



Unpublished Report

Document ID:	SheepCRC_2_100
Title:	Review of factors affecting sheep weaner survival
Author:	Campbell, A.
Key words:	sheep; review; weaner; survival; nutrition; growth

This report was prepared as part of the Sheep CRC Program 2007-2014. It is not a refereed publication. If the report is quoted it should be cited as:

Sheep CRC Report 2_100

Sheep Innovation CRC Project 1.2.3—Improved Weaner Survival

Milestone Report 31/12/07 by Angus Campbell

Table of Contents

[The heading titles correspond to topics in the work schedule.]

1. Collation of existing weaner survival extension material	2
Tasmania.....	2
Victoria.....	2
NSW	3
Queensland	3
South Australia	4
Western Australia	4
National	4
2. Draft scientific literature review—Mortality of Weaner Sheep.....	5
The Extent of Merino Weaner Mortality in Australia	5
The Limitations of Weaner Mortality Investigations	9
Causes of Mortality & Illthrift.....	9
Bodyweight.....	13
Growth Rate.....	16
Associations between Bodyweight & Death from Causes Other Than Malnutrition...20	
Physiology Underlying the Association between Mortality & Bodyweight	21
Season & Year of Birth	23
Disease.....	24
Maternal Factors Affecting Weaner Survival.....	25
Sex.....	27
Weaner Mortality—Summary	28
Methodologies for Analysing Survival & Mortality	29
References	33
3. Draft ‘Recommended Management Summary’	38
Preamble.....	38
Background Management Procedures.....	38
Weaner Management.....	39
4. Draft protocol for Field Trial to Evaluate Efficacy of Updated Management Strategies to Improve Weaner Survival & Validate Quantitative Supplementary Feeding Models	43
Trial Aim & Background.....	43
5. Collation of existing analyses of the economics of weaner survival.....	46
MLA Report AHW.087.....	46
Mackinnon Project modelling	46

1. Collation of existing weaner survival extension material

This is a list of resources currently available to guide management of weaner sheep, organised by state and provider.

Tasmania

8x5 Program

Conducted five workshops in 2004–05 and has produced other printed material related to weaner management. Resources include:

- a powerpoint presentation—this appears to be part of a specific ‘education module’ on weaner management produced by the 8x5 Program; Warren Hunt is chasing this up (as of January ’07)
- a Weaner Monitoring record sheet
- case studies and articles in various 8x5 monthly newsletters, including:
 - May 2005: poor correlation between bodyweight at different weaner ages
 - January 2003: ‘Weaner management over summer’
 - January 2004 management reminders
 - April 2003 worms vs. nutrition case study
- a case study of adoption of best-practice weaner management (July 2004)
- Staple Strength Project report, including weaner staple strength analyses
- commissioned GrassGro case study of changing lambing time on a Tasmanian farm, including modelled effects on weaner bodyweight and supplementary feeding requirements

‘Tas Regions’ magazine

- ‘Weaner management starts in spring’—September 2004

Victoria

DPI

- ‘Sheep Nutrition in the Victorian Environment’ (Foot *et al.* 1987) contains recommended bodyweight targets for different ages post-weaning
- Sheep Drought Notes contains the replicated bodyweight target table from Foot (1987) and weaner ME targets total drought rations, plus some brief notes on common diseases of weaners in drought (p. 37)

Rural Industries Skills Training

Runs a ‘Productive Weaner Management’ course, including a manual, written by the Mackinnon Project. This has been delivered to four producer groups across Victoria (Gippsland, Western District and Central District)

NSW

DPI NSW

Primefacts:

- ‘Supplementary feeding of sheep in southern NSW’
- ‘Creep Feeding Lambs’—helps with early weaning
- ‘Full hand feeding of sheep—management’ contains weaning ages and post-weaning bodyweight targets (that don’t seem quite right)
- ‘Full hand feeding of sheep—quantities’ contains comprehensive minimum feed requirements for weaners table
- ‘Supplementation guide for sheep: central & southern NSW’ comments on weaner protein requirements and management of the tail (“< 20 kg”)

Sue Hatcher has been involved in several weaner management/survival research and extension projects:

- Yass Rural Lands Protection Board monitored 50 ewe and 50 wether weaners on several properties over seven visits in 2004–05. From this, a folder containing monthly liveweight targets and management guidelines was produced and distributed to sheep producers within the Board. A copy is being sent to me (as at 31/1/08).
- In the Central Tablelands, 200 weaners on 11 farms were monitored three times at two-monthly intervals starting in November 2006. The producers involved in this work then attended extension meetings and a final report was produced. Two scientific papers have been from this work have also been submitted for presentation at the 2008 Australian Society of Animal Production conference.

Queensland

DPI Queensland

- ‘Producing better weaners in north-western Queensland’—some quite different recommendations to southern areas
- ‘Net reproduction rate’—gives examples of calculations and shows how they can be used to identify losses between lamb marking and 1st joining
- ‘Sown pastures and fodder crops for prime lambs’
- *Drought feeding recommendations seem to have low quantities of grain for weaners* (*‘Feeding grain to sheep during a dry season’*)
- ‘Lot feeding Merino lambs during a drought’
- Other articles mention weaner-related information:
 - amounts of cottonseed meal to feed young sheep (‘Supplementary feeding of sheep using cottonseed’)
 - need true protein plus NPN from ‘Supplementary feeding using the Toorak urea block’

- ‘Supplementary feeding when protein levels in pastures are low’
- ‘Vitamin requirements of sheep and cattle during a dry season’

An article by Bortolussi (2004) in AJEA indicates hormonal implants in ewe weaners have disadvantages, despite some conditional weight gains

South Australia

No information found.

Western Australia

Agriculture & Food WA

- ‘Feeding & Managing Sheep in Dry Times’ has weaner rations and bodyweight/growth rate guidelines
- Grazing weaners on stubbles: ‘Grazing weaner sheep on Phomopsis-resistant lupin stubbles’, ‘Lupin stubbles : getting the best with weaner sheep’, ‘Blue lupins : good feed for weaner sheep’, ‘Supplementing weaner sheep grazed on oat stubbles with sandplain lupin seed’
- ‘A feed investment strategy for young merino sheep’ details timing of supplementation in WA
- There’s mention of plans to develop a ‘Weaner Planner’ wheel, similar to the Lamb Planner, but it doesn’t seem to have come to fruition

National

AWI

- ‘Weaner management’ in Planning For Profit publication—excellent summary; could form good backbone for recommended management summary
- ‘Managing sheep in droughtlots: A best practice guide’ has some weaner management case studies

Lifetime Wool

- Sheep Updates 2004: ‘Effects of nutrition during pregnancy and lactation on mortality of progeny to hogget shearing’ mentions weaner survival

2. Draft scientific literature review—Mortality of Weaner Sheep

This review discusses the extent of Merino weaner mortality in Australia, its underlying causes and factors that have been shown to be associated with mortality in weaner sheep flocks in Australia and overseas. In Merinos, weaning is recommended to occur at approximately 12 weeks of age (Lean *et al.* 1997), and the term ‘weaner’ usually refers to a sheep between weaning and about 12 months of age. No maximum acceptable mortality rates of sheep between weaning and 12–18 months of age exist in the published literature, however a maximum of approximately 4% has been suggested as a realistic target (Larsen 2002; Behrendt 2003).

The Extent of Merino Weaner Mortality in Australia

The problem of excessive mortality of weaner sheep, and Merinos in particular, is not new to the Australian sheep industry. For example, whilst visiting the Midland and Great Southern Districts of Western Australia, Sir Ian Clunies Ross reported that farmers were experiencing “considerable difficulty” rearing young sheep (1934). It is difficult to assess the current extent of Merino weaner mortality in Australia because very few recent surveys or scientifically-based estimates of weaner mortality in pasture-based grazing enterprises exist. Despite a paucity of reports concerned primarily with weaner mortality, commercial surveys and field experiments that incidentally or indirectly report mortality data allow estimates to be made. The average and range of Merino weaner mortality obtained from such studies in Australia are listed in Table 1. It indicates that rates of Merino weaner mortality exceeding 10% per annum occur in many regions of Australia, and that death rates have not decreased in recent times.

Excessive post-weaning mortality can have important, adverse effects on the efficiency of a farming enterprise. The death rate in Merino weaners of 24% reported by Rose (1972) in the semi-arid environment of north-western Queensland was more than twice the maximum that could be sustained by the flock if any form of genetic selection through culling were to occur. In an analysis of reproduction over 4 years in a Merino flock in a similar environment, post-weaning mortality was identified as one of the three most serious causes of reproductive wastage (Kennedy *et al.* 1976). Such high rates of mortality in northern Australia have also been reported more recently; in only three months 14% of weaner sheep died in an experiment conducted in the late 1980s under grazing conditions common to the region (Cobon *et al.* 1990).

The mortality results from some of the studies listed in Table 1 warrant further discussion because of particular details or because it is difficult to summarise the reported death rates. Harris and Nowara's (1995) survey of sheep mortality was of mixed cropping-sheep enterprises in the Victorian Mallee. Mortality patterns in these enterprises may differ from grazing-only farms because of the availability of grain for supplementary feeding and the opportunity to graze crop stubbles. In this study, average Merino weaner mortality was 4% per annum, which is low when compared to the other listed studies. However, more than one fifth (6/29) of Merino flocks had annual weaner mortality rates higher than 5% and, in 8% of all flocks surveyed, between 10 and 25% of weaners died each year.

Studies reporting specific animal health conditions, such as trace element or vitamin deficiencies, or gastrointestinal parasitism, may include mortality data. In such situations, high mortality might not be unexpected in the absence of treatment. However in the studies listed in Table 1, weaner mortality was still high in the groups that received treatment. For example, an average of 59% of Merino weaners died of vitamin A deficiency in a feeding trial

Table 1: Mortality of Merino and Merino-cross sheep between weaning and approximately 18 months of age reported in Australian commercial enterprises or field experiments

Post-weaning mortality (range)	Location	Reference
16%	feedlot	(Franklin <i>et al.</i> 1955)
up to 50%	south-eastern South Australia	(Mulhearn 1958)
25%	north-western Queensland	(Moule 1966)
7%	Western District, Victoria	(Russell 1968)
14%	Western Slopes, NSW	(Drinan 1968)
6% (up to 24%)	southern Western Australia	(Gabbedy 1971)
24%	Julia Creek, Queensland	(Rose 1972)
12–22%	Western District, Victoria	(Anderson <i>et al.</i> 1976)
18%	Central Victoria	(McDonald 1975)
14%	Broken Hill, Queensland	(Kennedy <i>et al.</i> 1976)
7–10%	feedlot	(Davis <i>et al.</i> 1976)
10%	Kybybolite, South Australia	(Brown 1977)
17% (11–29%)	Kangaroo Island, South Australia	(Walker <i>et al.</i> 1979)
5% (up to 13%)	Katanning, Western Australia	(Norris 1984)
6%	Western Slopes, NSW	(Langlands <i>et al.</i> 1984)
up to 56%	Kybybolite, South Australia	(Brown <i>et al.</i> 1985)
39%	Condobolin, New South Wales	(Denney <i>et al.</i> 1988)
22%	n/a	(Mulholland 1986 cited by Allworth 1994)
14%	Julia Creek, Queensland	(Cobon <i>et al.</i> 1990)
11%	East Gippsland, Victoria	(Holmes 1992)
4% (up to 25%)	Mallee, Victoria	(Harris and Nowara 1995)
4% (1–10%)	Hamilton (Vic), Struan (SA) & Cowra (NSW)	(Fogarty <i>et al.</i> 2005)
12% (2–27%)	Victoria	(J. Webb Ware pers. comm.)

of drought rations (Franklin *et al.* 1955). However, the death rate was still 16% amongst weaners that received vitamin A. In selenium supplementation trials in Victoria, Western Australia and South Australia, 6–16% of Merinos receiving selenium still died after weaning (Gabbedy 1971; Walker *et al.* 1979; Holmes 1992). Mulhearn (1958) reported up to 50% post-weaning mortality amongst Merinos and Corriedales in the high-rainfall zone of South Australia but could only attribute some of these cases to trace element deficiency or specific diseases.

