

live export

LIVE.112

Salmonellosis control and best-practice in live sheep export feedlots – final report

October 2002

Final Report prepared for MLA and LiveCorp
by:

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Simon More

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Executive summary

Background

This project was undertaken in response to industry concern about losses from salmonellosis during live sheep export feedlotting.

Current practice relating to live sheep export feedlotting

Live sheep export feedlotting is an important part of live sheep export. Its purpose is two-fold. Firstly, it enables large numbers of sheep to be assembled over a short period prior to export. Secondly, during this period sheep have an opportunity to acclimatise to ship-like conditions of feeding and general management. In paddock-based feedlots, which are located in Victoria, South Australia and Western Australia, sheep are held at high stocking density in a series of small paddocks. In shed-based feedlots, which are located only in Western Australia, sheep are held in large, raised sheds, each holding approximately 7,500 animals. The standard of management in all large Australian live sheep export feedlots, including the paddock- and shed-based systems, is very high. Regardless of whether sheep are owned by the feedlot operator or managed under contract, there are very strong incentives for operators to minimise sheep losses during feedlotting.

Salmonellosis during feedlotting

There are two different syndromes of salmonellosis in the live sheep export trade. The current problems during feedlotting are due to feedlot-related salmonellosis, which has become a significant problem for many animal based industries following intensification. The second syndrome, the persistent inappetence-salmonellosis-inanition (PSI) complex, is the main cause of death of sheep during shipping. The PSI complex was the focus of detailed research by scientists from Agriculture WA during the 1980s and early 1990s.

During a normal feedlotting period, paddock- and shed-based feedlots suffer background losses of approximately 6 to 7 deaths per 10,000 sheep (0.067%). However, in approximately 20% of consignments each year, feedlot operators describe worrying – but sporadic – outbreaks of salmonellosis, which can result in an additional overall mortality rate of approximately 100 deaths per 10,000 animals (1%), and a much higher mortality rate in affected paddocks. Since early 2000, these outbreaks have occurred in each of the large paddock-based feedlots in Victoria, South Australia and Western Australia. Similar outbreaks have not been reported in the shed-based feedlots, nor have there been significant losses attributable to salmonellosis in animals held in paddocks surrounding these facilities. There have been few detailed outbreak investigations, with most diagnoses based solely on clinical presentation.

Outbreaks are sporadic and unpredictable, but may be more common between the autumn break and early summer. All outbreaks are related to high throughput, and are believed to involve *Salmonella typhimurium* and/or *S. bovis-morbificans*. In all outbreaks of salmonellosis during feedlotting, deaths have been highly clustered in a small number of non-contiguous paddocks. However, 'problem' paddocks did not persist from one consignment to the next. Although not consistently affected, high-risk lines include young animals, animals in poor conditions and long-haul and pastoral sheep. Risk of disease is substantially higher if animals arrive when the weather is cold, windy and wet. Goats are highly susceptible to salmonellosis. Similar outbreaks of salmonellosis have occurred in goats, which are highly susceptible to the disease, but not in cattle. In feedlots, cattle and sheep are generally managed separately.

Based on currently-available information, deaths during feedlotting contribute between 15.0 and 27.3% of total losses experienced between the start of feedlotting and unloading at the first port of destination. There has been a progressive decrease in the mortality rate during the shipboard phase for Fremantle-loaded sheep. In contrast, for sheep loaded in Portland and Adelaide, this rate has been both higher and progressively worsening in recent years. Based on results from Voyage 1 of the LIVE.212 project, and supporting anecdotal evidence from a number of voyages, this difference in mortality rate by port of loading cannot be explained by length of voyage. Feedlot-related salmonellosis may contribute to increasing losses during the first 7-12 days at sea for sheep loaded in eastern ports. Other factors that differ between the eastern and western ports of loading may also be important.

Why the problem is occurring

A number of factors are critical to the development of feedlot-related salmonellosis, including the size of the *Salmonella* challenge, the level of host resistance and the virulence of the serovar involved. There is a dose-response relationship between *Salmonella* challenge and clinical disease, and as host resistance is reduced, a much smaller challenge of *Salmonella* organisms is needed to produce clinical disease.

