live export

Investigation of Ventilation Efficacy on Live Sheep Vessels

Project Number LIVE.212

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Executive Summary

The scope of project LIVE.212 was truncated from three voyages to two voyages as the principal objectives had been met and the work had been overtaken by the heat stress risk management project LIVE.116.

The literature review and the two voyages undertaken provided data on the response of sheep and goats to heat stress. These data have assisted in the estimation of the base heat stress threshold and mortality limit figures required for LIVE.116 and the HS software. The data were also used to assess the factors through which acclimatisation, weight and coat are taken to adjust the assessed heat stress threshold and mortality limit.

Voyage 1 sailed to the Middle East in June/July 2002, having loaded sheep in both Portland and Fremantle. All decks were closed at the ship sides and were single tier, giving high headroom.

Voyage 2 sailed to the Middle East in September 2002, carrying a range of sheep, all in low headroom decks. Closed deck ventilation rates (pen air turnover) varied significantly between sample pens. Several open deck pens were also studied on Voyage 2.

Ambient wet bulb temperature peaked at 27.9^{o}C on day 13 of Voyage 2. The highest corresponding wet bulb peak in the closed observation decks was 33.2^{o}C, a rise below decks of 5.3^{o}C.

The heat stress threshold (HST) for sheep was estimated from Voyage 1 to be 28 to 30^{o}C wet bulb. The Voyage 2 data confirmed that the majority of animals have a HST below 30^{o}C wet bulb, but also indicated elevated rectal temperatures at wet bulb temperatures as low as 26^{o}C wet bulb.

Although Voyage 2 was generally cooler than Voyage 1, an increase in mortality was seen coincident with the hottest conditions. Wet bulb temperatures around 32^{o}C appeared to trigger a rise in mortality rate among Merino sheep. The peak daily mortality rates were still relatively low. The rise is considered to be the result of heat stress compounding the problems for sheep already weakened by other effects. A heat event causing healthy sheep to die would be expected to affect very large numbers.

The overall wet bulb temperature difference between ambient and exhaust air was consistent with an estimate made using methods developed previously, applying a metabolic heat production rate of 3.2W per kg of liveweight for sheep. The deck wet bulb temperature rises were also consistent with earlier work.

A number of Voyage 2 experiments did not give useful results because the conditions were too mild or, in the case of open decks, too breezy. It is recommended that understanding of open decks is best advanced by computational studies, possibly followed by unattended data logging on ships. Such computational studies have now been done as part of LIVE.116 and the authors are assisting the industry to set up the data logging.

Weight change data from the voyages varied widely and were not self-consistent. We consider that the weight change data are not informative.

1 Introduction

1.1 Background

Following the successful project SBMR.002 on the ventilation efficacy of (mainly) cattle vessels, project LIVE.212 was commissioned to look at ventilation effects specific to vessels carrying sheep and goats.

The project was planned to include three research voyages. The first two voyages collected good data on the essential parameters. Timing prevented the last voyage being undertaken in the northern summer of 2002. After several voyages were affected by heat stress that year, a project to create a heat stress risk estimation tool was born as LIVE.116. The final report presentation for that project and release of version 2.1 of the "HS" software took place in October 2003. During the 2003 northern summer, the heat stress research and development focus was very much on establishing the HS software rather than finessing the sheep data through LIVE 212. There was also no driving need for the types of data which could be provided with any certainty by undertaking the third voyage. The project scope was consequently truncated by mutual agreement in November 2003.

All the pertinent data reported here have already been reduced and applied in the HS software and documented in the LIVE.116 final report. The scope of this final report was then restricted to collecting together the voyage conclusions, relevant data and descriptions to create an archival record of the project. The analysis documented has previously been documented in the LIVE.116 final report.

The project has been a great success in exploring the ventilation and heat stress issues for sheep, achieving the central objectives and feeding data into follow-on work at a cost significantly lower than envisaged at the start of the project.

1.2 Objectives

The objectives as given in the project proposal are as follows:

- More accurately determine the relationship between the long haul shipboard environment and the performance of sheep, lambs and goats, including as far as possible, the effects of:
    - Open deck ventilation,
    - Relationship of wet bulb temperature to animal performance,
    - Air distribution,
    - Air speed effects,
    - Recirculation of exhaust air,
    - Breed effects,
    - Stocking density,
    - Environmental comfort indices and their relationship to animal performance, and
    - Measures to minimise heat stress on open decks where there is no natural or artificial air movement.
- Comment on the ventilation performance of existing sheep carriers including the design and construction of the ventilation systems.
- Present a means of risk management in the shipment of sheep, lambs and goats that can be readily adopted by industry,
- Provide options for heat stress management planning,
- Summarise the findings in a form that can be included into the Livestock Export Accreditation Program (LEAP).
- Prepare recommendations to the industry that are supported by relevant financial analysis.

These objectives formed a comprehensive list of desirable outcomes from the project. It was understood that the nature of research and the physical and commercial constraints on voyages undertaken by the sheep export industry meant that dramatic progress would not be possible on all issues.

1.3 Terminology

The adopted terminology of heat stress as applied to sheep export is explained in the LIVE.116 report as follows.

Although the concepts of 'thermoneutral zone' and 'upper critical temperature' appear to be universally accepted, definition of these particular concepts remains somewhat problematic. The upper critical temperature (UCT) is a common term in the literature, used to describe the dry bulb temperature at the upper boundary of the thermoneutral zone. Unfortunately UCT as defined cannot exist unless heat stress is closely related to dry bulb temperature. In the project proposal we suggested an Upper Critical wet bulb Temperature (UCwbT) to recognise that heat stress is more closely related to wet bulb temperature. Industry representatives agreed that UCwbT was too much of a mouthful and, by consensus the term Heat Stress Threshold (HST) was adopted.

HST was defined as '*the maximum ambient wet bulb temperature at which heat balance of the deep body temperature can be controlled using available mechanisms of heat loss'.*

That is; when the local air wet bulb temperature reaches any animal's HST, the animal is on the verge of becoming stressed. As implied above, incipient stress in this sense means the first uncontrolled rise in core body temperature. We take this as the core temperature being 0.5^{o}C above the level it would otherwise have been at.

For the descriptor of the wet bulb temperature at which an animal will die, the LIVE.116 report preferred "Mortality Limit" or ML.

1.4 Observations of Heat Stress Threshold and Mortality Limit

Table 0.1 below is taken from the LIVE.116 final report. It summarises the observations from the two voyages of the LIVE.212 project as well as the 'normalisation' of the observations to produce estimates for 'standard' animals. Table 0.3 below is an extract from one in the LIVE.116 report, with the cattle data omitted.

Table 0.3 tabulates the adopted scaling factors by which weight, fat score, coat and acclimatisation are used to adjust the base numbers in Table 0.2 to give HST and ML estimates for individual lines. The scaling is explained in the next section.

Table 0.1 Original and Inferred Sheep Parameters

DATA SET		ACCLIMATISATION WB TEMP	WEIGHT (KG)	COAT	FAT SCORE	Facc	Fweight	Fcoat	Fcond	HST	ML	HST diff	ML diff	MLdiff / HSTdiff	REFERENCE
MERINO TABLE															
10	Voyage 1 adults	12	52	shorn	3	1.057	1.01	1	1	29.5	35.0	10.5	5	0.48	LIVE.212 v1, lower mort.~32
	inferred base, 40kg	15	40	shorn	3	0.995	0.96	1	1	30.6	35.53	9.38	4.47	0.48	
11	Voyage 1 woolly ewes	12	54	woolly	3	1.057	1.02	1.12	1	28	34.29	12		0.48	LIVE.212 v1 D8, P30
	inferred base, 40kg	15	40	shorn	3	0.995	0.96	1	1	30.5	35.47	9.5		0.48	
12	Voyage 1 lambs	12	38	shorn	3	1.057	0.95	1	1	26	35.0	14	5	0.36	LIVE.212 v1, D5, P1&2
	inferred base, 40kg	15	40	shorn	3	0.995	0.96	1	1	26.7	35.24	13.3	4.76	0.36	
13	Voyage 2 adults	11	60	shorn	3	1.077	1.04	1	1	29.5	35.0	10.5		0.48	LIVE.212 v2, lower mort.~32.5
	inferred base, 40kg	15	40	shorn	3	0.995	0.96	1	1	31.1	35.74	8.94		0.48	
AWASSI TABLE															
14	Voyage 1 lambs	12	38	hairy	3	1.057	0.95	1	1	28	35.71	12		0.36	LIVE.212 v1, D9, P20
	inferred base, 40kg	15	40	hairy	3	0.995	0.96	1	1	28.6	35.92	11.4		0.36	

Table 0.2 Base Heat Stress Threshold and Mortality Limit Values for the 'Standard' Animals

Base Parameter	Merino		Awassi	
	adult	lamb	adult	lamb
Weight (kg)	40	40	40	40
Core Temperature (degrees C)	40	40	40	40
Condition (Fat Score)	3	3	3	3
Coat	shorn	shorn	hairy	hairy
Acclimatisation WB Temp	15	15	15	15
Base HST (degrees C)	30.6	26.7	31.9	28.6
Base ML (degrees C)	35.5	35.20	36.1	35.90
Beta distribution lower limit (degrees C)	33.58	33.17	34.52	34.15
Beta distribution upper limit (degrees C)	36.52	36.29	37.03	36.83

Table 0.3 Scaling Factors

Factor		Sheep
Base Weight (kg)		50
Weight Index n		0.2
Core Temperature (^{o}C)		40
F Condition	Fat Score 0	9
	Fat Score 1	0.9
	Fat Score 2	0.95
	Fat Score 3	1
	Fat Score 4	1.07
	Fat Score 5	1.2
F Coat	Hairy (Awassi only)	1
	Mid (10 to 25mm)	1.08
	Shorn (under 10mm)	1
	Woolly (over 25mm)	1.12
F Acclimatisation	Fully Acclimatised	0.79
	Fully Unacclimatised	1.26
	Slope	-0.0235 (per degree)
Twb Break	Fully Acclimatised	25
	Fully Unacclimatised	5

It is particularly difficult to get good data on mortality limits. It is clearly not acceptable to kill animals in the lab and, when significant mortality occurs at sea, the crew are understandably more concerned with managing the situation than making careful records of the weather and pen environments. Consequently, mortality limit data are also scaled from limited observations of mortality, using the more common HST observations. Further details of this process are given in the next section. The distributions below give the resulting ML distributions for 'standard' animal lines.

Figure 0.1 Beta Function Mortality Limit Probability Distribution – Merino - Adult

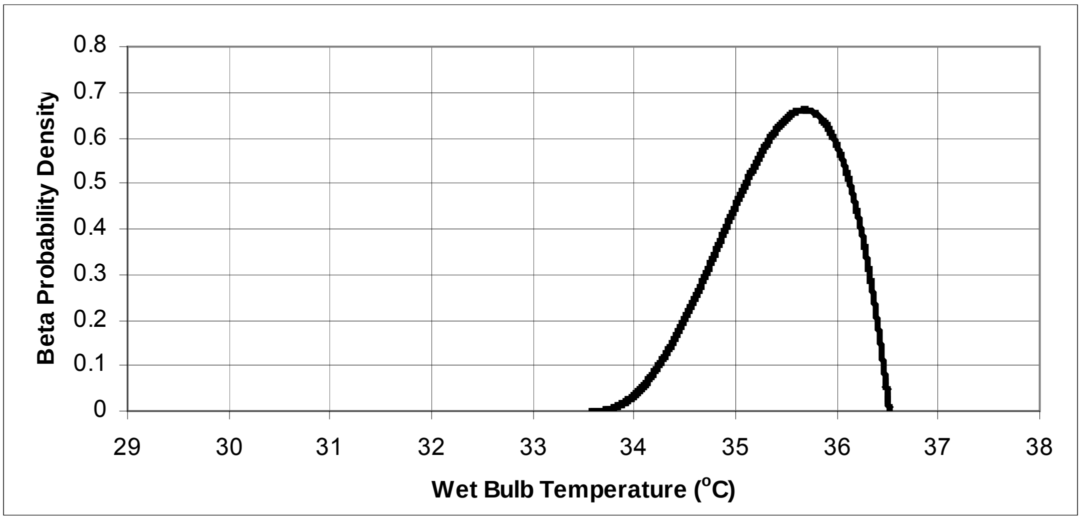


Figure 0.2 Beta Function Mortality Limit Probability Distribution – Merino - Lamb

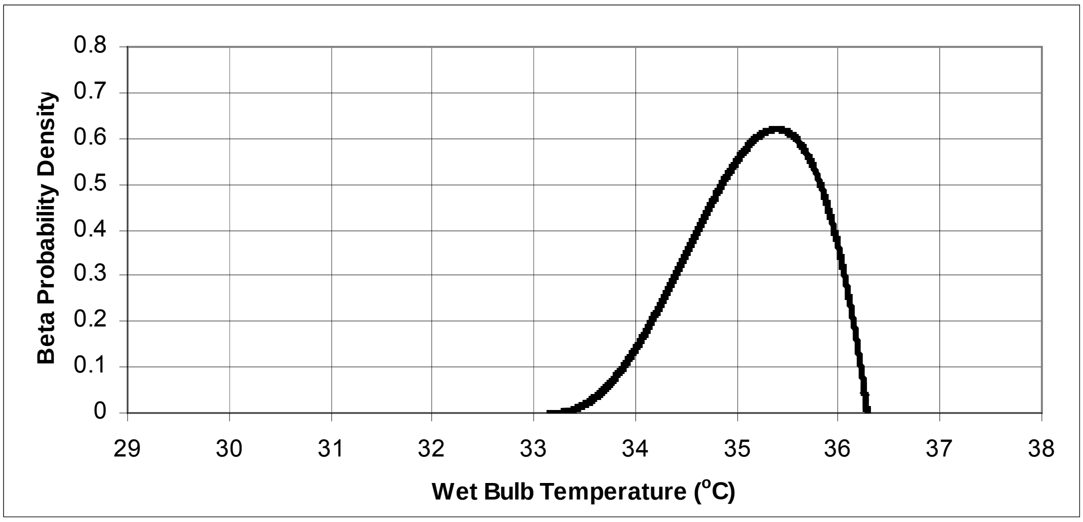


Figure 0.3 Beta Function Mortality Limit Probability Distribution – Awassi - Adult

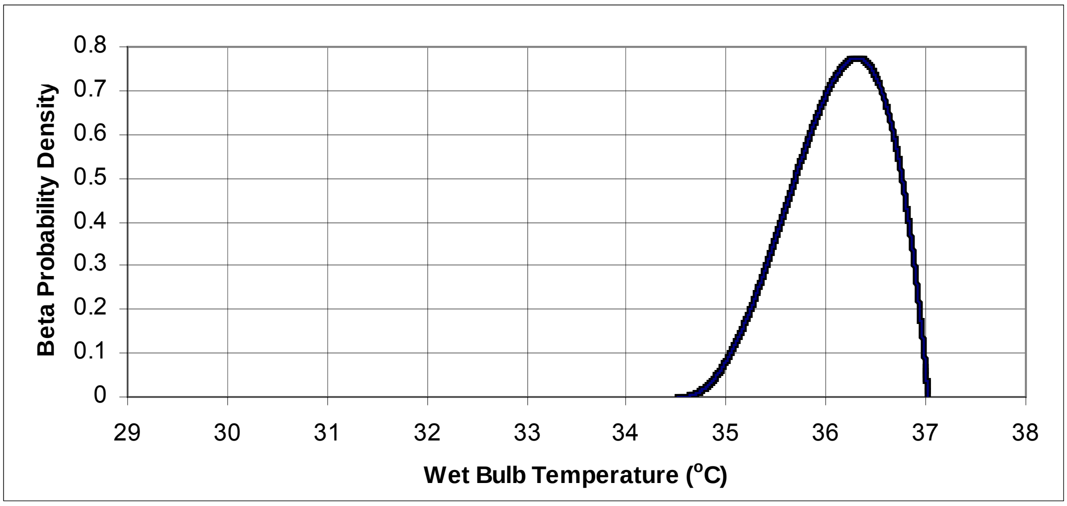
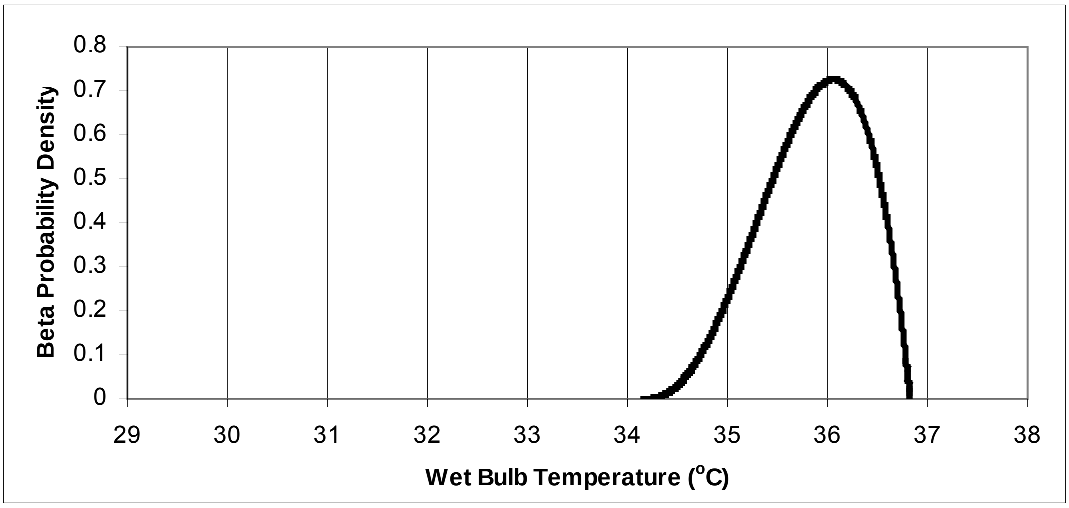


Figure 0.4 Beta Function Mortality Limit Probability Distribution – Awassi - Lamb



1.5 Scaling HST and ML

This section is substantially as produced in the LIVE.116 report and is included here for completeness of the explanations in this report.