Field trials assessing parasite control programs have reported high mortalities even in weaner groups receiving recommended worm control treatments. For example, 12% of Corriedale weaners died in a trial in the Western District of Victoria, despite the use of double summer drenching, a strategy which remains the mainstay of effective worm control in that environment (Anderson *et al.* 1976). In a similar experiment involving *Haemonchus*, *Trichostrongylus* and *Ostertagia* infections of sheep in East Gippsland, 13% of Merino weaners died in one year despite weekly anthelmintic treatment and 19% died in groups managed under the common district approach of the time, which involved giving between three and six annual treatments (Barton and McCausland 1987). All of these results suggest that excessive weaner mortality cannot always be attributed to a single, treatable aetiology.

It is striking that virtually none of the studies listed above comment on the rates of weaner mortality that they report. This suggests that mortality rates of 10%, or even 20%, are not considered unusual or noteworthy, and may explain how excessive mortality could exist in the Australian sheep industry and receive little attention. For example, in Barton's (1987) trial of parasite control, 'salvage' drenching "to...prevent...high mortality" only occurred once deaths exceeded 10%, implying that 10% mortality was not considered to be concerning or controllable. This attitude does not appear to differ from one expressed in the 1950s, when Franklin (1955) considered that supplementary feeding during drought satisfactorily reduced mortality when only 15% of Merino weaners died. In an extensive review of progress in reproductive research in the Australian sheep industry, Scaramuzzi (1988) discussed the improvements made over many decades in our understanding of drivers of neonatal lamb mortality but made no mention of the extent, or role, of post-weaning survival in the intergenerational 'efficiency' of sheep reproduction. Nonetheless, excessive weaner sheep mortality has been labelled one of the "biggest issues for Merino producers" (Ripper 2003, p. 2) and a recent economic evaluation suggested it is the fourth most costly animal health issue in the Australia sheep industry (Sackett 2006). Many farmers have difficulty successfully managing weaner survival. More than one quarter of Western District woolgrowers enrolled in an extension program for innovative farmers nominated successful weaner feeding, and

achieving target growth rates and bodyweights, to be their primary concern (Larsen 1999). Despite this, the fatalistic and frustrated attitude expressed by many farmers, and the very fact that so few recent reports of mortality on commercial farms exist, implies that the problem is under-reported, under-researched and possibly one that the industry feels is beyond its control.

The Limitations of Weaner Mortality Investigations

Studies that seek to elucidate the risk factors underlying mortality must necessarily be observational because it is not ethical to observe animals dying without intervening. No study has specifically examined mortality in Merino weaners grazed in southern Australia or a similar, Mediterranean-type environment. Thus, because reports of weaner mortality are frequently incidental to a study's principal aims, associations between proposed risk factors and mortality are frequently confounded with other variables. Plausible physiological explanations of the observed data can be offered, however ethical considerations prevent their testing in controlled experiments. Furthermore, interpretation of mortality data is difficult in small trials where differences in mortality proportions may be due to the death of only one or two extra animals, and no Australian studies have used statistical techniques appropriate for analysing mortality data. Therefore, despite the different production systems examined, some quantitative estimates of the association between risk factors and weaner mortality must be obtained from overseas studies of sheep and goats.

Causes of Mortality & Illthrift

Although weaner sheep can die from numerous diseases and syndromes, no single aetiological agent is consistently associated with Merino weaner mortality in Australia. It has thus been identified as a component of the 'weaner illthrift' syndrome (Gordon 1981) and a manifestation of illthrift in its most extreme form (McLaughlin 1967). However, its importance is usually alluded to without being specifically identified. For example, Wilkinson (1981) defines illthrift as a "failure of weaner sheep to thrive...when all other classes of sheep appear to be of satisfactory health" but does not mention mortality, despite going on to list illthrift's primary manifestation as "survivability".

Weaner illthrift is a syndrome of multiple aetiologies that is frequently associated with the grazing of dry pastures (McLaughlin 1967). Inadequate nutrition more generally, ranging from insufficient protein or energy intake to specific trace element deficiencies, has been identified as the primary factor predisposing Merino weaners to illthrift and high mortality in Australia (Gordon 1981). Weaners in poor body condition, particularly whilst grazing dry summer pastures and suffering insufficient energy or protein intake, are considered to be more

susceptible to other diseases (Allworth 1983). After inadequate nutrition, gastrointestinal parasitism is a common secondary contributor to weaner illthrift and death (Gordon 1981). In winter rainfall environments, death solely due to parasitism is thought to be rare during summer (Wilkinson 1981). Rather, it commonly is considered that undernutrition places weaners at risk of mortality and that parasitism then precipitates death (Beveridge *et al.* 1985). A variety of diseases, either following these two major predisposing conditions or independent of them, have also been implicated in outbreaks of weaner mortality in southern Australia. These include myopathies (usually associated with selenium or vitamin E deficiency), acidosis due to cereal grain overload, polioencephalomalacia, grass seed infestation, flystrike, mycotic dermatitis, scabby mouth and lupinosis (Wilkinson 1981; Hungerford 1990).

The risk factors associated with weaner mortality are discussed in the following sections, and the design and methodologies of the experiments cited therein are outlined in Table 2.

Table 2: Summary of methodologies of studies reporting risk factors for post-weaning mortality

Breed/ Species	Location	Features of production system	Observation period*	Experimental or Observational n [†]	or Analytical methodology Study;	Study
Merino, Merino ×	Kybybolite, SA [‡]	autumn lambing	6–12	Exp; ~20×3	descriptive	(Allden and Anderson 1957)
Merino	Adelaide, SA	autumn lambing	6–12	Exp; 24×4	descriptive, χ^2 test of proportions	(Allden 1968a)
Merino, other	western Vic	autumn lambing	~6–12	Obs; unspecified	descriptive case reports	(Engel 1958)
Rambouillet	north-western (temperate climate)	India extensive grazing + supplementary feeding	5–12	Obs; 3285	difference of least squares means	(Ganai and Pandey 1996)
Merino, other	Mallee, Vic	mixed enterprises (sheep + cropping)	?–12	Obs; 79 farms × 2 years	descriptive	(Harris and Nowara 1995)
goat	Kenya (semi-arid savannah)	extensive grazing + supplementary feeding	4–24	Obs; 270	discrete-time logistic regression based on cubic spline hazard functions	(Hary 2002)
Merino	Werribee, Vic	spring lambing; feedlot then pasture	~4–12	Exp; 10×3×3	χ^2 test of mortality proportions	(Hodge 1990)
goat	subhumid Nigeria	smallholder; foraging access to reserved fodder	± 5–12	Obs; 877	univariate analysis of cumulative mortality using maximum likelihood estimates	(Ikwuegbu <i>et al.</i> 1995)
Merino, Merino x	SA	autumn lambing	3–16	Exp; 591	χ^2 test of mortality proportions	(Kleemann <i>et al.</i> 1983)
Merino	WA	autumn, winter or spring lambing at average to high district stocking rates	3–12	Exp; 375	χ^2 test of mortality proportions	(Lloyd Davies 1983)
Merino	NSW	drought feedlot	3–6	Obs; 209	t-test of survivor vs. non-survivor weaning weights	(Lloyd Davies <i>et al.</i> 1988)
goat	French West Indies	irrigated pasture	3–9	Obs; 837	parametric & semi-parametric survival analysis	(Mandonnet <i>et al.</i> 2003)
Merino, Corriedale	Hamilton, Vic	autumn, winter or spring lambing	3–~11	Exp; unspecified	χ^2 test of mortality proportions	(McLaughlin 1973)
Merino, Corriedale	Kangaroo Island, SA	winter lambing	6–10	Exp; 20–40/group	descriptive	(Mulhearn 1958)
African sheep	Kenya (sub-humid tropics)	extensive grazing	3–12	Obs; 1785	semi-parametric survival analysis, including time-varying covariates	(Nguti <i>et al.</i> 2003)

Indian sheep	north-western (temperate)	India	extensive grazing + supplementary feeding	3–6	Obs; 1272	difference of least squares means	(Nivsarkar <i>et al.</i> 1982)
sheep	north-western (temperate)	India	extensive grazing	3–6	Obs; 10000	descriptive	(Sharma <i>et al.</i> 1981)
meat sheep	USA		feedlot	2–12	Obs; 8642	logistic regression, semi-parametric & parametric survival analysis	(Southey <i>et al.</i> 2001)
goat	Ghana		extensive grazing	3–12	Obs; 351	χ^2 -test of mortality proportions; univariate odds ratios	(Turkson <i>et al.</i> 2004)
African sheep	Ghana		extensive grazing	5–12	Obs; 453	χ^2 -test of mortality proportions; univariate odds ratios	(Turkson and Sualisu 2005)
African sheep & goat	Ghana		extensive grazing, average flock size = 10	~5–12	Obs; 868	χ^2 -test of mortality proportions; univariate odds ratios	(Turkson 2003)
Merino x	n/a		pen-study	1–3	Exp; 26	correlation between weaning weight and duration of post-weaning survival	(Walker and Hunt 1980)
?	California		extensive grazing	22+	Obs; ~26 × 3 × 3 years	comparison of mortality proportions	(Weir and Torell 1967)

* age in months, beginning at weaning

† x × y means x number in y groups

‡ Abbreviations refer to Australian states: NSW: New South Wales; SA: South Australia; Vic: Victoria; WA: Western Australia

Bodyweight

Poor body condition and low growth rates at various ages have been shown to be associated with reduced survival of small ruminants after weaning. A postal survey of 79 enterprises in the Victorian Mallee (Harris and Nowara 1995) characterised patterns of sheep mortality on mixed farms (i.e. cereal cropping and sheep). In flocks experiencing more than 5% weaner deaths, loss of body condition was the clinical sign most frequently reported by farmers, with 86% of flocks in moderate or thin body condition when high mortalities were most likely to occur.

A number of field studies have further characterised the relationship between mortality and bodyweight (Ganai and Pandey 1996 ; Hary 2002 ; Turkson and Sualisu 2005). In general, these have shown that the relationship is independent of a weaner's age at death and the cause of death. For example, in studies of Rambouillet lambs in India (Ganai and Pandey 1996), East African Dwarf goat kids in Kenya (Hary 2002) and Sahelian lambs in Ghana (Turkson and Sualisu 2005), animals lighter than the average birthweight of 2–3 kg, were approximately twice as likely to die after weaning than heavier-than-average birthweight animals, even when weaning occurred up to five months after birth. In all instances, the association between birthweight and mortality persisted for as long as the progeny were observed, which was to one (lambs) or two (kids) years of age.

Weight at weaning has been shown to have a similar, persistent association with post-weaning survival. Increases in weaning weight of 5–10 kg in Merinos have been associated with approximately two- to four-fold decreases in post-weaning mortality risk, as follows:

- 9% deaths at 22 kg vs. 2% at 27 kg (Allden 1968a)
- 80% at 12 kg vs. 33% at 21 kg (Lloyd Davies 1983)
- 18% 11 kg at vs. 6% at 15 kg (Lloyd Davies *et al.* 1988)
- 21% at 15 kg vs. 4% at >27 kg (Holmes 1992)

All of these results equate approximately to an odds of death ratio of 1.3–1.5 for a 1 kg decrease in weaning weight. A similar mortality pattern across weight groups was also observed in a drought feeding study, even though the sheep were only followed until four months of age (Franklin *et al.* 1964).

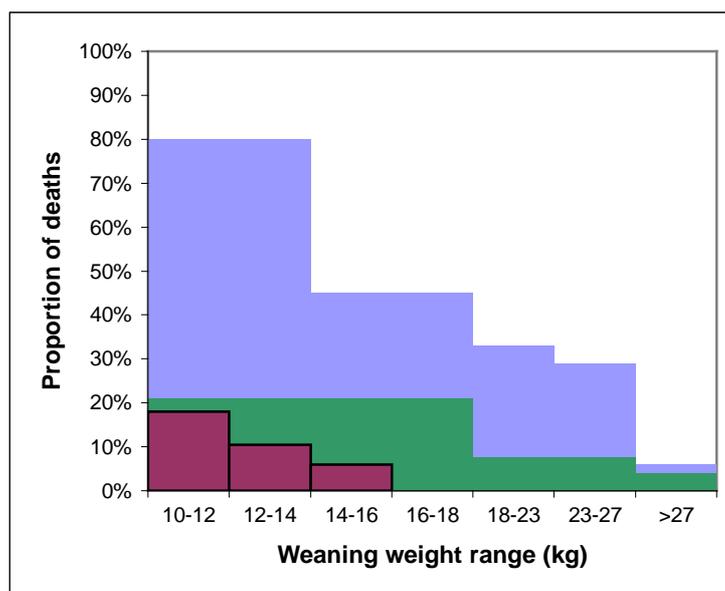
Two trace element supplementation trials showed that a greater proportion of weaners that were below average bodyweight at weaning died after weaning than ones of above average bodyweight. Amongst sheep grazing native pastures in East Gippsland, Victoria, 21%, 8% and 4% sheep died from the lightest, middle and heaviest third of weaners respectively

(Holmes 1992; Figure 1). On Kangaroo Island, South Australia, 75–83% of weaners grazing improved pastures that died were lighter than the average breed/strain weaning weight (Walker *et al.* 1979). Similar results were observed in a feedlot trial involving Merino-cross weaners receiving wheat-based rations, where survivors were significantly heavier than weaners that died (6.5–9.5% deaths between 3 and 9 months of age; Davis *et al.* 1976).

