST answer would be unchanged at 24°C to 25°C.

From the consideration of the above data, a figure of 25°C is chosen as the heat stress threshold for these animals, with the cautionary note that the interpretation is made in the context of significant diurnal range in the experiment. The HS model gives a value of 25.3°C for the HST of these animals, assuming that they had developed a winter coat. This is essentially the same number and, given the limits an applicability of the experiment, no change is required to the HS database.

The text above implies some uncertainty on the criteria for assessing HST. There has been much discussion on the relative merits of respiration rate, respiratory character and rectal temperature as indicators of stress. The LIVE.224 project (Sections 3.6 and 3.7) concluded that respiratory character was a better indicator than respiration rate. While rectal (or core) temperature may be better still, it is a difficult measurement to make for cattle on ships and so voyage data are not available. The University of Queensland Angus data afforded the opportunity to look for correlation between the rectal temperatures and respiration rates.

Figure 3.13 shows respiration rate plotted against rectal temperature for all the animals in this experiment. By referring to similar plots for individual animals, it was possible to estimate, for each animal, a respiration rate corresponding to rectal temperatures 0.5°C and 1.0°C above ‘normal’. Table 3.2 gives the respiration rates assessed as corresponding to each temperature rise.

**Table 3.2 Respiration rates estimated for each animal in the Gatton Angus experiment, at the points where rectal temperatures rose 0.5°C and 1.0°C above normal.**

| Animal | Respiration rate (bpm) | |
|---|---|---|
| | R.T. rise of 0.5°C | R.T. rise of 1.0°C |
| 1-1 | 100 | 115 |
| 1-2 | 90 | 110 |
| 1-3 | 110 | 140 |
| 1-4 | 105 | 115 |
| 2-5 | 110 | N.A. |
| 2-6 | 90 | 90 |
| 2-7 | 95 | 110 |
| 2-8 | 95 | N.A. |
| 3-9 | 90 | 105 |
| 3-10 | 80 | 105 |
| 3-11 | 90 | 110 |
| 3-12 | 80 | 105 |
| 4-13 | 85 | 100 |
| 4-14 | 90 | 105 |
| 4-15 | 95 | 115 |
| 4-16 | 80 | 100 |

A rectal temperature rise of 0.5°C is seen to correspond to respiration rates in the range 80 to 110 bpm (mostly 90 to 100), while a rise of 1.0°C corresponds to a range of 90 to 140 (mostly 100 to 115). These data suggest that the rectal temperature rise moves from 0.5°C to 1.0°C with only a slight further increase in respiration rate, and that the respiration rate of 100bpm suggested as a criteria for HST appears most consistent with the 0.5°C criteria for rectal temperature rise, although it is not inconsistent with the higher rectal temperature criteria. To the extent that experimental data show the rectal temperature rise moving from 0.5°C to 1.0°C over a narrow range of wet bulb temperature, the distinction between the two may be less important.

It would seem that a respiration rate of 100bpm corresponds to a range of perhaps 0.5 to 0.8°C rise in core temperature. A rectal temperature rise of 0.5°C corresponds to a respiration rate around 90 or 95bpm.

For the purposes of this work, HST criteria for cattle of 90 or 100bpm and 0.5°C rectal temperature rise both seem appropriate.

**Figure 3. 1  University of Queensland Gatton Angus Steers – Wet bulb histories for the four trials.**

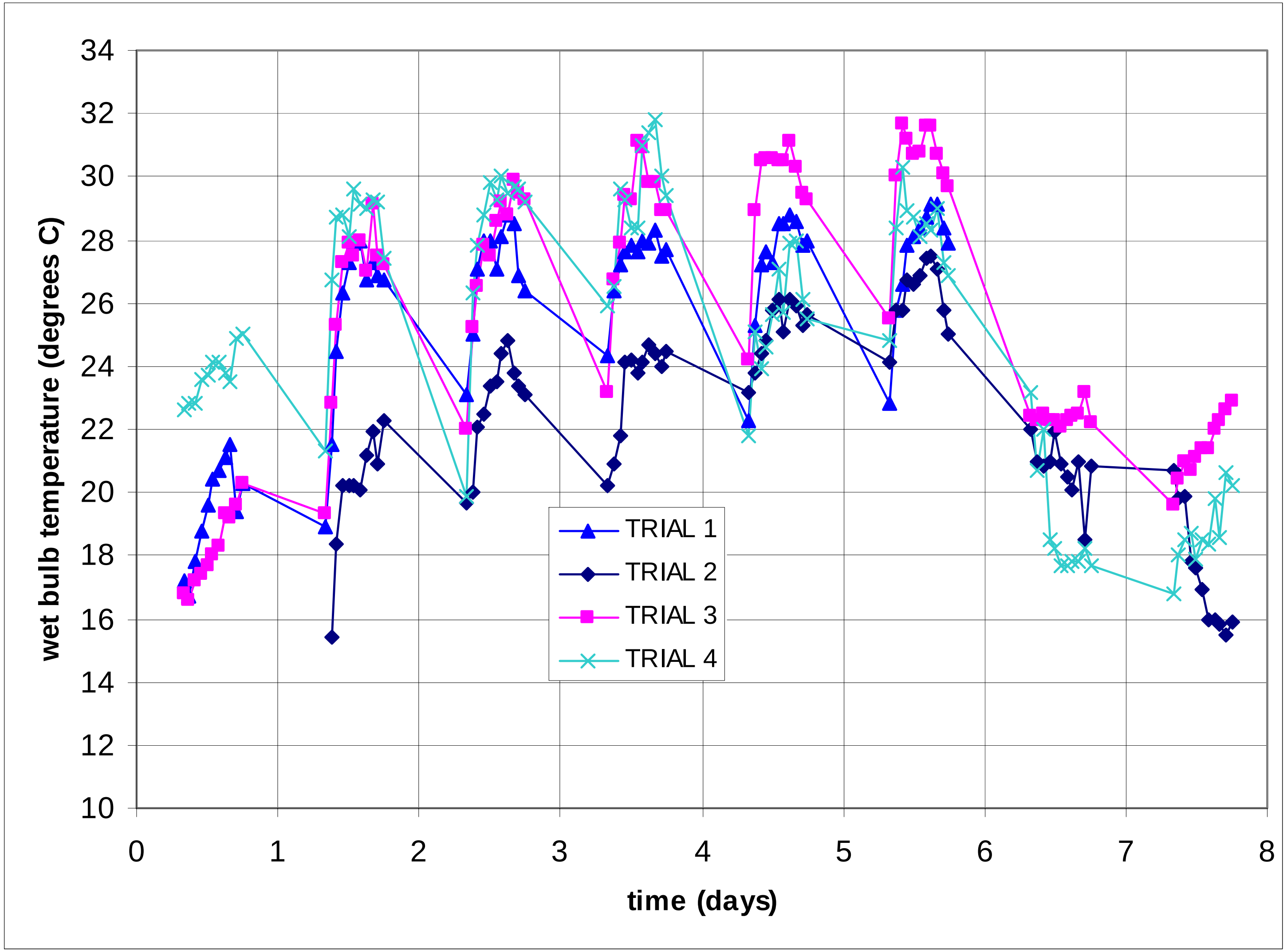


**Figure 3. 2 University of Queensland Gatton Angus Steers – respiration rates by time of day vs wet bulb temperature.**

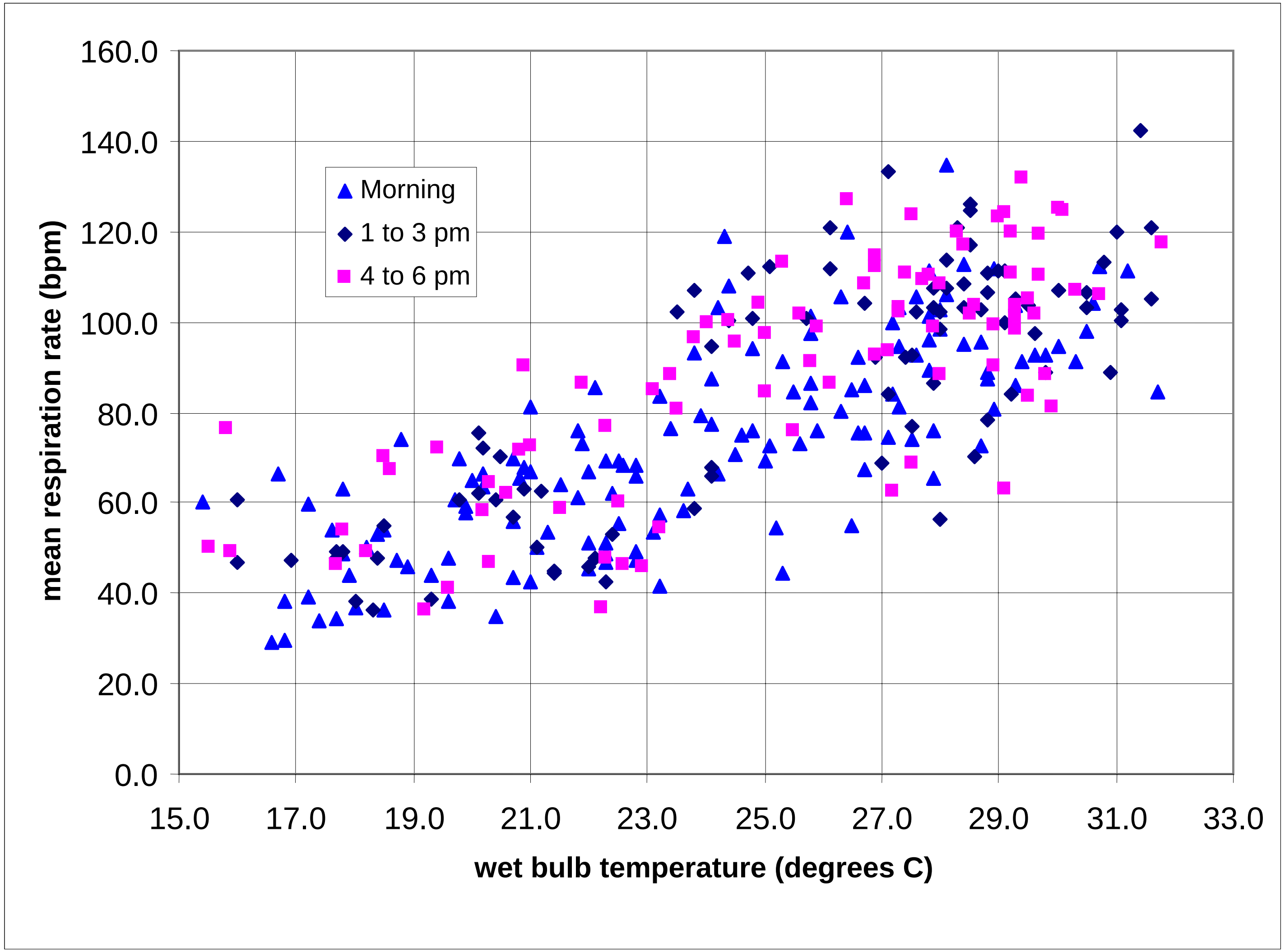


**Figure 3. 3 University of Queensland Gatton Angus Steers – rectal temperatures by time of day vs wet bulb temperature.**

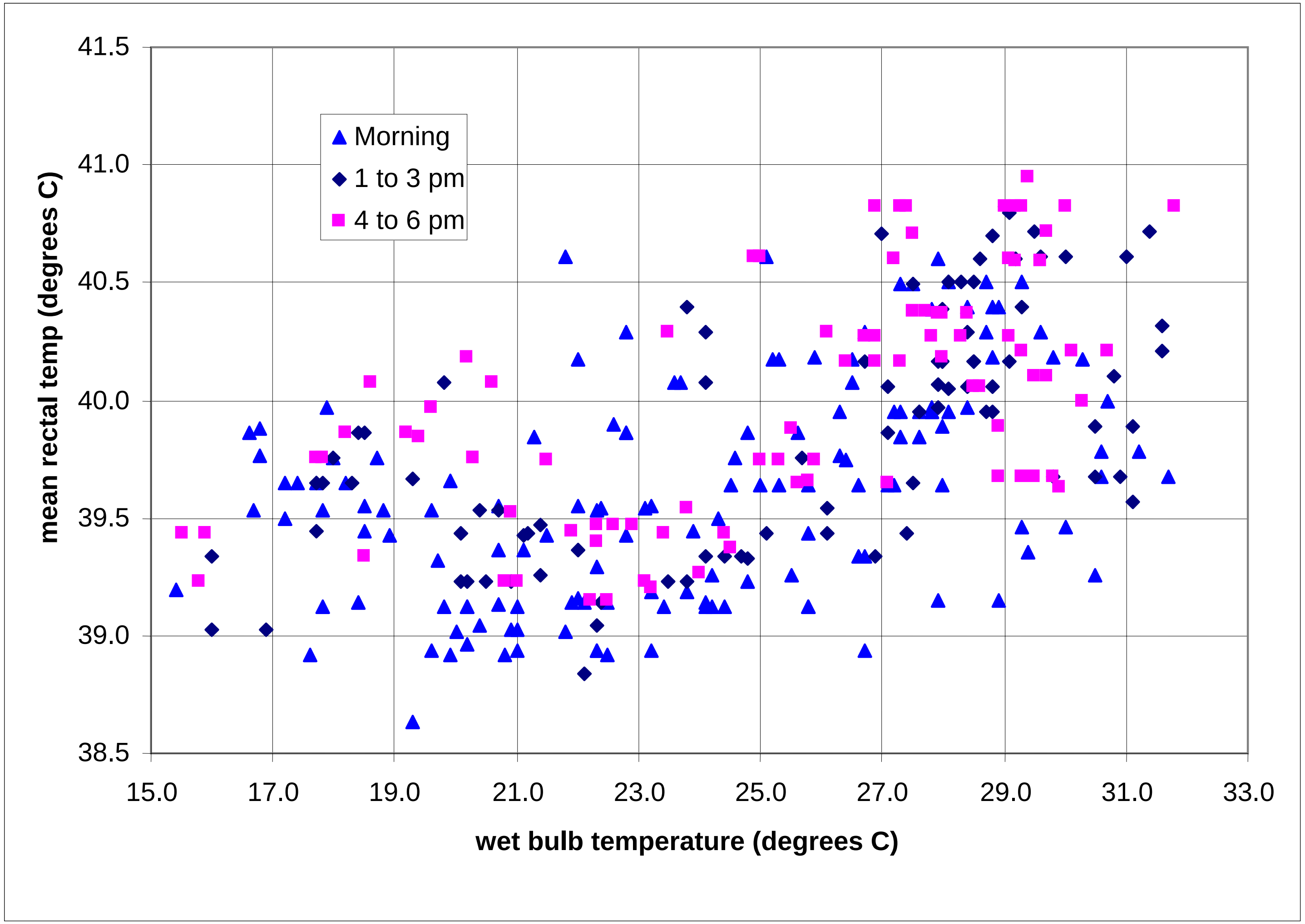


Figure 3. 4 University of Queensland Gatton Angus Steers – respiration rate for each animal plotted against wet bulb temperature.

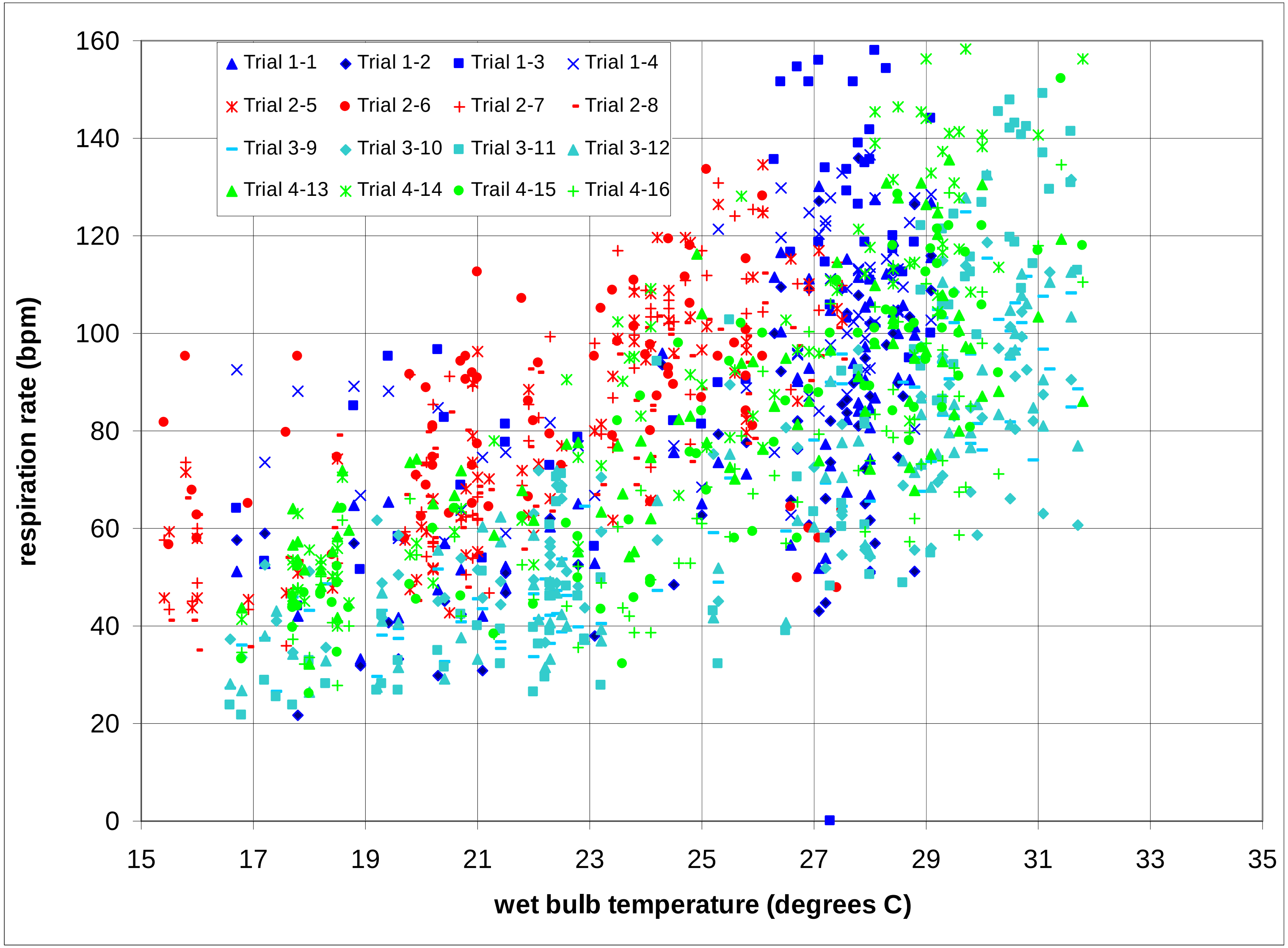


**Figure 3. 5 University of Queensland Gatton Angus Steers– rectal temperature for each animal plotted against wet bulb temperature.**

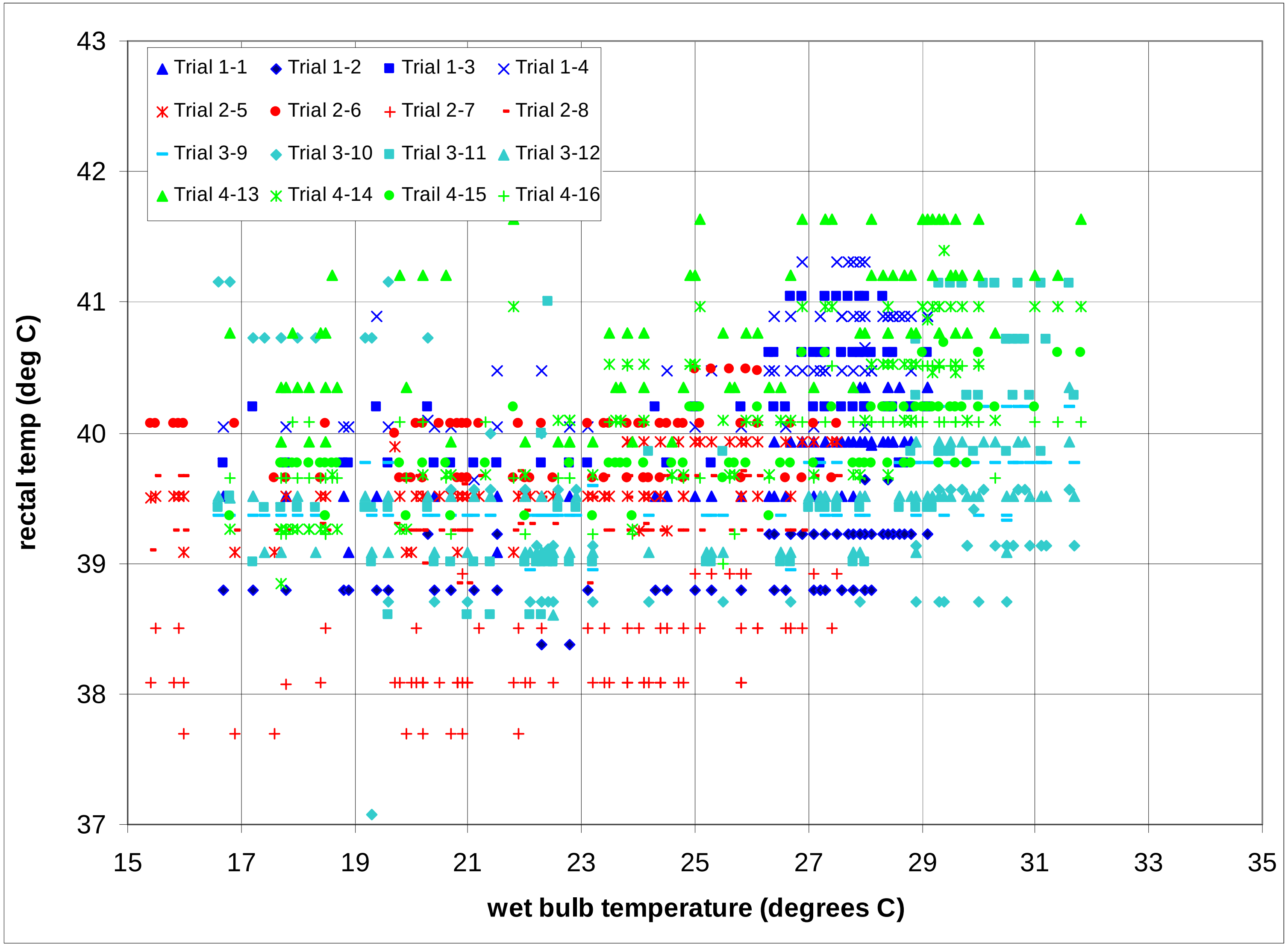


**Figure 3. 6 University of Queensland Gatton Angus Steers – respiration rates by time of day vs wet bulb temperature. Animal 1-3 has been removed from the data.**