As mentioned in the above section, heat stress threshold and mortality limit for any given line of animal are estimated by scaling the values from those of a standard animals of the same type. The various physical characteristics (weight, acclimatisation, coat and condition) will affect the temperature difference required between the animal and its environment for rejection of metabolic heat. The factors assigned to each feature act in the model to modify this temperature difference. That is; using T_{CORE} as the animal's core temperature and adjustment factors 'F' for each characteristic:

$(T_{CORE} – HST) = F_{ACC} \times F_{WEIGHT} \times F_{COAT} \times F_{CONDITION} \times (T_{CORE} – \text{base HST})$

and similarly for mortality limit:

$(T_{CORE} – ML) = F_{ACC} \times F_{WEIGHT} \times F_{COAT} \times F_{CONDITION} \times (T_{CORE} – \text{base ML})$

As the probability beta distribution of HST and ML for any one animal type is uncertain, the scaling of the beta distribution limits with animal characteristics cannot be any more certain. Following again the principle that the difference between core and ambient wet bulb temperatures gives the controlling temperature scale, the spread of the beta distribution is adjusted in proportion to that difference. That is; 'softer' lines of animals, with a lower HST, will also have a wider spread of HST within the line. The shape parameters (P and Q) which determine the skewness of the beta distribution were set by judgement after reviewing the data and have been kept constant across all animals. For the record, we have used P = 3.50 and Q = 2.00. For a 50 percentile of 35.09°C, the minimum and maximum of the beta distribution are 33°C and 36.2°C respectively. Other distributions, including those in Figure 0.1, Figure 0.2, Figure 0.3 and Figure 0.4, are scaled from this as described above.

The following sections describe the development of each adjustment factor.

1.5.1 Weight Scaling

The initial estimate of the weight factor is based on geometry. We make the simplifying assumption that animals of one breed are geometrically similar. This gives a surface area proportional to the two-thirds power of body mass. If the rate of production of metabolic heat per unit mass is constant (a fair approximation but perhaps giving a little too much heat for heavy animals) then obviously the heat generated is proportional to mass. Assuming further, that the coefficients of heat transfer are independent of body mass, the required minimum temperature difference between core and wet bulb temperatures goes as the one-third power of mass. That is;

$$\Delta T_{CRIT} \propto m^{1/3} \qquad (m \text{ is animal mass})$$

This gives the first estimate of the weight factor as

$$F_{WEIGHT} = \left(\frac{m}{m_{STANDARD}} \right)^{\frac{1}{3}}$$

or, if we believe that the one-third power may not be quite right;

$$F_{WEIGHT} = \left(\frac{m}{m_{STANDARD}} \right)^{n}$$

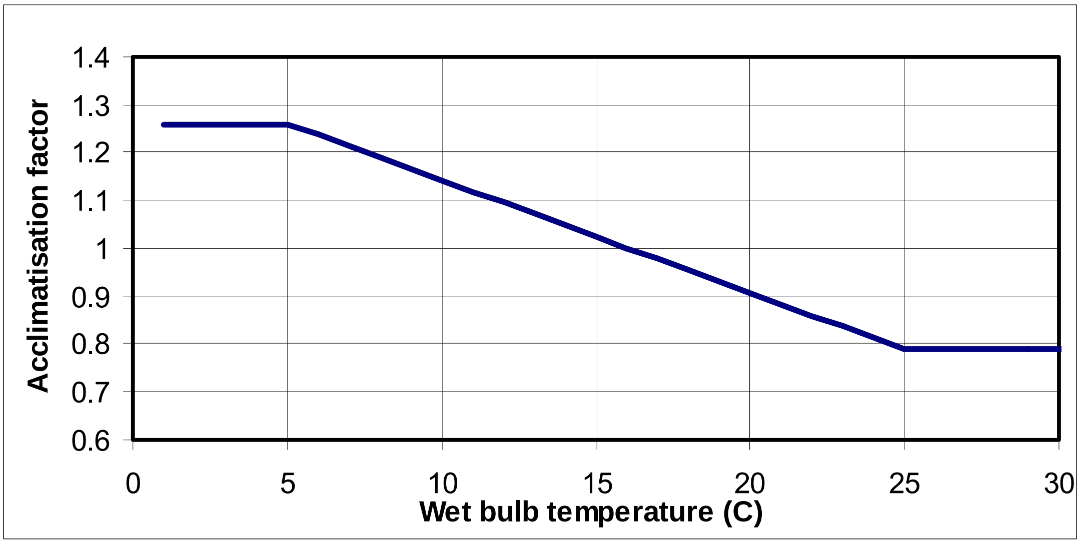
When an animal of a given frame puts on weight, it does not follow the geometric rules above, with surface area growing more slowly with mass than described. This has the effect of increasing the exponent n, above, beyond 0.33. Animals with lots of weight for their frame may also attract a high condition factor and so we must be careful not to 'double count' the weight influence in both weight factor and condition factor.

We have also not seen a strong weight influence in moderately sized (up to 60kg) sheep. For now we have somewhat arbitrarily decreased this to $n = 0.2$ for sheep. Late data and a validation voyage mentioned in the LIVE.116 report indicate that $n = 0.2$ may underestimate the mass influence.

1.5.2 Acclimatisation

The form of the acclimatisation factor is shown in Figure 0.5. Wet bulb limits of 5°C and 25°C are taken as causing animals to be fully unacclimatised or fully acclimatised respectively. There is no physiological basis for this however the rarity of wet bulb temperatures outside that range prevents it being a problem anyway. The calibration of acclimatisation within the range between 5°C and 25°C wet bulb is based on Voyages 3 and 4 of the SBMR.002 cattle ship ventilation project.

Figure 0.5 Variation of Acclimatisation Factor with Acclimatising Wet Bulb Temperature



It may well be that sheep acclimatise differently to cattle, however, we have no solid data on this.

It should be noted that sheep are only exported in large numbers from the southern ports and so come from a limited range of climates. Because of this, an acclimatisation effect would be difficult to establish experimentally from voyages. Also because of this, errors in the slope of the Figure 0.5 curve will have a smaller impact on risk estimates. For now we have adopted the cattle curve as also applying to sheep.

The weighting to be given to coat in the risk assessment is also based on limited data. Table 0.3 shows the outcome as assessed. The standard sheep is taken as shorn, with a 12% 'de-rating' of woolly sheep. Awassis are assumed to come in only one coat type (hairy).

1.5.3 Condition

Many of the comments on the coat factor apply also to the condition factor. The descriptors for condition are fat score 1 to 5, following the well defined industry standard. Following industry opinion, and with no experimental verification, we have taken a fat score 5 as significantly de-rating the ability of all animals to cope with heat. Animals with a high fat score will also be accustomed to high fodder intakes and are likely to have a higher rate of metabolic heat generation, compounding their 'softness' under heat stress. Variation of response with fat score is one area where controlled environment room research is needed.

2 Voyage Results

The following explanation of the voyage results has been edited from the two voyage reports. Voyage 1 was conducted during June/July 2002 and Voyage 2 during September 2002. Detailed information about each of these voyages was presented earlier in the voyage-specific reports.

2.1 Overall Data

Figure 0.1 and Figure 0.2 illustrate the correlation between deck wet bulb temperature and rectal temperature on Voyages 1 and 2:

Figure 0.1 Voyage 1 Correlation of Rectal Temperature with Wet Bulb Temperature by Observation Pen

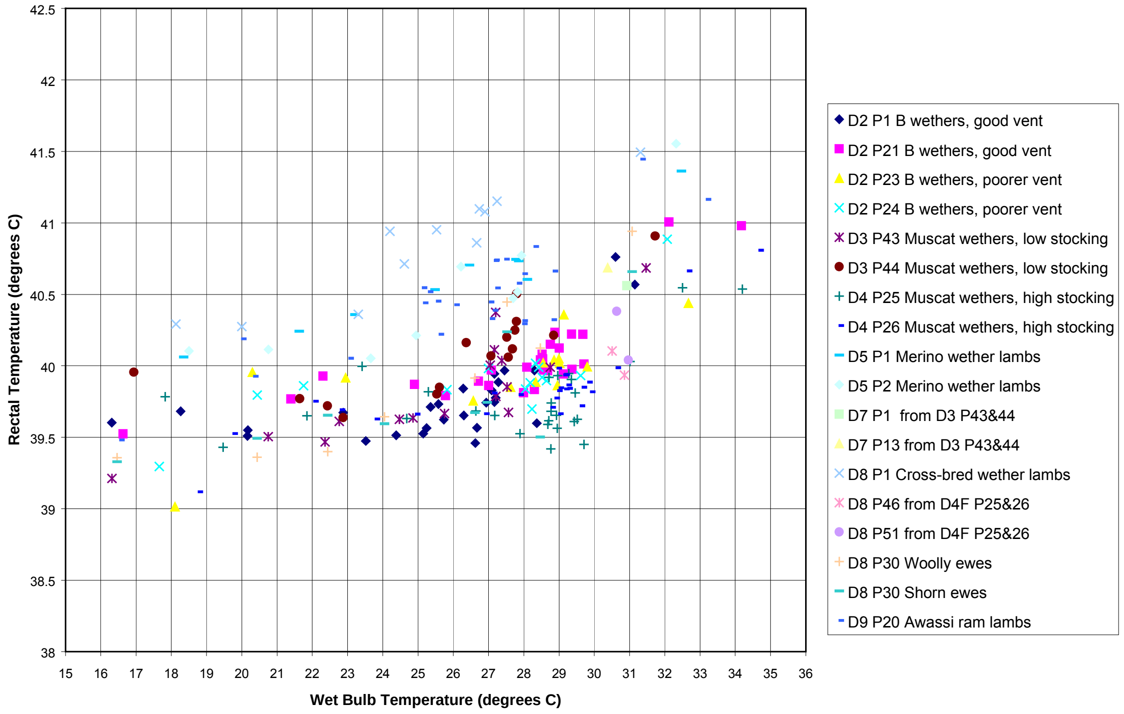
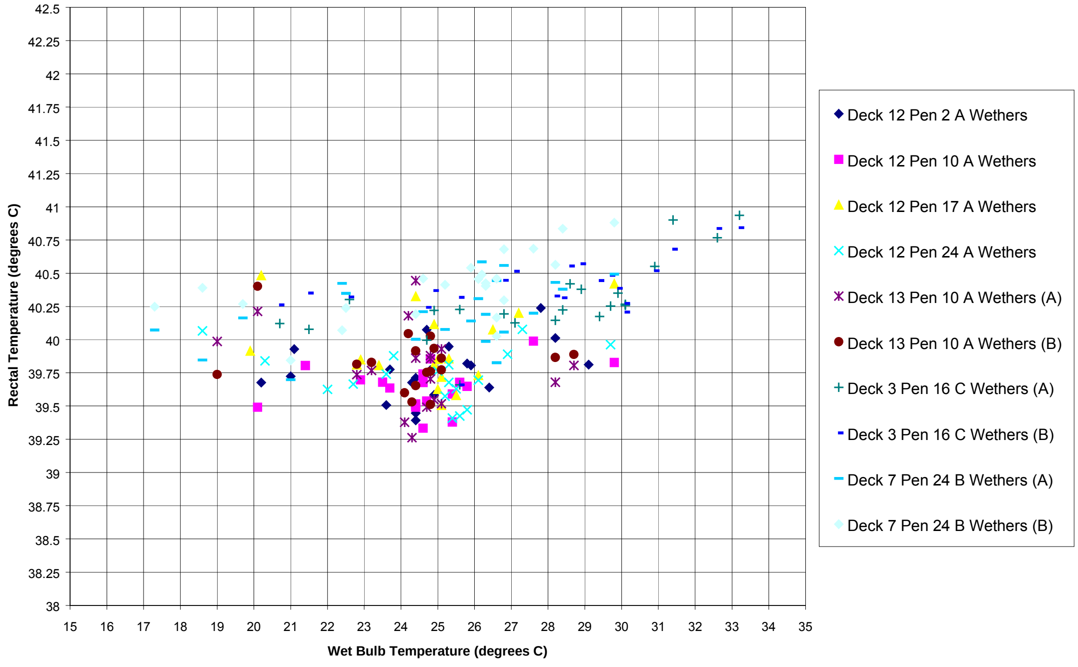


Figure 0.2 Summarised Voyage 2 Data (a range of Merino wethers)



2.1.1 Voyage Details

Voyage 1

Voyage 1 was undertaken on a fully-enclosed ship with no double tier pens. The route of the voyage, annotated with noon positions each day, is shown in Figure 0.3.

Figure 0.3 Noontime Position of the Voyage 1 Ship by Day Number

Voyage 1 sailed from Australia to the Middle East during June/July 2002. Sheep were loaded in both Portland and Fremantle. The Portland-loaded sheep were drawn from a range of classes, sexes and ages, including Muscat, B and C wethers, A and B young wethers, A and B Merino lambs, A and B cross-bred lambs, mixed-breed rams and Merino ewes. These animals were loaded during wet, cold conditions. The sheep loaded in Fremantle were drawn from a similarly wide range of classes, but also included 2,000 Awassi animals (ranging from ½ to ⅞ Awassi). The ship unloaded in Bahrain, Kuwait, Jebel Ali (UAE) and Muscat.

The Voyage 1 ship has four longitudinal rows of vertical risers. The risers alternate in chequer board fashion between supply and exhaust. Each riser is fed by one fan. There is no interconnection between the risers and no horizontal distribution ducting on the decks.

The relative ventilation efficacy in the stock-carrying areas of the ship was assessed whilst sailing from Portland to Fremantle through visual inspection, inspection of the ship drawings, and monitoring of CO_2 levels in fully stocked areas of the ship. During this assessment, all supply and exhaust fans were operating.

With the regular supply riser spacings, relatively even levels of ventilation are provided to all stock holding areas on all decks of the Voyage 1 ship. With minor exceptions (for example pen 23 on Deck 2), supply ports provide fresh air directly to stock in all pens on the ship.

Voyage 2

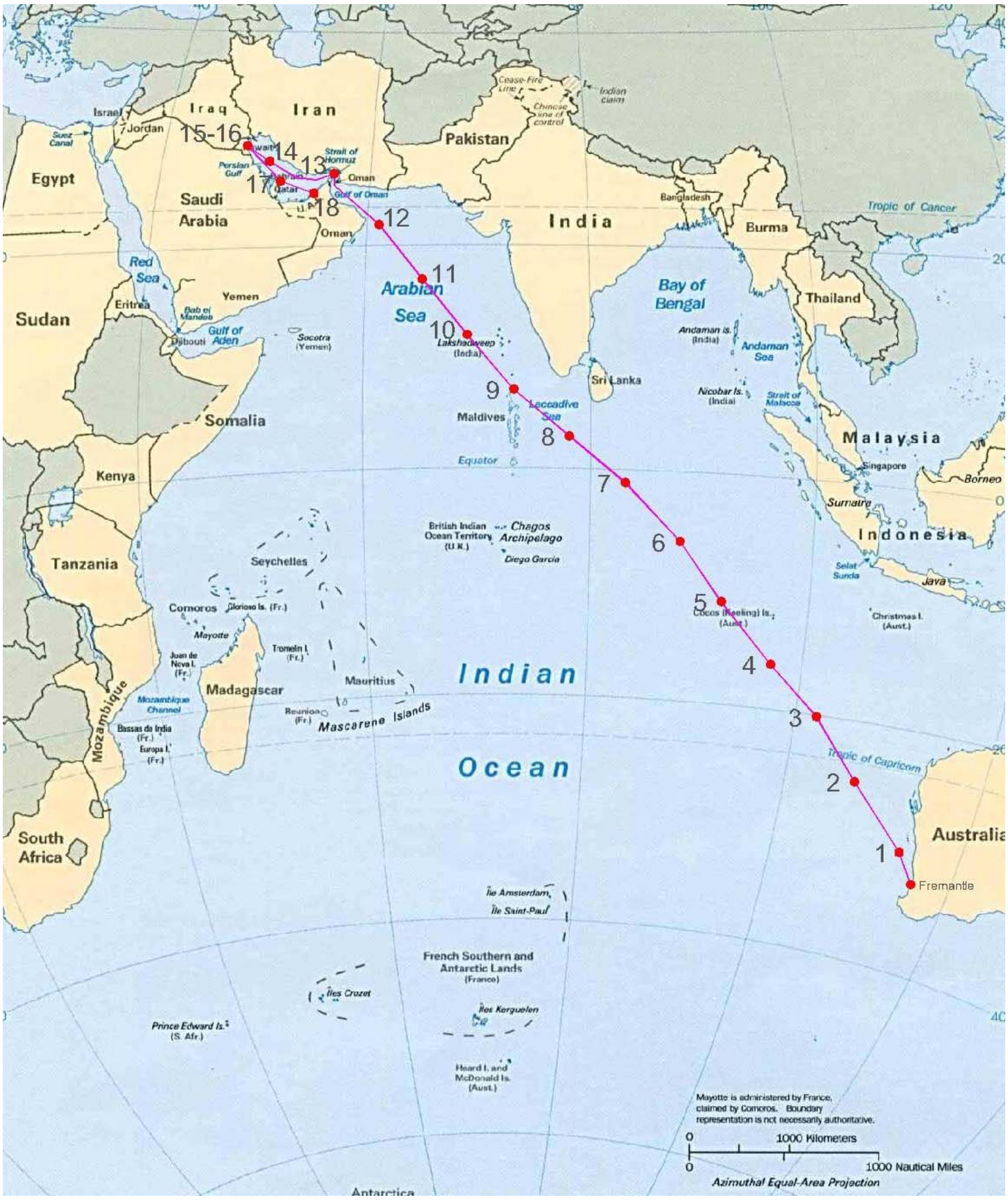
Voyage 2 sailed from Australia to the Middle East during September 2002. The ship was loaded in Fremantle only, and carried sheep representing a range of classes, sexes and ages, including A, B and C wethers, A and B young wethers, Merino ewes, and a range of Awassi lambs (½ and ¾ ewe lambs and ¼, ½ and ¾ ram lambs). ‘A’, ‘B’, and ‘C’ refer to animal weight classes.

The animals were loaded in Fremantle during warm and dry conditions. The ship unloaded in Kuwait and Dubai. Figure 0.4 shows the route and progress of Voyage 2.

The sheep pens on each deck of the Voyage 2 vessel are arranged in four rows; port, mid-port, mid-starboard and starboard. The ventilation risers are in four corresponding rows, with the risers generally at the ends of every pen such that each pen has a supply outlet at one end and an exhaust point at the other end.

The four risers at each station (frame) along the ship are of the same type (supply or exhaust). That is; a row of four supply risers across the ship is followed by a row of four exhaust risers, one pen length further back. There was considerable variation in the pen air turnover (PAT) provided to each deck. Low PAT on some decks also meant that significant variations in wet bulb temperature could be measured in a local area of the deck.