The similar results reported by all the studies discussed above is striking because they were conducted in widely differing environments in Western Australia, South Australia and New South Wales, and in different production systems with different lambing times. They also included studies of sheep grazing pasture or being fed in drought or production feedlots.

No studies have directly compared weights at birth, weaning and later times to survival, making it difficult to assess the relative importance of weight at different times to survival. However, two studies have shown that bodyweight had a similar association with risk of death of weaners, regardless of when it was measured. One examined survival of Red Maasai, Dorper and crossbred sheep in Kenya between weaning (at three months old) and twelve months of age (Nguti *et al.* 2003), during which time 31% (443/1442) of weaners died. Decreased weaning weight was associated with increased mortality rate, with the largest effect at low bodyweights. A 1 kg decrease in weaning weight increased the mortality risk of lightweight weaners by about 60%, equating to a hazard ratio of about 1.6, and this effect

Figure 1: Mortalities in Merino weaner sheep, classified by weight at weaning, from: 3–12 months of age on pasture (Lloyd Davies 1983), 3–6 months of age in a drought feedlot (Lloyd Davies *et al.* 1988), and 4½–6 months of age on pasture (Holmes 1992)



became progressively smaller for heavier weaners. A similar effect was estimated for bodyweight at any time in the post-weaning period if this time-varying term was used instead of weaning weight in the statistical model. Although no techniques exist to readily estimate how comprehensively one survival model accounts for observed variation compared to another, this result suggests that it is bodyweight in general, rather than birth or weaning weight in particular, that is associated with mortality.

The second study to analyse the effects on mortality of both weaning weight and general bodyweight examined deaths caused by gastrointestinal parasites of Creole goat kids grazing irrigated pastures in the tropical French West Indies (Mandonnet *et al.* 2003). The hazard ratio for a 1 kg decrease in weaning weight was 1.33. The hazard ratio for a bodyweight decrease of 1 kg at any time was 1.69. The reason for the difference between the hazard ratios for weaning weight and time-varying bodyweight was not discussed. The inclusion of bodyweight as a time-varying covariate eliminated significant associations between mortality and three other explanatory factors, sex, rearing method and anthelmintic treatment. The authors noted that this did not necessarily imply that bodyweight was the only factor to significantly influence mortality. This was because kids in the study died after severe weight loss and, although other factors may have contributed to mortality, the reduction in bodyweight prior to death was so profound that other effects were statistically diminished to the point of non-significance. Only death caused by gastrointestinal parasites, which are not typically associated with acute mortality, was examined.

All the results discussed above show that similar associations between post-weaning mortality risk and bodyweight exist, regardless of whether the sheep are weighed at birth, weaning or a later time. Generally, a 1 kg weight decrease was associated with an odds or hazard ratio ranging from 1.3 to 2. The consistency of these observations is remarkable because they were made in widely ranging environments (Mediterranean-type, semi-arid and tropical), involved very different breeds and crosses of sheep and goats and were independent of the cause of death. Weaning weight has been shown to be well correlated with weight at subsequent times (Lloyd Davies *et al.* 1968 in Merinos), so it is likely that the association between mortality and weight at a particular time such as weaning is actually a reflection of a more general association between bodyweight and survival.

Lamb bodyweight at premature weaning has also been shown to be associated with risk of death in several experiments. Within groups of Merino lambs weaned at different ages between 4 and 12 weeks, survivors were 1–2 kg heavier when weaned onto a cereal grain and chaff diet than those that died (Franklin *et al.* 1964). The heavier weaning weight of survivors was associated with a heavier birthweight, and a higher pre- and post-weaning

growth rate. All the lambs that died either lost weight or experienced negligible gain after weaning. Lambs weaned at a younger age also died more quickly than later-weaned lambs, despite being of similar bodyweight (7–9 kg) at weaning. For lambs weaned at the same age, there was no association between weaning weight and survival time but the range in weaning weight was small. In contrast, when Merino-cross lambs were weaned at three weeks onto a pelleted ration, there was a strong correlation ($r = 0.94$) between weaning weight and duration of survival after weaning (Walker and Hunt 1980). In this experiment, the distribution of weaning weights was greater and three quarters of the lambs died within four weeks as a result of poor consumption of the ration. Walker and Hunt concluded that bodyweight was associated with post-weaning survival in these young sheep because increasing weight represents the accumulation of energy stores required to sustain the lamb during adaptation to a new nutritional situation. Thus, lightweight lambs were more likely to die because their lower body energy stores were exhausted before full adaptation to the new diet rendered the reserves unnecessary. This concept is discussed in more detail below.

Growth Rate

Allden's (1968a) study of the effects of undernutrition of growing Merinos on lifetime production presented data that suggest associations between post-weaning growth rate, as well as weaning weight, and survival. The sheep were born in May in South Australia and weaned at six months of age. Nutrition was restricted before or after weaning by varying the stocking rate of ewes and lambs grazing green pasture during winter and spring, or withholding supplementary feeding when weaners grazed dry pasture throughout summer and

Table 3: Post-weaning mortality of sheep in different nutritional groups reported by Allden (1968a)

Nutritional treatment		Average weight at end of period (kg)	Post-weaning mortality
pre-weaning:	low	22.0	9%
	high	27.0	2%
post-weaning:	low	n/a	9%
	high	n/a	2%
pre- & post-weaning:	low-low	17.4	13%
	low-high	26.0	4%
	high-low	22.8	5%
	high-high	31.2	0%

autumn. Thus “low” and “high” pre-weaning nutrition groups were further divided by “low” and “high” post-weaning nutrition. This created four groups of 24 sheep that had experienced different nutritional regimes throughout their first year of life. The mortality proportions are summarised in Table 3. No vaccination against clostridial diseases was performed and 13% of lambs died of enterotoxaemia before weaning. These deaths, from a preventable disease, obscure any relationship between bodyweight, growth rate and survival in the 0–6 months period, and the 0–12 months period. However, from 6 to 12 months, more light weaning weight (average 22 kg) sheep died than heavy weaning weight (average 27 kg) sheep. In addition, more weaners that were nutritionally restricted after weaning (average weight loss 0.8 kg/month from 6–12 months of age) died than weaners fed *ad libitum* after weaning (average growth rate 0.8 kg/month). Alden commented that, “It is probable that under extensive grazing conditions and with no immediate access to water more of these [low pre- and post-weaning nutrition] sheep would have died.” The trial involved low numbers of animals, so no difference between proportions was statistically significant. Furthermore, because the survival of individuals was not analysed, it is not clear whether weaner survival was associated with absolute bodyweight or rate of weight change. Nevertheless, the results point to relationships between mortality and both weaning weight and post-weaning growth rate consistent with those of the more specific mortality studies discussed previously.

There was no relationship between the level of supplementary feeding and mortality in Merino weaners kept in a drought feedlot in New South Wales (Lloyd Davies *et al.* 1988). However, weaner growth rate and final bodyweight in each treatment were similar, despite the diets differing in metabolisable energy 2 MJ/kg. This lack of difference in growth rate might explain why similar numbers of sheep died in each group. Similarly, weaner bodyweight and the rate of weight loss were related to survival of Merino-cross sheep being fed wheat-based rations for production in feedlots (Davis *et al.* 1976). In that experiment, 43% of sheep that died lost more than 100 g/day prior to death and the weaners that died were significantly lighter than those that survived. The deaths were independent of ration formulation and feedlot management.

Mulhearn’s (1958) reports of Merino weaner management in South Australia contain information about bodyweight and mortality, although it is confounded with the effect of season and property-specific management practices, such as supplementary feeding. He observed that no winter-born weaners died during summer in a year when the average peak summer bodyweight was 37 kg. However 15% died in the following year when post-weaning growth rates were lower and average peak summer bodyweight was 27 kg. In the high-mortality year, groups of weaners grazing dry pasture were supplemented with oats or linseed

meal *ad libitum* and compared to weaners receiving no supplement. Supplemented weaners gained an average of 2.5 kg/month (linseed) and 1.6 kg/month (oats) but unsupplemented weaners lost 1 kg/month between February and May. In the oats and linseed groups, 8% and 10% died, respectively, compared to 28% of weaners in the control group. Deaths also continued for longer in the control group and nearly all the weaners that died were of low weight or emaciated. In the supplemented groups, it was noted that the weaners that died were lighter prior to the start of supplementation. This pattern of mortality was similar to those described by Allden (1968a) and Lloyd Davies (1983; 1988) and Hodge (1990). Mulhearn described a situation of fewer deaths and smaller differences between groups on another property where different supplements were used. However on this farm the controls experienced only a slight weight loss whilst grazing dry pasture. This suggests that it is the bodyweight or growth rate achieved by supplementary feeding, rather than the provision of feed itself, that is associated with mortality.

In a field experiment in the same environment, 20% (3/15) of a monitor group of unsupplemented autumn-born Merino weaners died, compared to no deaths in groups receiving various supplementary feeds (Allden and Anderson 1957). During summer it became necessary to start feeding the unsupplemented group, as “many of the young sheep were...in critical condition” (p. 75). The unsupplemented sheep were at least 1 kg lighter than their counterparts at the start of feeding in January and lost 4 kg throughout February, when the deaths occurred, compared to gains of 0.2 and 2.2 kg/month by the weaners receiving supplementary feed. In another study in Victoria, approximately four times as many deaths occurred in a group of Merino weaners grazing dry pasture over summer without supplementation (McLaughlin 1973). Although detailed data were not presented, unsupplemented and supplemented weaners were approximately the same weight at weaning but unsupplemented weaners always grew at a slower rate than the supplemented groups.

Mortality patterns also coincided with bodyweight changes rather than feeding regimes in a seven-year trial of supplementary feeding strategies for weaner wool sheep in a Mediterranean-type climate in inland California (Weir and Torell 1967). Significant mortalities occurred in only one year, which was associated with light weaning weight and weight loss over summer when the nutritional quality of pastures was particularly poor. In this year, 17% of unsupplemented (control) weaner sheep died between the start of summer and the following spring, whereas there were only “minor...losses” in the groups receiving supplementary feed. These results were in contrast to those from another year, when, although similar weight loss occurred during summer, sheep had been considerably heavier at

weaning and the death rate was much lower. These results are similar to those of Allden *et al.* (1968a), discussed above.

In the studies described above, the associations between bodyweight, bodyweight change and mortality rate were confounded with the provision of supplementary feed. However the patterns of mortality across the different bodyweight or growth rate groups were similar, regardless of the type of supplementary feed provided. Furthermore, supplementary feeding was only associated with differences in survival if it was accompanied by a growth rate response. This suggests that bodyweight or bodyweight change, rather than supplementary feeding *per se*, is associated with survival of weaner sheep. However the notion that generally providing supplementary feed to Merino weaners effectively prevents excessive mortalities was challenged by Norris (1986), who found no correlation between the cost of supplementary feed and Merino weaner survival on 10 different farms in south-west Western Australia. He concluded that farmers did not understand the specific protein and energy requirements of Merino weaners and therefore failed to prevent weaner mortalities because they provided inappropriate supplementary feed, especially hay.