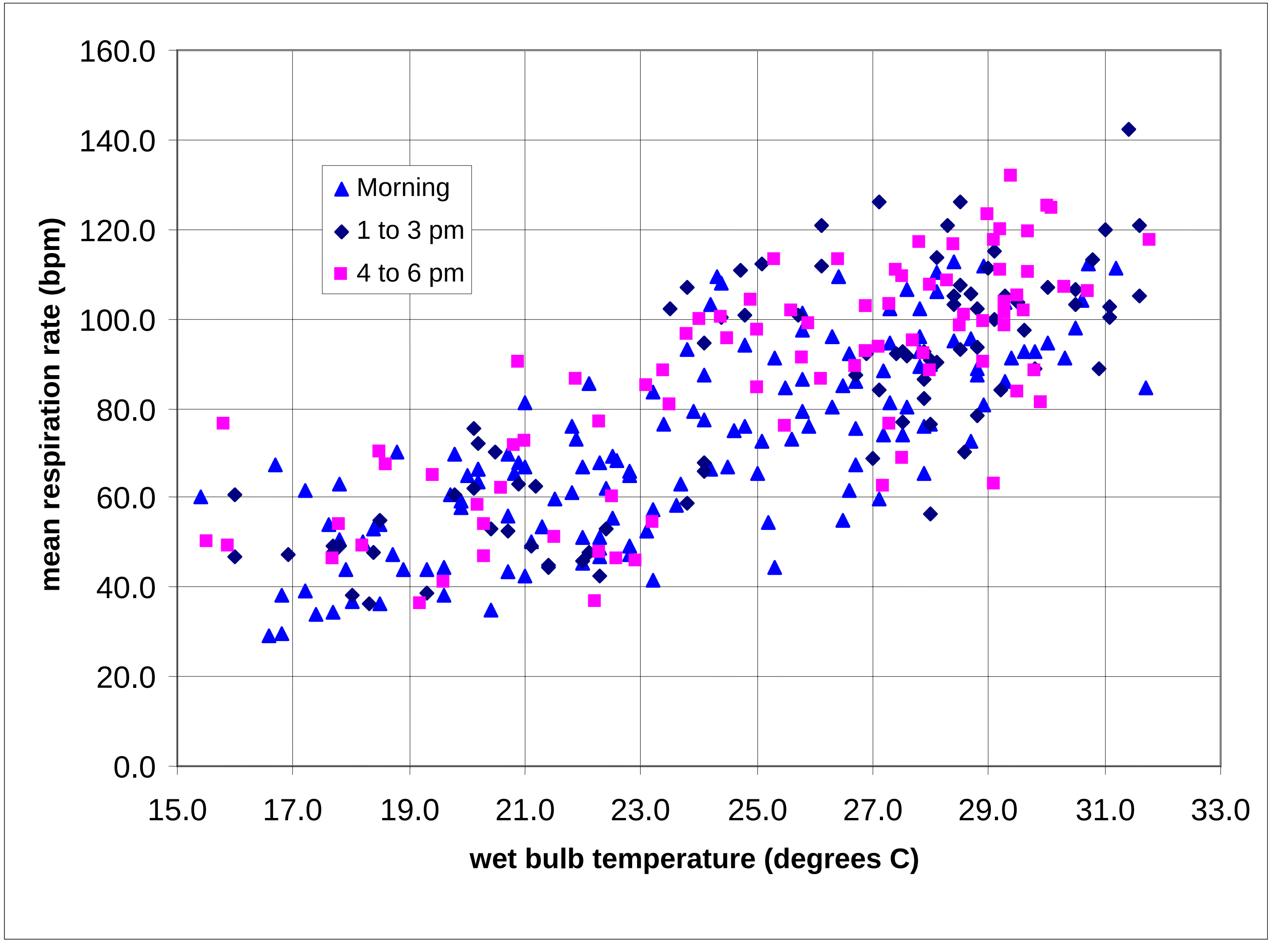


**Figure 3. 7  University of Queensland Gatton Angus Steers – respiration rate vs wet bulb temperature for the afternoon period.**

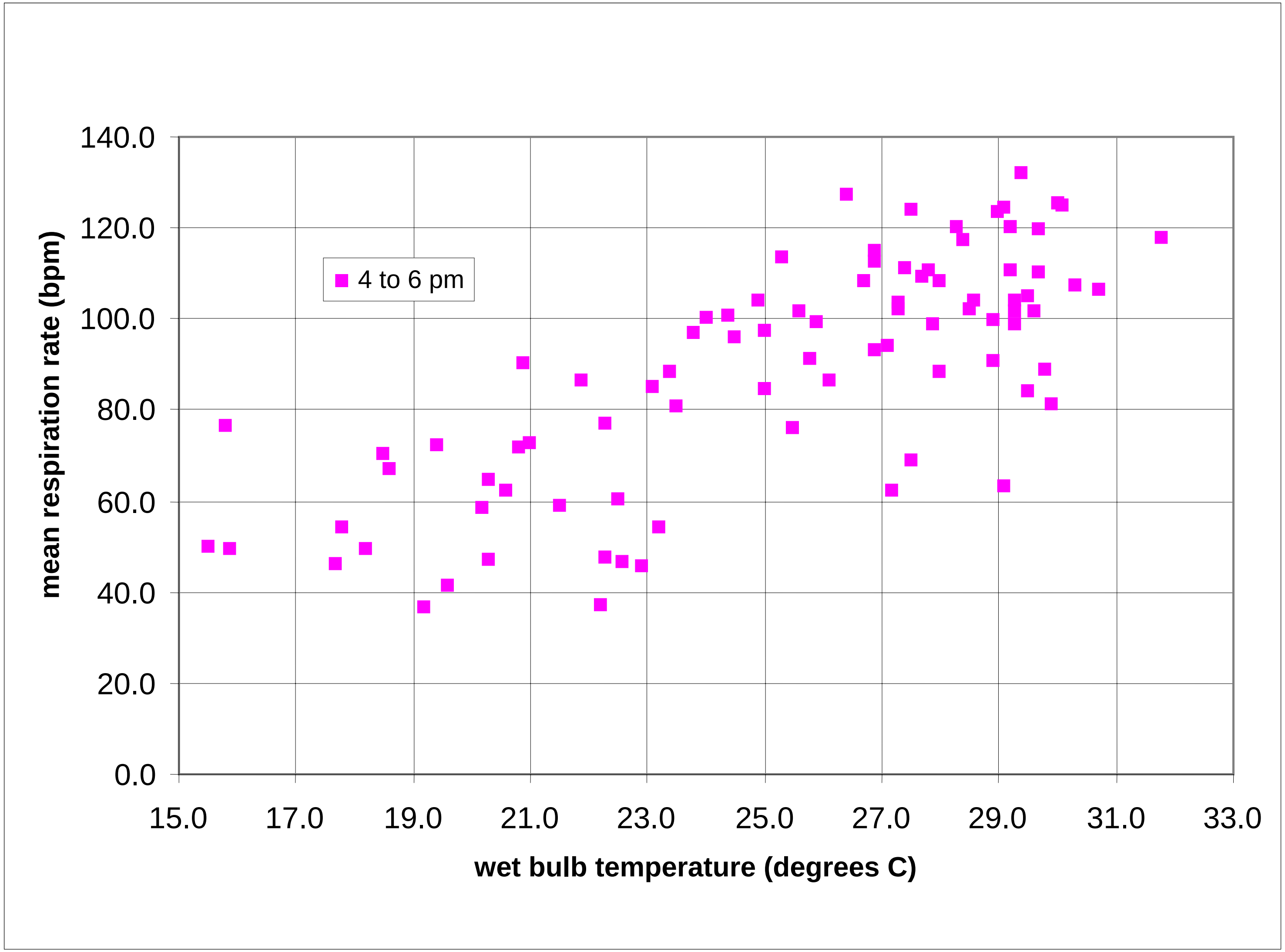


**Figure 3.8 University of Queensland Gatton Angus Steers – rectal temperature vs wet bulb temperature for the afternoon period.**