Figure 0.4 Map showing noontime position of the Voyage 2 ship by day number



2.2 General Observations

Voyage 1 wet bulb temperatures calculated from automatically logged data and the manually collected data for the same locations are plotted in Figure 0.5. The dry bulb temperatures and relative humidities are plotted in the same way in Figure 0.6 and Figure 0.7. The figures show clearly that, although the dry bulb temperature and relative humidity may oscillate considerably, the wet bulb temperature changes more slowly with time. In particular, during the hottest weather (day 17) there may be no overnight respite from the oppressive conditions. Some respite is seen (during daylight hours) on days 18 and 19.

A general summary of the response of Voyage 1 sheep to hot conditions is presented in Figure 0.1. Apart from the cross-bred lambs (Deck 8, pens 1 & 5) and to a lesser extent the Merino lambs (Deck 5, pens 1 & 2), below a wet bulb temperature of 25^{0}C the observed sheep maintained a steady body temperature of approximately 39.5 to 40.0^{0}C. The body temperature of some lines rose as the wet bulb temperature rose above 24^{0}C. The point at which the rise started, and the rate of rise, varied with different classes of animals. All animals had elevated body temperatures for wet bulbs above 30^{0}C. On the basis of Figure 0.1, the heat stress threshold (HST) for adult sheep was estimated to lie between 28 and 30^{o}C wet bulb.

A similar assessment was possible from Voyage 2, using the data presented in Figure 0.2. At wet bulb temperatures below approximately 26^{o}C, the rectal temperature of observation animals fell within the range of 39.25 and 40.5^{o}C. A rise in rectal temperature (compared to the ‘normal’ range of 39.25 to 40.25^{o}C) was first seen at a wet bulb temperature of 26^{o}C, and occurred consistently (always above 40.25^{o}C) once the ambient wet bulb temperature exceeded 30^{o}C. These data are in general agreement with earlier findings, but suggest that the HST may range between a low of 26^{o}C and the same upper limit of 30^{o}C seen from Voyage 1. These data provide no information about the HST distribution between these points.

The onset of stress based on observations of the breathing rate taken across the whole pen was generally consistent with the onset of stress as seen by rectal temperature rise.

Figure 0.5 Voyage 1 – Wet Bulb Temperatures

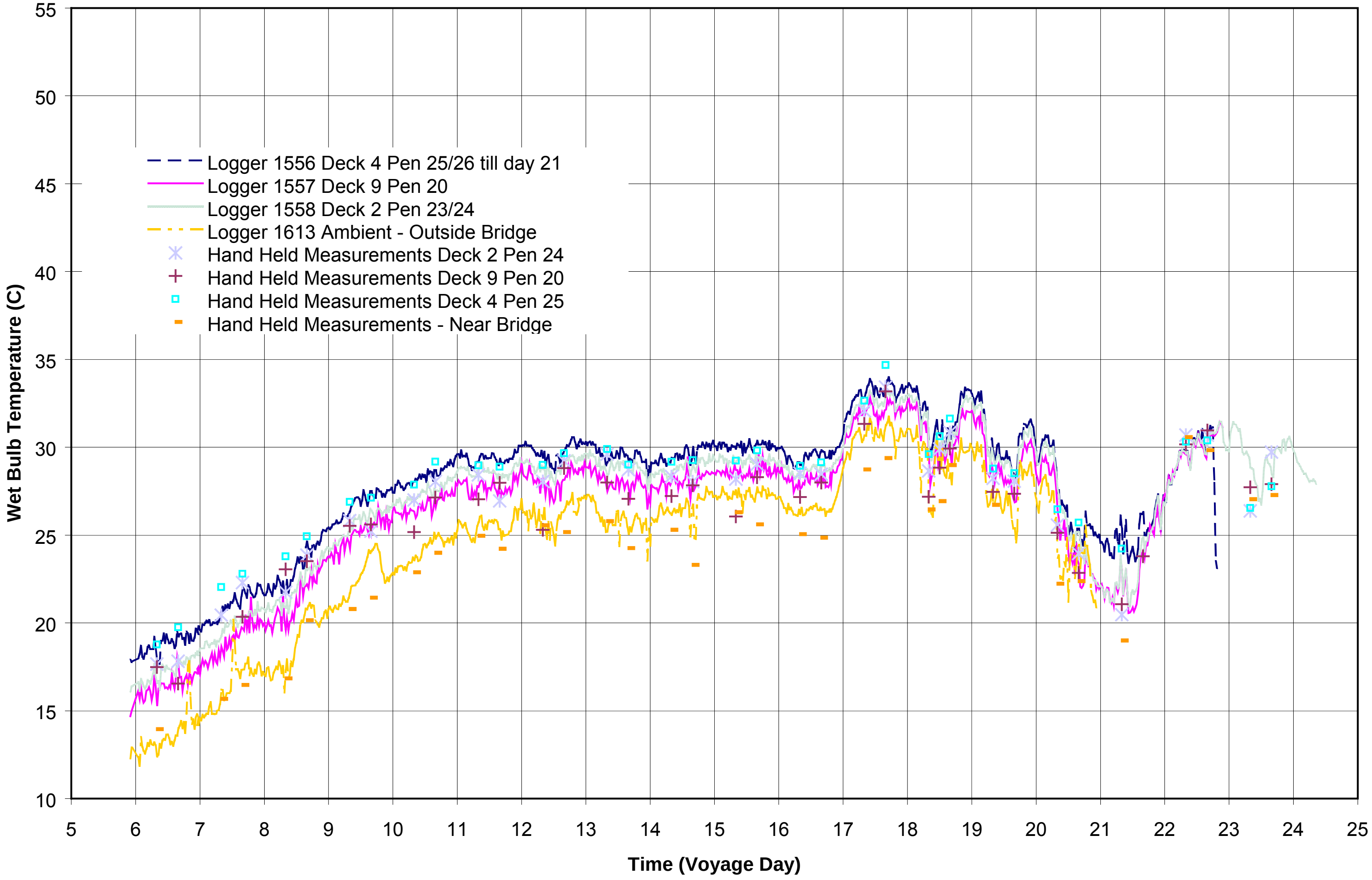


Figure 0.6 Voyage 1 – Dry Bulb Temperatures

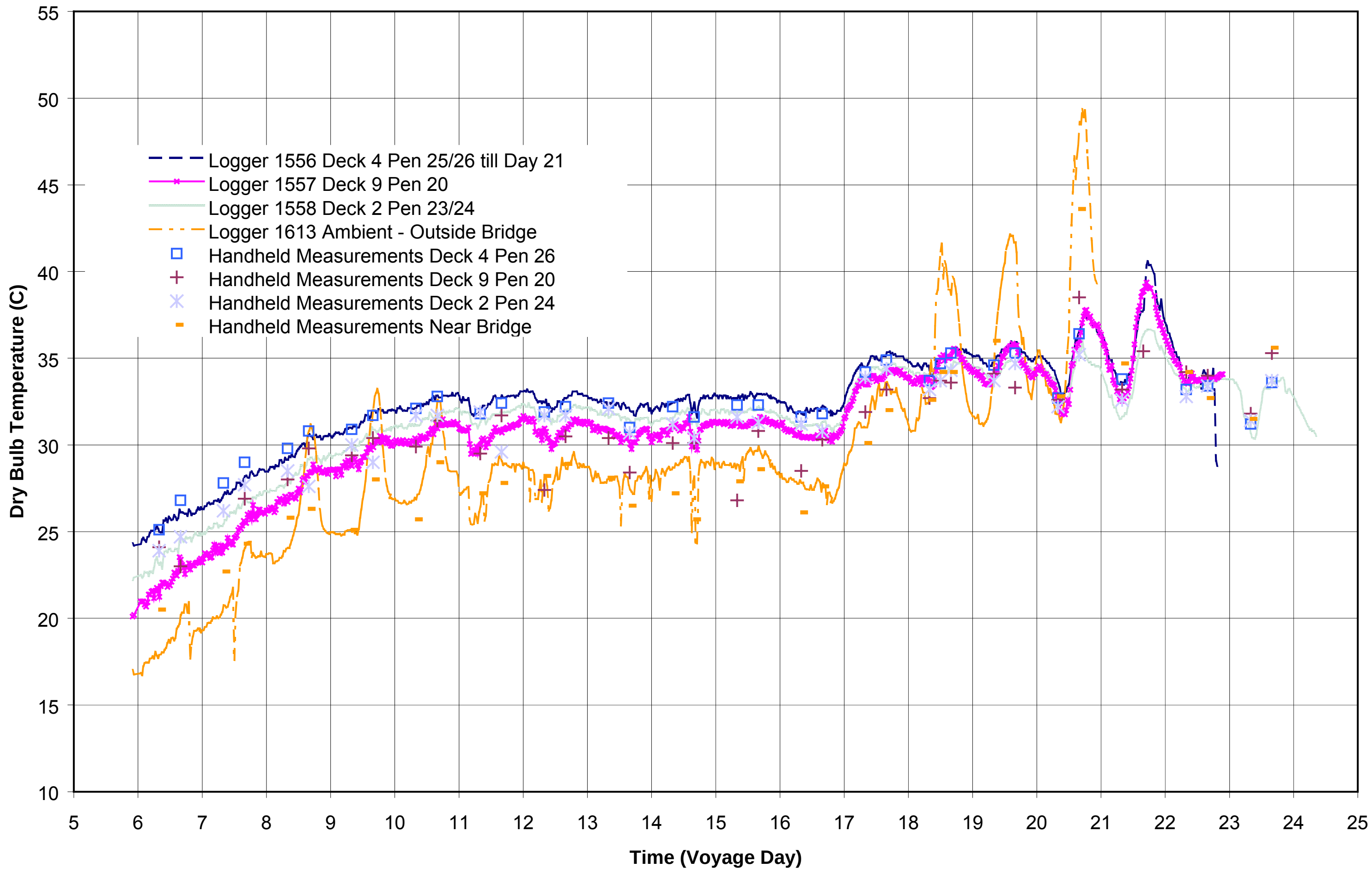
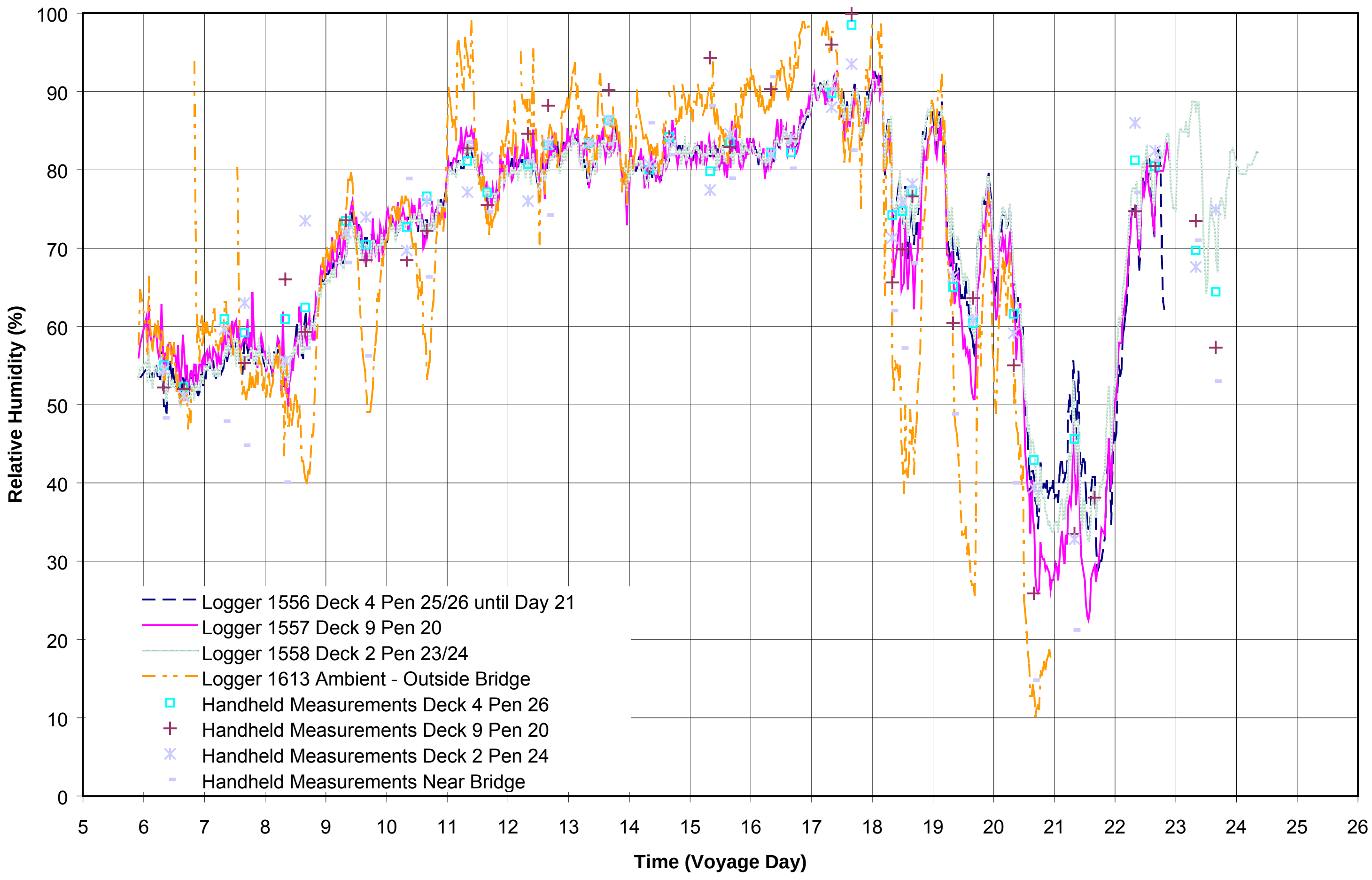


Figure 0.7 Voyage 1 – Relative Humidity



2.3 The Effect of Stocking Rate

The effect of stocking rate on sheep responses to hot conditions was assessed during Voyage 1 by comparing the Muscat wethers penned in areas with higher and lower stocking densities. The higher densities were in Deck 4, pens 25 & 26 then Deck 8, pens 46, 51 & 52 and the lower densities were in Deck 3, pens 43 & 44 then Deck 7, pens 1, 7, 13 & 19. Figure 0.8 indicates that the more lightly stocked animals, which also had a lower pen wet bulb temperature, had higher rectal temperatures. This is confirmed by Figure 0.9 which shows higher rectal temperatures in the lightly stocked sheep for any given wet bulb temperature. This finding goes against expectations. The full story may be that body temperature has more to do with feeding rate than stocking density. Figure 0.10 indicates that in the early part of the voyage, the lightly stocked sheep had considerable weight gain whereas the fully stocked sheep simply maintained weight. The higher metabolic rate and possibly higher feed intake associated with rapid weight gain is also likely to cause an early increase in core body temperature with rising wet bulb temperature. This may rationalise the unexpected result. It is possible that the weight gain had a causative effect in the behaviours associated with lighter stocking, however such a relationship cannot be demonstrated from the data in Figure 0.10. Further doubt was cast on the usefulness of the weight data by the results of Voyage 2.

Figure 0.8 Voyage 1 – Wet Bulb Temperature and Rectal Temperature for Muscat wethers by Stocking Density

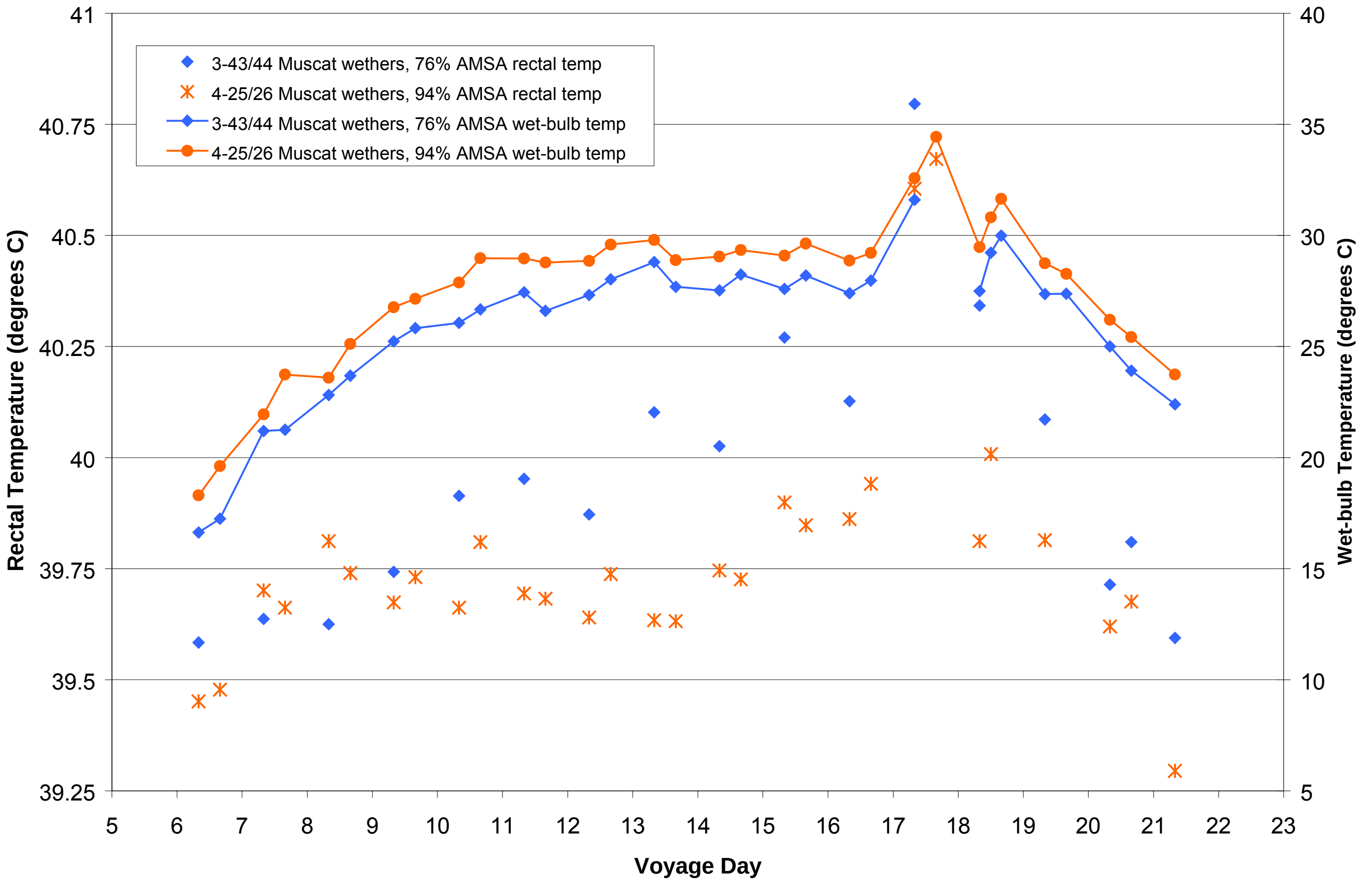


Figure 0.9 Voyage 1 – Correlation of Body Temperature with Wet Bulb Temperature by Stocking Density