It is difficult to make general statements about the extent to which dry pastures match the nutritional requirements of weaner sheep because the nutritional characteristics of summer pastures vary tremendously between locations and seasons. Furthermore, the nutritional requirements of weaners also change as they grow older. One study of supplementary nutrition for Merino weaners grazing typical dry, summer pastures in southern Australia showed a linear response of liveweight gain to increasing energy supplementation but a declining response to increasing levels of supplementary protein (Allden 1959). From these results Allden concluded that such pastures primarily fail to meet weaners' energy requirements but are only nominally deficient in protein. Similarly, Foot *et al.* (1983) commented that weaners do not show a response to supplementary protein if even small amounts of green feed, which is high in protein, are present in the pasture being grazed. In contrast, another experiment achieved higher growth rates in Merino weaners by increasing the protein content of isocaloric supplementary rations offered from December to May (9–15 months of age) (Lloyd Davies *et al.* 1968). Weaners offered a supplement containing 22% crude protein (CP) grew at 1 kg/month from December to March, whereas weaners offered a supplement containing 8% CP gained 0.6 kg/month, whilst a control group offered no supplement lost 0.8 kg/month throughout this time. However, no comparison was made between these diets and the expected protein intake from grazing pastures containing different quantities of green feed.

Associations between Bodyweight & Death from Causes Other Than Malnutrition

Many of the studies reporting an association between bodyweight and survival have focussed on deaths of weaners during summer, when growing sheep frequently suffer malnutrition while grazing the dry pastures typical of the Mediterranean-type environment of southern Australia (Bellotti *et al.* 1993). An association between bodyweight and survival of sheep grazing dry pastures and dying principally from malnutrition is unsurprising, as weight loss inevitably precedes death. However several studies have reported a similar association between bodyweight and death at other times of the year and when weaners die from other causes. For example, a study of three strains (Merryville, Peppin and Collinsville) of Merino weaners showed that bodyweight was related to risk of death due to gastrointestinal parasitism during winter in southern Victoria (Hodge 1990, summarised in Table 4). In that study, lambs born in October were weaned at between nine and 20 weeks of age, in order to create different weaning weight groups. They were then fed to maintain weight until the following April. At this time they were either grazed on abundant or restricted pasture (>1500 kg DM/ha or <700 kg green DM/ha), resulting in growth of 3.3 kg/month or approximate maintenance of weight (lost or gained < 0.3 kg/month) respectively. This resulted in bodyweights at the end of the autumn break that varied approximately twofold—from 16 kg to 30 kg (for Merryville and Peppin strains), and 21 kg to 37 kg (Collinsville). Most deaths occurred in the groups that were light at weaning and then only maintained weight during autumn. Significantly fewer weaners died in the two groups that achieved an intermediate weight by the end of autumn. No deaths occurred in the group that were heaviest at weaning and then gained weight throughout autumn. It is of significance that similar deaths occurred in the two groups of equal weight at the end of autumn, regardless of how it was achieved. This suggests that it is absolute bodyweight, rather than the timing of its acquisition, that is associated with survival. No association was observed between proportion of weaners dying and their rate of growth during winter. However results for individual animals were not reported and so more detailed relationships between growth rates and mortality may have been overlooked.

An association between bodyweight and mortality that extended beyond times of malnutrition was also observed in survival analyses conducted overseas of sheep (Nguti *et al.* 2003) and goats (Mandonnet *et al.* 2003). In these analyses, the ratio between death rates of animals from different weight group classes remained constant over time. This indicated that bodyweight differences accounted for the same difference in risk of death, regardless of the time of year. Additionally, no cause of death was specified in Nguti *et al.*'s (2003) study, yet bodyweight was significantly associated with survival. In Hary's (2002) study, gastrointestinal parasites, and not malnutrition, were a leading cause of death. These results are particularly significant, since bodyweight was associated with survival even though the cause of death was not directly related to nutrition.

Physiology Underlying the Association between Mortality & Bodyweight

It is appropriate to consider briefly how bodyweight might confer a survival advantage on weaner sheep and whether such mechanisms are consistent with the results described above. Following a period of weight loss, death occurs when body energy reserves have been fully consumed and the function of the vital organs is compromised as they are catabolised in an attempt to meet the animal's daily metabolic requirements (Thornton *et al.* 1979). Lightweight sheep are at greater risk of death from this process than their heavier counterparts for several different reasons, which are discussed in more detail below.

An important aspect of the association between bodyweight and survival is that the total body energy stores of weaner sheep increase with liveweight. A linear relationship, independent of breed, between total body energy and liveweight was demonstrated in an experiment that measured body composition and total energy of Merino and Merino × Dorset Horn sheep between weaning at 7 weeks (average liveweight 15 kg) and 10 months of age (average liveweight 45 kg; Allden 1970). Heavy sheep had a higher energy density than lightweight ones and the proportion of energy stored as fat also increased as the animals grew. For

Table 4: Mortality of weaners with different weaning weights and autumn growth rates reported by Hodge (1990)

Weaning weight	Autumn growth rate (kg/month)	
	0	3.3
low	11–22% *	4–5%
intermediate	0–5%	0%
high	0–4%	0%

* range is for different strains

example, at 15 kg, energy density was approximately 1 MJ/kg and 13% of total body energy was stored as fat, whereas the energy density of weaners weighing 30 kg was 2.2 MJ/kg and 70% was stored as fat. The variation of fat content with bodyweight has also been shown to be independent of the growth rate of sheep of different breeds (Kellaway 1973).

These results indicate three mechanisms by which heavy weaners can mobilise body energy with less risk of dying than light weaners. Firstly, heavy weaners have a greater total body energy reserve upon which they can draw. Secondly, heavy weaners will lose less weight in mobilising a given quantity of body energy than light weaners because of their higher energy density. Finally, more of this reserve is fat, the catabolism of which spares protein in the vital organs (Thornton *et al.* 1979). Therefore, light weaners forced to mobilise body energy, for any reason, will lose more weight than heavy weaners, and a greater proportion of this weight loss will be protein contained in vital tissues, to the detriment of organ function and ultimately survival (Allden 1970; Doyle and Egan 1983).

Once weaners are lightweight, their mortality risk is increased further because they replace lost body protein more slowly than heavy sheep under conditions of limiting protein and energy intake (Allden 1970). Such nutritional conditions are typically experienced by sheep grazing dry summer pastures in southern Australia. For example, in a field study of Merino weaners grazing poor quality, dry phalaris/subterranean clover pastures in South Australia, heavy (average 36 kg) sheep prior to the period of summer weight loss regained bodyweight more quickly than light (28 kg) ones during the following winter (Donald and Allden 1959). This was despite the more severe nutritional circumstances during summer experienced by the heavier group.

The age at which growth is restricted also affects how quickly young sheep regain weight, which in turn influences the length of time they remain at risk of death from low bodyweight. Merinos whose growth was restricted before 6 months of age recovered bodyweight more slowly than weaners restricted between 6 and 12 months of age (Allden 1968b). When Corriedale ewes were nutritionally restricted (by weaning onto dry pasture) at 8 weeks of age, they were 10% lighter at their first mating (38 vs. 42 kg) than if they were weaned at 12 or 16 weeks (McLaughlin 1966).

Finally, weaner sheep can consume nearly 20% more highly digestible feed than adults, relative to metabolic liveweight but their relative feed intake decreases at lower digestibilities, and is similar to adults at feed digestibilities of 46% and 56% (Egan and Doyle 1982). Thus, nutritional deficiencies of dry summer pastures are exacerbated for weaner sheep because their intake is relatively lower when grazing feeds of lower digestibility.

The nutritional deficiencies that occur when grazing dry pasture explain the improvement in survival achieved by providing weaners with appropriate supplementary feed. Providing high-digestibility supplementary feed during times of nutritional deprivation increases, or at least reduces the decline in, the fat and total body energy content of the weaner sheep's carcass (Weir and Torell 1967). Furthermore, the growth response to supplementary feeding over a weaner's first summer of life has been shown to be independent of the weaner's age (Marshall 1985). This shows that weight loss, and its associated survival outcomes, is not obligatory for even young sheep grazing summer dry pastures, provided they receive appropriate supplementary nutrition.

Season & Year of Birth

Studies that have spanned more than one year show that weaner mortality can vary substantially from season to season and/or year to year, although the effects have not always been reported directly or quantified. In southern Australia, most weaner deaths occur during summer. For example, in field experiments in South Australia, 82% and 79% of all weaner deaths occurred between January and March, regardless of the age of the sheep (Lloyd Davies *et al.* 1968; Lloyd Davies 1983). Similarly, in western Victoria, half of all the occurrences of excessive mortality in weaner flocks occurred between February and April (Engel 1958). Such seasonal peak in mortality is consistent with the decline in bodyweight, and increase in risk of death, experienced by weaners grazing the dry summer pastures of southern Australia, as discussed in the previous section.

In contrast to these findings, Harris and Nowara (1995) reported that the deaths in nearly all weaner flocks with greater than 5% mortality occurred between May and August, or during December. Unfortunately, no breakdown between Merino and non-Merino flocks was provided. This survey was primarily of cereal grain cropping enterprises, where weaners often graze crop stubbles during summer and autumn. Summer weaner mortality may therefore have been lower than in solely pasture-grazing enterprises because of the improved nutrition afforded by stubbles and residual grain soon after harvest.

In contrast to the association between dry conditions and increased weaner mortality, some studies have reported that weaner mortality is greater during seasons of higher rainfall, when it would be expected that feed quantity and quality would satisfy the nutritional requirements of weaner sheep (for example, Beveridge *et al.* 1985; Mandonnet *et al.* 2003; Nguti *et al.* 2003). In these situations, gastrointestinal parasites are invariably implicated in the increased mortality risk. For example, an Australian field study that reported the seasonal distribution of deaths of Merino weaner sheep compared different parasite control strategies at Kybybolite

in the high-rainfall zone of South Australia (Beveridge *et al.* 1985). Significant deaths only occurred in the groups that were not treated for gastrointestinal parasites, and then most occurred during the winter months (up to 15%/month). However, significant numbers of untreated weaners did die between December and April in two of five years. In these instances, the poor nutrition of weaners during summer was considered to have predisposed them to death from gastrointestinal parasitism, despite the relatively low parasite burdens at this time.

Disease

Many studies have reported associations between weaner mortality and specific diseases, although there are few surveys of causes of weaner mortality in Australia. Amongst Merino weaner flocks in the Victorian Mallee, loss of condition, blowfly strike and diarrhoea were the signs most frequently reported by farmers in flocks experiencing more than 5% mortality (Holmes 1992; Harris and Nowara 1995). The authors more generally considered that pyrrolizidine alkaloid poisoning from grazing heliotrope (*Heliotropium europaeum*) was a leading cause of mortality in the Mallee and that gastrointestinal parasitism was less common because of the low rainfall environment and the fact that many sheep grazed crop stubbles for a part of each year. However they did not discuss weaner mortality in more detail.

Oral selenium supplementation reduced mortalities (6% *vs.* 16%) in the first 52 days after weaning amongst Merino weaners in a field trial in the East Gippsland region of Victoria, where soil deficiencies of selenium, cobalt and copper were suspected (Gabbedy 1971). Selenium administration appeared to have a direct effect on mortality because it was not associated with increased growth rate or bodyweight. Similar reductions, independent of bodyweight change, were observed on some farms in south-western Western Australia during a selenium supplementation trial (McDonald 1975). However in another study, repeated oral selenium supplementation increased weaner bodyweight by 2 kg between 3 and 12 months of age, as well as decreasing mortalities (0% *vs.* 18% in the untreated groups), despite untreated lambs showing no post-mortem signs of white muscle disease (Nguti *et al.* 2003).

An overseas study quantified the risk of death associated with weaner faecal egg count (FEC), packed cell volume (PCV) and anthelmintic treatment (Hodge 1990). This study was conducted in the sub-tropics and *Haemonchus contortus* was the most commonly identified endoparasite. An increase of 1000 eggs per gram was associated with a hazard ratio of 1.0–2.1, which is similar to the hazard ratio associated with a 1 kg decrease in bodyweight, and a 1% decrease in PCV was associated with a 16% increase in mortality rate. All causes of death were examined and changes in PCV were not all associated with clinical haemonchosis.

Anthelmintic treatment also reduced the risk of death by 77% in the 3 weeks following treatment. As has been discussed previously, increased bodyweight prior to acquiring nematode infection has also been shown to reduce the risk of death from parasitism (Lloyd Davies 1983).