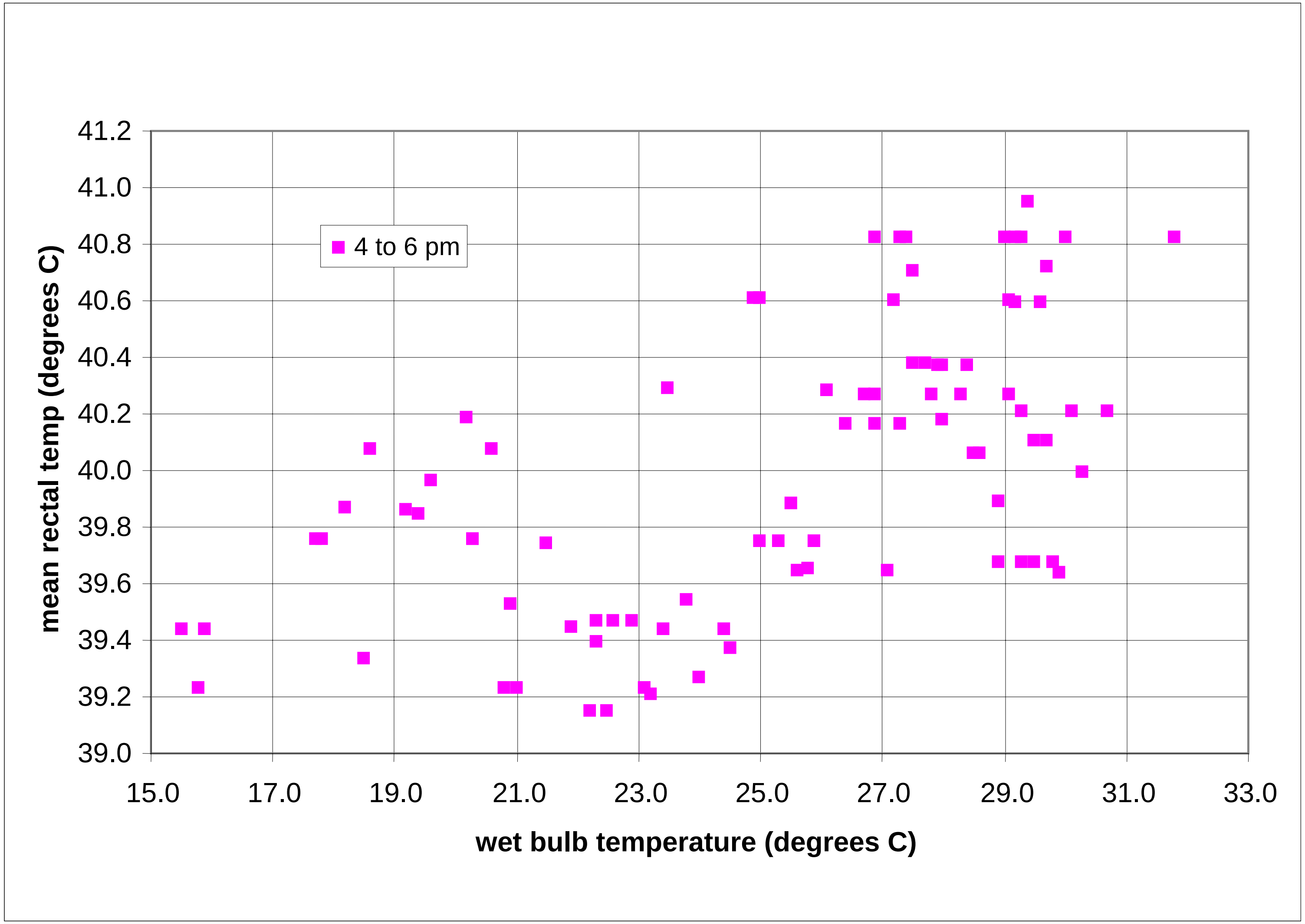


**Figure 3.9 University of Queensland Gatton Angus Steers – rectal temperature vs wet bulb temperature for Trial 1.**

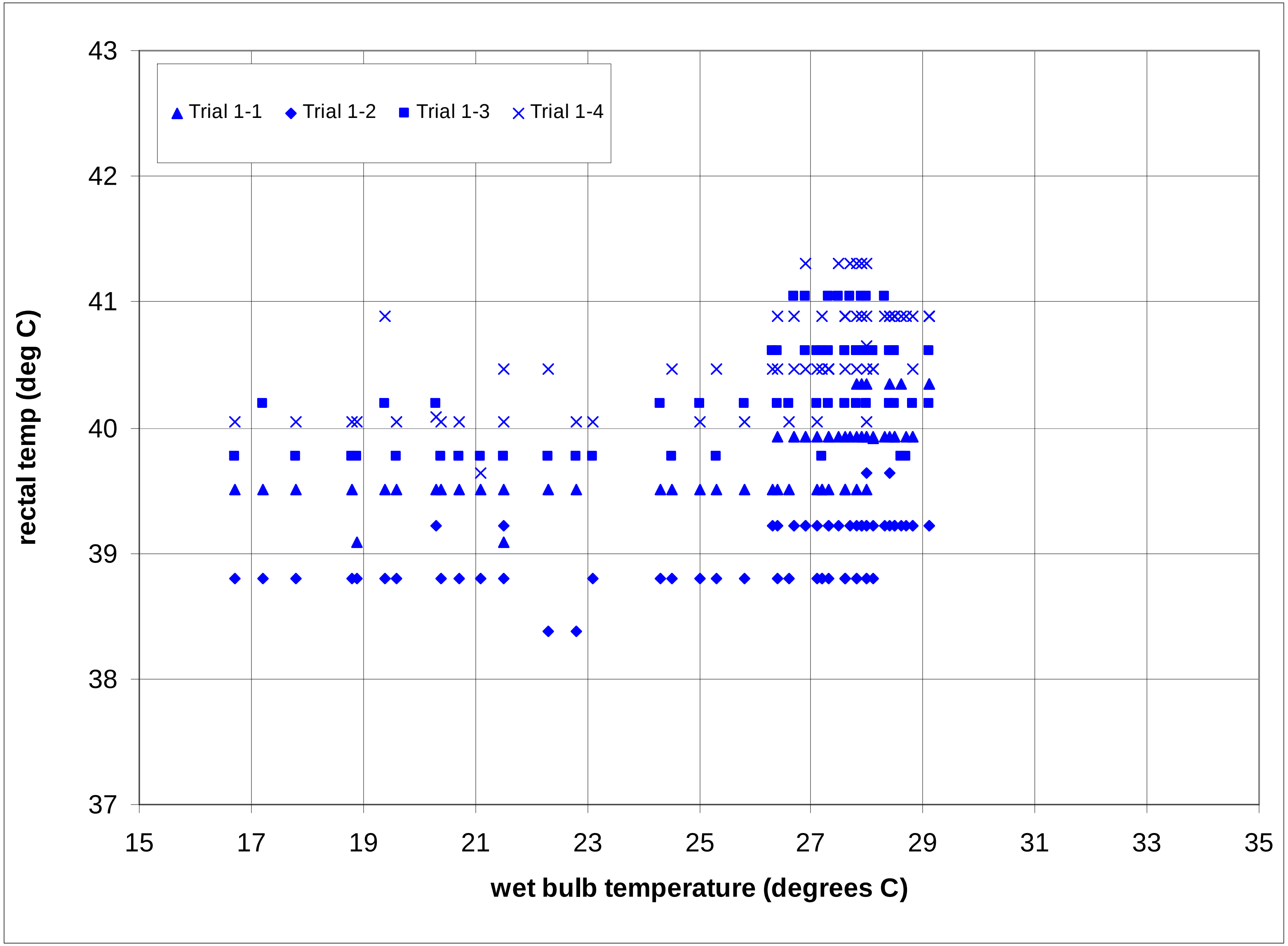


**Figure 3. 10  University of Queensland Gatton Angus Steers – rectal temperature vs wet bulb temperature for Trial 2.**

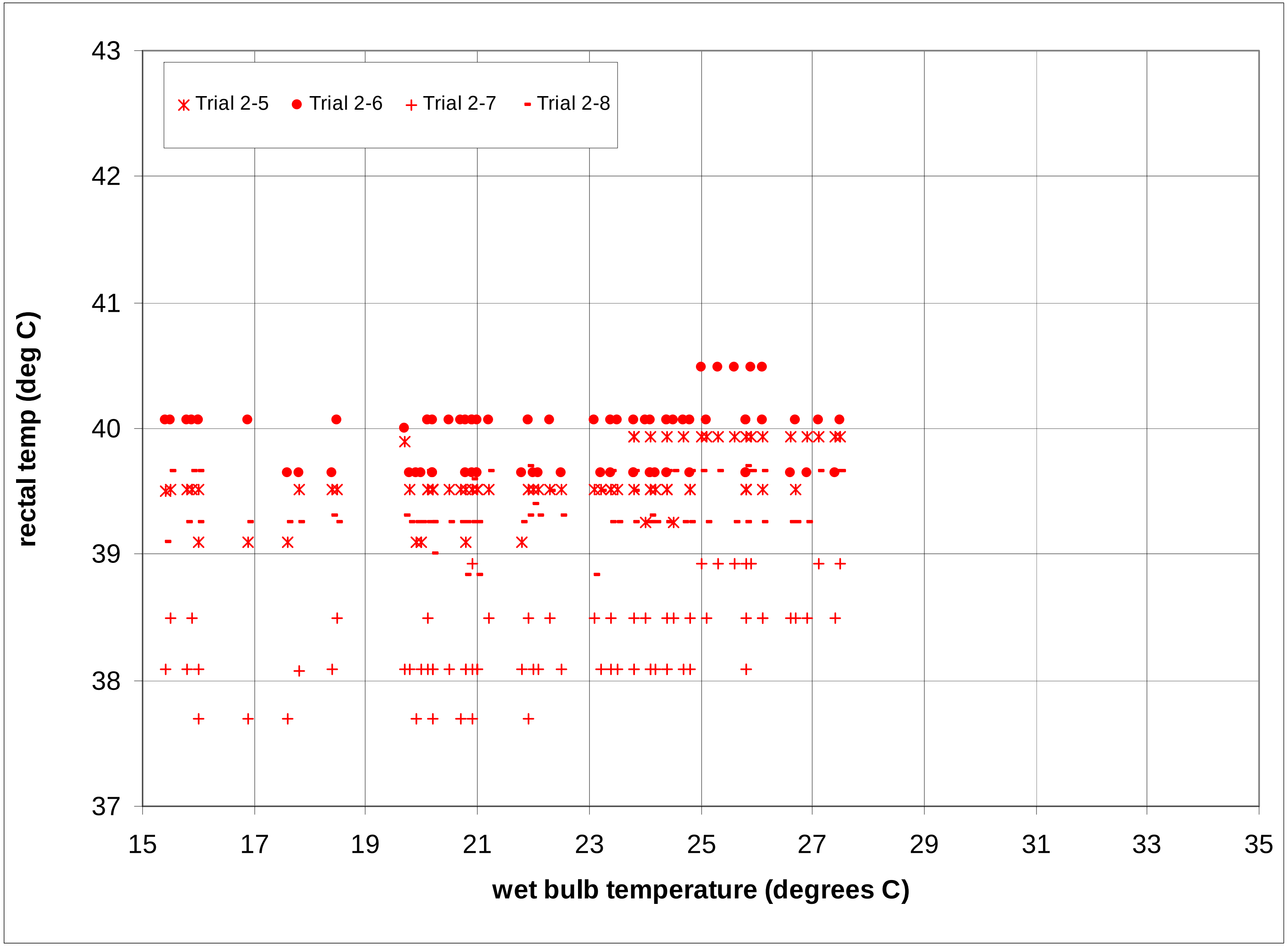


**Figure 3. 11 University of Queensland Gatton Angus Steers – rectal temperature vs wet bulb temperature for Trial 3.**

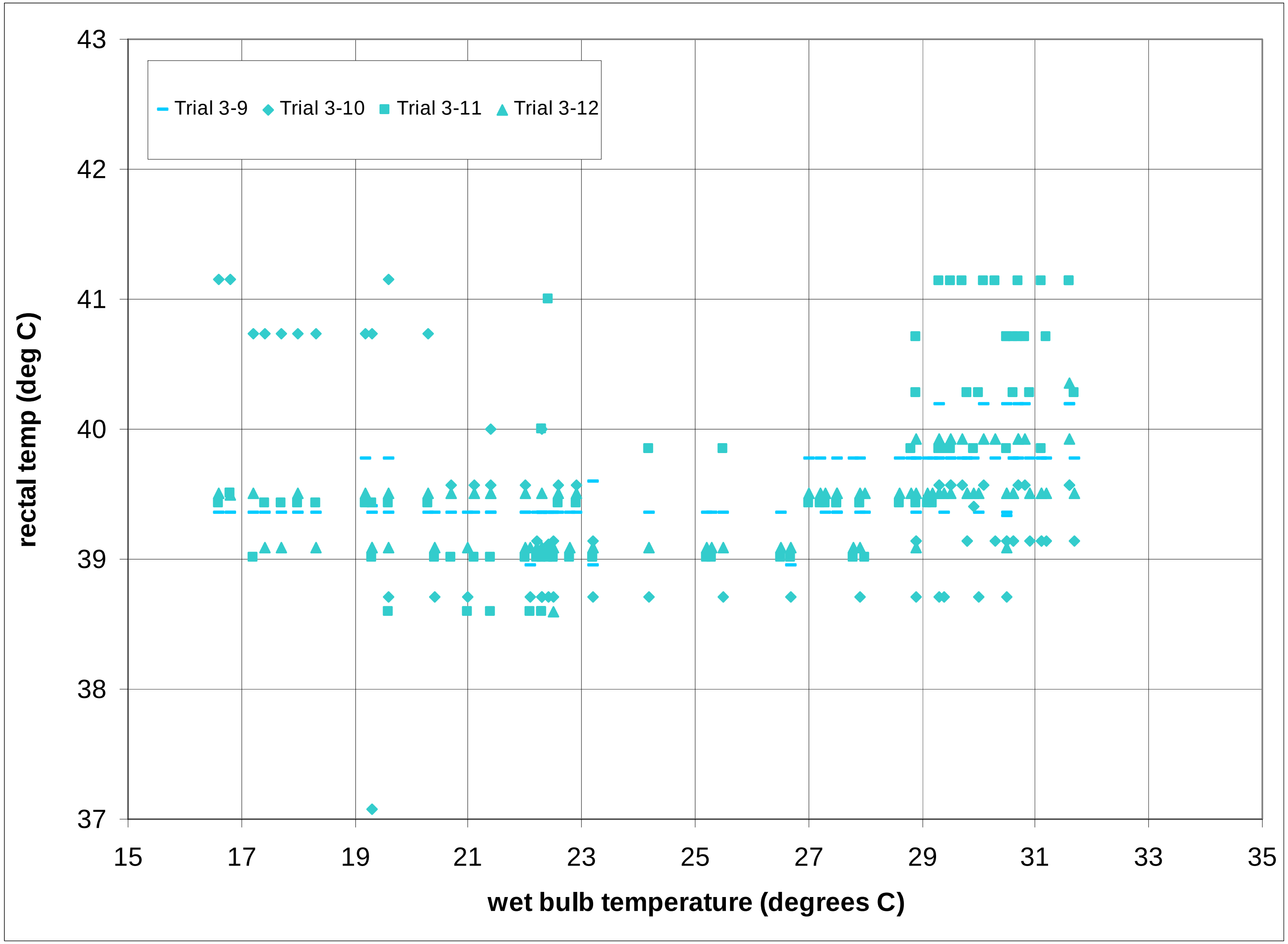


**Figure 3. 12  University of Queensland Gatton Angus Steers – rectal temperature vs wet bulb temperature for Trial 4.**

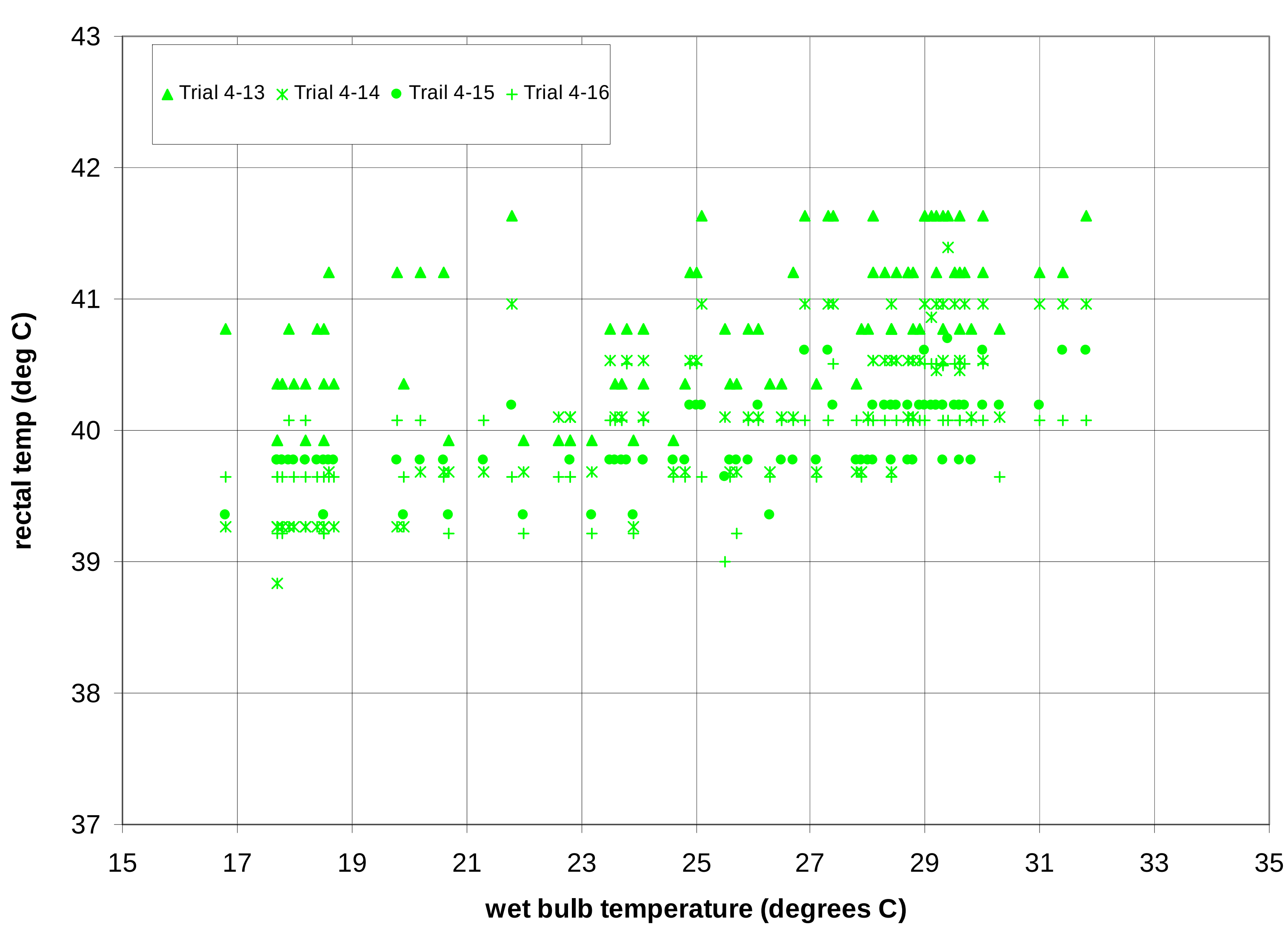
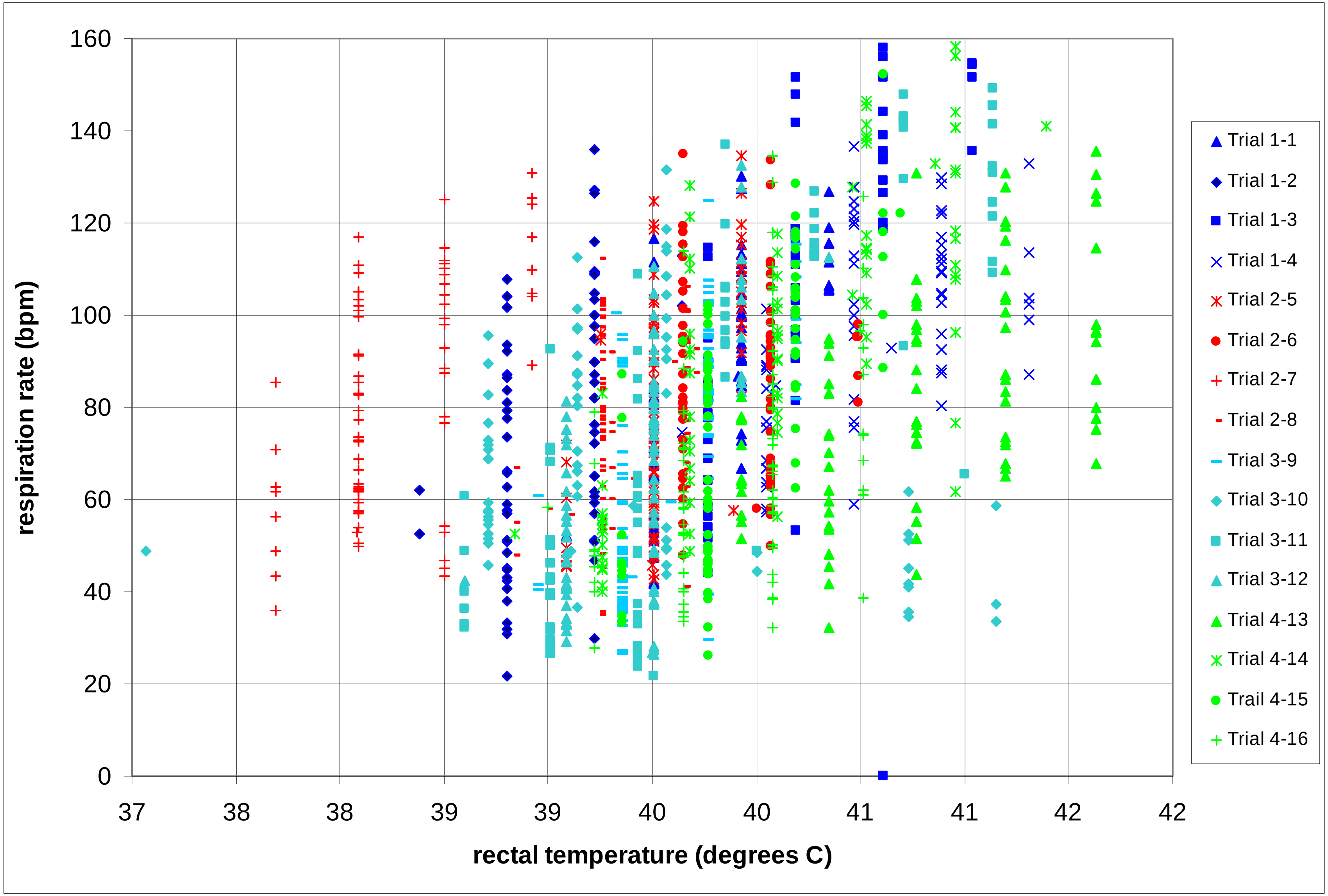


Figure 3 13 Respiration rate against rectal temperature for the Gatton Angus experiment



## 3.2 University of Queensland – Herefords

The University of Queensland Gatton Hereford experiment (Gaughan, not yet published) was run in four repetitions, each with 6 animals in the hot room for 12 days, with temperatures rising over 5 days and being at the hottest for the next 4 days.

The dates at the start of each trial were:

Trial 1 10 August 2003
Trial 2 23 August 2003
Trial 3 13 September 2003
Trial 4 25 September 2003

The animals in these tests were Hereford steers, with a liveweight of 380 to 420kg, 0 to 2 tooth and body condition score 4. They had been on feedlot rations for 100 days prior to the experiments. As for the Angus tests, the wet bulb acclimatisation of the animals was estimated from the Gatton meteorological records. The weather in Gatton was changing fairly rapidly during the test period so the animals in the four trials had quite different acclimatisation. Approximate wet bulb averages for the two weeks prior to each trial are:

Trial 1 11°C
Trial 2 13°C
Trial 3 15°C
Trial 4 18°C

The consequence of this variation is that each trial needs to be treated separately in estimating the HST from the data. Only respiration rates were recorded, with no body temperatures taken. As for the Angus experiments, conditions cooled overnight. This makes the experiment quite different to the shipboard situation and the data can only be used to identify plausible ranges of HST as discussed below. The diurnal wet bulb temperature range was about 6°C. This is a significant reduction in temperature overnight, giving the animals opportunity to recover from the heat and metabolically prepare for the next hot 'day'. Figure 3.14 shows the record of wet bulb temperature for each of the four trials. Temperatures typically rose around 8 am each day and cooled off after 6 pm. Learning from the Angus experiments, only the data from the end of each hot period were used to assess HST. Figure 3.15 shows all observations coded by time of day. Figure 3.16 shows only the data recorded from 4 to 6pm each day, coded by individual animal with each trial also given its own colour. Again, heat stress thresholds were assessed from the plotted data. The results are tabulated below.

**Table 3.3 Heat stress observations for the Hereford steers.**

| Data Type | Figure | HST(°C) |
|---|---|---|
| All data, respiration rate vs wbt | 3.15 | 24 to 25 |
| All 4 - 6 pm data respiration rate vs wbt | 3.16 | 24 to 26 |
| Trial 1 4-6pm respiration rate | 3.16 | 21 to 25 |
| Trial 2 4-6pm respiration rate | 3.16 | 26 to 28 |
| Trial 3 4-6pm respiration rate | 3.16 | 26 to 28 |
| Trial 4 4-6pm respiration rate | 3.16 | 26 to 29 |

It is noted that the diurnal variations in wet bulb temperature resulted in many data points below the HST and many data points above the HST, with relatively few data in the region where respiration rate first rises consistently above 80bpm. This makes interpretation of the data more difficult. Due to the gaps in the wet bulb range for each trial, it was not possible to pick a unique value for HST. Consequently a definitive HST value can not be interpreted and Table 3.3 gives plausible ranges for the HST value. Again, the diurnal variation under which these data were collected requires that the result be treated cautiously.

HST values estimated by the HS model are given in Table 3.4. Two coat types are referenced as the weather was warming rapidly, and the coats may have been in transition.

**Table 3.4 HS model estimates of HST for the Gatton Hereford experiment.**

| Trial | HST estimate (°C) | |
|---|---|---|
| | Winter coat | Mid coat |
| 1 | 25.4 | 26.7 |
| 2 | 26.0 | 27.3 |
| 3 | 26.7 | 27.9 |
| 4 | 27.7 | 28.8 |

These are consistent with the observations and so no change is required to the HS database.

**Figure 3. 14 University of Queensland Gatton Hereford Steers – wet bulb histories for the four trials.**

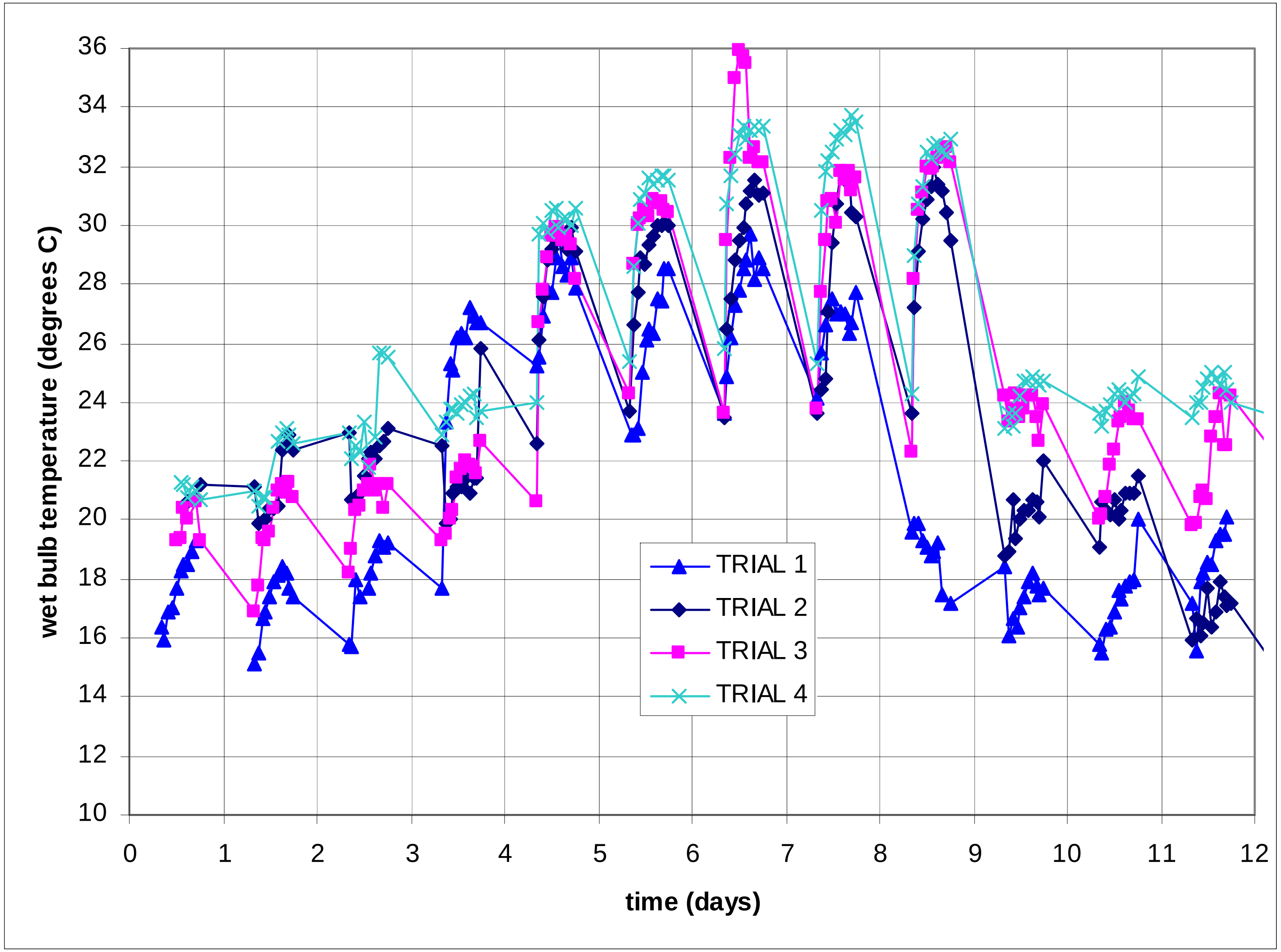


**Figure 3. 15 University of Queensland Gatton Hereford Steers – respiration rate by time of day vs wet bulb temperature.**

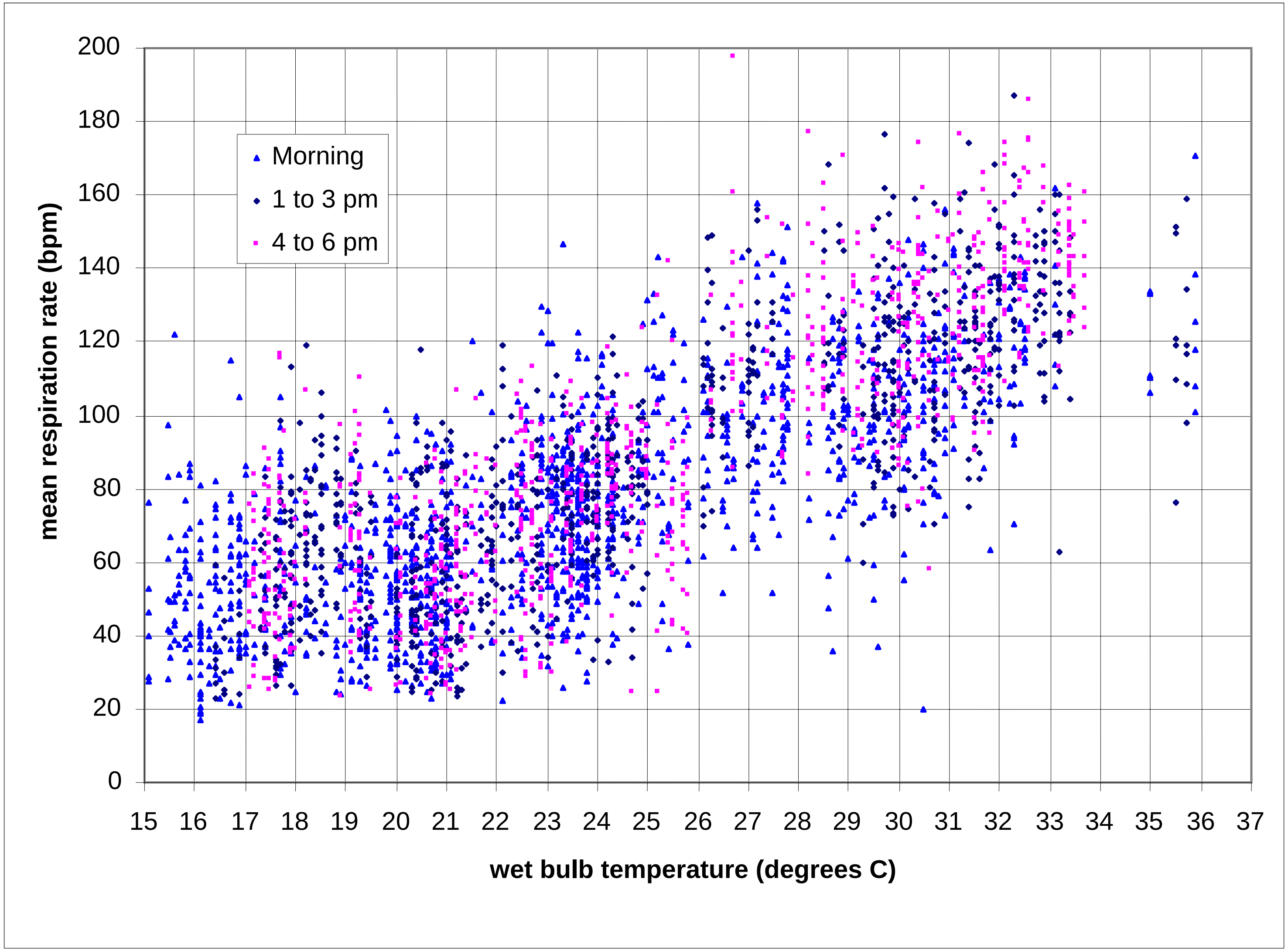
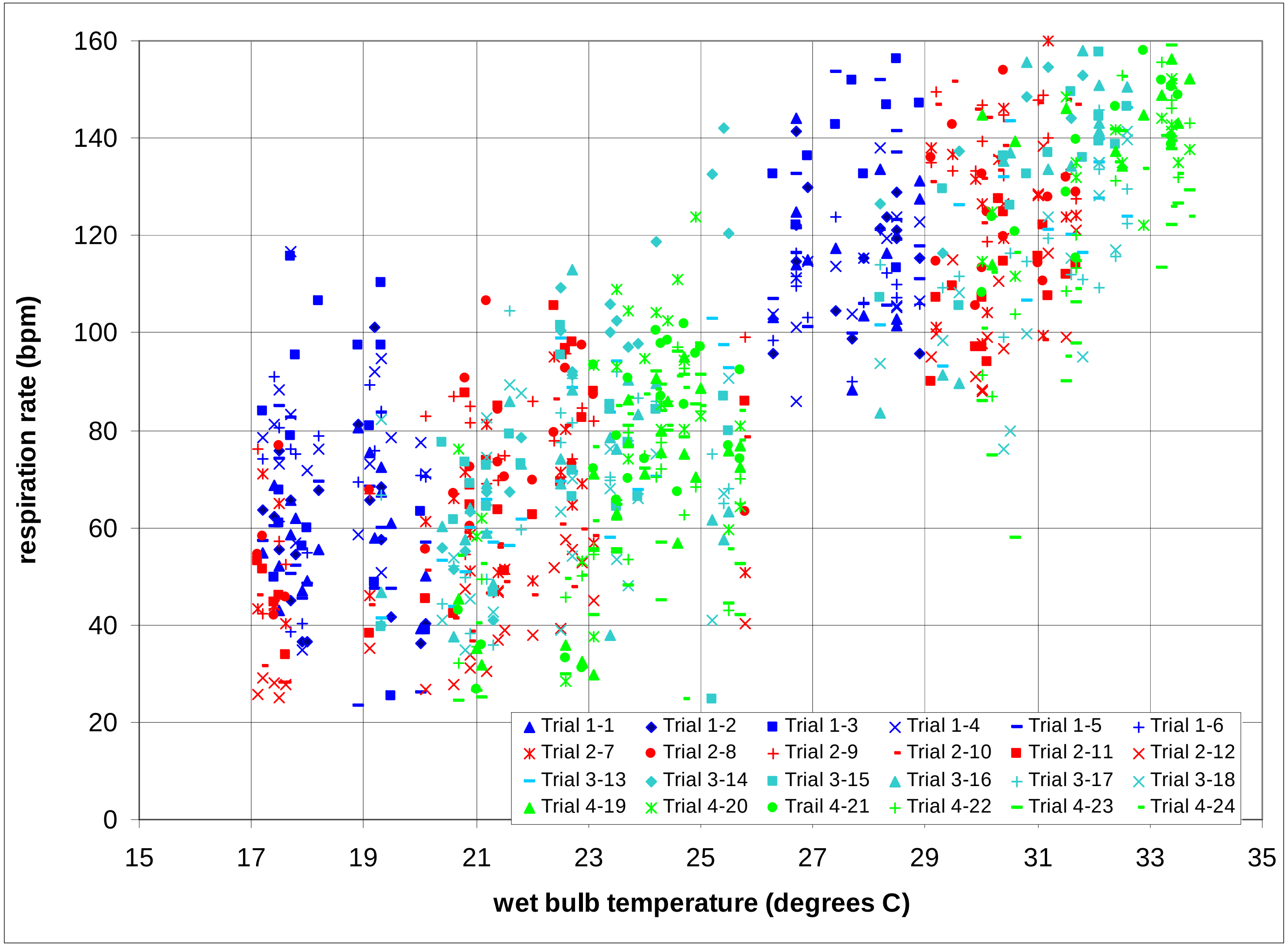


**Figure 3. 16  University of Queensland Gatton Hereford Steers – respiration rates vs wet bulb temperature for each animal in the afternoon period (4pm-6pm)**



## 3.3 LIVE 223 Logged Data

Project LIVE.223 (McCarthy, 2005a) was a pilot study funded by MLA and LiveCorp on gathering of heat stress data through the use of temperature - humidity data loggers and animal observations. Records from nine voyages were made available. The logged data were dry bulb temperature and relative humidity above the pen space, recorded every 10 minutes. Observations were made of respiration rate and respiratory character. The data had not been analysed prior to the review for this project. One problem with analysing data long after collection is that the ability to critically examine data accuracy is diminished. Some data were clearly nonsensical and were discarded from the set. Other data which appear somewhat anomalous could not be shown to be wrong and so remain with the data set.