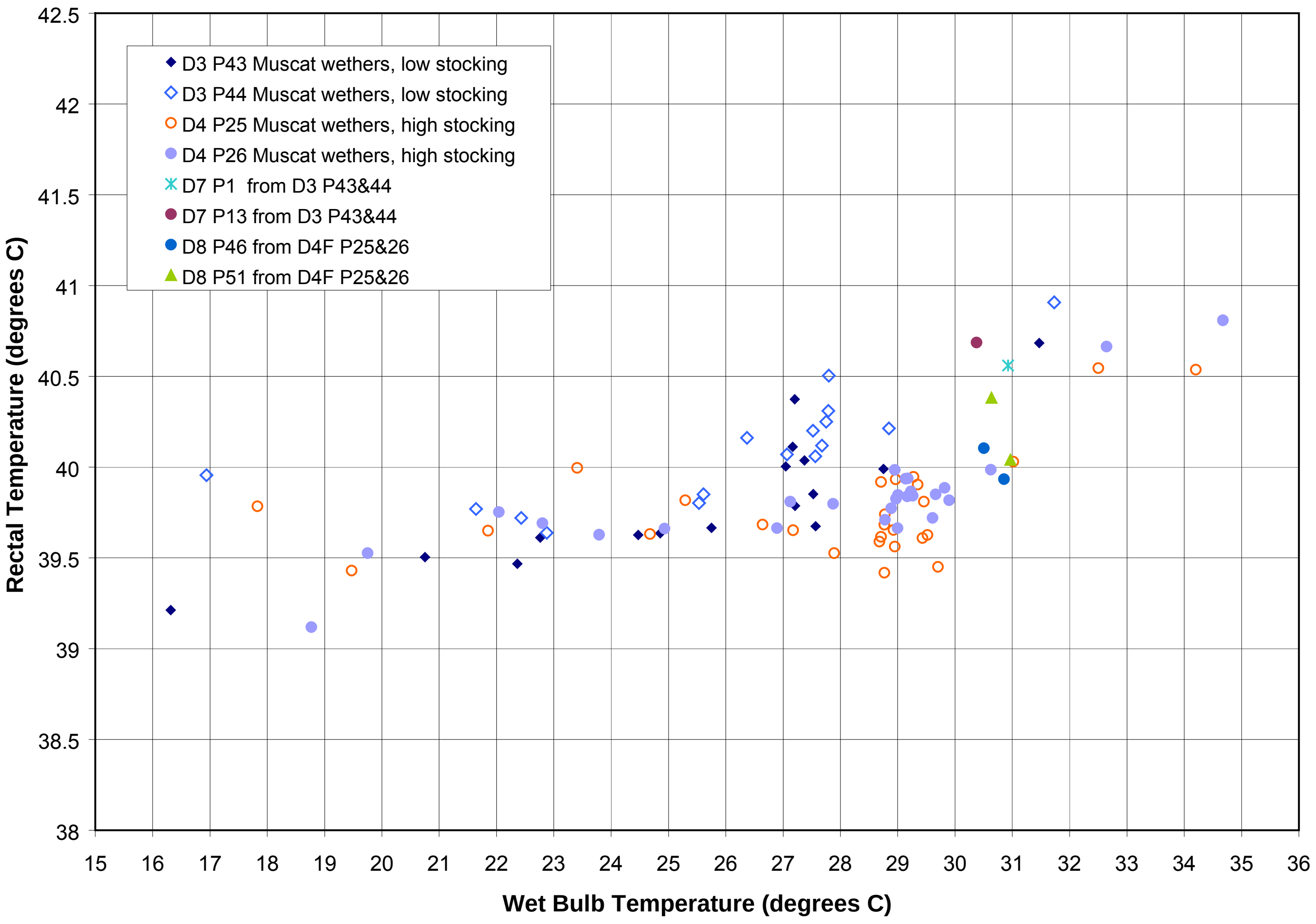
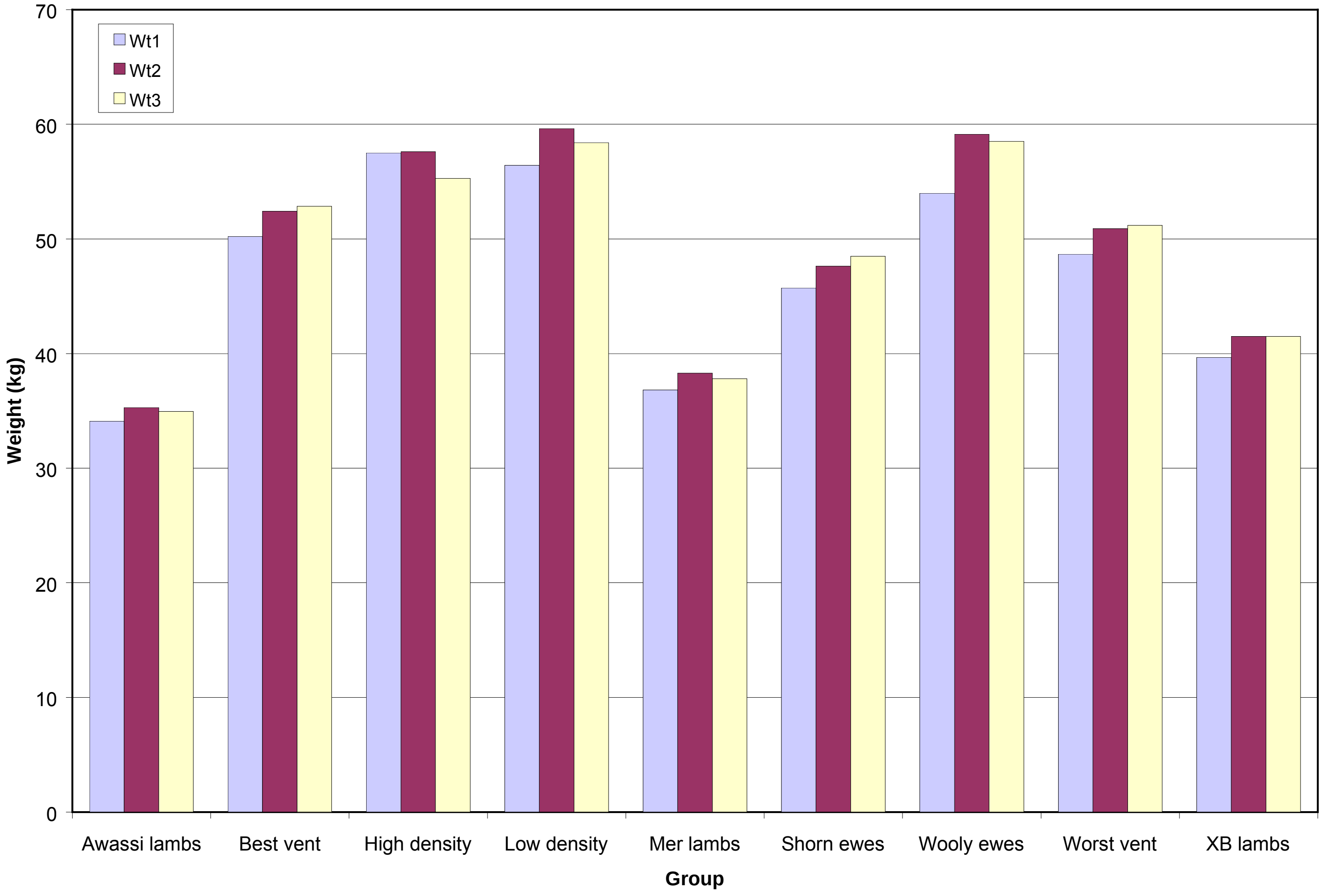


Figure 0.10 Voyage 1 – Mean Body Weight by Weighing and Group



2.4 The Effect of Breed

The effect of breed on sheep responses to hot conditions was assessed during Voyage 1 by comparing the Merino wether lambs (Deck 5, pens 1 & 2), the crossbred wether lambs (Deck 8, pens 1 & 5) and the Awassi ram lambs (Deck 9, pen 20). As illustrated in Figure 0.11, the body temperatures of the crossbred and Merino lambs were generally higher than the Awassis. Given the pattern of the difference, the crossbred and Merino lambs may naturally have a higher body temperature (given the higher body temperatures at low wet bulb temperatures). As illustrated in Figure 0.12, the ‘resting’ body temperature in all the lambs appears to be relatively high, and to increase gradually with increasing wet bulb temperature.

Figure 0.11 Voyage 1 – Wet Bulb Temperature and Rectal Temperature by Breed

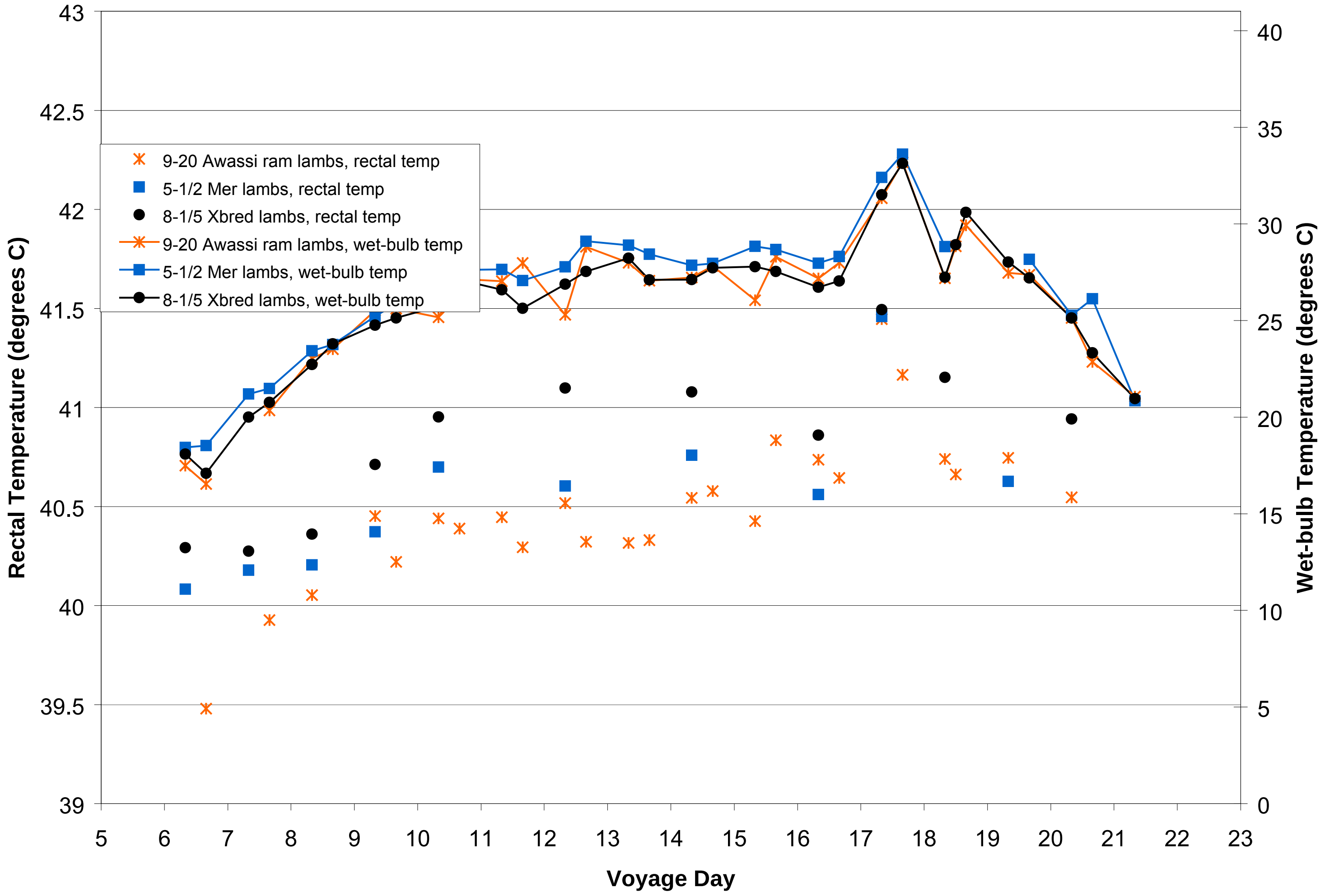
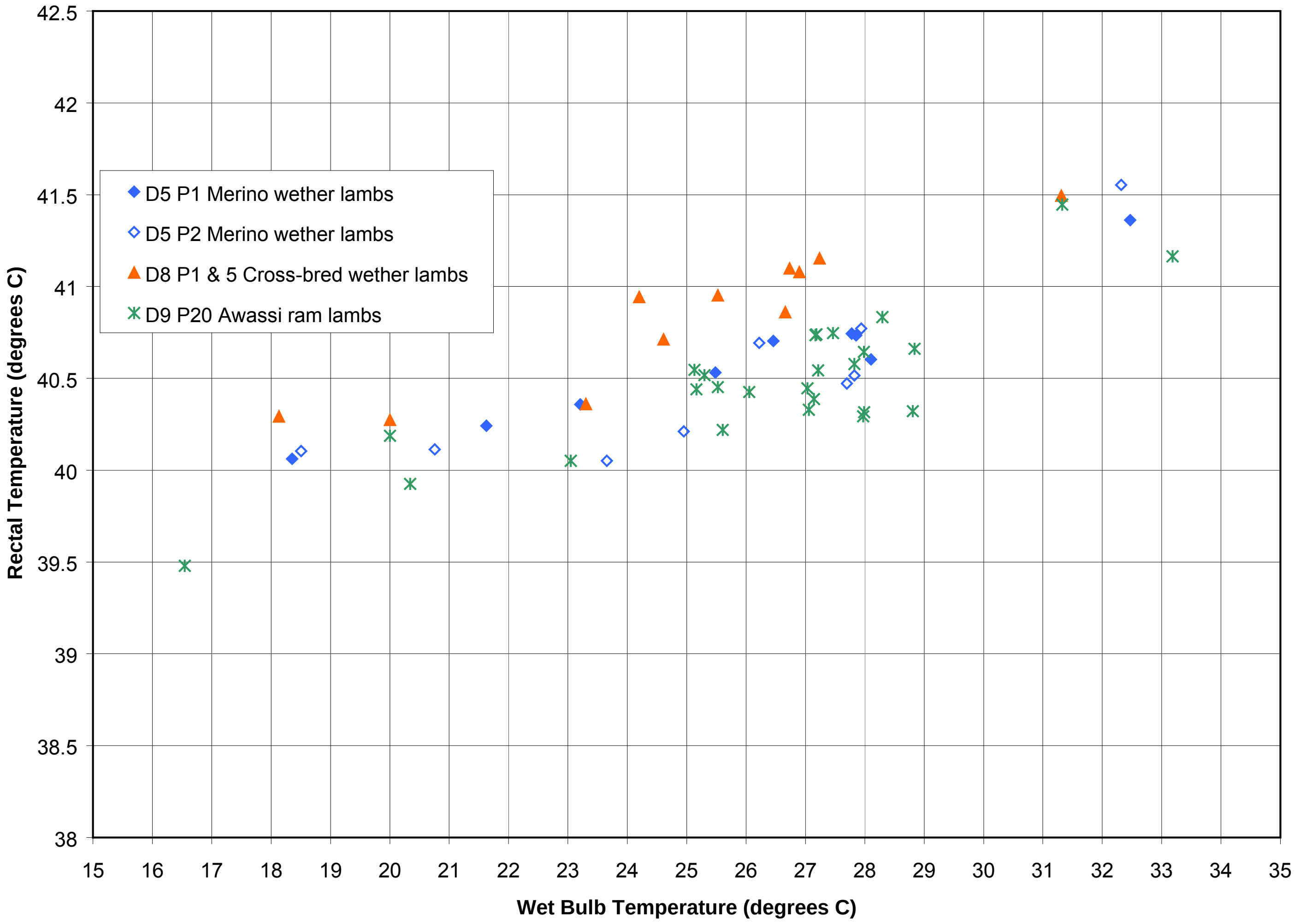


Figure 0.12 Voyage 1 – Correlation of Body Temperature with Wet Bulb Temperature by Breed



2.5 The Effect of Age and Bodyweight

The effect of age and bodyweight on sheep responses to hot conditions was assessed during Voyage 1 by comparing the Muscat wethers (Deck 4, pens 25 & 26 then Deck 8, pens 46, 51 & 52) and the B wethers (Deck 2, pens 1 & 21) with the Merino wether lambs (Deck 5, pens 1 & 2). Figure 0.13 illustrates the higher ‘resting’ body temperature of Merino lambs, and indicates minimal difference between the body temperatures of Muscat and B wethers. As illustrated in Figure 0.14, there is a significant increase in the body temperatures of Muscat and B wethers as the wet bulb temperature reaches 29 to 30^0C. As mentioned previously, although the resting body temperature of lambs is higher, this temperature rises more gradually in the face of increasing wet bulb temperatures.