Maternal Factors Affecting Weaner Survival

Maternal bodyweight, body condition, parity, stocking rate and milk yield, as well as size of the litter produced, have been shown to be associated with the survival of offspring following weaning (Table 5). However, no studies have actually investigated the mechanism of action of these associations.

The results of one study suggested that some of these factors may indirectly influence

Table 5: Maternal factors associated with weaner mortality

Maternal factor	Species/Breed	Measurement of mortality	Magnitude of effect	Reference
Stocking rate/ liveweight	Merino	% mortality	20% at 12 ewe/ha & 48 kg vs. 9% at 4/ha & 52 kg	(Ganai and Pandey 1996)
Parity	Rambouillet	% mortality	lower mortality from lower parity ewes	(Ganai and Pandey 1996)
Litter size	Rambouillet	% mortality	77% twins vs. 79% singletons (P < 0.05)	(Nguti <i>et al.</i> 2003)
Age	Dorper & Maasai sheep	hazard ratio	0.7–0.4 for >2 y.o. vs. 2 y.o. (P < 0.001)	(Southey <i>et al.</i> 2001)
	meat breed sheep	hazard ratio	0.63: 4 yo vs. younger	(Nivsarkar <i>et al.</i> 1982)
Weight at lambing	Indian sheep breeds	% mortality	decreased as maternal weight at lambing increased	(Ikwuegbu <i>et al.</i> 1995)
	West African Dwarf Goat	cumulative mortality	mortality lowest for 2nd & 3rd parity ewes (P > 0.05)	(Mandonnet <i>et al.</i> 2003)
Rearing method	Creole goats	hazard ratio	2.5 ± 1.2 artificial vs. maternal	(Southey <i>et al.</i> 2001)
	meat breed sheep	hazard ratio	5.9 ± 1.2 artificial vs. maternal	(Hary 2002)
Milk yield	East African Goat	hazard ratio	≈ 2 for total dam milk yield < 22.5 kg vs. ≥ 22.5 kg	(Hary 2002)

survival through their effect on weaner bodyweight (Lloyd Davies 1983). Although maternal

milk yield was significantly associated with mortality rate, the relationship between litter size and post-weaning survival became non-significant once the statistical model was adjusted for birthweight and total dam milk production. This suggested that litter size was not a “primary risk factor” for weaner mortality but acted via direct factors such as neonatal bodyweight and growth. An indirect relationship between litter size—or other similar factors—and post-weaning survival, mediated via weaning weight, is appealing. However other mechanisms of action—increased colostrum intake and improved offspring immune function, for example—cannot be excluded. Indeed, total milk yield continued to account for variation in survival along with bodyweight. This suggests that the effect of the former was, at least in part, independent of the latter.

Other studies have also suggested associations between maternal factors and weaner survival but do not propose or elucidate mechanisms of action for them. In a study of the effect of stocking rate and time of lambing on Merino ewe and weaner production in Western Australia, post-weaning mortality was two times greater (20% vs. 9%) amongst ewes and lambs stocked at 12 ewes/ha than those stocked at 4 ewes/ha (Lloyd Davies 1962). Lloyd Davies did not comment on the cause for this difference but, in a subset of this data, average ewe liveweight declined from 52 kg to 48 kg as stocking rate was increased over this range (Foot *et al.* 1987). This, in turn, may have been associated with decreased maternal milk production, to the detriment of offspring weaning weight, since heavier dams in better condition usually produce more milk (Nivsarkar *et al.* 1982).

In a less sophisticated analysis than Hary’s or Lloyd Davies’, a lower proportion of weaner deaths was observed amongst the offspring of ewes that were heavier at lambing (Ganai and Pandey 1996), although no summary data were presented. An explanation of this relationship was not proposed, although it is reasonable to assume that ewe bodyweight was related to milk production, as in the other studies. Similarly, the slightly lower survival noted amongst Rambouillet weaner sheep in India born as twins, compared to singletons, was presumed to be mediated via birthweight, although no further analysis was performed (Southey *et al.* 2001).

In Ganai and Pandey’s study, associations between weaner survival, litter size and ewe parity were also “largely explained” by the effect of the latter two factors on birthweight, although these relationships were not explored in detail. Over the three months following weaning, more offspring of seventh parity ewes died than offspring of younger ewes (10% vs. 6%). Conversely, in two other studies, weaners born to primiparous ewes had a greater risk of death than the offspring of multiparous ewes (Southey *et al.* 2001; Nguti *et al.* 2003). All of these results might be explained by younger, multiparous ewes having higher milk yields and thus weaning heavier offspring, to the benefit of weaner survival. This was demonstrated in

Ikwuegbu *et al.*'s study, in which kids born to first-parity does had lower weaning weights and post-weaning growth rates than kids born to second- and third-parity does.

Southey *et al.* (2001) reported that artificially reared weaner sheep in feedlots died at 5.9 times the rate of maternally reared weaners.. In Mandonnet *et al.*'s study, the association between rearing method and mortality, along with other factors, became non-significant when time-varying covariates representing FEC, PCV and bodyweight were added to the model. As with the other maternal factors discussed above, such a change in the statistical model suggests that rearing method is not a primary risk factor. Instead, it is likely that its association with post-weaning survival is mediated via another factor or factors. Although likely mechanisms were not proposed by Southey *et al.* or Mandonnet *et al.*, possibilities could include an effect of rearing method on lamb bodyweight or immunocompetence.

Sex

Several overseas studies have consistently demonstrated that male weaners face a greater risk of death than females, although no comparable results have been reported in Australia. Southey *et al.* (Turkson and Sualisu 2005) reported the odds of male weaner meat sheep dying in feedlots to be 40% higher than the odds of females dying. This is consistent with the odds (OR) and hazard ratios (HR) reported in Sahelian (Nguti *et al.* 2003, OR 1.7), and Maasai, Dorper and crossbred (Turkson *et al.* 2004, HR 1.4) sheep in Africa, as well as West African dwarf goats (Barger 1993, OR 1.8). Similarly, in a study of survival of Indian sheep breeds, 10% of male weaners died between 3 and 6 months of age, compared to 5% of females. In a study of Creole goat kid deaths due to gastrointestinal parasitism, males died at 3 times the rate of females. No explanation of this widely observed phenomenon has been offered. It has been previously recognised that males are more susceptible to strongyle infection than females, although the reason remains unclear (Nguti *et al.* 2003). However this does not explain the higher mortality rate reported in the other studies, where deaths were not only caused by parasitism. In fact, in the analysis of the subset of Maasai and Dorper weaners that died of gastrointestinal parasitism, there was no difference in mortality rate between the sexes (Mersmann 1987).

Since male lambs and kids, but not females, are often castrated, increased deaths amongst males may be associated with post-operative infection or other complications following this procedure. However castration was not routinely performed in all studies discussed here. When it was performed, it was often done at birth, yet sex differences in mortality sometimes persisted to 12 months of age. This is an unlikely duration of effect for a surgical procedure that heals in several weeks. Another potential reason for the difference in mortality risk could

be differences in body composition between male and female weaners. Sex hormones are known to affect the deposition of muscle and fat (Allden 1968c) and the consequent difference may influence risk of death.

Weaner Mortality—Summary

Few surveys, and no specific mortality studies, of Merino weaners have been conducted in southern Australia but the available evidence suggests that post-weaning mortality commonly exceeds 15%, which is no better than that achieved in goat and sheep flocks run by subsistence farmers in Africa. In overseas studies, survival analyses have demonstrated associations between mortality and a variety of factors that have been incidentally suggested or remarked upon in Australian experiments involving Merinos. The outstanding feature of this review is that remarkably similar results have been obtained over a tremendous variation in countries, climatic conditions, ruminant species and production systems.

Bodyweight is the factor most frequently reported to be associated with post-weaning mortality and this association has also been the most widely investigated. Weaners of lower bodyweight invariably have been shown to be at higher risk of death than heavy weaners, regardless of when weight is measured or the actual rate of weight gain, with a 1 kg bodyweight decrease usually associated with a 30–70% increase in risk. In several studies, specifically increasing the bodyweight of lightweight weaners has reduced mortality more than weight increases amongst heavy weaners. Providing supplementary feed to weaners appears to reduce mortality by increasing bodyweight, rather than via some direct effect of the feed itself. Similarly, weaner bodyweight has appeared, at least partly, to mediate the association between mortality and maternal factors such as parity, litter size and condition score.

Seasonal and annual variation in weaner mortality is common, with more favourable survival associated with increased availability of high quality pasture to meet the critical nutritional requirements of weaner sheep. Perversely, such environmental conditions may also favour the development of increased burdens of gastrointestinal nematodes, which can lead to the death of large numbers of weaner sheep. The association between mortality and specific measures of the severity of some parasite infections, such as faecal egg count and packed cell volume, have also been quantified.

The modest body of work concerning post-weaning survival has translated into few quantitative recommendations for the management of Merino weaners in Australia. Allden's findings that Merino weaners can resume normal growth if they reach 40% of adult weight before experiencing summer weight loss (1969) and that weaners can substitute a substantial

amount of summer pasture for supplementary feed (1987) led him to conclude that “supplementation [is un]attractive except when feeding for survival”. The principal advice given for minimising post-weaning mortality is that lambs should reach at least of 45% of adult bodyweight by weaning or drying-off of pastures, whichever is the later, and then grow at 1 kg/month until the onset of autumn rains (Hosmer and Lemeshow 1999). Furthermore, as has been discussed here, for the Merino weaner in southern Australia, the relationships between bodyweight and growth, let alone other potential risk factors, remain unquantified.

Methodologies for Analysing Survival & Mortality

Survival analysis is the term commonly used to describe the statistical procedures that uniquely analyse time-to-event (also known as ‘survival time’ or ‘failure time’) data. It can be applied to the analysis of the occurrence of any well-defined event, not just death. However, the event of interest is usually non-recurring.

Data describing survival or other ‘time-to-event’ outcomes typically consist of two variables for each individual: (1) a continuous variable describing how long the individual was under observation, and (2) a binary variable indicating whether or not the individual experienced the event of interest, such as death (Hosmer and Lemeshow 1999).

Analysis of this data must take into account several characteristics unique to it. The ‘classical’ approach to analysing survival data involves analysis of variance or linear regression of survival proportions from specific points in the time under study. These methods, however, assume that all error terms are normally distributed and have equal variance. These assumptions are infrequently met by survival time data (Allison 1997; Hary 2002). On the other hand, logistic regression is suitable for analysing a binomially distributed outcome such as death. It provides intuitive information on the probability of an event’s occurrence but ignores the extra information offered by survival data on the timing of events (Southey *et al.* 2001). No information can be gleaned from logistic regression regarding differences between an individual that dies early in a study’s course and one that dies at the end (Dohoo *et al.* 2003). Survival analysis methodology addresses these key characteristics of time-to-event data that limit the use of other statistical techniques.

Survival analysis uses a variety of techniques to examine time-to-event data (Cox 1972). They are used to estimate the hazard and survivorship functions, make comparisons between them or estimate the effect of particular factors (or ‘covariates’ or ‘predictors’) on survivorship outcomes. Parametric models assume that the hazard is distributed as a defined

function, whereas semi-parametric models makes no assumption about the underlying hazard function but both techniques model multivariate effects of categorical and continuous predictors. In contrast, non-parametric techniques graphically describe survival data or make univariate comparisons between levels of a categorical covariate. The most commonly used technique is the semi-parametric Cox proportional hazards model (Royston and Parmar 2002).

A more recent parametric approach to survival analysis starts with a non-parametric graph of the hazard, which is then described mathematically using functions known as cubic splines (Royston and Parmar 2002). Covariates are then modelled in terms of their effects on this cubic spline function. This approach has the advantage of generating a more accurate mathematical representation of the observed hazard function, rather than approximating it by a simpler curve, such as the commonly used Weibull hazard (Hosmer and Lemeshow 1999).

In practical terms, survival analysis must accommodate censored data (Dohoo *et al.* 2003). Right-censoring occurs when individuals are present throughout the observation period but do not experience the event of interest before it ends. This may have occurred because the observation period simply ended before these individuals experienced the event, or the subjects were lost to follow-up during the observation period. Left-censored observations are ones where the event has already occurred before a subject comes under study. Finally, interval censoring occurs when an event has taken place within a certain time interval but the precise time of the event is not known (Radke 2003). Interval-censored data can take two different forms. When all individuals are observed at common time points, the data are termed synchronous interval-censored data. However if the censoring intervals are not the same for all individuals—if there is overlap, for example—then the data are termed asynchronous (Radke 2003). Interval censoring occurs almost universally in data from veterinary and agricultural experiments but is seldom taken into account during analysis (SAS Institute Inc. 2004).