The data are plotted in Figures 3.17 to Figure 3.22**.** The plots identify individual pen results with similar animals grouped on one plot. Note that cattle with both *Bos taurus* and *Bos indicus* breeding are shown on both cattle plots.

Heat stress thresholds for sheep evaluated from the plots are given in Table 3.5 below.

**Table 3.5. Heat stress thresholds for sheep from LIVE.223 data.**

| Animal Type | Figure | HST (°C) |
|---|---|---|
| Merino less than 40kg Voyage 3 | 3.18 | 30 |
| Merino less than 40kg Voyages 4 and 5 | 3.18 | 25 |
| Merino 40 to 50kg Voyage 3 | 3.19 | 30 |
| Merino over 50kg Voyages 6 and 8 | 3.20 | 30 |
| Merino over 50kg Voyages 2, 4 and 5 | 3.20 | 26 |
| 36 to 38kg Damarra and Damarra cross lambs Voyage 3 | 3.17 | 30.5 |

From the sheep HST table above, and the supporting plots, there are two specific examples to note in support of the earlier comment about apparent anomalies in the data. Table 3.5 notes two very different HST values for Merinos less than 40kg. Figure 3.18 shows the data sets behind these two values to have almost no overlap with each other even though the animals were apparently very similar. The Voyage 3 animals are noted as 38kg ‘B’ Merino lambs, condition score 2 with short wool and loaded in Fremantle. The voyage 4 animals were 39.5kg ‘A’ Merino lambs. Wool length and condition score were not noted. The voyage 5 animals were noted as 38kg ‘B’ Merino lambs, condition score 2.5, short wool and also loaded in Fremantle. They are apparently very similar to those of Voyage 3. An obvious possible difference is the sailing date and the acclimatisation prior to sailing. Table 3.6 gives the sailing dates for these voyages and the average wet bulb temperatures in Fremantle for the week prior to sailing.

**Table 3.6 Prior acclimatisation for the LIVE.223 data for sheep lighter than 40kg**

| Voyage | Sailing Date (Fremantle) | Average wet bulb for the two weeks prior (°C) |
|---|---|---|
| 3 | 23 June 2004 | 12.5 |
| 4 | 15 July 2004 | 9.5 |
| 5 | 5 August 2004 | 9.2 |

While there is some difference in prior acclimatisation, as the effects are currently understood, it is not sufficient to account for the 5°C difference in the apparent HST. The voyage 3 value of 30°C is close to the HS model estimate of 29.9°C while the voyage 4/5 value of 25°C is very much lower than the HS estimates of 28.5 and 28.7°C. No explanation has been found as to why the voyage 4/5 answers are so different. It may simply be errors introduced by different estimation of respiration rate, or there may be other voyage or animal factors not recorded.

The voyage 4/5 data for sheep below 40kg are ignored simply on the basis that the HST values are so much lower that they are arguably inconsistent with previous shipping experience and hot room data. It would be preferable to isolate the cause of the variation, however the time window for that has passed.

Table 3.5 also notes two very different HST values for merinos over 50kg, with voyages 2, 4, and 5 giving 26°C and voyages 6 and 8 giving 30°C. Taken together with the anomaly above, we now have data from voyages 3, 6 and 8 contradicting data from voyages 2, 4 and 5. Animal descriptions and acclimatising wet bulb temperatures for the 'over 50kg' data are given in Table 3.7 below.

**Table 3.7 Prior acclimatisation for the LIVE.223 data for sheep heavier than 50kg**

| Origin | Voyage | Sailing date (Fremantle) | Animals | 2 weeks prior average wet bulb (°C) |
|---|---|---|---|---|
| WA | 2 | 4 June 2004 | 57kg C merino wethers | 8.9 |
| WA | 4 | 15 July 2004 | 60kg 'Muscat' wethers | 9.5 |
| WA | 5 | 5 August 2004 | 54kg B and C merino wethers c.s.2, 10 mm wool, some with 20mm wool | 9.2 |
| WA | 6 | 9 August 2004 | 53kg heavy merino wethers c. s.2-3 | 9.5 |
| Unknown | 8 | 30 September 2004 | 55 kg merino wethers, c.s. 4 short wool | 10.0 |

As for the lighter sheep, the acclimatisation history does not explain the discrepancy in HST for the heavy wethers. We note without further comment that one vet recorded data on both voyage 3 and voyage 6 and another vet recorded data on both voyage 2 and voyage 4. There were no vets who recorded data in both the higher HST set (voyages 3, 6, & 8) and the lower HST set (voyages 2, 4 & 5).

Heat stress thresholds for cattle evaluated from the plots are shown in Table 3.8 below.

**Table 3.8 Heat stress threshold for cattle from LIVE.223 data**

| Animal Type | Figure | HST (°C) |
|---|---|---|
| 390kg Shorthorn x Droughtmaster steers<br>Condition score 3.5 to 4, Voyage 2 | 3.21 &<br>3.22 | 24 |
| 415kg *Bos indicus* bulls<br>Voyage 5 | 3.21 | 31.5* |
| 445kg *Bos indicus* steers<br>Voyage 5 | 3.21 | 30* |

*There were very few data near the HST, and none beyond it, so it is difficult to assess the threshold.

Figures 3.21 and 3.22 also show other *Bos taurus* data from Voyage 1, however the data don't seem credible in that they show low respiration rates at extreme wet bulb temperature (up to 32.7°C). The Voyage 1 data have not been analysed further.

In summary, it is hard to be certain of the quality of the LIVE.223 data. They are broadly consistent with existing HS model parameters. The extent of any departure from the HS model was no greater than the internal inconsistencies in the data. The variation of acclimatisation of the animals was small and so no conclusions could be drawn on acclimatisation effects. The discrepancies may also point to practical difficulties in the accurate assessment of respiration rate on voyages.