Figure 0.13 Voyage 1 – Wet Bulb Temperature and Rectal Temperature by Age and Bodyweight

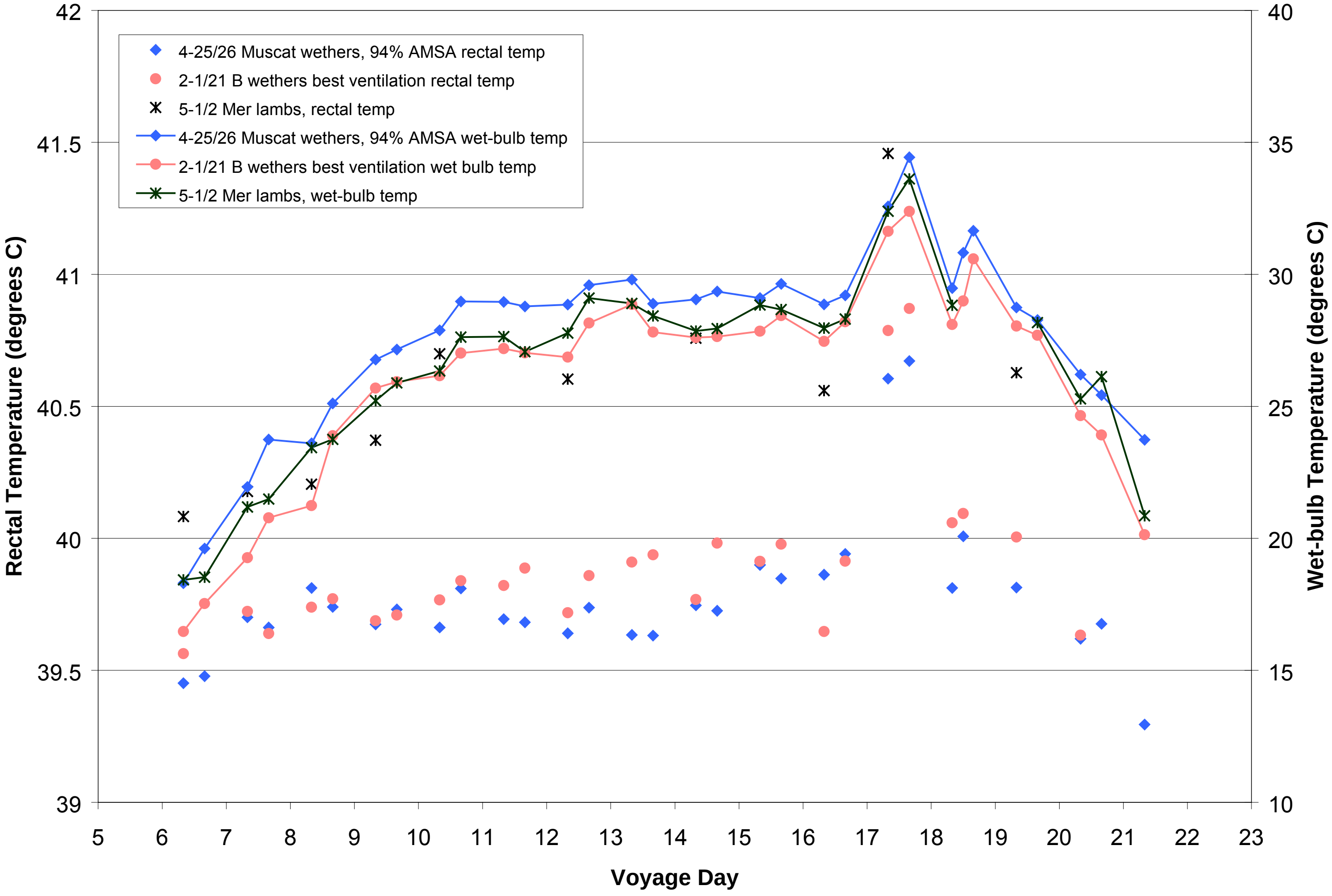
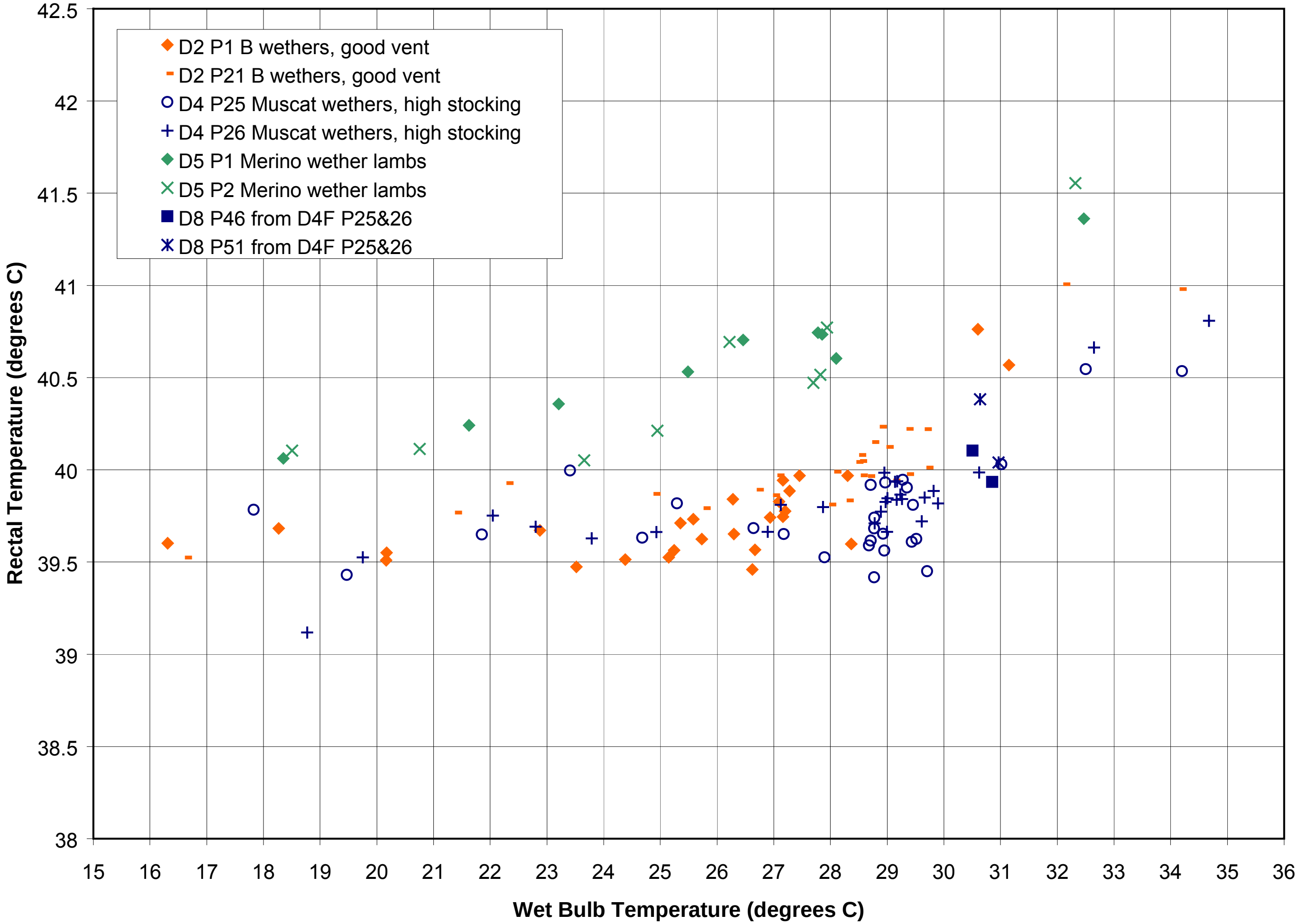


Figure 0.14 Voyage 1 – Correlation of Body Temperature with Wet Bulb Temperature by Bodyweight and Age



2.6 The Effect of Wool Length

The effect of wool length on sheep responses to hot conditions was assessed during Voyage 1 by comparing shorn and woolly Merino ewes (Deck 8, pen 30). Both woolly and shorn ewes were in the same pen (pen 30). In the plots, the data sets are referred to as pen 30S for shown ewes and pen 30W for woolly ewes. As illustrated in Figure 0.15 and Figure 0.16, the body temperature of the woolly ewes at moderate wet bulb temperatures (below 25^{0}C) was the same as, or slightly lower than that of the shorn ewes. When wet bulbs went above 26^{0}C the woolly ewes were hotter than the shorn ewes by 0.2 to 0.4^{0}C. The woolly sheep may also have become stressed earlier, however the lack of data in the region 29 to 31^{0}C prevents this second suggestion being stated conclusively.

Figure 0.15 Voyage 1 – Wet Bulb Temperature and Rectal Temperature in Merino Ewes by Wool Length

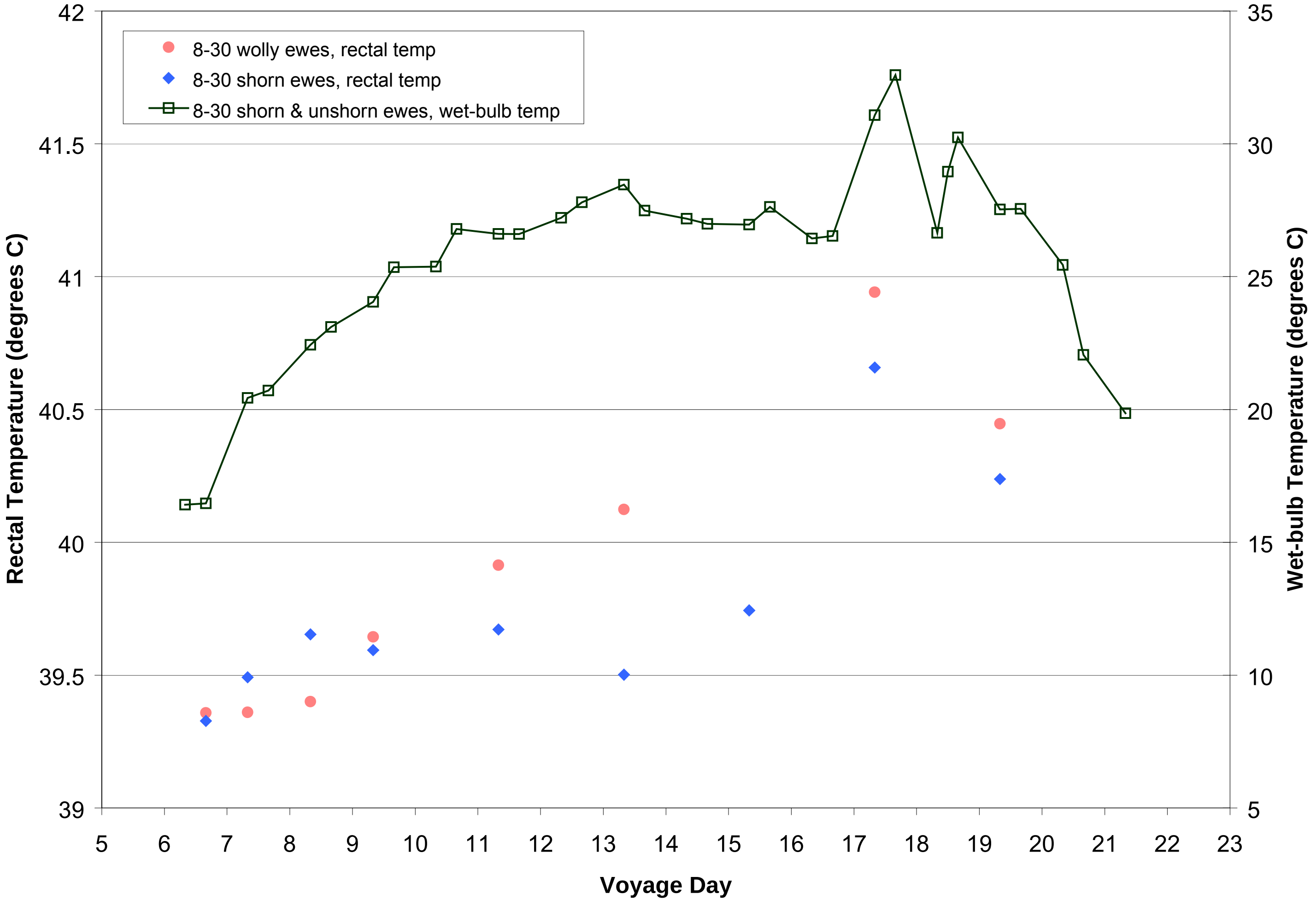
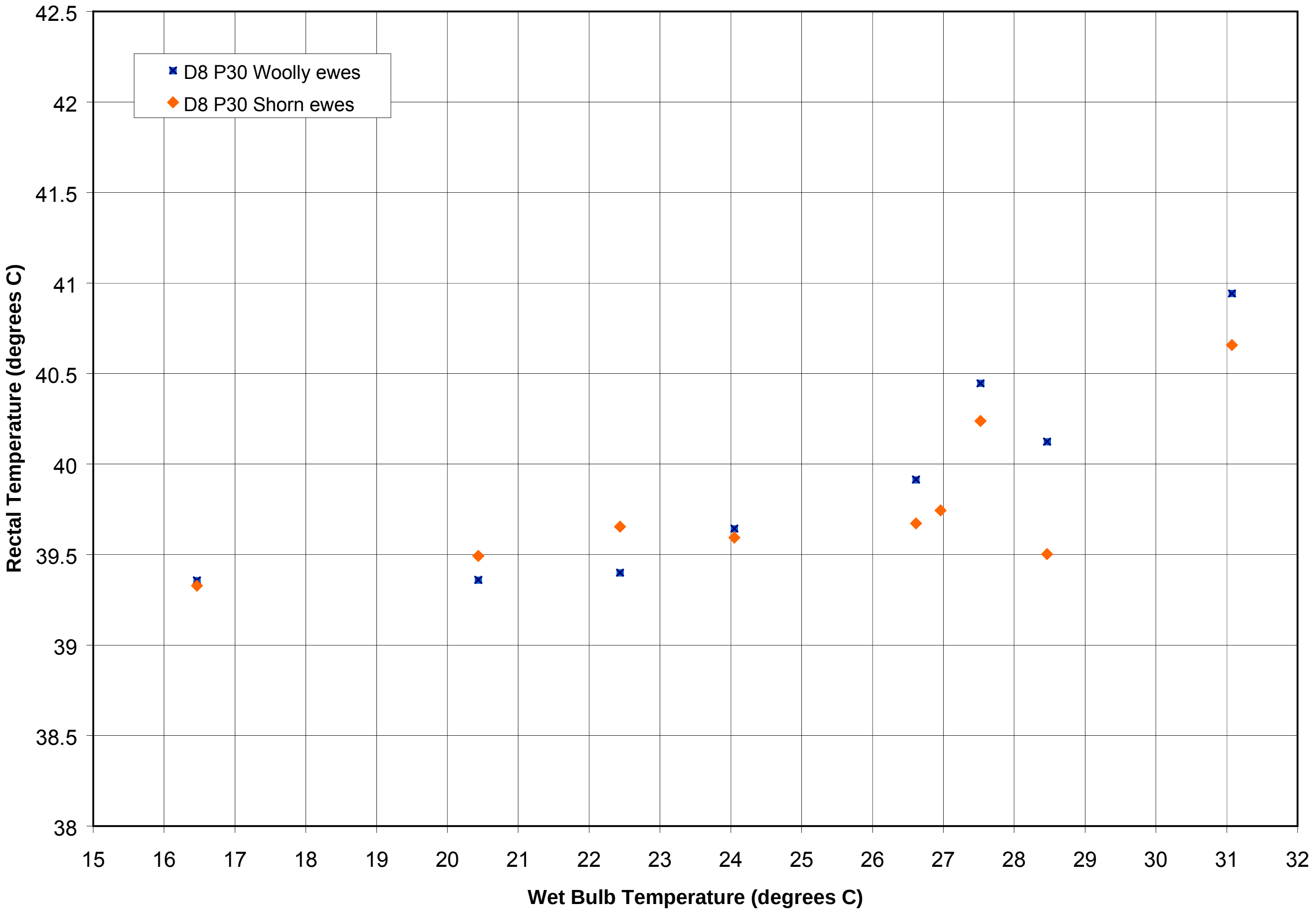


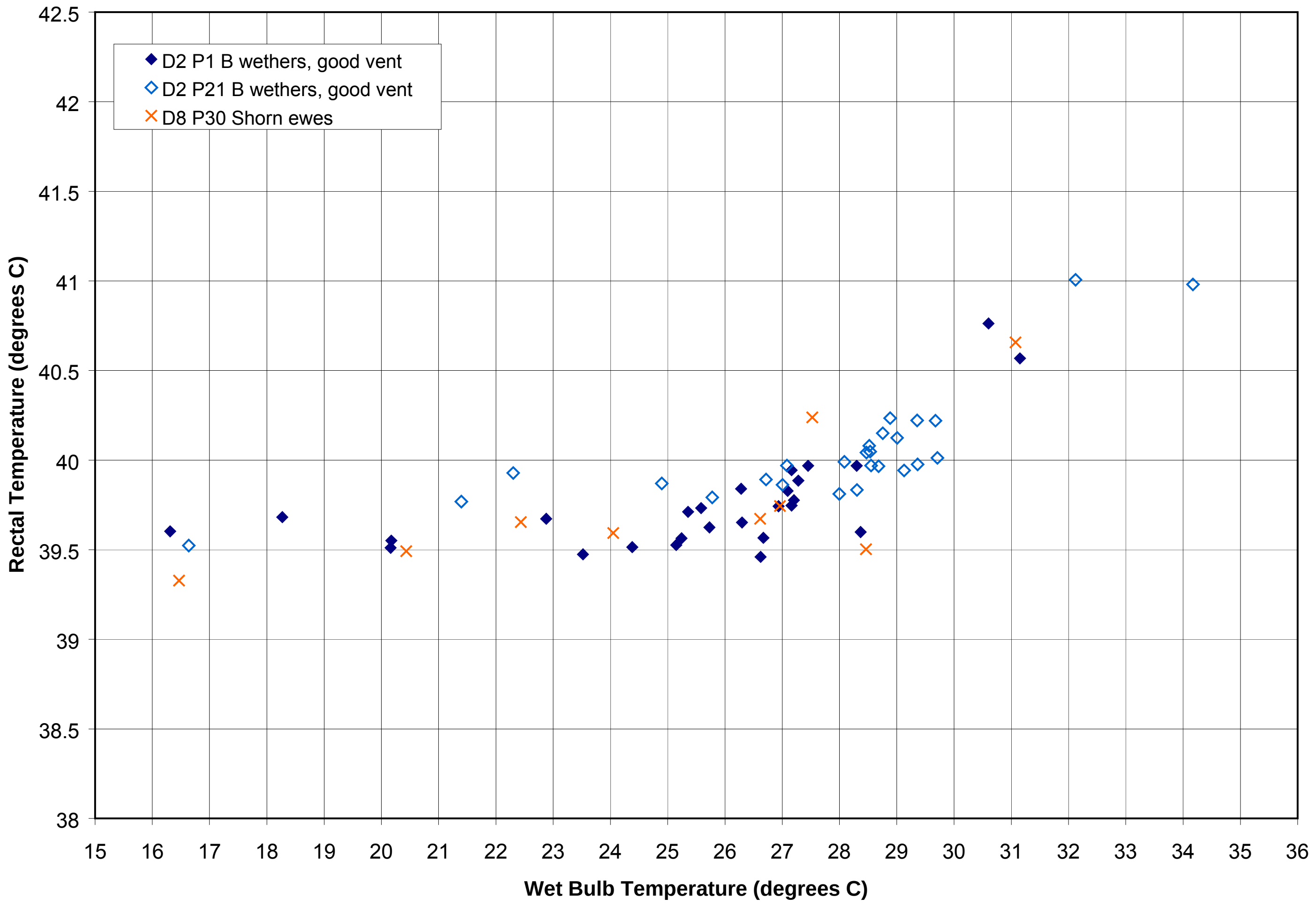
Figure 0.16 Voyage 1 – Correlation of Body Temperature with Wet Bulb Temperature by Wool Length



2.7 The Effect of Sex

The effect of sex on sheep responses to hot conditions was assessed during Voyage 1 by comparing the shorn Merino ewes (Deck 8, pen 30S) and B wethers (Deck 2, pens 1 & 21). As illustrated in Figure 0.17, there was no measurable difference between these two groups in terms of response to hot conditions.