Several commonly used statistical software packages are capable of analysing interval-censored data, including SAS/STAT (Insightful Corp. 2004), S-plus (Minitab Inc. 2005), Minitab (StataCorp 2005) and Stata (Lindsey and Ryan 1998). All of these programs are restricted to parametric or non-parametric analytical techniques and cannot perform semi-parametric interval-censored data analysis (Leung *et al.* 1997).

Interval-censored data can be approximated by using the beginning, midpoint or end of the censoring interval as an exact failure time and then performing the analysis with standard techniques. Approximating data using any of these approaches can produce variable results

(Radke 2003), depending on the extent of interval censoring in a survival dataset, as well as the methodology used. For example, Radke (1998) compared parametric analyses of interval-censored data and approximated data that used the beginning, midpoint or end of the intervals as exact failure times. In this data, many observations shared common censoring intervals and 61% of cases were left-censored. He used the same parametric hazard function *a priori* in all four analyses but its fit of the data was not tested. The models that ignored interval censoring substantially underestimated the categorical covariate effects. For example, several of the effects estimated from the approximated data were non-significant. Even when they were significant, they were not large enough to be considered important in a practical sense.

Alternatively, it has been suggested that interval censoring in parametric analysis can often be ignored and the midpoint of each failure interval used to approximate exact failure times instead (Lindsey and Ryan 1998). This author examined “difficult” datasets, although all had relatively few left-censored observations. Although indicating that the results may not always be reliable, he nevertheless stated that conclusions drawn from such analyses are remarkably robust, irrespective of the hazard function chosen for the parametric analysis.

J. C. Lindsey and L. M. Ryan (1998) compared both commercially available and novel interval-censored data analysis methods to Cox proportional hazards analysis of approximated data. All methods estimated similar covariate effects in one reasonably large data set (n=94; 54 interval-censored observations). However in smaller (n=31) and more heavily censored data with wide intervals and many right-censored observations, the Cox analysis of the approximated failure times underestimated the magnitude of the covariate effects by 25–50%. In conclusion, it appears that approximating interval-censored data using the midpoint of the censoring intervals is generally considered to produce satisfactory results, although the magnitude of the covariate effects may be underestimated.

Other techniques do exist for the analysis of interval-censored survival data. These include the piecewise constant (or piecewise exponential) hazard model, as well as non-parametric estimators and statistical tests (Hosmer and Lemeshow 1999). The piecewise constant model provides a result similar to the more common techniques. It analyses the survival outcomes from each censoring interval with logistic regression, which is applied to a dataset that has been transformed by what is known as a ‘link’ function (Hary 2002). This method was used by Hary (2003) and Southey *et al.* (1999) in analyses of weaner survival. In both these examples, all animals were observed at common time points. Therefore the data were synchronously interval-censored. Although a technique for applying this methodology to asynchronous interval-censored data has been suggested (Carstensen 1996; Farrington 1996), it is not implemented in any commercially available statistical software packages. It is also

difficult to obtain correct standard errors from this technique when it is applied to a proportional hazards model containing time-varying covariates (Allison 1997).

Survival analysis is also suited to the analysis of time-to-event data where the covariates to be analysed may take on different values over time, such as whether an animal has received an anthelmintic drench or not in the last month (Radke 2003). Such factors are termed time-varying covariates. However no commercial software exists that can analyse time-varying covariate effects in interval-censored data (Mandonnet *et al.* 2003).

Survival analysis of interval-censored data containing time-varying covariates therefore requires a compromise. If commercial software is to be used, then one of these aspects of the data must be approximated. Whether this occurs with the time-varying effect or the interval censoring will depend on which is considered the least important to the analysis.

Several studies illustrate the advantages of survival analysis and the difference between the results produced by different methodologies when analysing weaner mortality. For example, Mandonnet *et al.* (2001) analysed survival of goat kids with the Cox proportional hazard and Weibull parametric models, although only the Cox model results were reported. They also used time-varying covariates to identify several factors that had important associations with survival throughout the entire post-weaning period. They did not discuss the manner in which time-to-death data was collected or interval censoring issues. Southey *et al.* (2003) also used Weibull and Cox models to analyse survival of meat lambs raised in a feedlot, and compared these results to those from logistic regression. The hazard ratios from the two survival analysis models and odds ratios from the logistic regression were all very similar, although the standard errors of the odds ratios were larger and the authors noted that a methodology that properly accounts for censoring, such as survival analysis, is preferable. Nguti *et al.* (2002) carried out a Cox survival analysis of post-weaning mortality of lambs in Kenya. Again, the method for recording deaths was not stated. It appears that weaners were yarded approximately every four to six weeks, which would have created interval-censored data if this were the time when deaths were noted. Hary estimated odds ratios for covariate effects by performing logistic regression on biweekly survival records for goat kids. Hazard curves for different covariate levels were estimated using cubic spline functions and hazard ratios were calculated from these curves. This approach appears to favour comparisons between a small numbers of categories only. It would not be practical for analysing the effect of a continuous covariate unless it could be subdivided in this way. Whilst detailed comparisons were made between different time points on various hazard rate curves, the methodology did not generate hazard or odds ratios that summarised covariate effects well across larger time periods, or indeed the entire study.

References

- Allden WG, Anderson RA (1957) Unthriftiness in weaner sheep. *Journal of the Department of Agriculture South Australia* **61**, 69-86.
- Allden WG (1959) The summer nutrition of weaner sheep: The relative roles of available energy and protein when fed as supplements to sheep grazing mature pasture herbage. *Australian Journal of Agricultural Research* **10**, 219-236.
- Allden WG (1968a) Undernutrition of the Merino sheep and its sequelae. III. Effect on lifetime productivity of growth restrictions imposed at two stages of early post-natal life in a Mediterranean environment. *Australian Journal of Agricultural Research* **19**, 981-996.
- Allden WG (1968b) Undernutrition of Merino sheep and its sequelae. Iv. Herbage consumption and utilization of feed for wool production following growth restrictions imposed at 2 stages of early post-natal life in a Mediterranean environment. *Australian Journal of Agricultural Research* **19**, 997-1007.
- Allden WG (1968c) Undernutrition of Merino sheep and its sequelae. I. Growth and development of lambs following prolonged periods of nutritional stress. *Australian Journal of Agricultural Research* **19**, 621-638.
- Allden WG (1969) Summer nutrition of weaner sheep - voluntary feed intake, body weight change, and wool production of sheep grazing mature herbage of sown pasture in relation to intake of dietary energy under a supplementary feeding regime. *Australian Journal of Agricultural Research* **20**, 499-512.
- Allden WG (1970) The body composition and herbage utilization of grazing Merino and crossbred lambs during periods of growth and summer undernutrition. *Australian Journal of Agricultural Research* **21**, 261-272.
- Allison PD (1997) 'Survival analysis using the SAS system. A practical guide.' (SAS Institute Inc.: Cary, NC)
- Allworth MB (1983) Weaner illthrift - treatment and prevention. In 'Proceedings no. 67: Sheep production and preventive medicine'. (Ed. TG Hungerford) pp. 435-442. (University of Sydney Post-Graduate Foundation In Veterinary Science: Sydney)
- Allworth MB (1994) Flock health. In 'Merinos, money and management'. (Ed. FHW Morley) pp. 263-293. (University of Sydney Post-Graduate Committee in Veterinary Science: Sydney)
- Anderson N, Morris RS, McTaggart IK (1976) An economic analysis of two schemes for the anthelmintic control of helminthiasis in weaned lambs. *Australian Veterinary Journal* **52**, 174-180.
- Barger IA (1993) Influence of sex and reproductive status on susceptibility of ruminants to nematode parasitism. *International Journal for Parasitology* **23**, 463-470.
- Barton NJ, McCausland IP (1987) Production and economic returns from Merino weaner sheep subjected to four frequencies of anthelmintic administration in East Gippsland, Victoria. *Australian Journal of Experimental Agriculture* **27**, 759-764.
- Behrendt K (2003) Wipe out weaner mortalities with better nutrition. *Farming Ahead* **141**, 54-56.
- Bellotti W, Collins W, Moore A (1993) The Mediterranean environments. In 'Proceedings of a national workshop on management for wool quality in Mediterranean environments'. (Eds PT Doyle, JA Fortune and NR Adams) pp. 50-59. (Department of Agriculture Western Australia: Perth)
- Beveridge I, Brown TH, Fitzsimons SM *et al.* (1985) Mortality in weaner sheep in south Australia under different regimes of anthelmintic treatment. *Australian Journal of Agricultural Research* **36**, 857-865.
- Bortolussi G, Bird AR, Playford CL, Moore J (2004) Effect of hormonal growth promotant implants in weaner and hogget ewes on subsequent growth and reproductive performance. *Australian Journal of Experimental Agriculture* **44**, 755-761.
- Brown TH (1977) A comparison of continuous grazing and deferred autumn grazing of Merino ewes and lambs at 13 stocking rates. *Australian Journal of Agricultural Research* **28**, 947-961.

- Brown TH, Ford GE, Miller DW, Beveridge I (1985) Effect of anthelmintic dosing and stocking rate on the productivity of weaner sheep in a Mediterranean climate environment. *Australian Journal of Agricultural Research* **36**, 845-855.
- Carstensen B (1996) Regression models for interval censored survival data: Application to HIV infection in Danish homosexual men. *Statistics in Medicine* **15**, 2177-2189.
- Clunies Ross I (1934) Parasitological and other problems in sheep in Western Australia. *Journal of the Council for Scientific and Industrial Research* **7**, 1-8.
- Cobon DH, O'Sullivan PD, Connelly PT (1990) The effect of management strategies on the productivity of weaner sheep in north west Queensland. *Proceedings of the Australian Society of Animal Production* **18**, 466.
- Cox DR (1972) Regression models and life-tables. *Journal of the Royal Statistical Society, Series B* **34**, 187-220.
- Davis CH, Saville DG, McInnes P (1976) Production feeding of weaner lambs with diets based on wheat - effect of diets and management. *Proceedings of the Australian Society of Animal Production* **11**, 433-436.
- Denney GD, Thornberry KJ, Sladek MA (1988) The effect of pre and postnatal nutrient deprivation on live weight and wool production of single born Merino sheep. *Proceedings of the Australian Society of Animal Production* **17**, 174-177.
- Dohoo IR, Martin W, Stryhn H (2003) 'Veterinary epidemiologic research.' (AVC Inc.: Charlottetown, Canada)
- Donald CM, Allden WG (1959) The summer nutrition of weaner sheep: The deficiencies of the mature herbage of sown pasture as a feed for young sheep. *Australian Journal of Agricultural Research* **10**, 199-218.
- Doyle PT, Egan AR (1983) The utilization of nitrogen and sulfur by weaner and mature Merino sheep. *Australian Journal of Agricultural Research* **34**, 433-439.
- Drinan JP (1968) The relative productivity of single and twin born Merino ewes. *Proceedings of the Australian Society of Animal Production* **7**, 208-211.
- Egan AR, Doyle PT (1982) The effect of stage of maturity in sheep upon intake and digestion of roughage diets. *Australian Journal of Agricultural Research* **33**, 1099-1105.
- Engel AE (1958) Unthriftiness of weaner sheep in south-western Victoria. *Australian Veterinary Journal* **34**, 391-397.
- Farrington CP (1996) Interval censored survival data: A generalised linear modelling approach. *Statistics In Medicine* **15**, 283-292.
- Fogarty NM, Ingham VM, Gilmour AR *et al.* (2005) Genetic evaluation of crossbred lamb production. 2. Breed and fixed effects for post-weaning growth, carcass, and wool of first-cross lambs. *Australian Journal of Agricultural Research* **56**, 455-463.
- Foot JZ, McIntyre JS, Heazlewood PG (1983) Supplements for Merino weaner sheep grazing mature pastures in summer and autumn. *Australian Journal of Experimental Agriculture* **23**, 374-382.
- Foot JZ, Egan JK, Love KJ (1987) 'Sheep nutrition in the Victorian environment.' (Victorian Department of Agriculture and Rural Affairs: Melbourne)
- Franklin MC, McClymont JL, Briggs PK, Campbell BL (1955) Maintenance rations for Merino sheep. II. The performance of weaners fed daily and weekly on rations of wheat and wheaten chaff at maintenance levels and the effect thereon of vitamin a supplements. *Australian Journal of Agricultural Research* **6**, 324-342.
- Franklin MC, Briggs PK, McClymont JL (1964) Early weaning of Merino lambs during drought. *Australian Journal of Experimental Agriculture and Animal Husbandry* **4**, 132-140.
- Gabbedy BJ (1971) Effect of selenium on wool production, body weight and mortality of young sheep in Western Australia. *Australian Veterinary Journal* **47**, 318-322.
- Ganai TAS, Pandey RS (1996) Survivability of Rambouillets in first year of life. *Indian Journal of Animal Sciences* **66**, 839-842.