**Figure 3. 17  Live.223 data - respiration rate vs wet bulb temperature for non-Merino sheep**

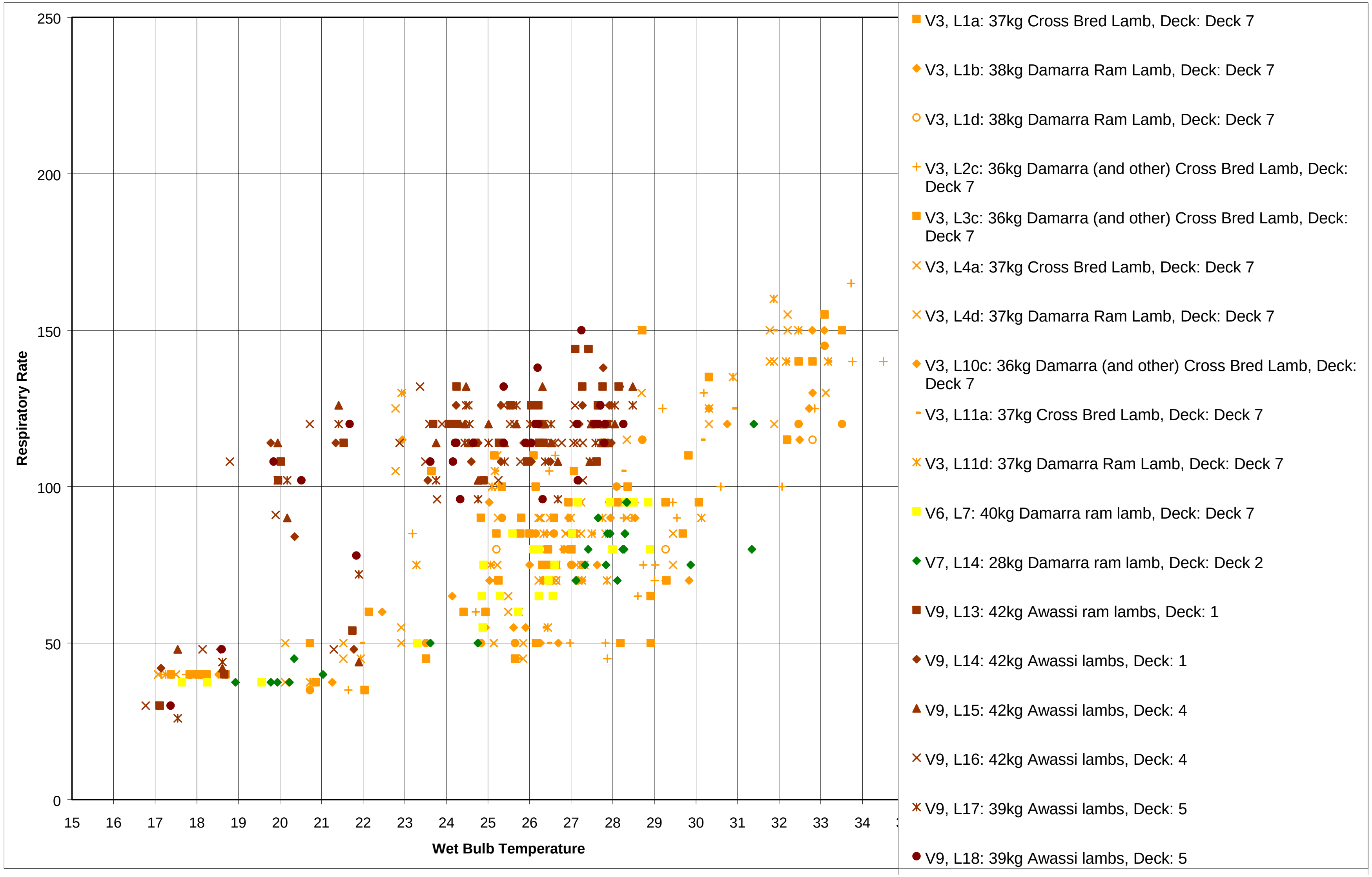


**Figure 3. 18 Live.223 data - respiration rate vs wet bulb temperature for Merinos less than 40kg**

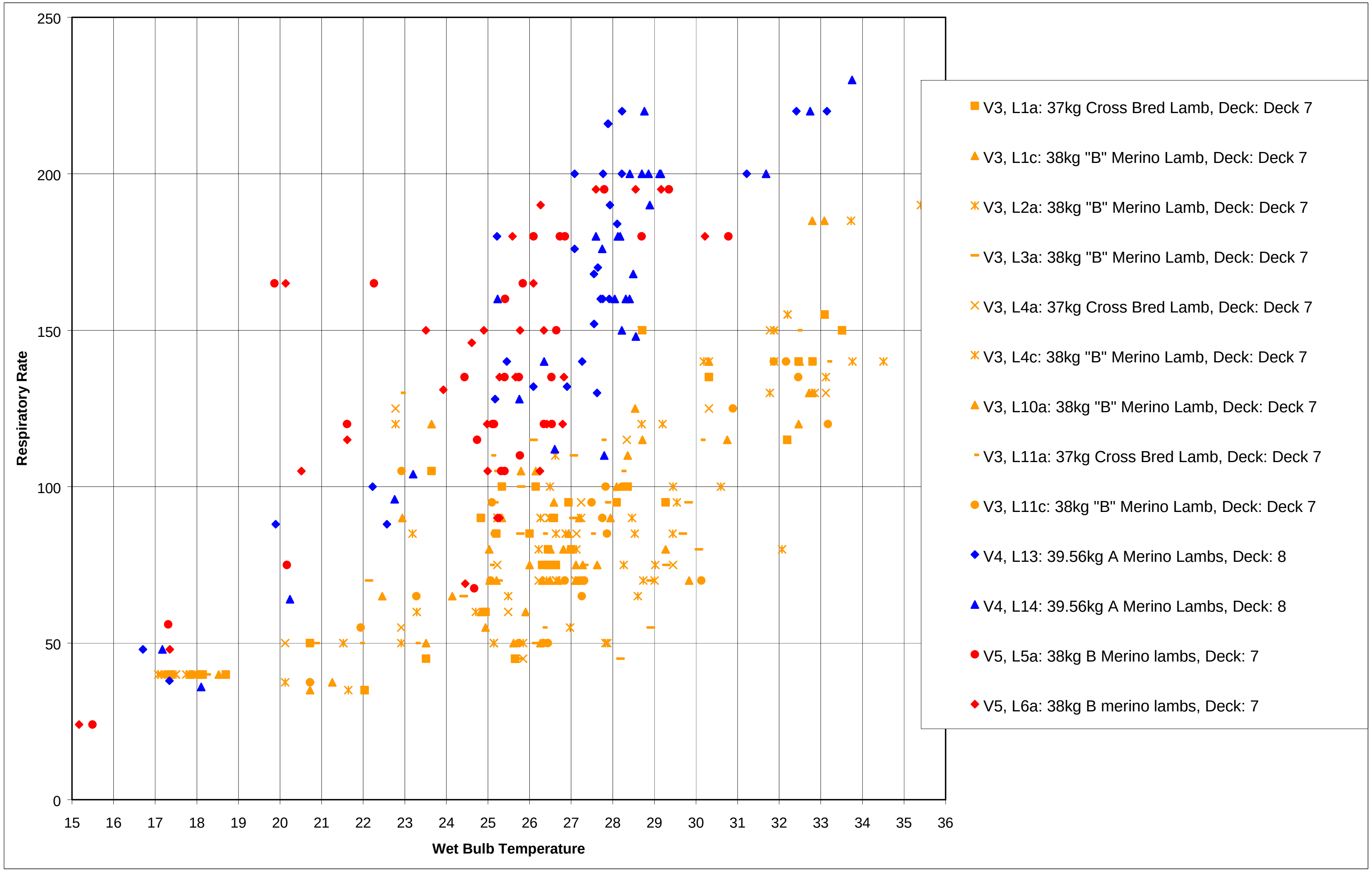


**Figure 3. 19 Live.223 data - respiration rate vs wet bulb temperature for Merinos between 40kg and 50kg**

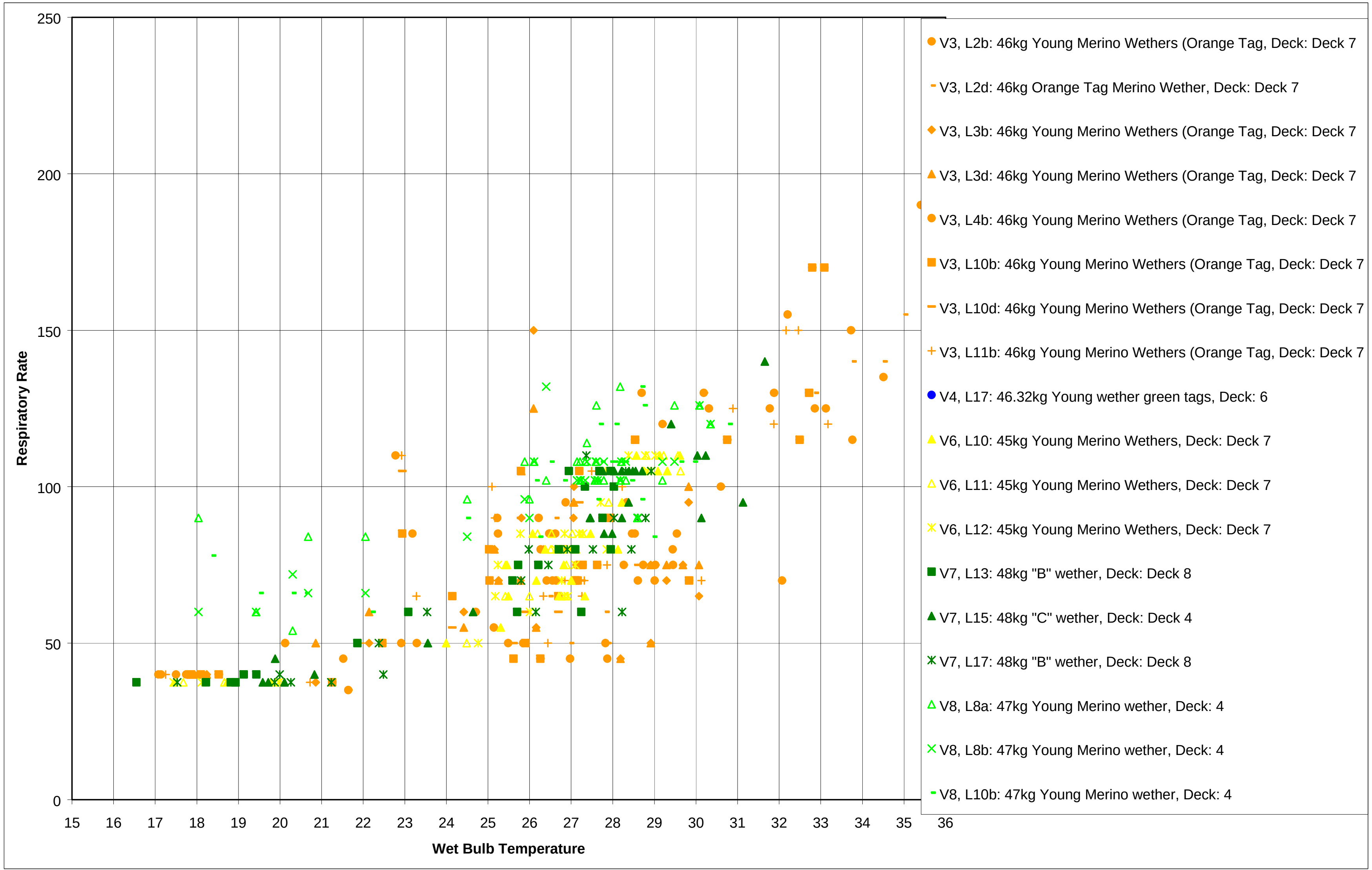


**Figure 3. 20 Live.223 data - respiration rate vs wet bulb temperature for Merinos over 50kg**

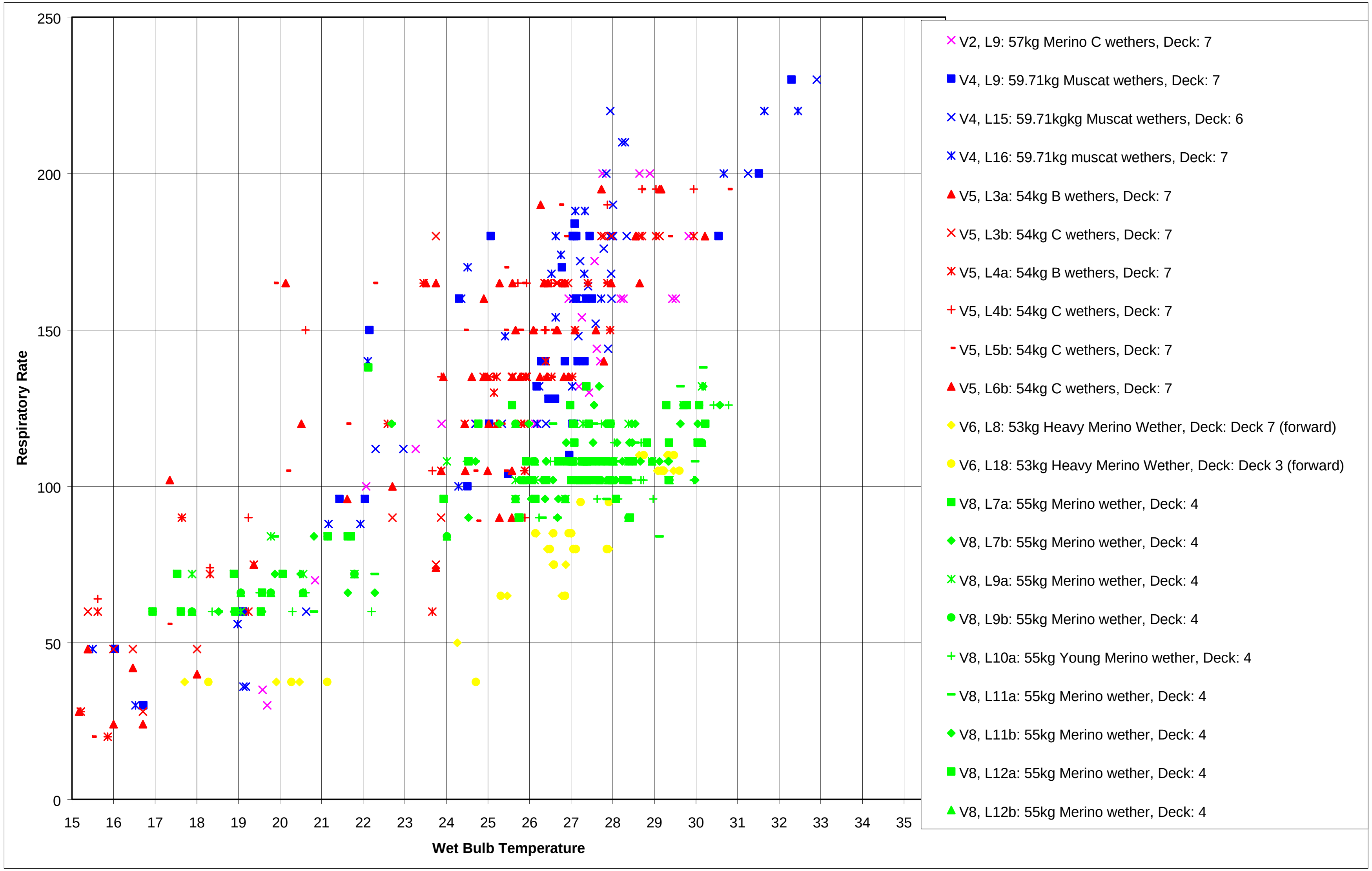


**Figure 3. 21 Live.223 data - respiration rate vs wet bulb temperature for Bos indicus cattle**

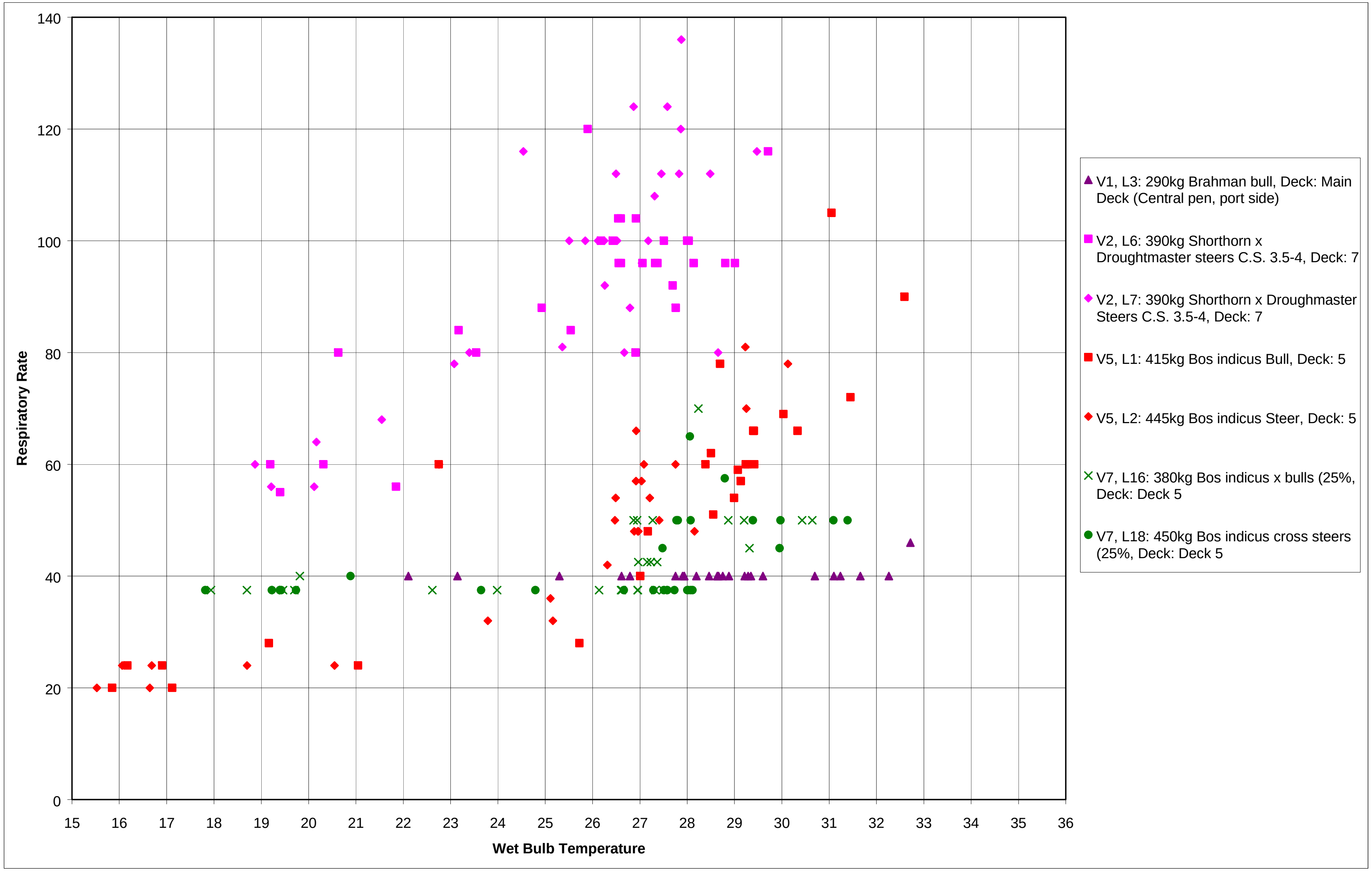
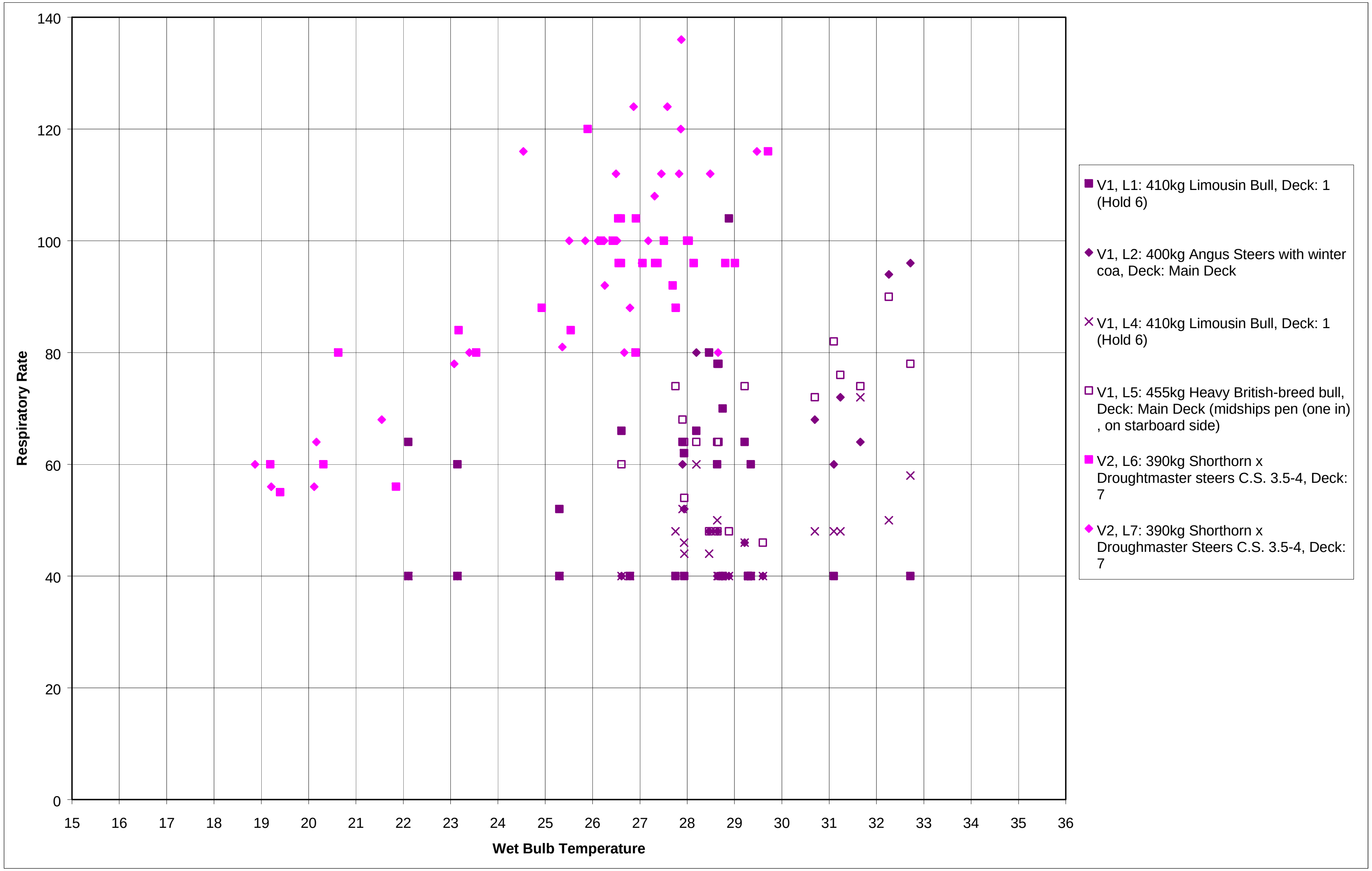


**Figure 3. 22 Live.223 data - respiration rate vs wet bulb temperature for Bos taurus cattle**



## 3.4 LIVE.223 Voyage 3 Observations

Voyage 3 of the LIVE.223 project experienced heat stress problems on open decks in Muscat. The vessel then cast off and sailed out, however some mortalities occurred and the accompanying veterinarian (Michael McCarthy) made observations during the incident (McCarthy, 2005b). Part of his record of the incident is reproduced as Tables 3.9 and 3.10 below.

**Table 3.9 Ambient condition observations in Muscat for Voyage 3.**

| Time | Temp (°C) | Humidity | Wet bulb | Breeze |
|---|---|---|---|---|
| 1000 | 39.6 | 24% | 23 | Land breeze 12 knots across port bow |
| 1100 | 40.3 | 27%` | 25 | Land breeze 12 knots across port bow |
| 1200 | 40.1 | 28% | 26 | Land breeze 12 knots across port bow |
| 1300 | 41.0 | 30% | 27 | Land breeze 12 knots across port bow |
| 1400 | 35.4 | 75% | 31.2 | Sea breeze 2-4 knots from starboard |
| 1500 | 35.5 | 74% | 31.3 | Sea breeze 4-6 knots from starboard |
| 1600 | 35.6 | 73% | 31.1 | Sea breeze 4-6 knots from starboard |
| 1700 | 34.3 | 78% | 31.1 | Sea breeze 4-6 knots from starboard |
| 1800 | 34.0 | 84%` | 31.1 | Sea breeze 4-6 knots from starboard |
| 1900 | 32.0 | 86% | 29.9 | At sea with head wind from ship speed |

**Table 3.10 Observations of ship operation and sheep behaviour.**

| |
|---|
| Arrived at 0800 with ship speed pushing air through open deck at about 16 knots. |
| Weather station out of action for wind speed and direction. |
| Conditions had been fairly uniform with strong headwind over port bow for many days. |
| Wind dropped approaching harbour. |
| Substantial land breeze evident. |
| Alongside at approximately 9.30am |
| 12 knot breeze across port bow, dry breeze. |
| Approximate orientation North. |
| Breeze pretty hot but low humidity at approximately 24% |
| Conditions on open decks pretty good at bout 26/27°C wet bulb. (A bit higher aft) |
| Deck 9 soon heated up due to effect of direct sun (up to 30°C wb) |
| Sheep in some areas demonstrating heat stress with open mouth panting (mostly on starboard side) |
| 1400 – Open mouth panting on deck 9 (c line), wet bulb 33.3 – 33.4 in alleyway (hand held) |
| In pens at E 1075 measured at -37.6, 86%, 35°C wb (hand held) |
| 1430 – Logger stations monitored. |
| 1500 – Deck 9 C line – again measured at 36.5, 90% and 35.4°C wb (hand held). Panting Score 4 – 4.5, HS3. |
| 15.45 – Merino lambs in a line (deck 8) noticed in trouble. In direct sun. 34°C in alleyway (hand held) some dead. |
| Ammonia 35ppm, bedding sloppy, PS 4 – 4.5, HS 3. |
| 1600 – Deck 7, a line, 35.3, 87%, 33.4wb (hand held), sheep panting and in trouble. |
| 16.10 – Deck 6 – Survey along alleyway between a & b race, 33.4 – 33.9 wb (hand held). |
| 16.15 – Enclosed decks at °C wb, and 85% R.H., Sheep not too bad, PS 3-4 HS 2-3. |
| No discernable difference port vs starboard on closed decks. |
| Open decks big difference port vs starboard, B line sheep also in trouble, PS 4.5, HS3 |
| 1700 – estimate up to 100 dead, pretty well all lambs from a line Decks 6, 7 & 8. |
| 1730 – decision to get out of there. |
| 18.15 departed. |
| 1900 – Logger stations monitored. |

This incident serves to demonstrate the risk involved in relying on breeze to ventilate open decks. The breeze was fine when docking. There was nothing in the notes to indicate whether there was any known risk of a weather change, however it is understood that the seawater temperature while in Muscat was 35°C.

The data can be interpreted to give mortality limit information for the lambs on decks 6, 7 and 8. With a short exposure to wet bulb temperatures around 34°C to 35°C, sheep were rapidly in trouble and started dying. Reading the notes, it seems likely that 34°C would have very rapidly caused a high death rate had the ship not sailed to improve conditions. Because the conditions changed suddenly and were short lived, it is hard to estimate what long term wet bulb temperature would have led to mortalities. It is clearly above 27°C (prior to the wind change) and below 35°C (causing problems after the change). Unfortunately the suddenness of the change leaves no data to narrow the range. The observations are consistent with a mortality limit of 32 to 35°C. The HS model predicts a mortality limit of 34°C to 34.5°C depending on other parameters.

## 3.5 Data from Exporters

One exporter made time available to discuss recent experiences. All of the in-house data made available for review also related to voyages which were part of the LIVE.223 programme. Information relevant to Voyage 3 of LIVE.223 has been included in Section 3.4 above. Information was also provided relevant to heavy rams on LIVE.223 Voyage 4. The relevant facts were:

A total of 479 70kg Merino rams, fat score 3 and with 10-25mm of wool were loaded on one deck. The wet bulb temperature reached 33°C on that deck on voyage day 18. The mortality counts on the morning of each day were as given in Table 3.11

**Table 3.11 Mortality by voyage day for a line of 479 heavy rams on LIVE.223 Voyage 4**

| Day No. | Mortality Count |
|---|---|
| 12 | 2 |
| 13 | 1 |
| 14 | 0 |
| 15 | 0 |
| 16 | 1 |
| 17 | 0 |
| 18 | 0 |
| 19 | 7 |
| 20 | 2 |

The dead rams found on day 19 would appear to be as a result of the wet bulb temperature reaching 33°C on day 18. Assuming that the animals were sourced from Fremantle, HS would expect the HST to be 27.2°C and the mortality limit to be 33.9°C. This figure applies to wethers as well as to rams. Thus the anecdotally reported wet bulb peak of 33°C with only 1.5% mortality, would imply that the rams were at least as hardy as expected by the HS figures. It would perhaps be premature to revise the mortality limit upward on the basis of this data alone. Certainly the expected reduction in mortality limit can also not be supported by the data.

Some of the previous anecdotes on heavy ram susceptibility related to rams as heavy as 120kg. It may still be that data on such animals would support a reduction in the mortality limit. No data are presently available to support such a conclusion.

## 3.6 Murdoch University Sheep (LIVE.224)

Dr Anne Barnes and PhD student Catherine Stockman ran hot room tests in August 2004 to examine the response of three types of sheep (Stockman and Barnes, 2005).

Eighteen sheep typical of the live export trade were sourced from southern Western Australia: six four-year old Merino wethers (average weight 56 kg, condition score 2.5-3), six five-year old Merino rams (average weight 71 kg, condition score 3) and six eight-month old Merino ram lambs (average weight 58 kg, condition score 2.5). The wethers and rams were within two weeks off shears, while the ram lambs had 25 mm of wool. Five animals of each type were tested, with two of each type as controls. The five test animals of each type were split between two rooms.

Original data from the tests were made available (Stockman, 2005). Results of core body temperature against wet bulb temperature were produced for each animal and used to estimate the heat stress thresholds. These plots, aggregated by animal type, are given below as Figures 3.23 to 3.25. Table 3.12 gives the inferred heat stress thresholds. The last line of Table 3.12 reproduces data from a draft LIVE.224 milestone report.

**Table 3.12 Heat stress thresholds –inferred from the Murdoch University merino experiment (LIVE.224).**

| Rams | | Ram lambs | | Wethers | |
|---|---|---|---|---|---|
| Animal | HST | Animal | HST | Animal | HST |
| 1163 | 26.5°C | 46 | 26° | 1166 | 28.5°C |
| 1170 | 26°C | 4 | 25.5°C | MIVG | 25.2°C |
| 1511 | 28°C | 1 | 25.5°C | 1195* | 27.5°C |
| 1165 | 27°C | 3 | 25.5°C | 1196 | 27°C |
| 1173 | 27°C | 44 | 25.5°C | 1280 | 28.5°C |
| 43 | 28°C | 54 | 25.5°C | 1278 | 25°C to 26.5°C |
| LIVE.224 average | 26.7° to 27.1°C | LIVE.224 average | 26°C to 26.1°C | LIVE.224 average | 26.1°C to 27.2°C |

*Not clear if animal 1195 was in room 44 or in room 45

Some plots lack a clear rise in core body temperature through a narrow temperature range. Where HST could not be narrowly interpreted, a range of possible values is given.
Both the rams and the wethers show some variation in HST between individual animals, while the ram lambs had remarkably consistent results. The ram lambs also show variation, but only in the response after the heat stress threshold has been passed. If the criterion for HST is to remain as a 0.5°C core temperature rise, then all the ram lambs showed the onset of heat stress at essentially the same temperature.