Figure 0.17 Voyage 1 – Correlation of Body Temperature with Wet Bulb Temperature by Sex

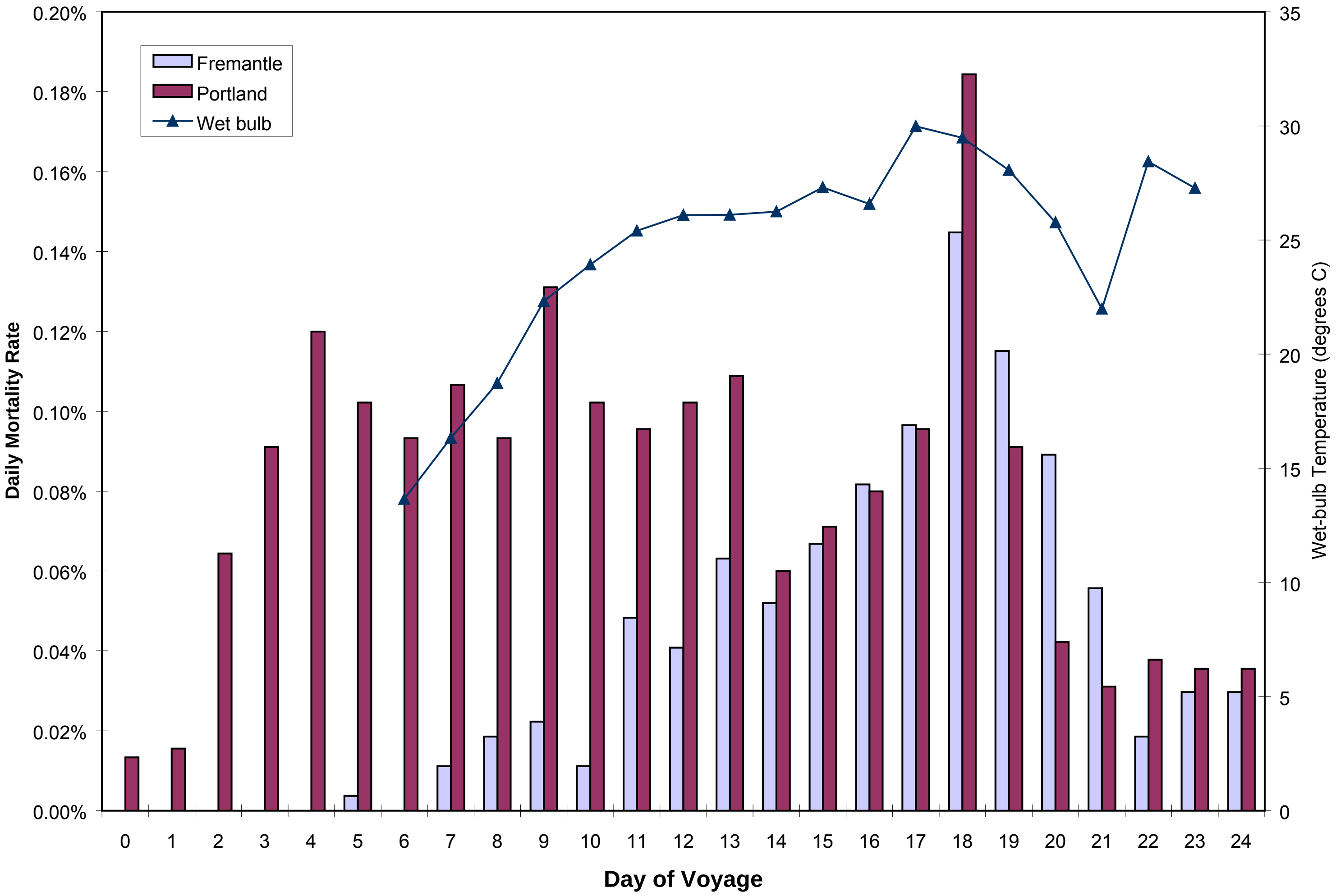


2.8 Mortality Limit

Voyage 1 pen wet bulb temperatures peaked in the range 32.5°C to 34°C on day 17 of the voyage, having risen by around 4°C from levels on previous days (Figure 0.5). The mortality count taken on day 18 shows a significant increase above that of previous days (Figure 0.18). The increase for Portland loaded sheep was greater than for Fremantle sheep, indicating that the Portland sheep may have been more susceptible to heat stress. It appears that the deck conditions experienced (32.5 to 34°C wet bulb temperature) may be at the low end 'tail' of the animal's mortality limit probability distribution. There will also have been an interaction between heat stress and weakness related to other conditions or stressors. This is consistent with Figure 0.1.

Conditions during Voyage 2 were less extreme than those experienced during Voyage 1. Among the observation pens, the deck conditions did not exceed 33°C at any stage, and only exceeded 30°C on Deck 3, which has the lowest pen air turnover of the decks observed. Consequently it was not possible to accurately assess the wet bulb temperature likely to cause significant deaths. Nonetheless, for animals already weakened by other conditions (and probably the PSI complex), the spike in ambient wet bulb temperature on days 13 and 14 of the voyage was sufficient to trigger a small subsequent mortality increase. Deck wet bulb temperatures of up to 30°C (deck 12) and 33.2°C (deck 3) were associated with increased mortality, with heat stress probably playing an important but secondary role.

Figure 0.18 Voyage 1 – Mortality Rate by Port of Loading and Day of Voyage



2.9 The Effect of Ventilation Standard

The effect of ventilation rate on sheep responses to hot conditions was assessed during Voyage 1 by comparing the B wethers penned in areas with more favourable ventilation (Deck 2, pens 1 & 21) and less favourable ventilation (Deck 2, pens 23 & 24). The difference in CO_2 level between these pens during initial assessment and subsequent was only small, illustrating the consistency in ventilation throughout this ship. As illustrated in Figure 0.19, the rectal and wet bulb temperatures were generally slightly higher in the groups with poorer ventilation. Based on Figure 0.20, the difference in wet bulb temperature reasonably explains all of the body temperature differences between these two groups of sheep. In both groups, there was an increase in the body temperature after the wet bulb temperature reached approximately 29 to 30^0C.

From measurements in the closed decks of the Voyage 2 vessel, and according to the ship's equipment documentation, there was considerable variation in the pen air turnover between decks. Decks 3 (lower PAT) and 7 (higher PAT) were compared for this experiment. As illustrated in Figure 0.19, the wet bulb temperatures on these decks varied by about 3^oC. This is slightly greater than expected from the wet bulb rises of 5.2 and 3.8^oC calculated according to methods described in earlier reports, assuming similar stocking densities and animal types. However, if the stocking densities in the observation pens reflect the densities throughout the respective deck, then the stocking densities on decks 3 and 7 were 112 and 79% respectively of the ALES maximum. In such circumstances, the calculated wet bulb rise on these decks is 5.9 and 3.0^oC, a difference in close agreement with the measurements.

When deck wet bulb temperatures were at their highest (days 13 and 14 of Voyage 2), the average rectal temperature of the deck 3 animals exceeded 40.75^oC (Figure 0.21). On Deck 7, with deck wet bulb conditions approximately 3^oC less, the average rectal temperature did not exceed 40.6^oC. As illustrated in Figure 0.2, evidence of heat stress is mainly confined to the deck 3 animals, which were the only animals faced with deck wet bulb temperatures above 30^oC for an extended period.

Where the deck wet bulb temperatures overlap, no difference can be seen between the two samples. This is seen more clearly in Figure 0.22 which compares only the highest and lowest PAT pens. This confirms that the resulting wet bulb temperature is a sufficient measure of the effect of different ventilation rates for sheep.

Figure 0.19 Voyage 1 – Correlation of Body Temperature with Wet Bulb Temperature by Ventilation Level

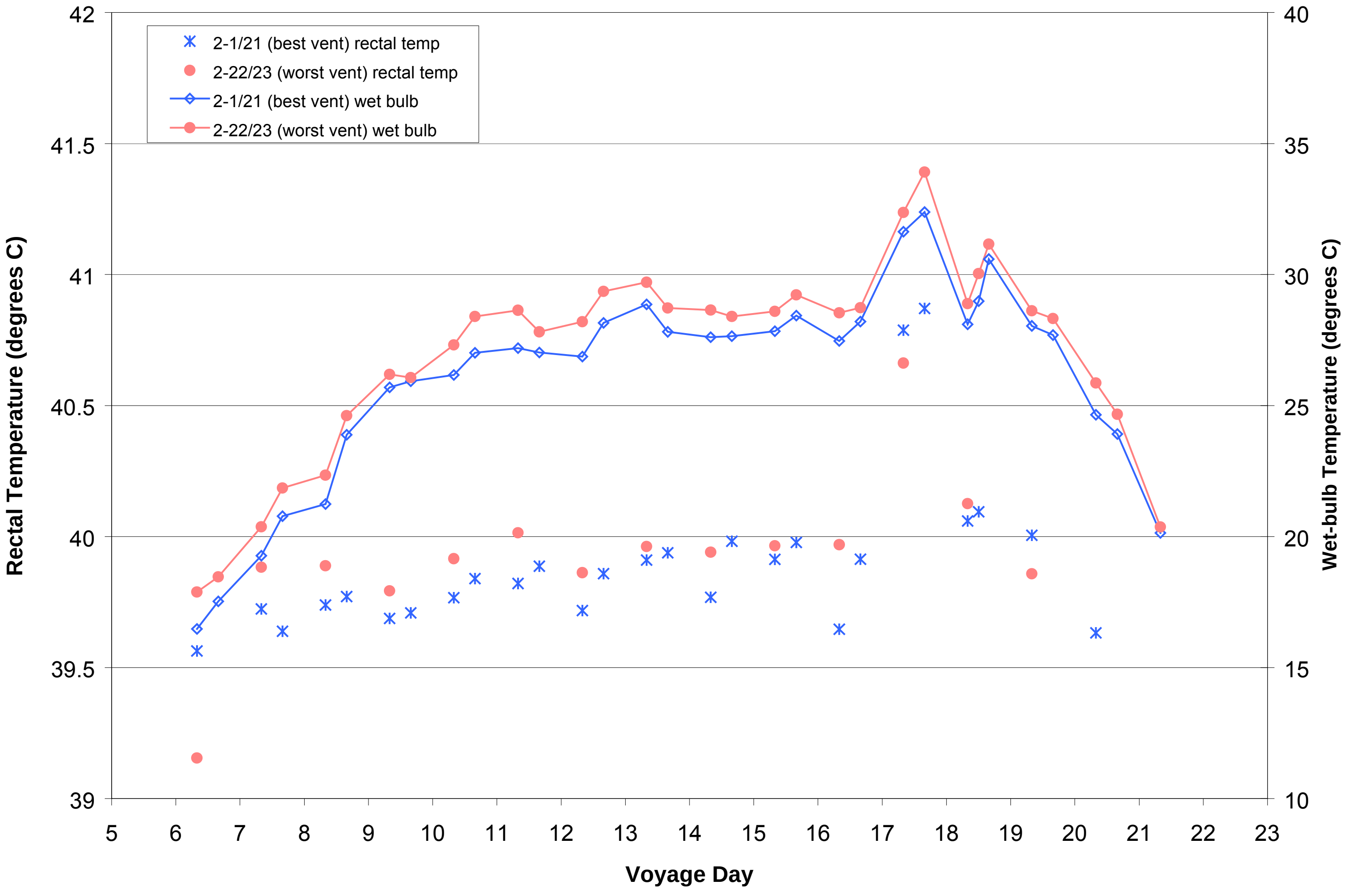


Figure 0.20 Voyage 1 – Heat Stress Response by Ventilation Standard

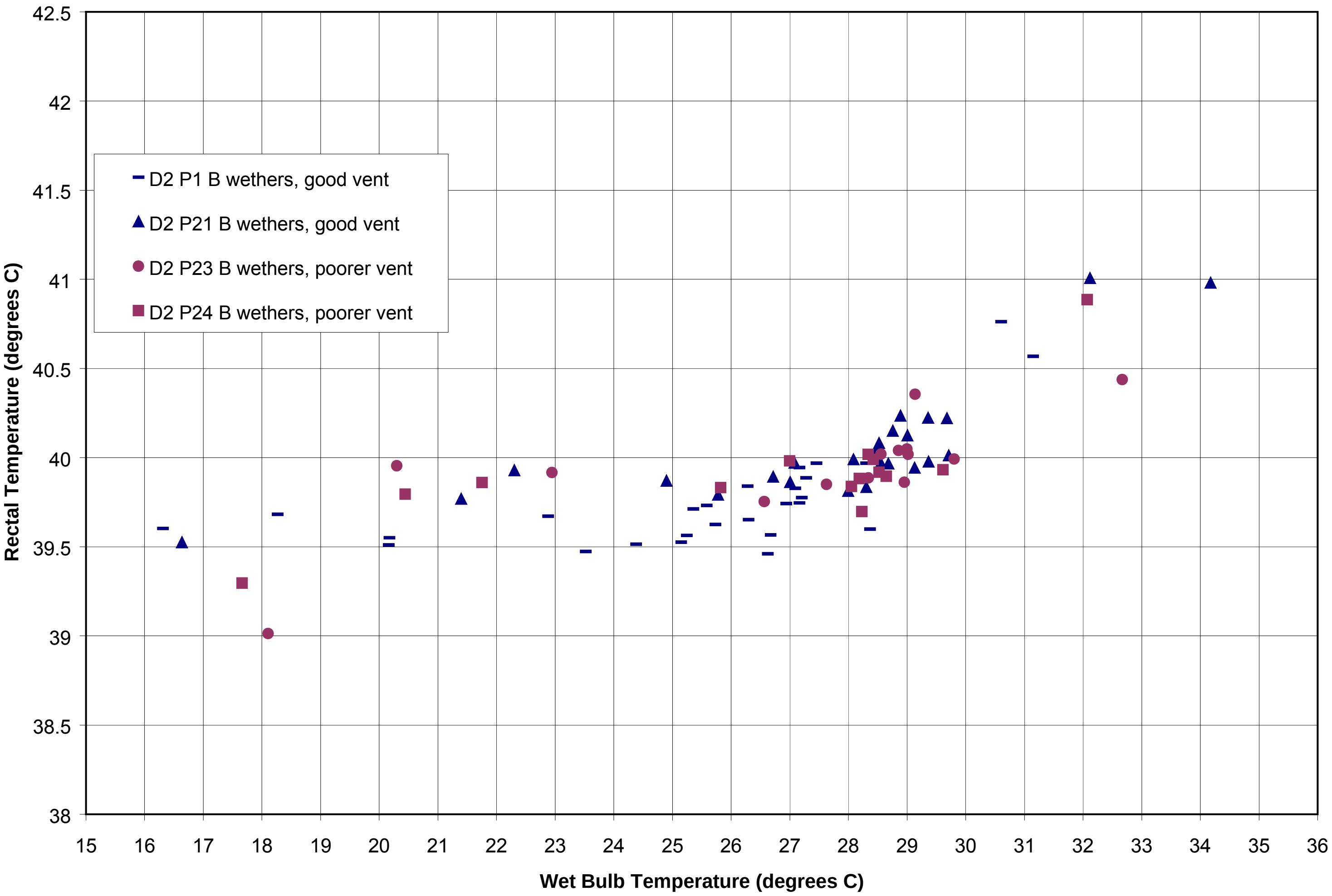


Figure 0.21 Voyage 2 – Wet Bulb Temperature and Rectal Temperature for Different Pen Air Turnover