- Gordon HM (1981) Differential diagnosis of unthriftiness. In 'Proceedings no. 58: Refresher course on sheep'. (Ed. TG Hungerford) pp. 543-550. (University of Sydney Post-Graduate Committee in Veterinary Science: Sydney)
- Harris DJ, Nowara G (1995) The characteristics and causes of sheep losses in the Victorian Mallee. *Australian Veterinary Journal* **72**, 331-340.
- Hary I (2002) Analysis of survival curves in seasonally mated pastoral goat herds in northern Kenya using logistic regression techniques. *Journal of Arid Environments* **50**, 621-640.
- Hodge RW (1990) The strategic use of supplementary feed to increase the live weight and onset of oestrus of spring born Merino ewes at 18 months of age. Australian Wool Corporation, Research Report Series No. 111, Melbourne.
- Holmes JHG (1992) Trace element deficiency in sheep in East Gippsland Victoria. *Australian Veterinary Journal* **69**, 292-293.
- Hosmer DW, Lemeshow S (1999) 'Applied survival analysis. Regression modelling of time to event data.' (John Wiley & Sons: New York)
- Hungerford TG (1990) 'Diseases of livestock.' (McGraw-Hill: Sydney)
- Ikwuegbu OA, Tarawali G, Rege JEO (1995) Effects of fodder banks on growth and survival of west African dwarf goats under village conditions in subhumid Nigeria. *Small Ruminant Research* **17**, 101-109.
- Insightful Corp. (2004) S-plus: Release 7 (Insightful Corp.: Seattle, Washington)
- Kellaway RC (1973) Effects of plane of nutrition, genotype and sex on growth, body composition and wool production in grazing sheep. *Journal of Agricultural Science* **80**, 17-27.
- Kennedy JP, Auld IH, Popovic PG, Reynolds JA (1976) Reproduction rate of Merino sheep in arid New South Wales. *Proceedings of the Australian Society of Animal Production* **11**, 149-151.
- Kleemann DO, South MLH, Dolling CHS, Ponzoni RW (1983) Survival, growth and wool production of south Australian strong-wool Merino and 1st-cross Merino lambs from birth to 16 months of age. *Australian Journal of Experimental Agriculture* **23**, 271-279.
- Langlands JP, Donald GE, Paull DR (1984) Effects of different stocking intensities in early life on the productivity of Merino ewes grazed as adults at two stocking rates. 1. Wool production and quality, lamb growth rate, and size and liveweight of ewes. *Australian Journal of Experimental Agriculture and Animal Husbandry* **24**, 34-46.
- Larsen JWA (1999) Weaners and aspirin. In 'Mackinnon Project Newsletter'. (Mackinnon Project, University of Melbourne: Melbourne)
- Larsen JWA (2002) Small ruminants s102 - weaner management and illthrift. In 'Veterinary Science Lecture Notes'. (University of Melbourne: Werribee, Victoria)
- Lean GR, Vizard AL, Webb Ware JK (1997) Changes in productivity and profitability of wool-growing farms that follow recommendations from agricultural and veterinary studies. *Australian Veterinary Journal* **75**, 726-731.
- Leung K-M, Elashoff RM, Abdelmonem AA (1997) Censoring issues in survival analysis. *Annual Review of Public Health* **18**, 83-104.
- Lindsey JC, Ryan LM (1998) Tutorial in biostatistics: Methods for interval-censored data. *Statistics In Medicine* **17**, 219-238.
- Lindsey JK (1998) A study of interval censoring in parametric regression models. *Lifetime Data Analysis* **4**, 329-354.
- Lloyd Davies H (1962) Studies on time of lambing in relation to stocking rate in south-western Australia. *Proceedings of the Australian Society of Animal Production* **4**, 113-120.
- Lloyd Davies H, Boundy CAP, Southey IN (1968) Summer nutrition of weaner sheep in south-western Australia. *Proceedings of the Australian Society of Animal Production* **7**, 255-258.
- Lloyd Davies H (1983) Some aspects of the production of weaner sheep in the winter rainfall regions of Australia. *Livestock Production Science* **10**, 239-252.

- Lloyd Davies H, McRae IR, Petrie DJ (1988) Feeding female weaner Merino sheep during drought on the central tablelands of New South Wales. *Proceedings of the Australian Society of Animal Production* **17**, 222-225.
- Mandonnet N, Ducrocq V, Arquet R, Aumont G (2003) Mortality of Creole kids during infection with gastrointestinal strongyles: A survival analysis. *Journal of Animal Science* **81**, 2401-2408.
- Marshall T (1985) Effect of month of birth and 1st summers nutrition on the productivity of Merino wethers. *Australian Journal of Experimental Agriculture* **25**, 777-782.
- McDonald JW (1975) Selenium-responsive unthriftiness of young Merino sheep in central Victoria. *Australian Veterinary Journal* **51**, 433-435.
- McLaughlin JW (1966) The effect of timing of birth and age at weaning upon the adult production of Corriedale sheep. *Proceedings of the Australian Society of Animal Production* **6**, 246.
- McLaughlin JW (1967) Management and weaner illthrift. *Victorian Veterinary Proceedings* **25**, 60-63.
- McLaughlin JW (1973) Management of weaner sheep in western Victoria. 2. The effects of supplements of oat grain or pasture hay or the periodic grazing of a green fodder crop upon current and subsequent production. *Australian Journal of Experimental Agriculture and Animal Husbandry* **13**, 637-642.
- Mersmann HJ (1987) Nutritional and endocrinologic influences on the composition of animal growth. *Progress in Food and Nutrition Science* **11**, 175-201.
- Minitab Inc. (2005) Minitab release 14.2: Release 14.2 (Minitab Inc.: State College, Pennsylvania)
- Moule GR (1966) Ovine production in tropical Australia. *Australian Veterinary Journal* **42**, 13-18.
- Mulhearn CJ (1958) Unthriftiness of weaner sheep in south Australia. *Australian Veterinary Journal* **34**, 383-390.
- Nguti R, Janssen P, Rowlands GJ *et al.* (2003) Survival of Red Maasai, Dorper and crossbred lambs in the sub-humid tropics. *Animal Science* **76**, 3-17.
- Nivsarkar AE, Acharya RM, Kumar M (1982) Note on factors influencing preweaning and post-weaning survival of Malpura and Sonadi lambs. *Indian Journal of Animal Sciences* **52**, 835-837.
- Norris RT (1984) Management, growth and mortality in weaner sheep. In 'Western Australian Department of Agriculture Division of Animal Health 1984 Scientific Conference'. Perth. (Eds FC Wilkinson and JG Allen) pp. 72-89. (Western Australian Department of Agriculture)
- Norris RT (1986) 'Technical bulletin: Survey of post-weaning management, growth and mortality of Merino weaners.' (Western Australian Department of Agriculture: Perth)
- Radke BR (2003) A demonstration of interval-censored survival analysis. *Preventive Veterinary Medicine* **59**, 241-256.
- Ripper L (2003) Gippsland pilots weaner management course. In 'BestWool 2010 Information Exchange'. p. 2.
- Rose M (1972) Vital statistics for an experimental flock of Merino sheep in north west Queensland. *Proceedings of the Australian Society of Animal Production* **9**, 48-54.
- Royston P, Parmar MKB (2002) Flexible parametric proportional-hazards and proportional-odds models for censored survival data, with application to prognostic modelling and estimation of treatment effects. *Statistics In Medicine* **21**, 2175-2197.
- Russell P (1968) The development of high stocking rates on a whole farm basis. *Proceedings of the Australian Society of Animal Production* **7**, 103-105.
- Sackett DM (2006) Assessing the economic cost of endemic disease on the profitability of Australian beef cattle and sheep producers. Meat and Livestock Australia Limited, North Sydney.
- SAS Institute Inc. (2004) SAS/stat: Release 9 (SAS Institute Inc.: Cary, North Carolina)
- Scaramuzzi RJ (1988) Reproduction research in perspective. *Proceedings of the Australian Society of Animal Production* **17**, 57-73.

- Sharma MM, Mathur PB, Kumar PN, Uppal PK (1981) Causes of mortality in lambs under semi-arid climatic condition of Rajasthan. *Indian Veterinary Journal* **58**, 859-864.
- Southey BR, Rodriguez-Zas SL, Leymaster KA (2001) Survival analysis of lamb mortality in a terminal sire composite population. *Journal of Animal Science* **79**, 2298-2306.
- Southey BR, Rodriguez-Zas SL, Leymaster KA (2003) Discrete time survival analysis of lamb mortality in a terminal sire composite population. *Journal of Animal Science* **81**, 1399-1405.
- StataCorp (2005) Stata statistical software for Windows: Release 8.2 (Intercooled) (StataCorp LP: College Station, Texas)
- Thornton RF, Hood RL, Jones PN, Re VM (1979) Compensatory growth in sheep. *Australian Journal of Agricultural Research* **30**, 135-151.
- Turkson PK (2003) Lamb and kid mortality in village flocks in the coastal savannah zone of Ghana. *Tropical Animal Health and Production* **35**, 477-490.
- Turkson PK, Antiri YK, Baffuor-Awuah O (2004) Risk factors for kid mortality in west African dwarf goats under an intensive management system in Ghana. *Tropical Animal Health and Production* **36**, 353-364.
- Turkson PK, Sualisu M (2005) Risk factors for lamb mortality in Sahelian sheep on a breeding station in Ghana. *Tropical Animal Health and Production* **37**, 49-64.
- Walker DM, Hunt SG (1980) Effects of birth-weight and energy gain preweaning on survival of lambs weaned at 21 days. *Australian Journal of Agricultural Research* **31**, 981-989.
- Walker SK, Hall GP, Smith DH *et al.* (1979) Effect of selenium supplementation on survival, liveweight and wool weight of young sheep on kangaroo island, south Australia. *Australian Journal of Experimental Agriculture and Animal Husbandry* **19**, 689-694.
- Weir WC, Torell DT (1967) Supplemental feeding of sheep grazing on dry range. University of California, Division of Agricultural Science Bulletin 832.
- Wilkinson FC (1981) Lamb survival from marking and weaner illthrift. In 'Proceedings no. 58: Refresher course on sheep'. (Ed. TG Hungerford) pp. 193-209. (University of Sydney Post-Graduate Committee in Veterinary Science: Sydney)

3. Draft 'Recommended Management Summary'

Preamble

Many farmers have difficulty managing young sheep, especially spring-born Merinos, from weaning until about 15 months of age and weaner ill-thrift is a common occurrence. Weaner ill-thrift is a syndrome that frequently has several concurrent causes but is almost invariably associated with poor nutrition.

It is generally suggested that mortality in weaner flocks should be less than 4% in the year after weaning, and although many farmers believe that mortality in their weaner flocks is below this value, they rarely verify their estimates by comparing changes in stock numbers over time. In contrast, data from field experiments and farm surveys in which sheep are counted suggest that weaner mortality usually exceeds 4% per annum. For example, a Victorian survey found that annual mortality exceeded 10% in more than one fifth of weaner flocks in the Mallee region. More recently, the average weaner mortality on six Merino farms in Victoria, over an average period of six years, was 11% and mortality of less than 4% was only achieved on six of 33 occasions (Mackinnon Project, unpublished). Few other direct surveys of weaner mortality have been published, but sheep numbers reported in many field studies using weaners suggest similar mortality occurs throughout Australia. For example, weaner mortality has been observed to be 10% in Western Victoria, 17% in South Australia, 13% in Western Australia, 14% in north-western Queensland and 39% in central New South Wales.