**Figure 3. 23 Core temperature vs wet bulb temperature for Live.224 Merino Rams**

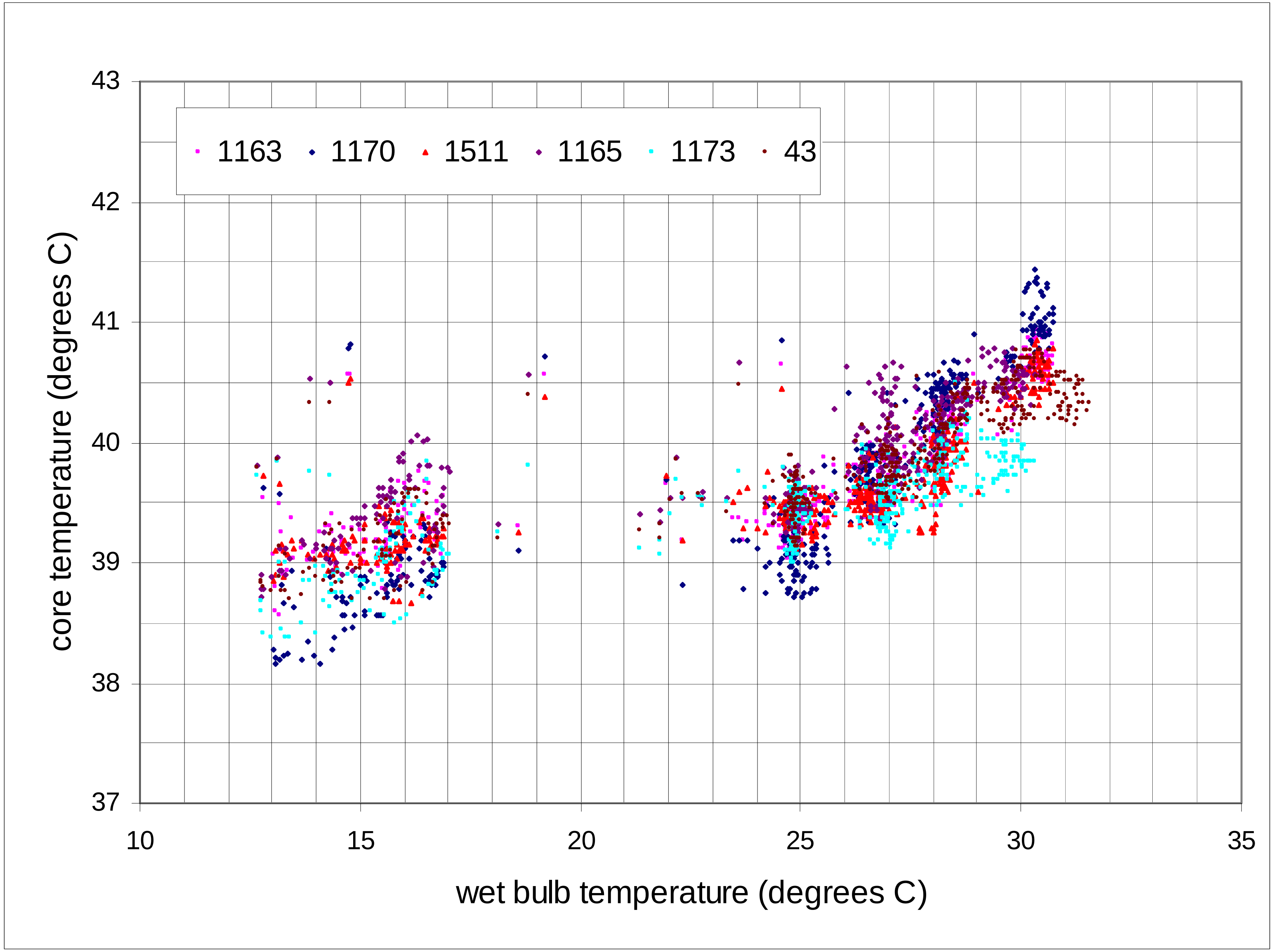


**Figure 3. 24 Core temperature vs wet bulb temperature for Live.224 Merino Ram Lambs**

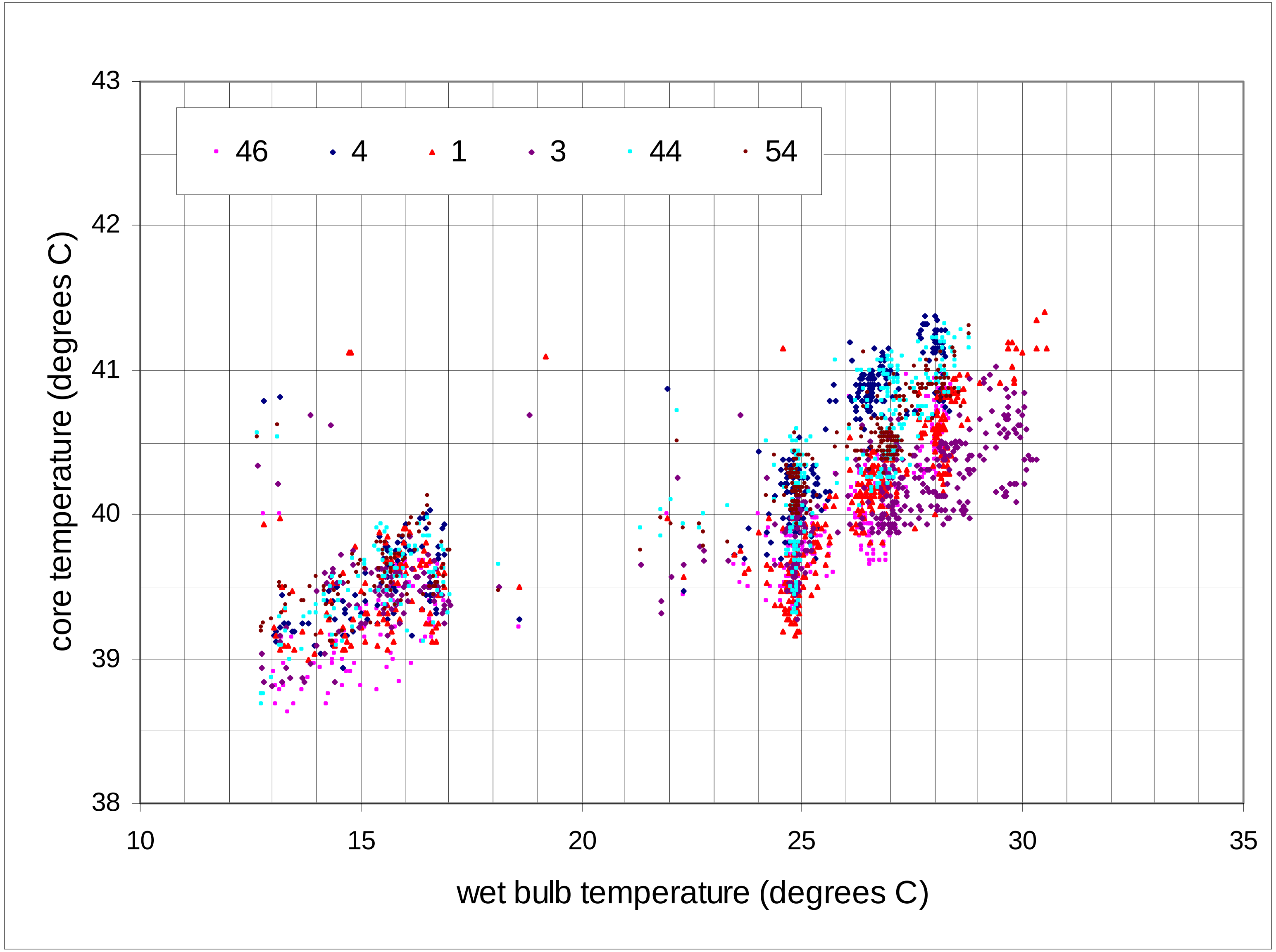
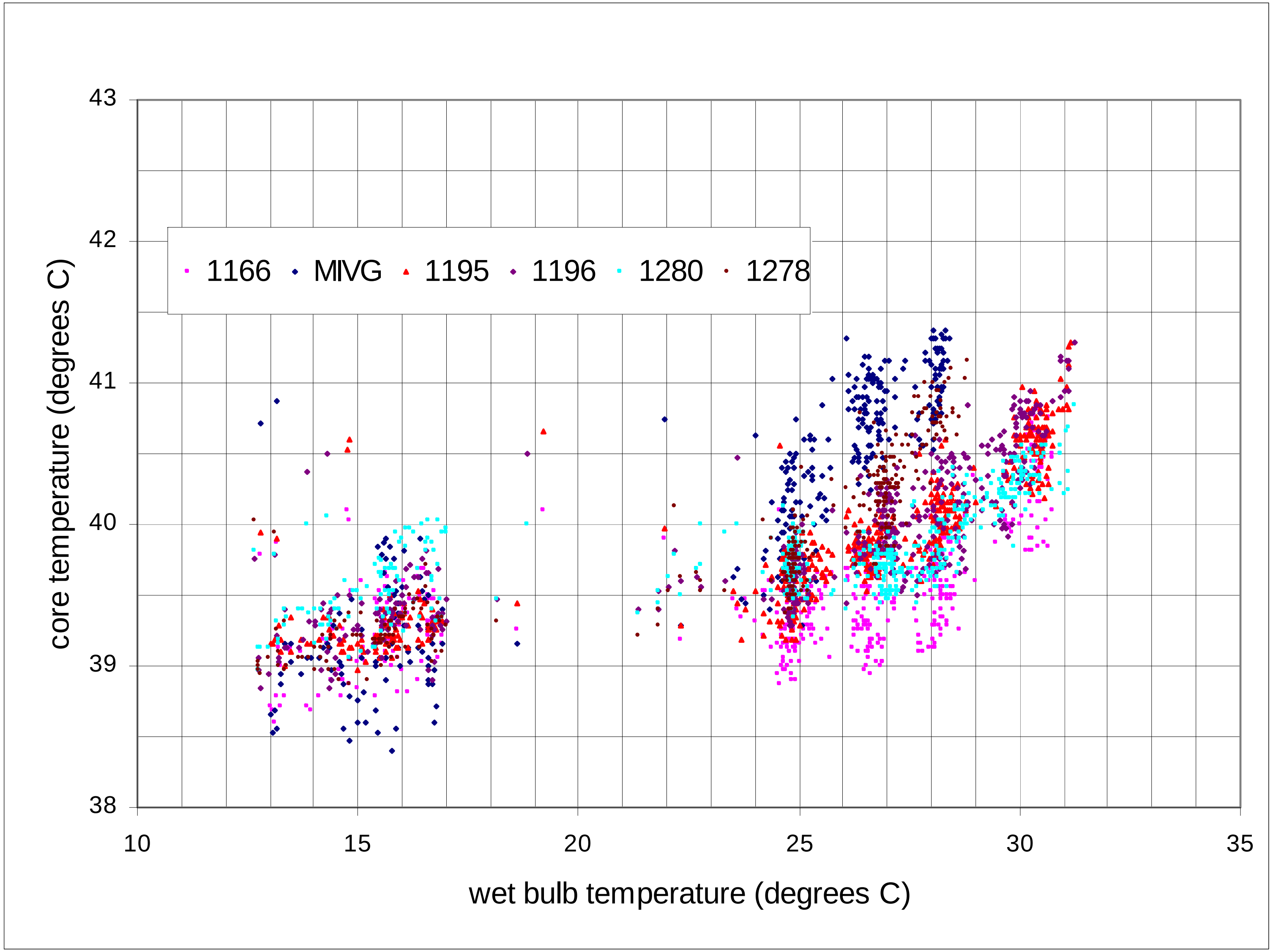


**Figure 3. 25 Core temperature vs wet bulb temperature for Live.224 Merino wethers**



## 3.7 Murdoch University Pregnant Friesian Heifers (LIVE.224)

Dr Anne Barnes and Dr David Beatty ran hot room tests commencing on 1 September 2005 to examine the response to heat of pregnant Friesian heifers (Beatty and Barnes, 2006).

Six pregnant Friesian heifers (420 ± 19 kg BW) were selected based on body weight and gestation period (3 to 5 months). Animals were surgically implanted with temperature loggers and subjected to increasing WBT until core body temperature reached 40.5°C or open mouth panting was detected.

The LIVE.224 project gave two possible measures of the heat stress threshold for these heifers. Both were in terms of the room wet bulb temperature. The first measure corresponded to the first significant increase in core temperature. The second measure corresponded to a 1.0°C rise in core temperature. A 0.5°C rise criterion is the preferred criterion for the present purposes and is seen to be consistent with a respiration rate criteria of 100bpm (Section 3.1), maintaining consistency with earlier work. All three core temperature rise criteria are discussed here.

Using the 1.0°C rise in core temperature as indicating the HST ("HST2") the LIVE.224 project assessed HST as 27.9°C.

Estimates of the HST for the heifers were also made using the current HS model and weather data for Jandakot for the period leading up to 1 September 2005. Averaging the 9am and 3pm wet bulb temperatures, the two-week average just before the tests was 10.8°C while one-week average was 11.4°C. the temperature was dropping at the end of August and the wet bulb on the day before the tests was 7.5°C. An acclimatisation temperature of 11°C was adopted. The estimate from the HS model is 25.5°C for condition score 3 and a mid season coat, or 24.0°C for a winter coat. The first of these values is closer to the 26°C HST assessed by LIVE.223 on the basis of the first sign of core body temperature rise.

The difference between the LIVE.224 findings and the original HS model data appear significant. The original HS model data had lower HST values for *Bos taurus* dairy cattle than for *Bos taurus* beef cattle. It may be that difference is not as large as was accepted at the time. It was also expected that the increase in metabolic heat production with pregnancy would further decrease the HST. In spite of this, the HST values reported by LIVE.224 are above the HS expected figures for *Bos taurus* dairy cattle.

The original LIVE.224 data (Beatty, 2005) were replotted and re-examined to give HST values for the six heifers individually. The plots are given as Figures 3.26 to 3.31. Noting that interpretations to fractions of a degree are not always meaningful, the values in Table 3.13 were estimated from the plots.

**Table 3.13 Reinterpretation of LIVE.224 data to give HST for individual animals.**

| Heifer | Heat Stress Threshold in °C | | |
|---|---|---|---|
| | first significant core temperature rise | 0.5°C core temperature rise | 1.0°C core temperature rise |
| R2 | 24.7 | 25.8 | 27.7 |
| P59 | 22.7 | 24.7 | 26.8 |
| R1 | 24.5 | 28.0 | 29.8 |
| R7 | 23.8 | 25.3 | 26.0 |
| P51 | 26.0 | 26.6 | 27.3 |
| P53 | 24.0 | 25.5 | 26.3 |
| Average | 24.3 | 26.0 | 27.3 |

Some of the HST values in Table 3.13 for a 0.5°C core temperature rise are quite close to the HS model estimates for these animals with a mid season coat, however, at the end of August, it is most likely the coat was as heavy as it gets. Of course Friesians do not show a strong variation of coat with season and it may be that the winter coat factor set up for *Bos taurus* beef animals is inappropriate for Friesians. It is suggested that, in this regard, Friesians might be treated in the same way as *Bos indicus*, having only one coat type in HS. Adopting then a mid season coat value, the HS prediction of 25.5°C is only slightly lower than the value of 26.0°C seen from Table 3.13. It is proposed that, as the new data are more reliable than the previous data, both the coat factor and the base HST should be adjusted accordingly.

**Figure 3.26 Core temperature against wet bulb temperature for pregnant Friesan heifer R2 in the LIVE.224 data**

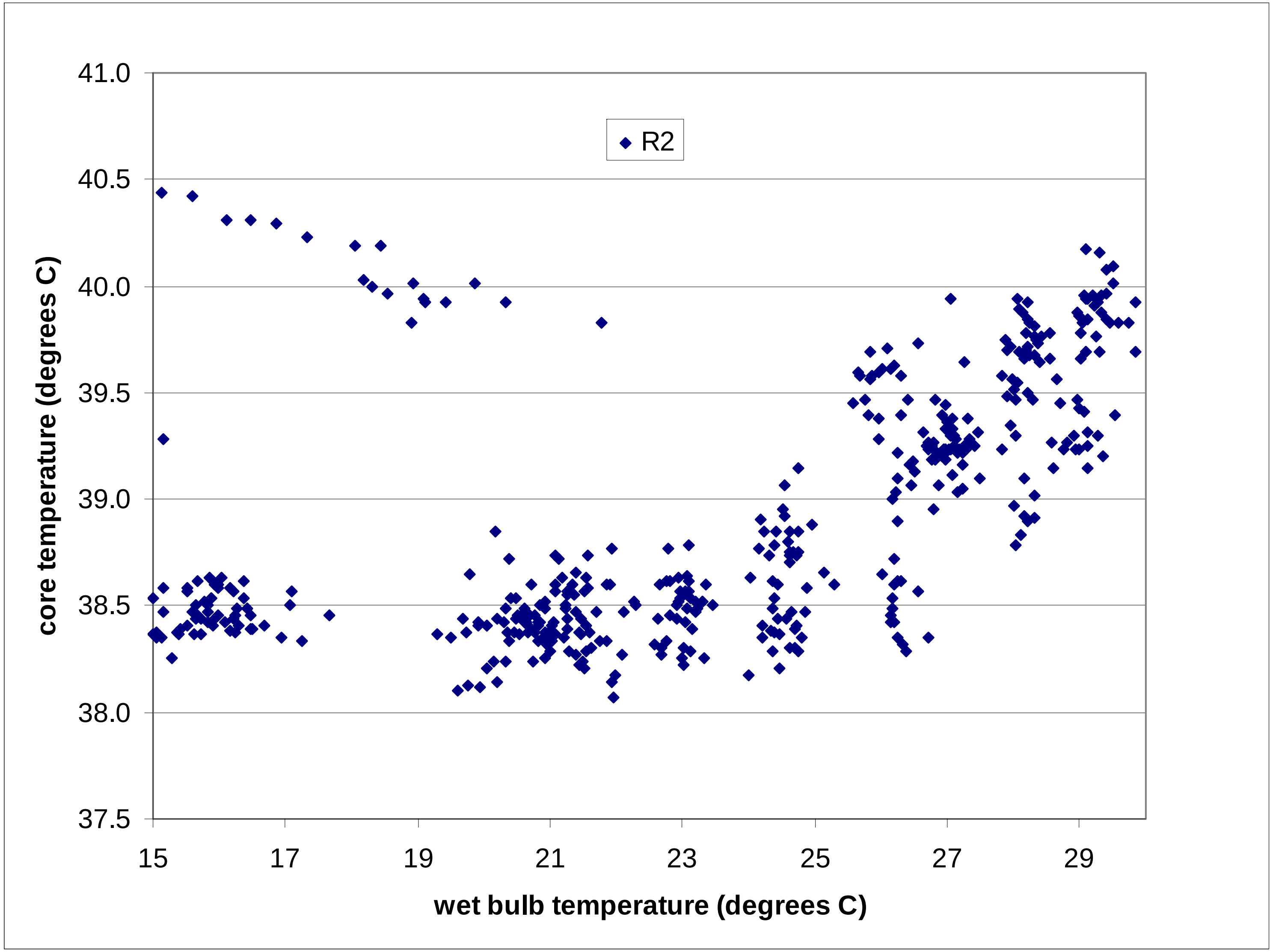


**Figure 3.27 Core temperature against wet bulb temperature for pregnant Friesan heifer P59 in the LIVE.224 data**

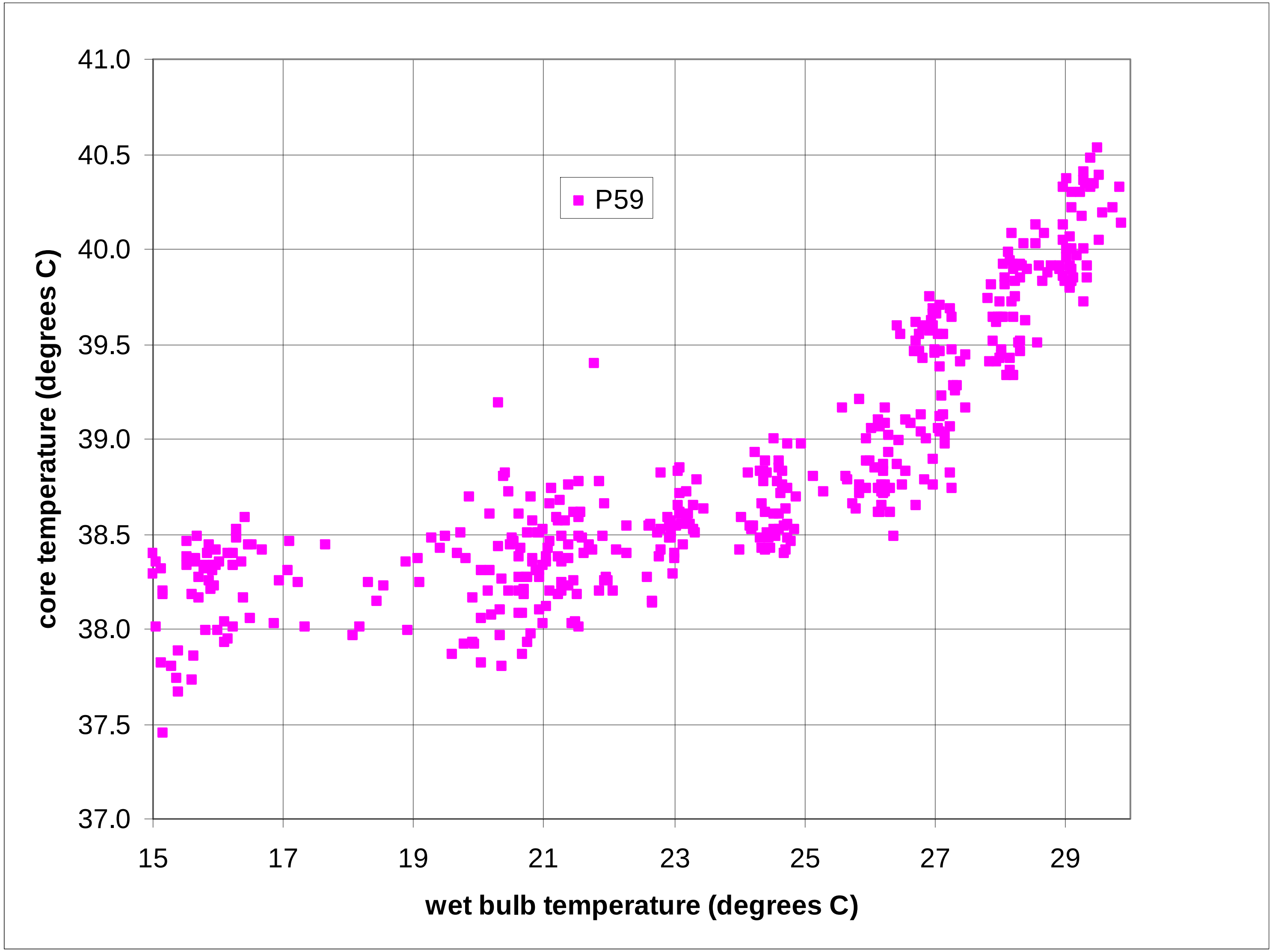


Figure 3.28 Core temperature against wet bulb temperature for pregnant Friesian heifer R1 in the LIVE.224 data.