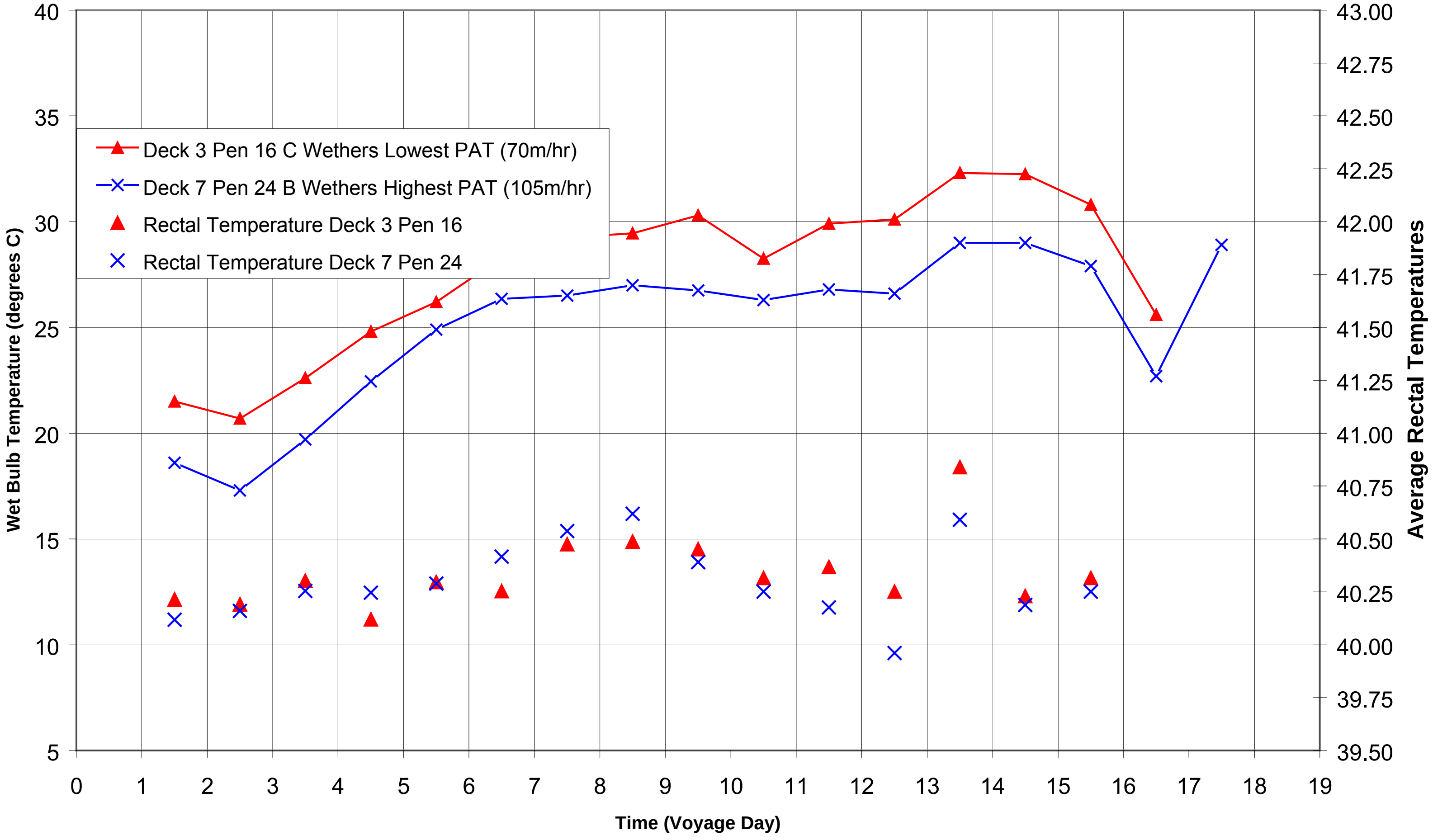
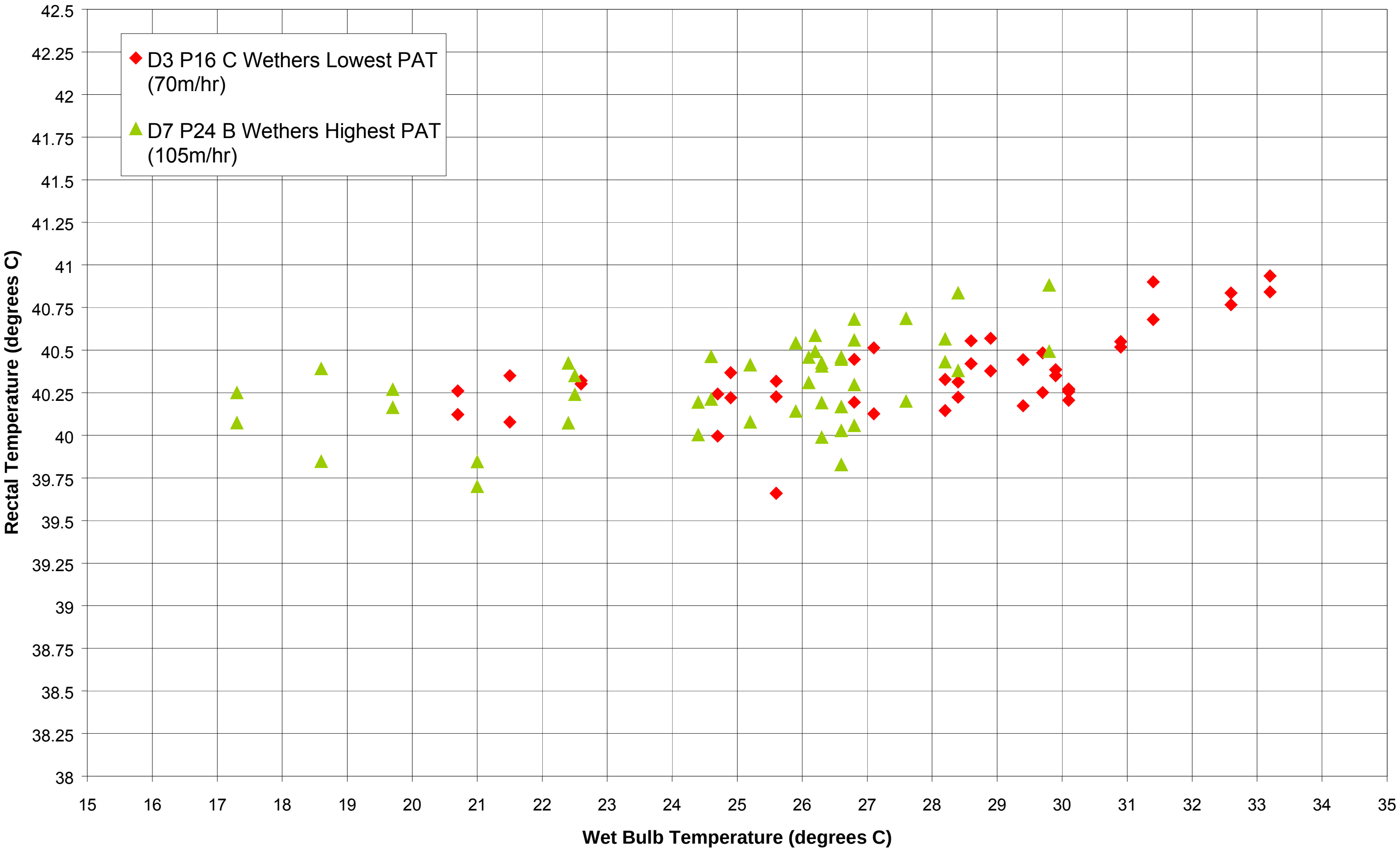


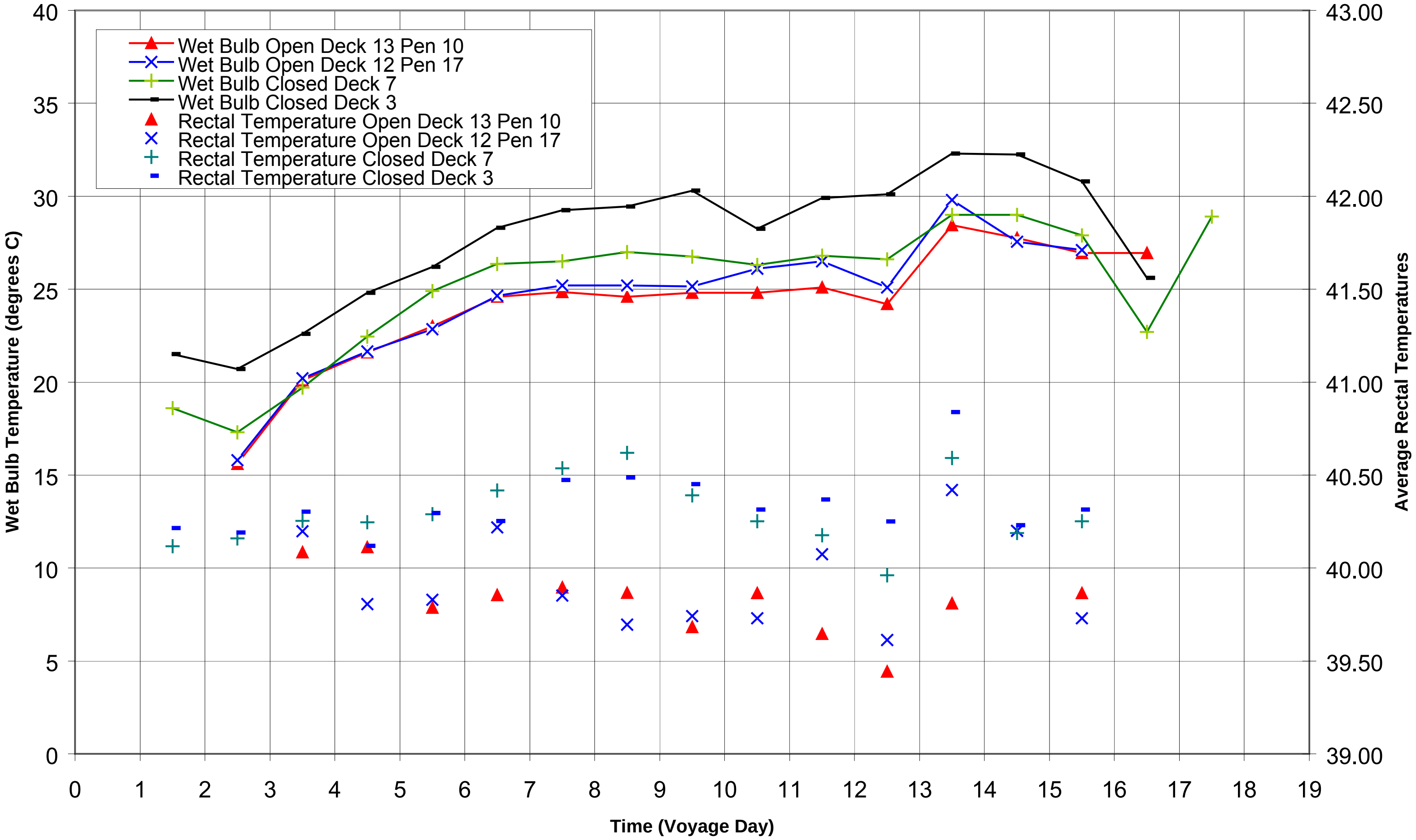
Figure 0.22 Voyage 2 – Correlation of Rectal Temperature with Wet bulb Temperature by Pen Air Turnover (PAT)



2.10 A Comparison of the Closed and Open Decks

Still with Voyage 2, Figure 0.23 is similar to Figure 0.21 but includes also open deck pen data from decks 12 and 13. It demonstrates that where a breeze is present, the effective ventilation rates on open decks will be high, with heat stress minimised. No still conditions are captured in Figure 0.23.

Figure 0.23 Voyage 2 - Wet Bulb Temperature and Rectal Temperature for Closed and Open Decks



2.11 Open Deck Cross Wind

The observation pens on Voyage 2 deck 12 (pens 2, 10, 17 and 24) formed an experiment investigating the effect of position on an open deck on animals' responses to heat. As a result of the prevailing breezes during the voyage, deck conditions were never extreme, reaching a maximum wet bulb temperature of 29.8°C on day 13 of the voyage. There was very little difference in the average rectal temperatures of animals in the four observational pens, and the HST of these animals was not exceeded during the voyage. Although wet bulb temperatures did approach 30°C, there was at best, only a minor indication of increased rectal temperature.

No findings on the effect of low crosswind could be demonstrated clearly.

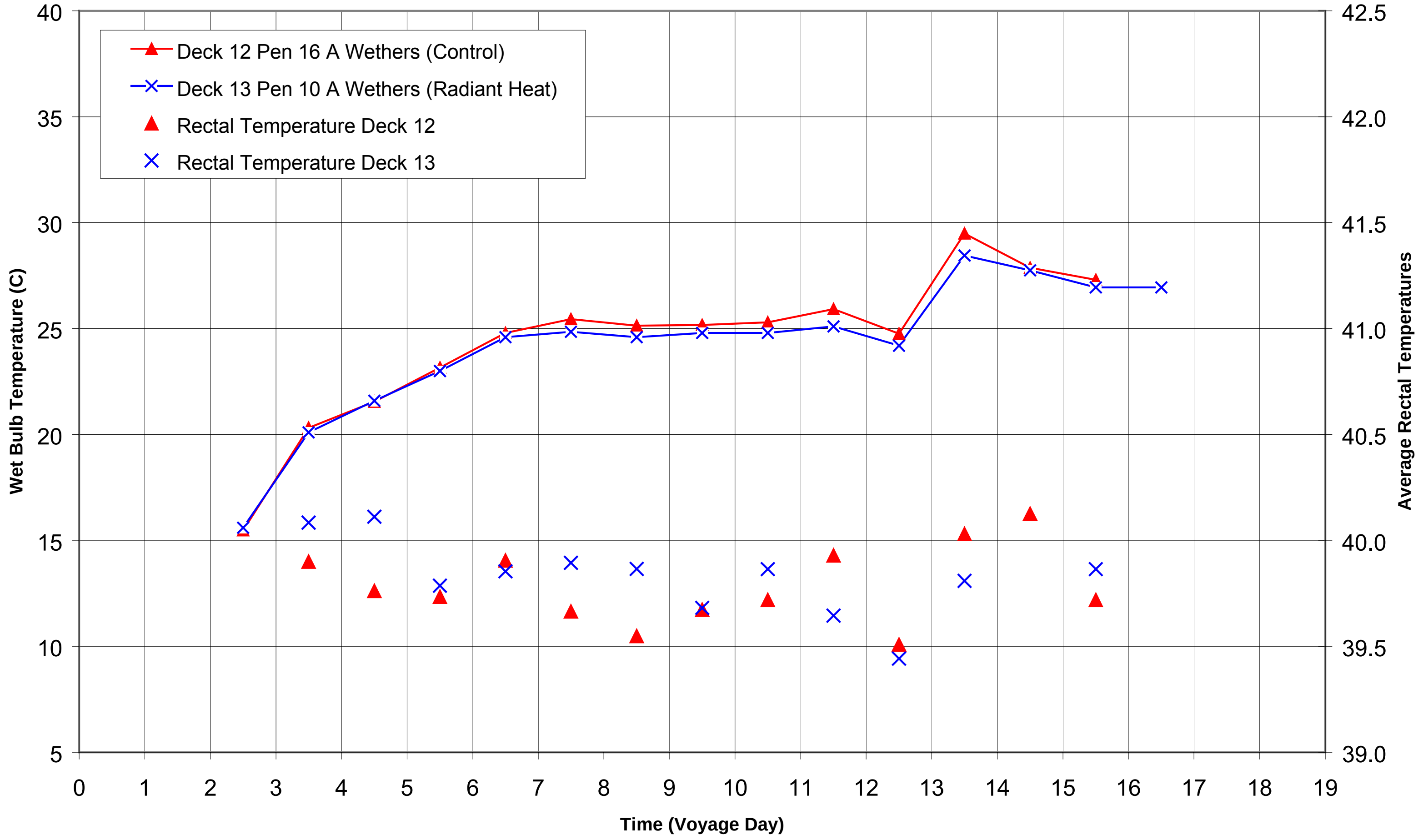
While further voyage studies could be 'lucky' and get good data in zero cross wind conditions, it is felt that understanding of open deck conditions is best advanced by computational modelling of the internal flows and conditions for various external breezes. This has now been done as part of the LIVE.116 project.

2.12 The Impact of Radiant Heat on Open-Deck Conditions

The effect of radiant heat on animal responses was investigated during Voyage 2 by comparing animals in deck 13, pen 10 (where animals were exposed to radiant heat from a hot ceiling) and deck 12, pen 10, (immediately below the deck 13 animals, where there was no impact of radiant heat). The maximum measured temperature of the ceiling above deck 13 was 50°C, on day 5 of the voyage. As illustrated in Figure 0.24, there was little measurable difference in the measured wet bulb temperature on these decks, suggesting that radiant heat was not a significant contributor to overall heat generation on deck 13 in these conditions.

Calculations of heat radiated by a 50°C ceiling suggest that it could add around 25% to the wet bulb rise on the deck. This effect could not be seen, as the overall wet bulb rise was kept low by the strong natural ventilation.

Figure 0.24 Voyage 2 – Wet Bulb Temperature and Rectal Temperature for Radiant Heat



2.13 Sheep Calorimetry

Available literature and limited experimental data have been used previously to suggest a figure of 3.2W/kg for the 'per liveweight' rate of metabolic heat production by sheep. This figure was used to predict an average wet bulb temperature rise of 3.05°C for the closed decks of Voyage 2. The measured figure varied considerably between measurements, but averaged 3.1 or 3.2°C. Given a small contribution to deck wet bulb temperature rise from the supply fan power (no more than 0.2°C), these two figures are consistent. That is; there is no reason to alter the current metabolic heat estimate of 3.2W/kg.

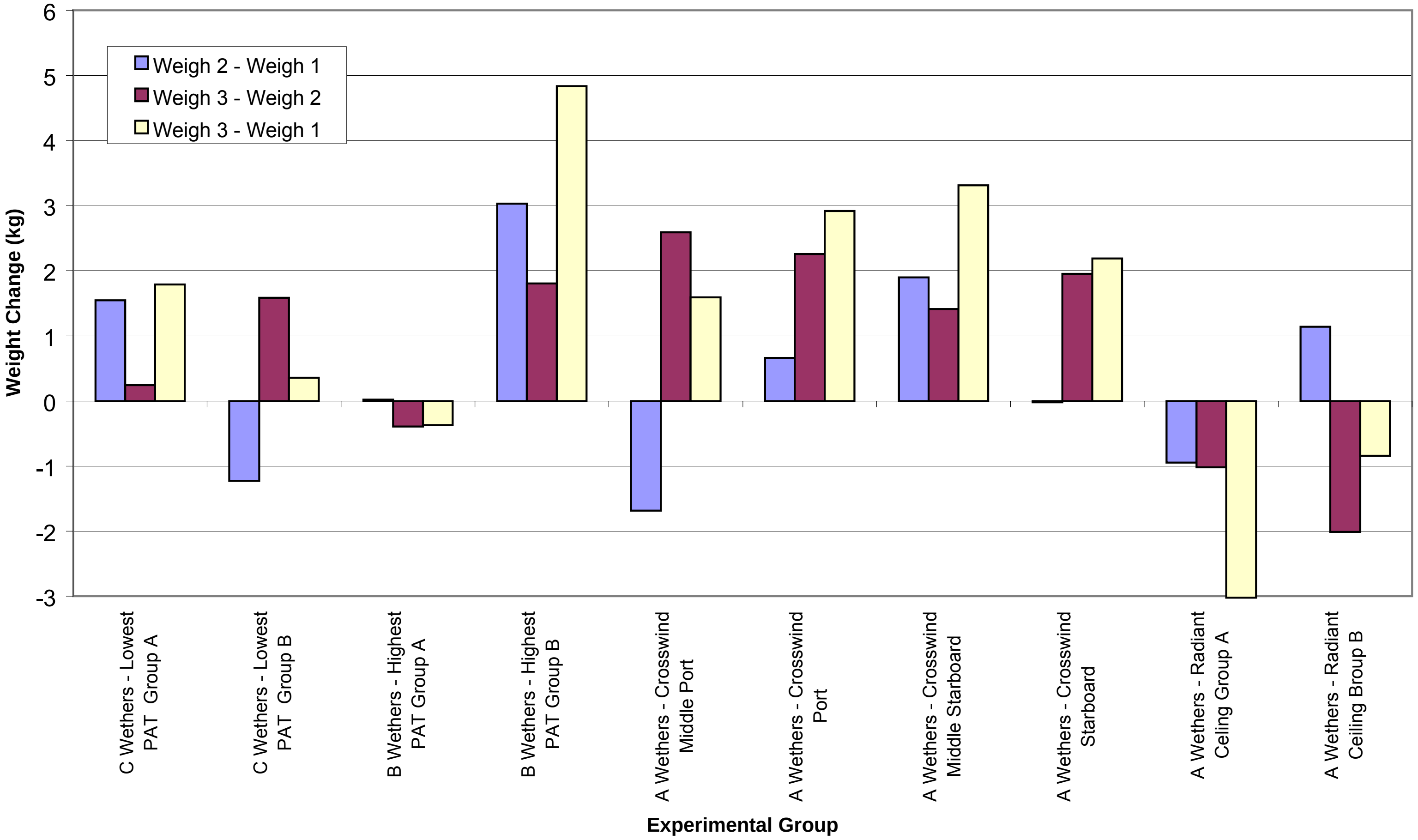
2.14 Body Weight Changes

The lines loaded on Voyage 2 were highly variable, with animals of the same class within the same observation pen varying greatly in terms of body weight.