Weaner mortality was recently estimated to cost about A\$89 million annually and was ranked the fourth most costly endemic health problem in the Australian sheep industry. Furthermore, the problem of weaner mortality extends beyond pure economics because the current scenario of deaths frequently exceeding 4% per annum represents a significant animal welfare issue.

This paper presents an initial draft of a recommended weaner sheep management summary for circulation and comment, which will eventually be used by farmers and advisors to improve management and survival of weaner sheep in Australia.

Background Management Procedures

- Join for 5 weeks.
- Mark (and mules, if relevant) 2 weeks after end of lambing.
- Wean 12–13 weeks after lambing start.
- Know your trace element status, especially:

- selenium
 - cobalt
 - iodine
- Don't change lambing time (to earlier) just to have bigger weaners
- Prepare low worm-risk paddocks to use:
 - after weaning
 - at other high-risk times of the year (e.g. first winter for southern Australia)
 - Strategies include grazing management (e.g. 'Smart Grazing') to prepare paddocks (including sheep-cattle interchange), use of stubbles, monitoring of egg deposition onto/parasite load on paddocks,
- Train weaners to eat supplementary feed by imprint feeding with all potential feed types prior to weaning
- Benchmark existing weaner mortality levels, preferably over several years, using counts from tally book and other stock inventory records, to:
 - document whether a problem exists
 - possible patterns of occurrence (particular seasons, years)
 - if an excessive mortality situation exists, how aggressively it should be tackled
- Optimised management of ewe condition during pregnancy and lactation will in turn optimise weaning weights and post-weaning survival.
 - Aim to have ewes in condition score 3 at lambing and grazing a minimum of 1200 or 1800 kg green DM/ha for single- and twin-lambing sheep, respectively. These values are for improved pasture and would need to be greater for ewes grazing unimproved pastures.

Weaner Management

Health

- Give an effective (based on drench resistance testing) drench at weaning and move to a prepared, low parasite risk paddock
- Instigate appropriate flystrike control/prophylaxis

Monitoring

- Weigh random sample of 80 (or sample of 50 tagged) weaners to determine average weaning weight
- Draft (visual) off the tail of lightweight weaners (regardless of absolute weaning weight) for differential management at weaning
- Monitor bodyweight monthly of random or tagged sample (see above) from weaning onwards

Weight & growth rate targets

- ‘Conventional’ recommendations:
 - Weaners to reach 45% of standard reference weight of mature sheep of the genotype by the time it faces nutritional pressure (e.g. 23 kg for a 50 kg mature-weight Merino)
 - If target of 45% of mature weight has not been reached by critical time, aim for growth to this weight as quickly as possible via supplementary feeding
 - Growth of 1 kg/month thereafter

Risk-based approaches may allow these recommendations to be fine-tuned because the effect of changes in weaning weight and average monthly growth rate on mortality risk have been quantified recently, as outlined briefly in Tables 1 and 2, below. This information could be broadly applied in two different ways. Firstly, the information could be used strategically by deciding how much weaning weight and/or growth rate need to be increased to reduce a farm’s historic average post-weaning mortality to below the industry recommendation of 4%. Alternatively, the information could be used tactically during the post-weaning period. In this situation, if ongoing monitoring during the year identified that death rates were increasing and likely to exceed the target of 4% by one year of age, the risk information could be used to determine the growth rate increase needed to reduce mortality risk sufficiently to reduce the projected mortality level back below the overall target.

For example, if previous records indicate 12% annual mortality occurs at an average weaning weight of 16 kg, increasing weaning weight to 18 kg would be expected to result in annual mortality of 8.4% (30% reduction of 12%).

On the same farm, if weaners grew an average of 0.5 kg/month over summer the same 30% reduction in mortality could be expected if average growth rates were increased to 0.75 kg/month.

Table 1: Relationship between mortality risk and changes in weaning weight of individual sheep

Weaning weight change	Predicted effect on total post-weaning mortality (% <u>decrease</u>)
6 → 8	38%
8 → 10	39%
10 → 12	39%
12 → 14	37%
14 → 16	34%
16 → 18	30%
18 → 20	25%
20 → 22	18%
22 → 24	10%
24 → 26	No significant effect on mortality risk for further weight increases
26 → 28	
28 → 30	
30 → 32	

Table 2: Relationship between mortality risk and average monthly growth rate during summer and early autumn of a weaner flock

Change in average growth rate over summer-early autumn (kg/month)	Predicted effect on total post-weaning mortality (% <u>decrease</u>)
0.25 → 0.5	85%
0.5 → 0.75	30%
0.75 → 1.0	12%
1.0 → 1.25	No significant effect on mortality risk for further weight increases
1.25 → 1.5	
1.5 → 1.75	
1.75 → 2.0	
2.0 → 2.25	

Nutrition & Supplementary Feeding

- Weaners need minimum 12–14% (younger-older) dietary crude protein and metabolisable energy density of 10 MJ/kg DM
- Do not delay starting supplementary feeding. Ruminants need 2–3 weeks to become accustomed to cereal grains, which is a long time for a weaner to continue to lose weight if pasture feed is insufficient.
- Once supplementary feed has been properly introduced, feed twice weekly.

Rules of thumb:

- Green feed present (even just a pick)—sufficient dietary protein available; if supplementary feeding required (from bodyweight monitoring) supply energy (e.g. via cereal grain); initial feeding rate 1.5 kg/grain/head/week
- No green pick present, good quality standing dry feed available—protein required (especially if grass-dominant pasture), provide high protein supplement such as lupins, initially 0.7 kg/head/week
- Increase supplementary feeding rates in response to measured bodyweight and change feed composition in response to changing pasture quality/composition

More precise feeding estimates can be made using software such as GrazFeed, following pasture analysis for energy and protein content.

Shearing

In southern Australia, shearing Merinos in March or May appears to increase post-shearing mortality risk significantly. Therefore, it may be advisable to avoid shearing during autumn in this area.

4. Draft protocol for Field Trial to Evaluate Efficacy of Updated Management Strategies to Improve Weaner Survival & Validate Quantitative Supplementary Feeding Models

Trial Aim & Background

This field trial will measure how effectively updated weaner management strategies, which may include a flock supplementary feeding model derived from survival analyses and specifically designed to reduce mortality, improve weaner survival compared to routine district management practices. It will also refine the model, using data from the study farms to validate the survival analysis on which the preliminary model is based. Typically, these farms graze 2,000–5,000 weaners each year. Recent years' management records from each farm will be examined to establish existing levels of weaner sheep mortality.

Preliminary requirements for trial:

- Animal Ethics approval.
- Finalise preliminary desktop flock feeding model (if being used).
- Recruit 1 or 2 commercial sheep farms (e.g. from Mackinnon Project clients) to take part in the project. Selection criteria will include:
 - being in a common geographic region
 - use of similar management practices, such as stocking rate, time of lambing and weaner supplementary feeding practices
 - use of management practices considered to be representative of the district
 - participation in pilot 'Productive Weaner Management' CRC extension program

Trial commences in summer:

- Farmer interviews to formalise 'conventional' weaner sheep nutritional management protocol.
- Identify all sheep with individually numbered electronic ear tags.
- Randomly divide the weaner flock on each farm, stratified on weight and sex, into two equal-sized groups to receive conventional ('control') or updated ('treatment', including use of feeding model) weaner management:
 - Control group: follows farm's conventional routine management plan.
 - Treatment group: use updated management practices and a flock supplementary feeding model to determine the increases in post-weaning bodyweight and seasonal growth rates required to reduce the flock's current average annual mortality to below the Australian industry target (<4% p.a.). GrazFeed® will be used to determine the supplementary feeding required to achieve these increases.

- On each farm, the two weaner groups will graze separate but similar paddocks and will otherwise be generally managed in the same way.

February–September:

Undertake monthly farm visits to perform the following:

1. Weigh all sheep.
2. Identify individual deaths & approximate timing based on absences at consecutive weighings.
3. Assess pasture availability in each paddock & collect pasture samples for nutritional analysis.
4. Conduct faecal worm egg counts to monitor groups' gastrointestinal parasite burdens.

After each visit:

1. Re-run the flock feeding model for the treatment group to estimate changes in bodyweight and/or seasonal growth rate that will be required to maintain projected mortality rate below target, and assess against current values. Reformulate feeding plan based on projected growth rates from pasture nutritional analysis to meet revised bodyweight and growth rate targets over the following month, if required.
2. Communicate supplementary feeding advice for the treatment flock to the farmer.

If mortalities in the control group are forecast to exceed 10% p.a. or are more than twice those in the treatment group, all weaners on the farm will be switched to the 'new' supplementary feeding regimen to prevent further excessive mortality.

Field work will finish in September.

October–December:

Analyse the effect of 'treatment' management in the following ways:

1. Calculate across-farm Mantel-Haenszel cumulative mortality risk ratios between the treatment and control groups, and fraction of change in mortality risk attributable to treatment.
2. Calculate partial budgets to compare the gross margins of the different treatments and cost-effectiveness of the feeding intervention.

Conduct survival analyses of the mortality data from each farm and validate the results of the preliminary model. Update feeding model parameters if required.

Comments:

The randomised control trial component of the study has some technical limitations because it will not be possible to blind the farmer or researcher to the treatments, making it difficult to avoid the feeding advice for the treatment group also being used on the control group. This will be dealt with, as much as possible, by communicating the study's aims clearly to the cooperating farmers and clarifying each farm's conventional management, which in practice is seldom formalised, at the start of the study. Similarly, a balance must be struck between experimental power and the logistics of running a large field trial. Ideally, more than two replicates (i.e., paddocks) would be used to increase the likelihood of observing differences in mortality between the control and treatment groups. However, running more small paddocks would represent a departure from commercial management conditions, be likely to affect potential mortality levels and their response to intervention, and significantly increase the resources needed for the study.

5. Collation of existing analyses of the economics of weaner survival

MLA Report AHW.087

This report, titled *Assessing the economic cost of endemic disease on the profitability of Australian beef cattle and sheep producers*, valued post-weaning mortality across the high rainfall, sheep-cereal and pastoral zones at \$89M annually. It assumed average post-weaning mortality of 10% in the high rainfall zone and 8% in each of the other two zones. (The figures for the estimate cost of weaner mortality in the pastoral zone do not appear to tally quite correctly, and it is possible that the overall cost is \$79M annually.)

I have spoken to Sandy McEachern of Holmes Sackett and Associates regarding the model used to cost weaner mortality in HS&A's report to Meat and Livestock Australia. He was not involved in producing the report and is checking the model details. However, it appears that the model used is a snapshot, steady-state model into which reported average weaner mortality figures were entered. As such, the model may not have accounted well for year-to-year variation in mortality, although I am waiting for more information from Sandy.

Mackinnon Project modelling

The Mackinnon Project has modelled weaner mortality by comparing gross margins associated with the different age structures of two self-replacing Merino flocks with annual weaner mortality of 12% or 4%. The different values for post-weaning mortality were entered into a spreadsheet that determined the flock's age structure at given ages for selling wethers and cull ewes (in this example, 1.5 and 6.5 years old, respectively). The resulting numbers in each sheep class and age group were then used to calculate the gross margins of the two different flocks.

Results of this modelling are detailed on the following page. Within a given farm capacity (say, 10,000 DSE), reducing weaner mortality changes a flock's structure by increasing the number of hoggets and reducing the relative number of adult ewes carried. This results in modestly greater wool income because more young sheep, with potentially valuable fine fleece wool, are shorn. Reducing weaner mortality increases stock trading income by increasing the number of wethers (hoggets, in this example) available for sale.

Overall, this approach estimated that reducing weaner mortality from 12% to the recommended maximum of 4% produced a difference in gross margins \$1.38/dse or \$23/ha for a typical farm grazing 10,000 DSE on 600 ha. Very modest supplementary feeding of

oats and lupins, costing \$0.40/head/month, could increase average monthly growth rates in a slow growing weaner flock over summer and early autumn, with big impacts on survival. If this cost of feed is included in the lower mortality flock's gross margin, the net increase in gross margin would be \$15/ha, or \$9,000 over the whole farm.