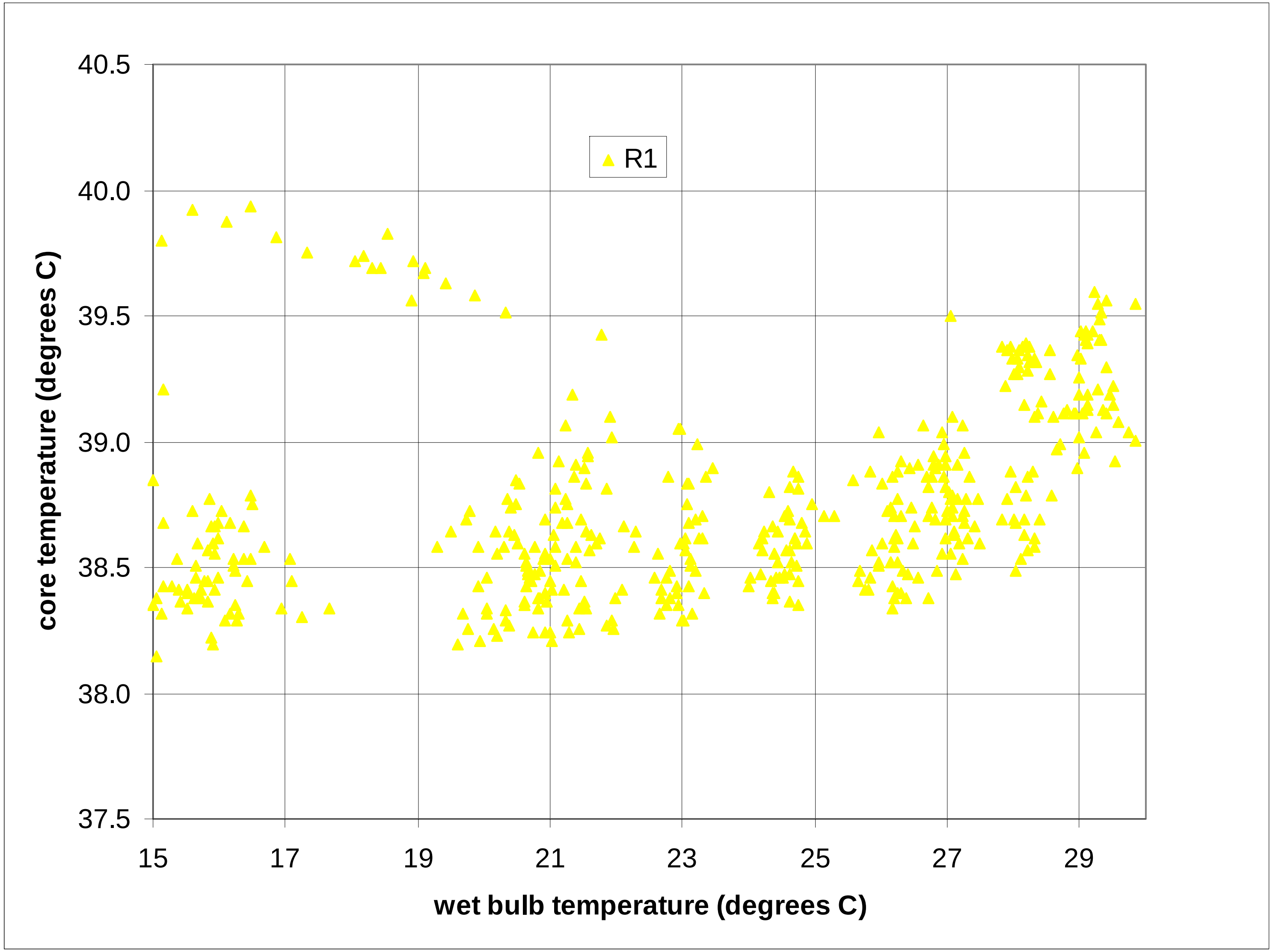


**Figure 3.29 Core temperature against wet bulb temperature for pregnant Friesan heifer R7 in the LIVE.224 data.**

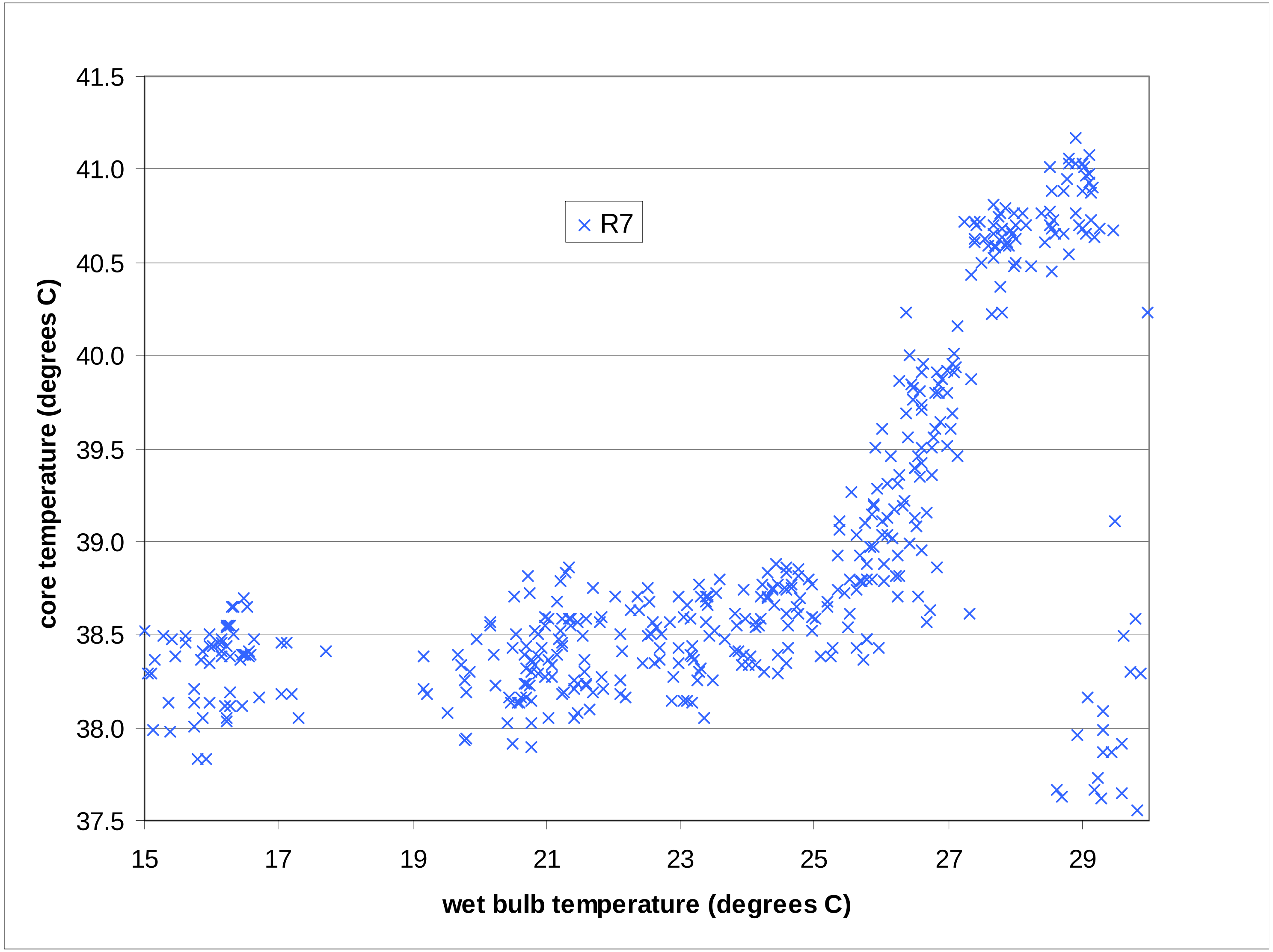


**Figure 3.30 Core temperature against wet bulb temperature for pregnant Friesan heifer P51 in the LIVE.224 data.**

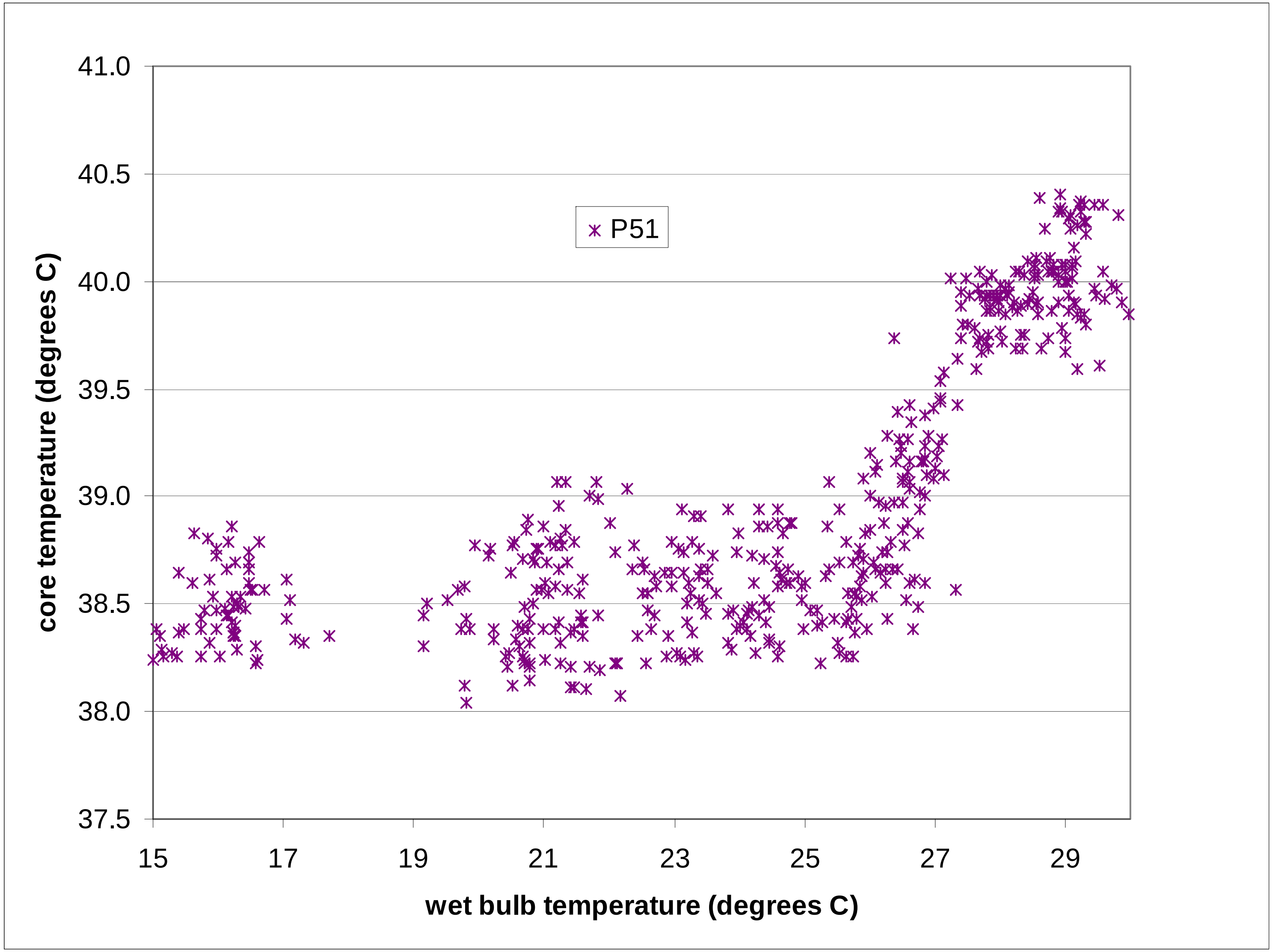


**Figure 3.31 Core temperature against wet bulb temperature for pregnant Friesan heifer P53 in the LIVE.224 data.**

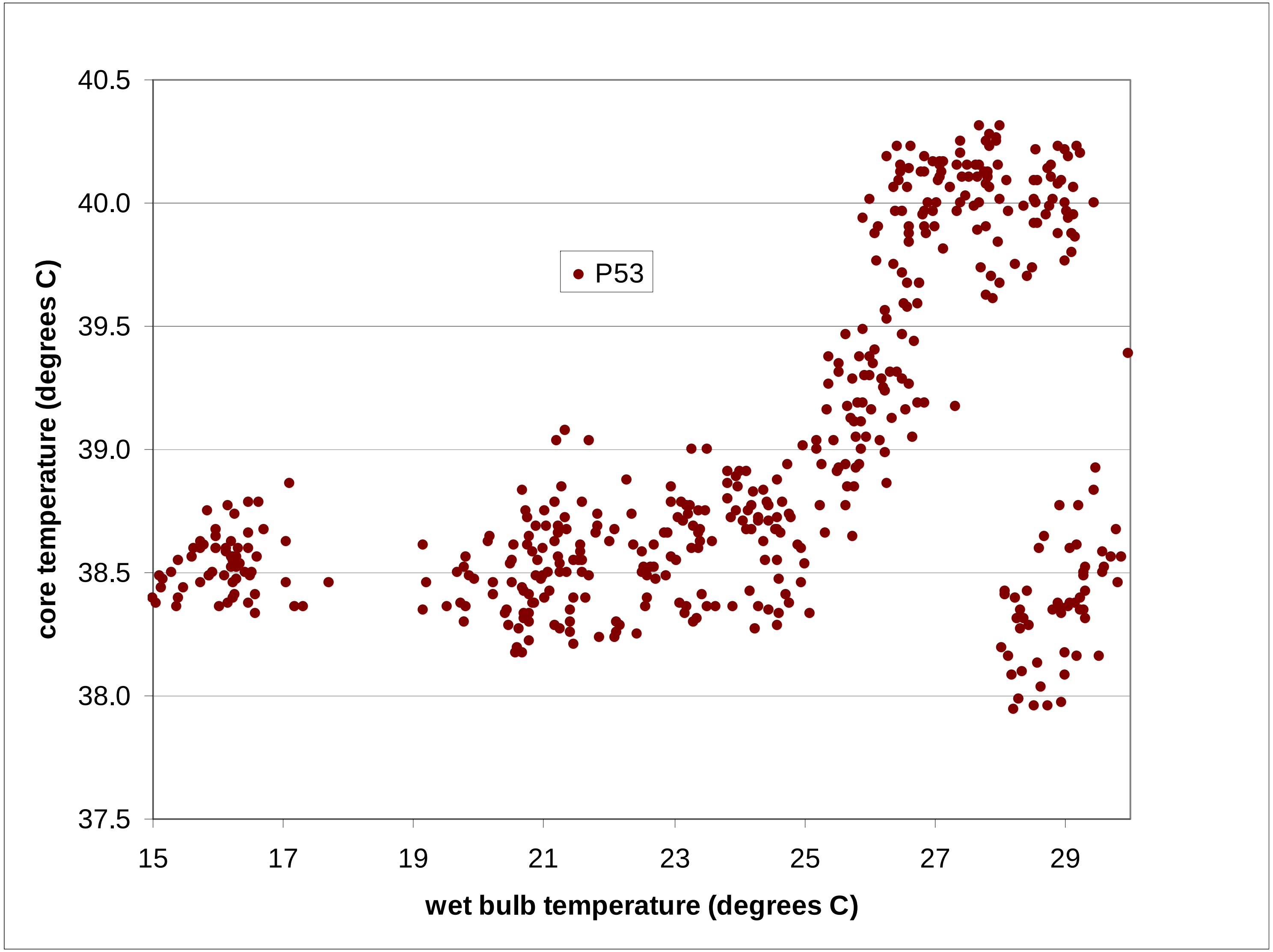


Table 3.14 below is the *Bos taurus* section of a table in the LIVE.116 report (Stacey and Eustace, 2003), with an additional entry for the new LIVE.224 data. When the data are scaled back to the ‘base’ or ‘reference’ animal, the new base HST becomes 28.4°C, with a mortality limit of 33.1°C. These numbers were previously 28.2°C and 32.9°C respectively. It is recommended that the new values be adopted, together with the adoption of mid-season coat factors for Friesian cattle through the winter. While the slight change to mortality limit will allow a very slight increase in some cargos, the change in coat factor may be more significant. Without the (physically reasonable) change in coat factor, a much larger change in HST and mortality limit would have been required by the LIVE.224 data.

**Table 3.14 Cattle heat stress thresholds and mortality limits, updated by this review.**

| DATA SET | | ACCLIMATISATION WB TEMP | WEIGHT (KG) | COAT | FAT SCORE | Facc | Fweight | Fcoat | Fcond | HST | ML | HST diff | ML diff | MLdiff / HSTdiff | REFERENCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **BOS TAURUS TABLE** | | | | | | | | | | | | | | | |
| 1 | Becrux soft southern cattle | 12 | 350 | winter | 5 | 1.057 | 1.05 | 1.1 | 1.2 | 26.0 | 30.0 | 14.0 | 10.0 | 0.71 | Ausvet report. ML looks OK. HST based only on first report of stress. |
| | Inferred base, 350kg | 15 | 350 | mid | 3 | 0.995 | 1.02 | 1 | 1 | 30.0 | 32.9 | 9.99 | 7.13 | 0.71 | |
| | Inferred base, 300kg | 15 | 300 | mid | 3 | 0.995 | 1 | 1 | 1 | 30.5 | 33.2 | 9.49 | 6.78 | 0.71 | |
| | Inferred, 350kg,summer | 18 | 350 | summer | 3 | 0.934 | 1.05 | 0.93 | 1 | 31.3 | 33.8 | 8.72 | 6.23 | 0.71 | |
| 2 | Murdoch Angus animals | 15 | 370 | mid | 3 | 0.995 | 1.07 | 1 | 1 | 28.0 | 33.0 | 12.0 | 7.0 | 0.58 | Murdoch 'experiment 1' ML is 1.0 deg above point where mortality seemed likely soon |
| | Inferred base, 300kg | 15 | 300 | mid | 3 | 0.995 | 1 | 1 | 1 | 28.8 | 33.5 | 11.2 | 6.53 | 0.58 | |
| | Inferred, 300kg,summer | 15 | 300 | summer | 3 | 0.995 | 1 | 0.93 | 1 | 29.6 | 33.9 | 10.4 | 6.07 | 0.58 | |
| 3 | Murdoch Murray Grey X | 13 | 340 | mid | 3 | 1.036 | 1.04 | 1 | 1 | 29.0 | 33.0 | 11.0 | 7.0 | 0.64 | Murdoch 'experiment 2' ML is 0.5 deg above point where mortality seemed likely soon |
| | inferred base, 300kg | 15 | 300 | mid | 3 | 0.995 | 1 | 1 | 1 | 29.9 | 33.5 | 10.1 | 6.45 | 0.64 | |
| | inferred, 300kg,summer | 15 | 300 | summer | 3 | 0.995 | 1 | 0.93 | 1 | 30.6 | 34.0 | 9.43 | 6.0 | 0.64 | |
| 7 | Friesian | 12 | 200 | mid | 3 | 1.057 | 0.87 | 1 | 1 | 29.0 | 33.4 | 11.0 | | 0.6 | SBMR.002, voyage 5, D4,P35. |
| | inferred base, 300kg | 15 | 300 | mid | 3 | 1.025 | 1 | 1 | 1 | 28.2 | 32.9 | 11.8 | | 0.6 | |
| 10 | Murdoch pregnant Friesians | 11 | 420 | mid | 3 | 1.077 | 1.12 | 1 | 1 | 26.0 | 31.6 | 14.0 | 8.4 | 0.6 | New data from LIVE.224 (Beatty and Barnes, 2005) |
| | inferred base, 300kg | 15 | 300 | mid | 3 | 0.995 | 1 | 1 | 1 | 28.4 | 33.1 | 11.6 | | 0.6 | |
| 8 | Euro cross bull calves | 12 | 200 | mid | 3 | 1.057 | 0.87 | 1 | 1 | 31.0 | 34.6 | 9.0 | | 0.6 | SBMR.002, voyage 5, D5,P5,P19,P29&P37. |
| | inferred base, 300kg | 15 | 300 | mid | 3 | 0.995 | 1 | 1 | 1 | 30.3 | 34.2 | 9.69 | | 0.6 | |
| 9 | Southern bulls | 12 | 385 | mid | 3 | 1.057 | 1.09 | 1 | 1 | 29.5 | 33.7 | 10.5 | | 0.6 | SBMR.002, voyage 5, D3,P7&P47. |
| | inferred base, 300kg | 15 | 300 | mid | 3 | 0.995 | 1 | 1 | 1 | 30.9 | 34.5 | 9.11 | | 0.6 | |
| | | | | | | | | | | | | | | | |

# 4 Literature Review

## 4.1 Introduction

The aim of this literature review is to locate and review new data and results from heat stress related research involving sheep, goats and cattle completed since the HS model was developed. The principal data sources have already been covered in detail in Section 3. This section notes additional material.

A database search was undertaken using CAB Abstracts, Biological Abstracts, Agricola and Agris. The search was restricted to the time period 2002 – 2005 inclusive. In addition unpublished research reports from The University of Queensland, South Dakota State University (SDSU), University of Nebraska (UNL), The Meat Animal Research Centre (MARC), and the University of Parma (UP), Italy were also accessed.

Discussions with the following scientists all of whom are currently involved in heat stress studies were undertaken in July and September 2005: Dr LeRoy Hahn (MARC, USA), Dr Tami Brown-Brandl (MARC, USA), Dr Don Spiers (Uni of Missouri, USA), Dr Simone Holt (SDSU, USA), Dr Terry Mader (UNL, USA), Dr Roger Eigenberg (MARC, USA), Dr Fabio De Rensis (UP, Italy), Dr Nicola Lacetera (Universita Tuscia, Italy), Dr Li Baoming (China Agricultural University, China), Dr Hesham Khalifa (Al-Azhar University, Egypt), Dr Silvia Valtorta (Conicet, Argentina) and Dr Michal Horowitz (The Hebrew University, Israel).

Conference proceedings from the following conferences/meetings were reviewed.

- European Association for Animal Production, September 2003, Rome & Viterbo Italy.
- Australian Society of Animal Production, July 2004, Melbourne.
- American Society of Animal Science, July 2004, St Louis USA.
- 16th Conference on Biometeorology & Aerobiology, August 2004, Vancouver Canada.
- Livestock Environment VII, May 2005, Beijing China.
- American Society of Animal Science, July 2005, Cincinnati USA.
- 17th International Congress of Biometeorology, September 2005, Garmisch-Partenkirchen Germany.

## 4.2 Brief Overview of Published Material and Discussions

The data search did not provide many new reports, conference papers or journal articles related to heat stress in the target species (beef, goat and sheep) for the years 2003 – 2005. Most papers dealing with ruminant heat stress involved dairy cows. In most cases nutritional aspects or reproductive aspects were the main focus. The majority of the papers dealing with beef cattle were concerned with feedlot animals, and only two related to housed animals There was however a considerable number (>60) papers covering heat stress and housing (ventilation) in poultry and pigs. Other species included rabbits, camels, buffalo and humans. Six papers covering sheep, 5 on goats and 1 covering both sheep and goats were found. Most of these were available in abstract form only, and were not published in English. It appears that most of the heat stress work with sheep and goats is currently being undertaken in the Middle East, Egypt and Brazil. Nineteen papers covering heat stress in cattle were presented at the three conferences in 2005, however only 4 of these papers involved beef cattle and 1 paper covered both sheep and goats.

The THI (in various forms) was the main index used in categorizing heat stress in the articles reviewed. Where climatic data were measured they usually consisted of ambient temperature and relative humidity. Wind speed, solar radiation and dewpoint were often measured in outdoor studies. Wet bulb temperature was rarely measured or quoted.

## 4.3 Overview of Specific Papers

The following provides a brief summary of the main points of recently published material. Not all of these may be directly relevant to the HS model parameters, but they are included for completeness.

**Smith et al. 2005a** *Practical methods for reducing heat stress on dairy operations*. Journal of Animal Science. 88(Suppl.1):235

The authors discussed using evaporative cooling, cool air and a low pressure soaker system to cool cows in a hot humid environment. No relevant information was presented.

**Smith et al. 2005b.** *Evaluation of environmental conditions in 4 and 6 row freestall barns that are tunnel ventilated with evaporative pads and located and in Indiana*. Journal of Animal Science. 88(Suppl.1):338

The authors described climatic factors (air temperature; TA, and relative humidity; (RH) over 8 weeks in two fully enclosed 4 row dairy barns and compared these to outside conditions. The average maximum ambient temperature (TA) was 30.3 $^{o}$C, and the minimum was 17.7 $^{o}$C. The average maximum relative humidity (RH) was 100.0% and the minimum was 63.2%. The dairy barn had lower a TA (2.9 $^{o}$C) than the outside TA, a lower THI (4.9 points) and a higher RH (23.6%). Air movement through the buildings increased TA and THI but lowered RH.

**Smith et al. 2005c** *Impact of using feedline soakers in combination with tunnel ventilation and evaporative pads to minimize heat stress in lactating dairy cows located in Thailand.* Journal of Animal Science. 88(Suppl.1):338

A two row tunnel ventilated free stall barn (16 m x 113 m) was used in this study involving dairy cows. The vaginal temperature of the cows was recorded and cows were exposed to (i) Feedline soakers that switched on when ambient temperature was 21$^{o}$C (0.5 min on, 4.5 min off), or (ii) Feedline soakers in combination with ventilation. Both treatments decreased heat load. Limited climatic data presented.

**Brouk et al.** 2005a *Combining air cooling and feedline soaking for heat abatement of lactating dairy cattle housed in north central Florida.* Journal of Animal Science. 88(Suppl.1):339

Dairy cows housed in a four row tunnel ventilated dairy barn (213 m long) were used to investigate the effects of air cooling and feedline soaking during periods of hot weather. Mean climatic conditions in barn were; ambient temperature 23.8 ± 3 $^{o}$C, relative humidity 84.6 ± 15.4% and THI 74.7 ± 5.3. Cooling reduced respiration rate by approximately 7 breaths per minute (58.5 vs. 66.9 bpm) and vaginal temperature by 0.3$^{o}$C (38.9 vs. 39.2$^{o}$C). A good study but limited data presented. (NB a journal paper has been submitted).

**Brouk et al. 2005b** *Utilizing data loggers and vaginal temperature data to evaluate heat stress in dairy cows.* Journal of Animal Science. 88(Suppl.1):339

The authors presented information on different types of data loggers that can be used to assess body heat in unrestrained cattle. The loggers presented have potential application for shipboard studies.

**Arieli et al. 2005** *Assessment of heat increment in dairy cattle by monitoring heart rate.* Journal of Animal Science. 88(Suppl.1):339

An interesting study, but confounded by dietary treatments. A small study which lacks data. Not relevant to the HS model.

**Pollard et al. 2005** *Use of physiological measures as predictors of heat dissipation during heat stress in dairy cattle*. Journal of Animal Science. 88(Suppl.1):339

Pollard et al. used infrared thermography to measure body surface temperature of cows. The study was undertaken in a climate room study and involved 36 cows. The ambient temperature regime ranged from 24 to 40 $^{o}$C; relative humidity from 12 to 39% and THI from 50 to 84. Respiration rate (RR), rectal temperature (RT), sweating rate (SW) and body surface temperature (ST) were all recorded. The measured parameters were tested for their ability to predict RR. The results were: ST ($R^2$ = 0.557), SW ($R^2$ = 0.435) and RT ($R^2$ = 0.035). The authors concluded that: "Overall, ST is a more predictive measure of heat dissipation through evaporative methods than rectal temperature and can be used as a tool to evaluate environments …."

**Al-Haidary et al. 2002** *The effect of progressively higher level of heat challenge on temperature control of cattle*. 15th Conference on Biometeorology and Aerobiology. Kansas City Missouri USA. p94.

Twelve steers were used in a climate room study. The steers were exposed to 3 weeks of thermonuetral conditions (TNC) followed by two hot periods. During the first hot period (HS1) the steers were exposed to a diurnal temperature pattern (26 to 33 $^{o}$C), after 10 days they were exposed to a temperature of 36 $^{o}$C which was held constant for 5 days (HS2). Body temperature (BT) was measured using an implanted telemetry probe. During TNC BT ranged from 37.6 – 38.2 $^{o}$C and followed a diurnal pattern. During HS1 BT ranged from 38.04 – 38.96 $^{o}$C and during HS2 the range was 38.04 – 39.40 $^{o}$C. Body temperature was higher during second exposure (but note that there was no night time relief). The cattle did not exhibit high body temperatures as seen in numerous studies (no explanation presented). During TNC RR was maintained within a narrow range (62 – 69 bpm). The RR range was greater for both HS1 (67 – 107 bpm) and HS2 (81 – 134 bpm). The higher RR in HS2 suggests that prolonged exposure increases stress. However this may be an indicator of no relief as well as a duration effect.

**Brown-Brandl et al. 2005a**. Evaluating modelling techniques for cattle heat stress prediction. Biosystems Engineering 91:513 – 524.