During Voyage 2, observation animals were weighed on three occasions, and the mean and median weights of each observation group at these weighings were calculated and reviewed. There were no consistent patterns in terms of body weight changes between weighings (Figure 0.25). In fact, examining those pens with 'A' and 'B' groups of animals, Figure 0.25 shows that the average responses of the 5 animals in each A group were completely different in every case from those for the 5 animals in each corresponding B group. In each case, A and B group animals were selected as apparently similar animals using the same selection techniques and were held in the same pen. From these data, we conclude that little useful information can be deduced from the sheep weights. It may be that much larger samples would give self-consistent data, however the effort in weighing 50 animals on Voyage 2 was considerable and an order of magnitude increase in sample size is not considered practical on a voyage.

As a result of this finding, the Voyage 1 weight data which were based on smaller samples are not reported here.

Figure 0.25 Voyage 2 – Average Change of Body Weight between Weighings by Experimental Group



2.15 Mortality Rates

The overall mortality at-sea to the final day of Voyage 1 was 1.63%. A further 37 sheep died during unloading at the final port, but are not included in these calculations. The voyage mortality rate for sheep loaded in Portland (at 2.0%) was twice that experienced by sheep loaded at Fremantle (1.0%). Figure 0.18 and Figure 0.26 illustrate the pattern of Voyage 1 deaths by day of the voyage and since day of loading, respectively. For Portland-loaded sheep, mortalities rose rapidly and were sustained at high levels for approximately 13 days. A further peak in mortality occurred 18 days after loading. In contrast, mortalities in sheep loaded in Fremantle rose steadily to day 13 after loading and then declined. Mortality was highest in a limited number of lines, including rams, B Merino lambs, and Portland-loaded B young wethers. A limited number of post-mortems were conducted during Voyage 1. Salmonellosis was the main cause of deaths in animals between Portland and Fremantle, whereas inanition predominated approaching the Middle East. Based on these data, the differing mortality rates by port of loading were not related to length of voyage. Based on information from the concurrent salmonella study, the difference appears due to differences between the ports of loading, such as differences in the type of sheep, the method of feedlotting (shed-based systems in Fremantle, paddock-based systems in Portland), or ongoing impact of feedlot-related salmonellosis (following paddock-based feedlotting in Portland).

The overall mortality rate during Voyage 2 was 1.6%. The daily mortality rate was low at voyage start, but increased as the voyage progressed (Figure 0.27). This temporal pattern of deaths is suggestive of the persistent inappetence-salmonellosis-inanition (PSI) syndrome, which generally occurs as the end-stage of a prolonged disease process. These findings are consistent with the general impression of the voyage veterinarian, with most deaths being associated with inanition. In any shipment, there are a small percentage of animals that refuse to eat at any stage after leaving the property-of-origin, eventually dying as a result of primary inanition and/or secondary salmonellosis.

As indicated in Figure 0.27, there was a ‘spike’ in the daily mortality rate on days 14 and 15 of Voyage 2, immediately prior to docking at Kuwait. This increase followed a modest rise in ambient wet bulb temperature, and was particularly evident on the lowest and highest decks of the vessel (Figure 0.28). This ambient temperature rise had effect throughout the ship, and was associated with a rise in mean rectal temperature in each of the observation groups. It is likely that heat stress contributed to, but was not the primary cause of, death during this period. Although the closed deck wet bulb temperatures, being the ambient wet bulb temperature plus the wet bulb rise, may have exceeded the HST of sheep, these conditions were unlikely to prove fatal in otherwise healthy animals. In contrast, animals already weakened by persistent inappetence (or other disease) may have depressed HST and ML, and be much more susceptible to the secondary effects of heat stress.

The Voyage 2 mortality rate varied dramatically between different classes of animals. The mortality rate among the Awassi animals was extremely low, and did not exceed 0.4%. Although location may have contributed to this result (the Awassi were loaded in favourable parts of the vessel), a comparison including only open decks suggests that breed is the main determinant of mortality in this instance. Among the A, B and C wethers, the voyage mortality rate was 1.26, 2.25% and 2.16% respectively.

Figure 0.26 Voyage 1 – Mortality Rate by Day Since Loading

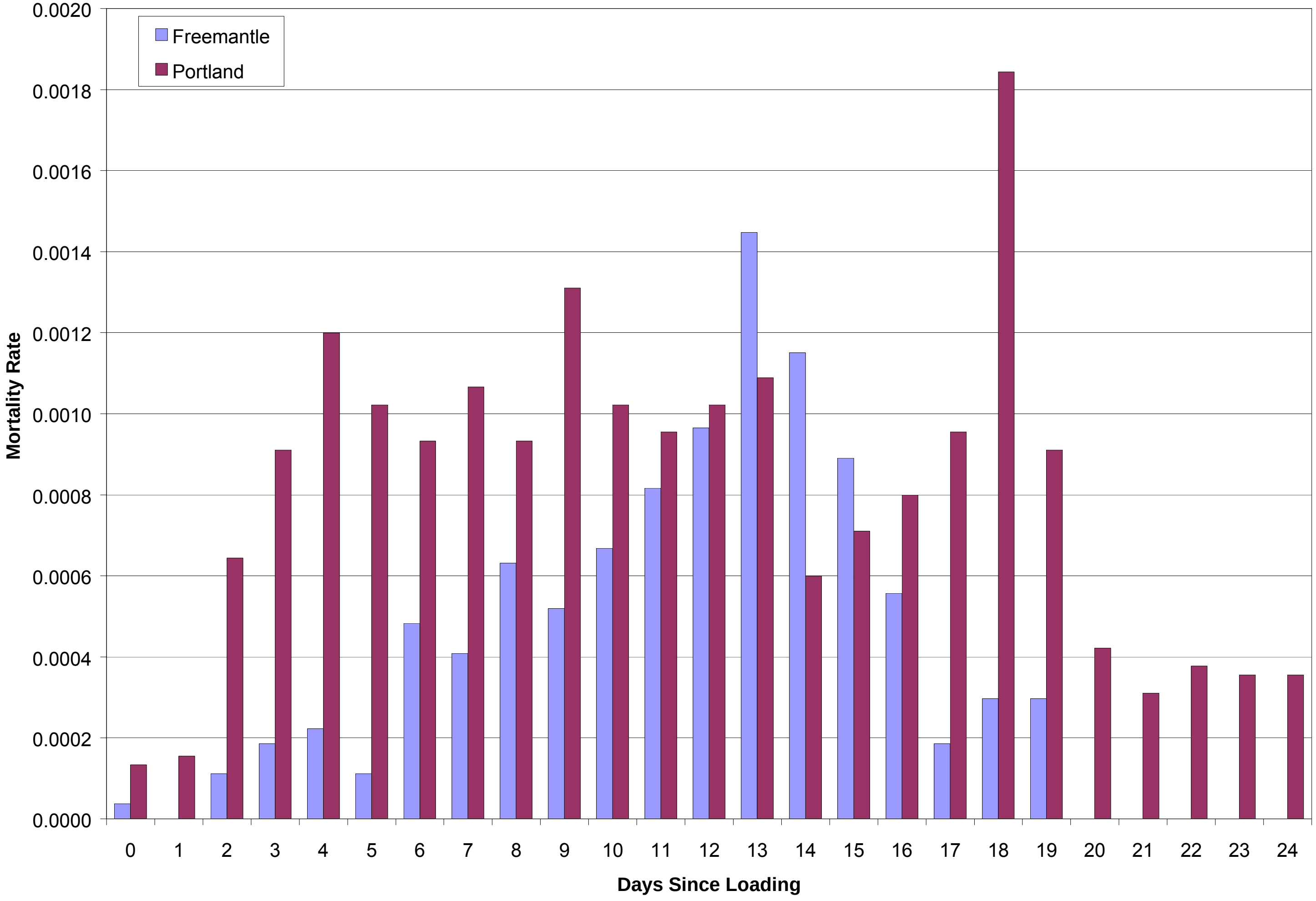


Figure 0.27 Voyage 2 – Daily Mortality Rates and Ambient Wet Bulb Temperatures

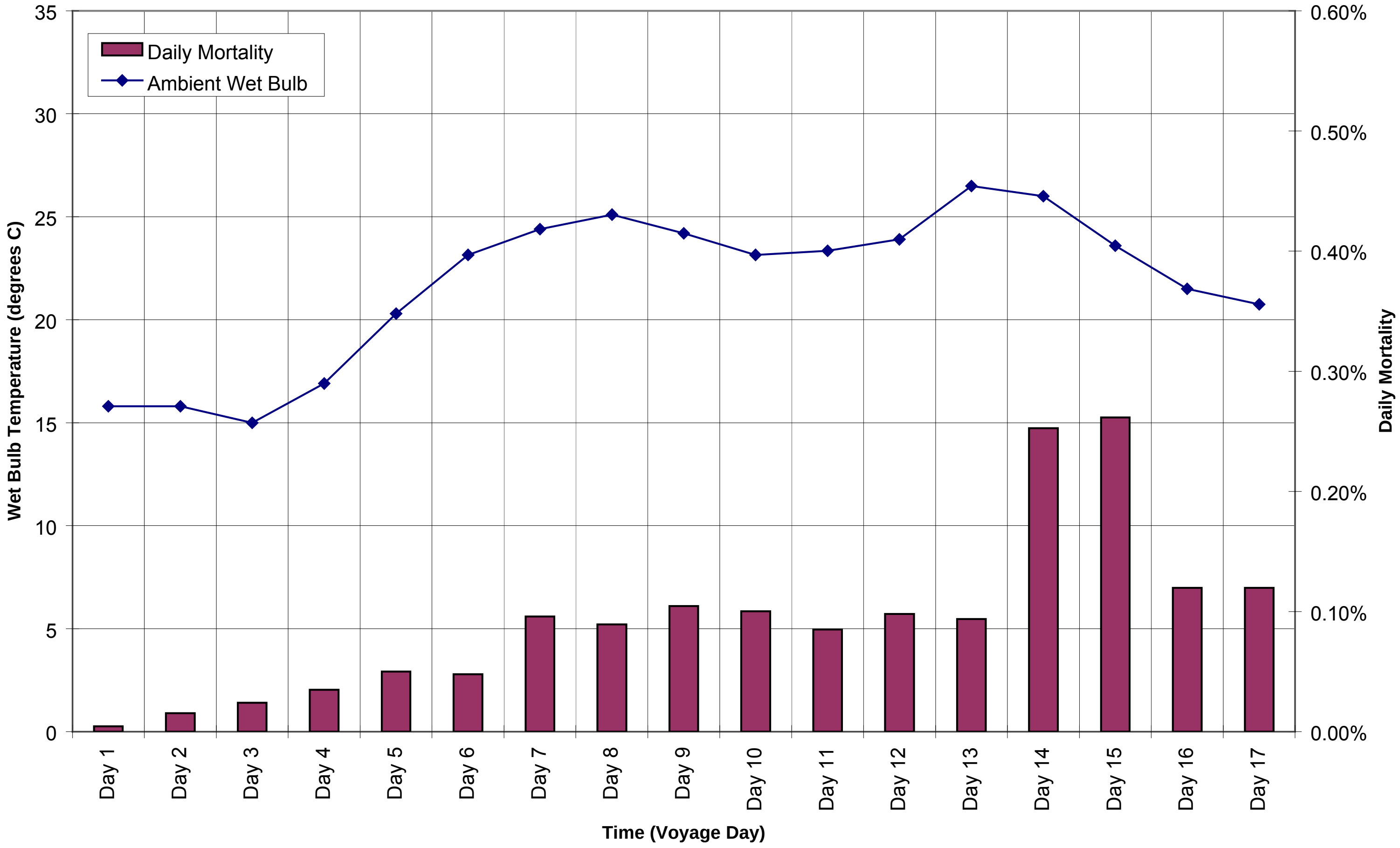
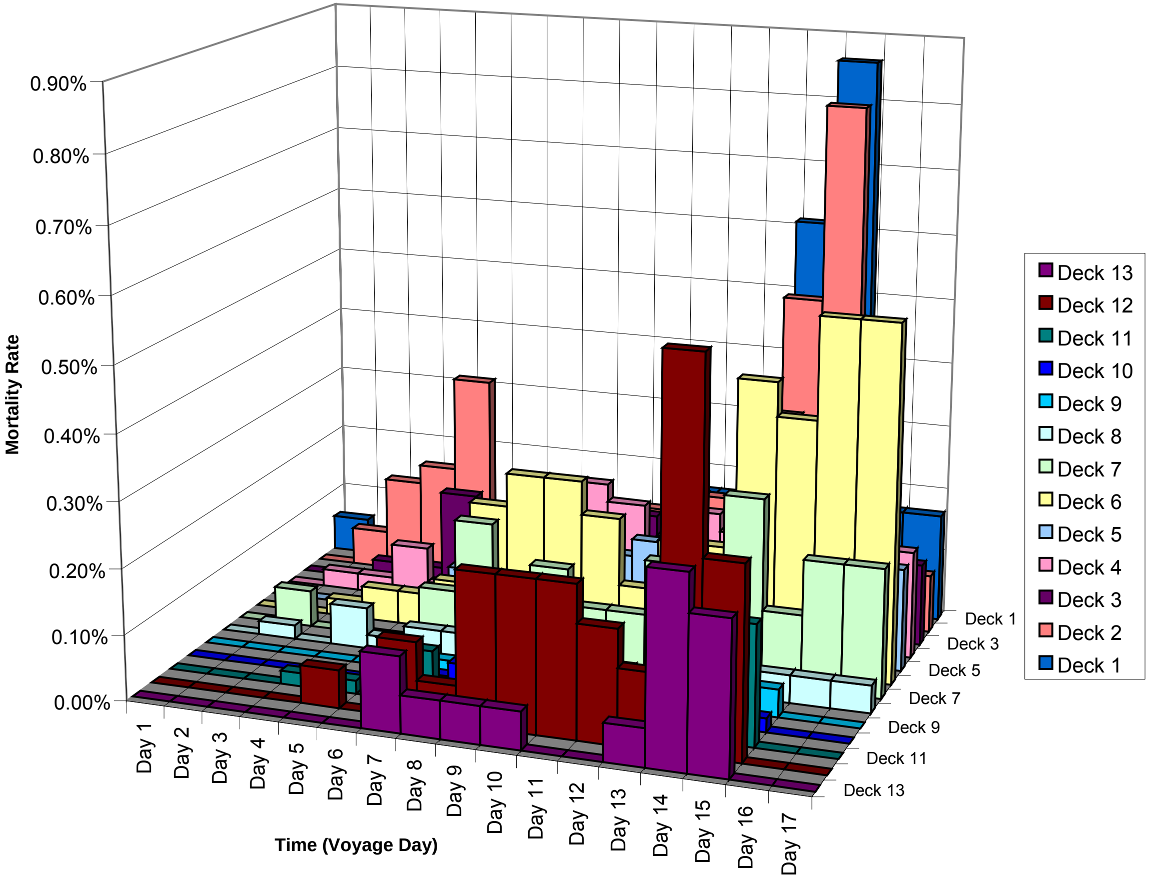


Figure 0.28 Voyage 2 – Daily Mortality Rates by Deck and Day



3 Conclusions

- During Voyage 1, the HST for *adult sheep* was seen to be between 28 and 30°C. During Voyage 2, this parameter was estimated to lie between 26 and 30°C, with the lower end of this range possibly being extended by animals that were compromised for other reasons (including disease). For *young sheep*, the HST may be lower, however, this is less clear given the gradual rise in rectal temperature as the wet bulb temperature rose above 22°C.
- During Voyage 2, there was a noticeable jump in mortality rate as the deck wet bulb temperature reached 32°C. A similar effect was noted in Voyage 1 after deck wet bulb temperatures reached 32.5°C to 34°C. This may represent the lower range of the mortality limit in adult Merino sheep.
- There were significant differences in animals' comfort on the closed decks during Voyage 2, as a consequence of substantial differences in pen air turnover between decks.
- Based on anecdotal information collected during the voyages, Awassi sheep were more heat tolerant than Merinos, even though they were woolly (hairy) at loading. The mortality rate was much lower in Awassi (0.1 to 0.4%) as compared with Merino sheep during Voyage 2 (average 1.6%). The mortality limit is likely to be higher in Awassi as compared to Merinos.
- During Voyage 1, the *Awassi lambs* were more resistant to heat than Merino lambs. Although data are scant, it appears that the HST for Awassi lambs is greater than 29°C.
- Once the wet bulb temperature exceeded 26°C, the Voyage 1 woolly ewes were hotter than the shorn ewes by a margin of 0.2-0.4°C. Because data were scarce when the ambient wet bulb temperature reached 29-30°C, it is difficult to determine the HST for these two different lines of animals.
- During Voyage 1, the ambient wet bulb temperature reached approximately 32°C on day 17 of the voyage. During voyage 2, the ambient wet bulb temperature did not exceed 27.9°C (a measurement taken with a hand-held instrument on day 13 of the voyage).
- Voyage 2 was not hot enough to reveal answers to several of the questions relating to this study, including the impact of radiant heat, differences between open and closed decks and the effect of minimal crosswind in open decks. Heat stress among the observation pens, with animals exceeding their HST, occurred mainly on deck 3.
- The study of open deck effects by voyage observations will always be problematic as the prevailing weather can prevent any useful results being recorded. A computational study was recommended, possibly followed by systematic (and unattended) data logging on all ships (such a computational study has now been done as part of the LIVE.116 project).
- Respiratory rate observation is difficult and it proved impractical to observe the respiratory rate of specific animals.
- The measured wet bulb rise on closed observation decks was in agreement with calculations presented in earlier work. The rise in wet bulb temperature through the decks to exhaust was consistent with the same calculations, using the earlier estimate of the metabolic heat production of sheep (3.2W/kg liveweight).
- On the basis of results obtained during Voyage 2, there is a high degree of within-class variability with respect to weight, and weight changes were inconsistent and difficult to explain. Given this difficulty, and the relatively insensitive relationship between weight change and heat stress, it is recommended that less attention be paid to body weight changes in future observational heat stress work.