In this paper 5 models (2 statistical, 2 fuzzy inference systems and 1 neural network) were developed and evaluated. The best of the models (neural network) described 68% of the variation in respiration rate. Cattle were housed in a feedlot in Nebraska USA; weather data was collected but was not presented in this paper. This paper disappointed in that the models were developed on a mathematical basics but without regard to the underlying physics or physiology. It seems there is an opportunity for the work to be revisited with models informed by current understanding of the animal heat balance.

**Brown-Brandl et al. 2005b** Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, part 1; analysis of indicators. Biosystems Engineering 90:451 – 462.

In this feedlot study 8 steers were used to examine the impact of shade on physiological responses when they are exposed to hot conditions. The cattle were housed in individual pens, with or without access to shade. The authors measured respiration rate, core body temperature and DMI. The data were collected over 37 days of summer. Fourteen days had a maximum THI>86. The authors reported that cattle with access to shade had lower respiration rates and body temperature than those without shade. A good study but not enough hot days were encountered. Presentation of more of the climatic data would have been useful.

Eigenberg et al. 2005 Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, part 2 predictive relationships. Biosystems Engineering 91:111 – 118.

This study was a follow on from part 1 (above). The authors developed linear regression equations that could be used to predict respiration rate. Respiration rate, core body temperature, DMI and liveweight were recorded. The following climatic factors were recorded and used to develop the regression equations: ambient temperature (TA), relative humidity (RH), solar radiation (SR), air speed (WS), and dew point (DP). A regression equation was developed that used TA, DP, WS and SR (RR = 2.8TA + 0.24DP – 1.5WS +0.038SR – 52.8). When TA>25 $^{o}$C, DP contributes 8.9% to RR, TA 32.2%, SR51.4%, WS 5.7% and animal weight 1.9%. This work further confirms the importance of SR for outside cattle. The ambient temperature threshold of 25 $^{o}$C (above which RR increases) is similar to findings from Australian studies.

**Berman 2005.** *Estimates of heat stress relief needs for Holstein dairy cows*. Journal of Animal Science. 83:1377 – 1384.

Berman used thermal balance models to estimate under what conditions (THI) heat stress alleviation is needed. The model included body weight, metabolic heat production, tissue and coat insulation, skin water loss, coat depth, and minimal and maximal tidal volume. This is a good paper and may give some insight to adjustment of response thresholds used in Australia. The inferred HST values are generally in the range expected. The figures are all from the modelling rather from animal experiments. The paper may well be useful in reviewing jetting effects. It notes the greatest benefit from air movement occurring in the first 0.6m/s of air speed.

**Davis et al. 2003**. *Strategies to reduce feedlot cattle heat stress: effects on tympanic temperature*. Journal of Animal Science. 81:649 – 661.

The authors evaluated the effect of different management strategies on body temperature in feedlot cattle. Not of much value to housed cattle, but some interesting ideas.

**Gaughan et al. 2004.** *Wetting and the physiological responses of grainfed cattle in a heated environment*. Australian Journal of Agricultural Research. 55:253 – 260.

**Gaughan et al. 2005.** *Hormonal growth-promotant effects on grainfed cattle maintained under different environments.* International Journal of Biometeorology. 49:396 – 402.

In this study, cattle were housed in individual stalls in a climate room. The authors investigated the effect of different hormonal growth promotants (HGP's) on heat production and heat tolerance. Cattle were exposed to both hot and cold conditions. Respiration rate, rectal temperature, oxygen consumption and DMI were measured. The THI was used (wet bulb was not recorded). During hot conditions, the mean THI was 78.3 (minimum was 75), mean respiration rate was 108.8 bpm, and mean rectal temperature was 38.93 $^{o}$C. During cold conditions the means were: THI = 63.4, ambient temperature = 17.6 $^{o}$C, RR = 28.7 bpm and RT = 38.67 $^{o}$C. Under hot conditions mean respiration rate was 114 bpm, mean rectal temperature was 39.6 $^{o}$C. The authors reported that oestrogen based HGP's increased rectal temperature while androgen based HGP's reduced rectal temperature.

The authors investigated the affect of altered water sprinkling duration on rectal temperature, respiration rate and DMI in heifers subjected to heat stress conditions. The cattle were housed in individual pens in a climate room. During hot conditions the THI was 81 ± 4, ambient temperature 30 ± 3 $^{o}$C and relative humidity was 70 ± 10%. During thermonuetral conditions THI was 70 ± 2, ambient temperature was 21 ± 2 $^{o}$C and relative humidity was 70 ± 2%. The cattle were exposed to no wetting or variations in wetting regime (number of applications in a 24 h period). The conclusions from this study were that water application will reduce rectal temperature and respiration rate in heat stressed cattle, and that inconsistent water application may impair cattle heat tolerance.

**Holt et al. 2004**. Feeding strategies for grain-fed cattle in a hot environment. Australian Journal of Agricultural Research. 55:719 – 725.

In this study 6 Hereford steers were used to examine the impact of various feeding strategies on respiration rate, rectal temperature and DMI when to exposed hot conditions. Three feeding systems used in the study: (i) *ad-libitum*, (ii) 85% of *ad-libitum*, and (iii) restricted access (limit). Under thermonuetral conditions mean ambient temperature was 20.6 ± 1.6 °C (ranged from 17.6 to 26.1 °C), mean relative humidity was 74.7 ± 8.9% and mean THI = 67.5 ± 2.4 (max 75). During hot conditions the mean ambient temperature was 23.4 ± 4 °C (ranged from 16.7 to 32.3 °C, mean relative humidity was 63.2 ±12.4 and mean THI was 70.7 ± 6.1 (max 82). Respiration rates were lower (93.5 bpm) for 85% fed cattle under hot conditions compared to 109 and 102 bpm for *ad-libitum* and limit fed steers. The a*d-libitum* fed cattle had higher intakes under both thermonuetral and hot conditions.

**Spiers et al. 2004**. Use of physiological parameters to predict milk yield and feed intake in heat-stressed dairy cows. Journal of Thermal Biology. 29:759 – 764.

The authors used dairy cows in a climate chamber study in an attempt to develop a thermal ‘strain’ model. Rectal temperature, respiration rate, DMI, and milk yield were recorded. The authors concluded that rectal temperature ($R^2$ = 0.89) was best indicator of thermal stress.

**Senthilkumar et al. 2003**. Influence of spray cooling and electrolyte supplementation on feed intake, milk yield and milk composition in cross bred dairy cows. Indian Veterinary Journal. 80:1037 – 1042.

No relevant data were reported in this study (only an abstract was available). Not relevant to the HS model.

**Brown-Brandl et al. 2005**. Analyses of thermoregulatory responses of feeder cattle exposed to simulated heat waves. International Journal of Biometeorology 49:285 – 296.

This study was novel in that the authors simulated actual heat wave conditions that occurred in USA. The cattle were housed in a climate chamber while being exposed to the simulated heat wave. Tympanic temperature, respiration rate and DMI were recorded. The response of cattle to the imposed conditions was similar to other published studies.

**Maia et al. 2005.** Sensible and latent heat loss from the body surface of Holstein cows in a tropical environment. International Journal of Biometeorology. 50:17 – 22. (also presented at 17th ISB).

This was a field study undertaken to investigate evaporative and non-evaporative heat loss in dairy cows. Fifteen grazing cows were used. A ventilated “capsule” was used to measure heat loss from body surface of the cows. The findings from this study were that heat loss by cutaneous evaporation (CE) accounted for 20 – 30% of total heat loss when ambient temperature ranged from 10 – 20 °C. When ambient temperature was greater than 30 °C CE accounted for 85%, and respiratory evaporation accounted for 15% of the heat loss. This is confirmation that evaporative heat loss dominates in extreme conditions, supporting the use of wet bulb temperature as an index.

**Gallardo et al. 2005.** Diet and cooling interactions on physiological responses of grazing dairy cows, milk production and composition. International Journal of Biometeorology. 50:90 – 95. (also presented at 17th ISB).

Fifty-eight dairy cows in a field study to investigate the affect of diet and cooling interactions on milk production. Physiological data was collected once per week and is therefore of little value.

**Lacetera et al. 2005.** Lymphocyte functions in dairy cows in a hot environment. International Journal of Biometeorology. 50:105 – 110. (also presented at 17th ISB).

This study was undertaken to investigate the effects of hot environments on lymphocyte function. Thirty-four cows housed in a commercial dairy. Peripheral blood mononuclear cells (PBMC) were evaluated. The main outcome from this study was that exposure to extreme events may impair the immune system and thereby increase the risk of disease. The findings from this study have implications for the live export and feedlot industries in Australia.

**da Silva and Starling 2003.** Cutaneous and respiratory evaporation rates of sheep in hot environments. Revista Brasileira de Zootecnia 32(Suppl.2):1956-1961.

Ten adult sheep were evaluated for respiratory (ER) and cutaneous (EC) evaporation rates. The animals were observed about 10 times each by recording changes in their liveweight with high-sensitivity strain gauges, under different conditions of air temperature (21.1 to 41.9 $^oC$) and partial vapour pressure (1.53 to 3.01 kPa). Average evaporation rates were $0.7599 \pm 0.0094$ $g.h^{-1}.kg^{-1}$ for ER and $1.3029 \pm 0.0591$ $g.h^{-1}.kg^{-1}$ for EC. Cutaneous evaporation was considered as an important heat loss mechanism for sheep in hot environments. The effects of sex, fleece thickness, air temperature, and air humidity were discussed.

**Alamer. 2003.** Heat tolerance of local goat breeds in Saudi Arabia. Arab Gulf Journal of Scientific Research 21:210 – 216.

Twelve bucks were used to evaluate the heat tolerance of 3 Saudi Arabian goat breeds. The goats were exposed to direct sun with or without access to water during hot summer. Exposure of goats to direct sun for 5 hours for 5 consecutive days (3 days with water and the last 2 days without water) resulted in a significant increase in rectal temperature in all goats. Respiration rate was also increased in response to exposure to solar radiation in all breeds but with varying degrees (133% to 290%). Sweating rate was slightly increased following exposure to direct sun. The author concluded that there were no differences between breeds in heat tolerance when the water supply was maintained ad libitum. However, when water was withheld, Aardi goats enhanced their evaporative heat loss and maintained higher levels of feed intake despite their relatively higher rectal temperature. An interesting study, access to the full paper may help in setting thresholds for goats.

**Medeiros et al. 2002.** Estimative of heat tolerance of goats. Revista Brasileira de Medicina Veterinaria. 24:30 – 35.

Heat tolerance was estimated in goats of different breeds. Six each of Anglo-Nubian, Saanen, and Germany Brown goats were included in the study. Air temperature and relative humidity during the study were 30 – 39 $^oC$ and 50 – 75%, respectively. Anglo-Nubian goats recovered the initial rectal temperature after 45 min rest in shade. Saanen and Germany Brown goats did not recover the initial rectal temperature even after 60 min rest in shade. The highest thermoregulation rate was achieved by Anglo-Nubian goats (93.07%), whereas the lowest was achieved by Germany Brown and Saanen goats (74.98 and 71.27%, respectively). It was concluded that Anglo-Nubian goats are more heat tolerant than Saanen and Germany Brown goats.

**Alexiev et al. 2004.** Thermoregulation in sheep. III. Respiratory cooling in unshorn and shorn sheep belonging to three breeds, kept in sun or in shade, with or without access to tap water, during warm summer days. Zhivotnov'dni Nauki 41:11 – 15.

The aim of this study was to determine the effect of heat load on the respiration rate of three breeds of sheep exposed to sun or kept in the shade, during the hot summer days (Bulgaria). The ewes were allocated into 3 groups (n = 5) based on their breed. Respiration rate was measured at 7, 14, 15 and 21h before and following shearing, exposed to sun or kept in shade, with or without access to tap water for 24h. Exposure to direct solar radiation caused breed specific acceleration of respiratory rate, which was used for the calculation of the tolerance to heat. Eleven blackhead sheep showed higher heat tolerance than the other two breeds. Shaded sheep had significantly lower respiratory cooling during the hot summer days. As only an abstract was available it is not possible to fully examine this study. Access to the full report may help establish heat load thresholds for Australian sheep. The original report is in Bulgarian. The authors have a number of publications in this area of research.

**Al-Haidary. 2004.** Physiological responses of Naimey sheep to heat stress challenge under semi-arid environments. International Journal of Agriculture and Biology. 6:307 – 309.

The effect of heat stress on body temperature, heart rate, respiration rate and haematological and serum biochemical parameters was evaluated in 8 sheep over a 5 week period. The sheep were divided into 2 groups which were placed in 2 rooms. One room (control) had an average temperature (23.6 $^{o}$C and 50% relative humidity), while in another room (experimental) the temperature was gradually increased from 23.6 to 33-38.5 $^{o}$C. The author reported that heat stress significantly reduced the daily average heart rate and increased rectal temperature, respiration rate, skin temperature and haematocrit. Serum triiodothyronine and thyroxine levels were also affected by heat stress, though not significantly.

**Starling et al. 2002**. Analysis of some physiological variables for the evaluation of the degree of adaptation in sheep submitted to heat stress. Revista Brasileira de Zootecnia. 31:2070 – 2077.

Rectal temperature, respiration rate and total evaporative heat loss rate were measured in 21 ewes. The ewes were housed in a climatic chamber at 45 deg C and variable humidity (PV), where respiration frequency (FR) and rectal temperature (TR) were recorded. Based on FR and TR, 10 animals including 5 ewes with the lowest values (heat adapted, Group 1) and 5 with the highest values (not heat adapted, Group 2) were selected. These animals were placed in the climatic chamber and exposed to ambient temperatures of 20, 30 and 40 $^{o}$C with variable PV, where TR, FR and total evaporation rate (TET) were measured. It was shown that there were no significant differences between both groups for the measured parameters. In conclusion, the use of physiological parameters such as rectal temperature and respiration rate for selection is not enough to evaluate the level of adaptation to hot conditions. The results from this study confirm that assessment of heat tolerance is not simple.

## 4.4 Books

Lacetera et al. (eds). 2003. Interactions Between climate and Animal Production. EAAP Technical Series No. 7. Wageningen Academic Publishers, The Netherlands. ISBN 9076998264.

This book contains the proceedings of an (EAAP) satellite meeting in 2003. The meeting covered aspects of heat stress, environmental management and the impact of heat on food quality. The heat stress papers cover aspects of general management, development of new assessment tools and future directions.

## 4.5 Conclusion

There is an apparent lack of recent ruminant heat stress research other than for dairy animals. This should not be interpreted as a lack of need for heat stress research especially for goats and sheep where little is known of their heat tolerance.

Immunological responses to heat stress, identification of ‘heat tolerance’ genes and changes in heat tolerance (susceptibility) assessment are areas where more research is urgently needed.

# 5 Loading Tolerance

Natural uncertainties in livestock weights, and the tight timelines involved in purchasing stock for a voyage, mean that the stock arriving at the wharf and loaded on ships will never exactly match the HS voyage loading plan as submitted to AQIS. This is a problem in that the voyage approval is for the plan as submitted, with no mention of variation or tolerance. This section proposes allowable variations in loading for which the original HS plan should be deemed sufficient. The key is obviously that the heat stress risk shown to be acceptable on the submitted plan should not be significantly higher for the final loading.

Two approaches to the loading tolerance are presented. In the first, variations are permitted on both the number and the average weight of each line, subject to the liveweight stocking rate not increasing beyond tight limits.

In the second approach, provided soft lines of livestock are not increased in number, only the total loaded weight needs to be assessed relative to the tolerance figures. Either approach may be used.

Ship stability is not addressed here. Nothing in this report should be taken as commenting on ship stability calculations which remain the responsibility of the ship's captain.

Many vessels will regularly load at, or close to the Australian Standards for the Export of Livestock (ASEL) maximum stocking tables. The tolerances given here do not override the ASEL, which must still be met. They are directed specifically at meeting the intent of HS without unintended dockside workload or unnecessary regulatory sanction.

The methodology adopted to arrive at the permissible variation took the form of a series of sensitivity tests centred around the maximum allowable risk (2% risk of 5% mortality). A range of voyages were set up with livestock lines at this maximum allowable risk and the lines were then de-stocked to produce given lower risk levels. The degree of de-stocking to reach a given risk level was then used to arrive at loading tolerances for lines originally assessed as being at that risk level.

Tolerances become tighter as the original HS risk figure approaches the maximum allowable. At 2% risk of 5% mortality, the tolerance was set to give minimal increase in risk. Animals with a lower apparent risk are given a wider loading tolerance. The two approaches and the resulting tolerances are given below. Neither of the methods allow the introduction of livestock lines not already represented on the HS printout.

## 5.1 Line by line loading tolerance

For this purpose, we define a "liveweight stocking density" equal to the ratio of the average animal liveweight for the line, and the area allowed per head. For example; 50kg wethers loaded at 0.315$m^2$/head would have a liveweight stocking density of 50/0.315 = 158.7kg/$m^2$. Using this measure of stocking allows one figure to cover the combined variations in both average liveweight and number loaded. For example; a 1% increase in the number and a 2% increase in average weight would give a 3% increase in the liveweight stocking density (assuming the same pens were used) (1.01 x 1.02 = 1.0302). The loading tolerance by this method is stated as:

> If there is room to allow it without exceeding ASEL loading tables, the liveweight stocking densities can be increased according to Table 5.1.

**Table 5.1 Line by line stocking rate tolerances**

| Declared risk of 5% mortality | Acceptable increase at loading in liveweight stocking density |
|---|---|
| 1.8 to 2% | 0 (No increase allowed) |
| 1.5 to 1.8% | 2% (subject also to ASEL) |
| 1.0 to 1.5% | 4% (subject also to ASEL) |
| Less than 1.0% | 10% (subject also to ASEL) |

## 5.2 Total cargo weight loading tolerance

The line by line method is useful when the loading is very close to that intended when the HS output was submitted to AQIS. However it is also possible to replace large numbers of one line with additional animals from another line, without increasing the voyage heat stress risk. The total cargo weight approach gives that flexibility, subject to some realistic constraints which it is hoped will prevent unreasonable manipulation of the tolerances.

Provided that no increase in numbers loaded occurs for any “relatively soft line”, the total liveweight loaded is permitted to increase above the submitted HS values following Table 5.2.

**Table 5.2 Total cargo weight stocking tolerances.**

| Median risk of 5% mortality | Acceptable increase in total loaded liveweight |
|---|---|
| 1.8 – 2.0% | 0 (no increase allowed) |
| 1.5 – 1.8% | 2% (subject also to ASEL) |
| 1.0 – 1.5% | 4% (subject also to ASEL |
| Less than 1.0% | 10% (subject also to ASEL) |

A “relatively soft line” is defined for this purpose as any line which must be de-stocked to 75% or less of the ASEL default loading table in order to meet the 2% limit on the risk of a 5% mortality incident. As an example to illustrate the intent, if thirty 120kg rams were planned to be loaded on a shipment of 30 to 50kg wethers then, provided no more than thirty rams were loaded and the risk for the wethers on the HS plan was 1.0 to 1.5%, the total loaded liveweight could be increased by 4% (Table 5.2). This example presumes that the voyage conditions required the heavy rams, but not the wethers, to be loaded at less than 75% of the ALES tables.

The “median risk of 5% mortality” called up by Table 5.2 is that risk value for which half the loaded stock have a lower risk, as given in the submitted HS loading plan.

# 6 Results and Discussion

## 6.1 Animal Parameters

In reviewing available data sets to estimate heat stress thresholds, the need for data quality again became clear. As long as there is significant doubt about any relevant aspect of a data set, it is very difficult to use that data at all.

Voyage data relies on individual observers and there may be a need for training and 'calibration' of the observers, to give greater confidence in the data.

Land based experimental data are often gathered for other purposes (eg feedlot research) and have differences (such as diurnal cooling) which make the data less relevant to the shipboard environment.

The recommendation from this is to put the effort upfront into experimental design and setup to ensure the best results. The Murdoch University hot room tests are the best data so far.

As noted in Section 3.7, the Murdoch data from LIVE.224 has allowed a revision in the parameters for *Bos taurus* dairy animals.

## 6.2 Voyage loading tolerance

The original intention was to produce a loading tolerance based only on the total liveweight loaded. On working towards that goal, the line-by-line method suggested itself and appeared to offer an appropriate method for some cases.

The loading tolerance methods have not been tested by industry. It is likely that some adjustment to the methods will be made following operational experience.

It is possible that more generous tolerances could be applied for many lines on many voyages. The tolerances selected were more or less a 'lowest common denominator' from the sensitivity tests conducted. As it seems that they will provide sufficient latitude for all practical loading variation, there is no case for seeking to stretch them.

# 7 Success in Achieving Objectives

Specific objectives 1, 2 and 4 were met. Objective 3 called for specific relative risk evaluations, some of which could not be made with the available data. The overall objective of updating and validating the animal parameters in the HS model was met.

# 8 Impact on Meat and Livestock Industry – now & in five years time

HS has had a major impact on the live export industry, by applying scientific engineering methods to control the risk of heat stress on voyages to the Middle East. By doing so, HS has also won the confidence of government that the industry is able to successfully address such problems. As a review and validation exercise, this project revalidates HS and reaffirms its efficacy.

As for the impact in five years time, it seems likely that HS will still be providing the same benefits and may again be reviewed in light of the latest data.

# 9 Conclusions and Recommendations

The following recommendations are made:

- The heat stress threshold and mortaility limit for *Bos taurus* dairy cattle should be increased from 28.2°C and 32.9°C to 28.4°C and 33.1°C respectively.
- The winter coat factor should be modified for those *Bos taurus* dairy cattle, such as Friesians, without strong coat changes in winter. The mid-season coat factor should be adopted in winter.
- No other adjustments to HS are suggested.
- Close attention to be paid (and costing allowance made) to pre-work and experimental set up on all future data gathering exercises.
- Shipboard data should be analysed as soon as possible, while some details may still be reliably added from memory.
- AQIS should be asked to adopt the loading tolerance methods as proposed, to avoid practical difficulties while maintaining control of heat stress risk.
- Where the loading tolerance is applied, a new HS printout should be produced after sailing, and kept with the original for later review of the effectiveness of the loading tolerance approach.

# 10 Bibliography

Recent relevant literature is noted and discussed in Section 4. Specific references from the other sections of the text are noted here.

*Beatty, D. and Barnes, A. (2006)* LIVE.224 Milestone Reports to MLA.

*Beatty, D*. Personal communication of LIVE.224 Friesian experiment data files.

*Gaughan, J. (University of Queensland, Gatton)* Heat stress experiments on Angus and Hereford Steers in 2003 and 2004. Data not yet published.

*McCarthy, M. (2005a)* Pilot monitoring of shipboard environmental conditions and animal performance. (LIVE.223 project report published by MLA).

*McCarthy, M. (2005b)* Personal communication of voyage notes from the LIVE.223 project.

*Stockman, C. and Barnes, A. (2005)* LIVE.224 Milstone Reports to MLA.

*Stockman, C (2005)* Personal communication of LIVE.224 sheep experiment data files