Host resistance and *Salmonella* challenge are both important causal factors for outbreaks during feedlotting, although there is good evidence suggesting that host resistance is the more important. Time-off-feed is a key risk factor for outbreaks.

Some sheep will be shedding the organism on-entry to the feedlot. Following rapid sheep-to-sheep spread during transport and following entry, there will be rapid and heavy contamination of the feedlot environment with *Salmonella* organisms. The absolute level of environmental contamination is variable throughout a feedlot paddock, and will be influenced by a range of management and microclimatic factors. Regardless, after arrival at a feedlot, the main challenge of *Salmonella* organism comes from the contaminated feedlot environment.

In paddock-based feedlots, the feedlot environment is heavily contaminated and animals can be exposed to very high levels of *Salmonella* organisms. In addition, the host resistance of many sheep will be reduced, following transport to the feedlot, and as a result of inclement weather and problems achieving consistent feed intake. In contrast, in shed-based environments, *Salmonella* challenge is minimal. The raised, mesh floors are a critical feature of shed-based feedlots. During shedding, faeces accumulate away from the immediate housed environment, thereby minimising faecal-oral cycling among sheep. In addition, because animals are sheltered and provided with a consistent supply of feed and water, host resistance is maintained.

Feedlot management in the face of an outbreak

In the face of an outbreak, sheep in affected paddock(s) should only be moved if this can be done with minimal stress, if suitable empty paddocks are located nearby and if sheep from non-affected paddocks are not put at-risk. Sheep should be given high-quality feed and water. Antimicrobial agents should not be used therapeutically (to treat clinically-affected animals). After the affected consignment has been removed, ground maintenance should be undertaken to limit survival of the organism, and the paddock should be spelled for at least one month.

Long-term control of feedlot-related salmonellosis

The development of a constructive and sustainable partnership between industry and relevant government regulatory bodies would assist with efforts to develop a culture of continuous improvement within industry.

The control of feedlot-related salmonellosis is based on efforts to increase the level of host resistance and reduce the size of the *Salmonella* challenge. Because the current standard of management in feedlots is high, further progress in controlling salmonellosis is likely to be incremental.

a. The strategic use of sheds in paddock-based feedlots

The strategic use of sheds in paddock-based systems is likely to be the most effective means to control feedlot-related salmonellosis. Sheds offer a range of advantages during feedlotting, including increased flexibility in sheep selection and management, reduction (and potential elimination) of outbreaks of salmonellosis, reduced labour costs, income from the sale of manure and reduced environmental concerns. It is important to note, however, that there are also a number of concerns relating to the introduction of sheds, including the high capital cost, concerns about the most appropriate floor design and potential concerns with sheep management in a partially-shedded feedlot. Obstacles to shed construction include market risk, location risk and cost. An economic analysis was undertaken, based on a number of possible scenarios, by considering the expected benefits and likely costs associated with the strategic use of sheds in vertically-integrated, paddock-based feedlots. The relevant MS Excel file is available from the author on request. An analysis was also conducted to determine the additional charge (in c/head) that would be required to enable a non vertically-integrated operation to cover shed construction costs plus a margin of 25% over a 15 year period. In vertically-integrated operations, the internal rate of return (IRR) using conservative assumptions is 1.7%. However, if conditions are favourable, and particularly if the incidence and severity of outbreaks of feedlot-related salmonellosis were to increase, this figure could increase to 19.1%. In operations that are not vertically-integrated and using similar conservative assumptions, an additional 20c for each sheep during the feedlotting period would need to be charged to cover shed construction costs plus a margin of 25%. If conditions are particularly favourable, this figure could reduce to 7.5c/hd. The addition of 20c/hd during the feedlotting period will increase the overall charge for feedlot contracting by 13.3%, based on current charges of 30c/hd/d for 5 days. The overall establishment cost, which is greatly influenced by the flooring used during construction, is particularly influential in the long-term benefit-cost of shedding. It is important to note that although the IRR (for vertically-integrated operations) or c/hd (for operations that are not vertically-integrated) for the 'best case' scenario is favourable, operators will need to make their own judgement regarding the likelihood that this scenario might occur. Additional less-tangible benefits associated with the introduction of sheds include reduced environmental impacts and improved animal welfare. After considering all the technical and economic issues, the following recommendations are made regarding the strategic use of sheds in paddock-based feedlots:

- *If sheds are to be constructed, it is critical that they are carefully planned to maximise host resistance and minimise Salmonella challenge. Sheds will be most effective if they enable shedded sheep to be comfortable, protected from wind and rain, and fed and watered using systems that maximise consistent feed intake and minimise faecal contamination*
- *Providing the economic fundamentals underlying the trade at this time remain in place, a policy of moving paddock-based systems to at least partial shed accommodation should be adopted*
- *Further research should be undertaken to assess the relative merits of raised and concrete flooring. An assessment of rumen health, Salmonella ecology, general animal health (particularly relating to the epidemiology of salmonellosis) and economics should be included in any such investigation*

b. Additional strategies to increase the level of host resistance

Vaccination is currently not a viable control option.

Consistent feed intake, which affects host resistance, appears to be critical to the prevention of feedlot-related salmonellosis.

Immediate opportunities available to industry to increase host resistance and reduce the risk of feedlot salmonellosis include:

- *Imposing curfews where producers withhold water but provide dry feed to sheep*
- *Using feeding systems that enable feed to remain dry, and with minimal faecal contamination, throughout the feedlot period*
- *Holding sheep in paddock-based feedlots for the shortest time possible before loading on-ship*

c. Additional opportunities to reduce the size of the Salmonella challenge

Efforts to reduce the size of the *Salmonella* challenge will play an important role, albeit secondary to efforts to increase host resistance, in controlling feedlot-related salmonellosis.

Relevant recommendations to assist in reducing *Salmonella* challenge for consideration by industry include:

- *Using feeding systems that enable feed to remain dry, and with minimal faecal contamination, throughout the feedlot period*
- *Minimising pooling of water in feedlots by maximising paddock draining and ensuring that water troughs do not leak*
- *Retrieving carcasses from affected paddocks in a manner that will minimise the possibility of disease spread. Feed-transport vehicles should not be used for this purpose*
- *Avoiding adding new sheep to paddocks where longer-duration sheep have been held for some days*
- *Adopting an all-in-all-out management system. Any carry-over animals that are retained for a subsequent consignment should be held in an area of the feedlot that is remote from the following consignment*
- *Oral antimicrobial agents must not be used prophylactically (as a preventive measure to apparently-healthy animals)*

Because *Salmonella* organisms can cause disease in people, relevant employees should maintain a high level of personal hygiene during outbreaks.

Opportunities for further focused research

There are a number of areas where further focused research would assist in filling gaps in existing knowledge and may help in providing practical solutions for industry. Proposed areas of research (in order of suggested priority) include:

- Improved understanding of reasons for increased sheep losses during voyages from Adelaide and Portland in comparison to Fremantle
- Improved understanding of the ecology of *Salmonella spp.* and the epidemiology of salmonellosis during feedlotting, with particular emphasis on differences between paddock and shed-based feedlot systems, and between shed-based systems with and without raised floors
- Improved understanding of rumen function during feedlotting
- Assessment of the efficacy and cost-effectiveness of existing and emerging feedlot products

The Australian Livestock Export Standards (March 2001)

After considering the above recommendations, an industry review meeting in Adelaide on 13 August 2002 recommended the following changes or inclusions (underlined):

7.5.2 (Best practice) “Sheep and goats should be inspected on arrival at the feedlot. They should be kept in mobs with other animals of a similar age, weight and duration since arrival at the feedlot. Where possible, sheep and goats should be retained in mobs with other animals of a similar origin.

After sheep and goats have been placed in their paddock or shed, they should be disturbed as little as possible whilst in the feedlot. All inspections and other management procedures should be done with the minimum possible disturbance to the sheep or goats.

7.5.7 Each Exporter must ensure that::

(a) all sheep and goats are provided with sufficient, suitable feed, as soon as practical following entry and throughout the feedlotting period;

(b) all sheep and goats are fed to meet at least maintenance energy requirements during the feedlotting period;

(c) sheep and goats with four (4) or less permanent incisor teeth are provided with sufficient, suitable feed for continued growth;

(d) feed troughs and self-feeders are designed so as to minimise faecal contamination and injuries, and to prevent pellets from being spoiled by water during inclement weather ; and

(e) if feed is not provided ad-libitum, there is at least five (5) centimetres of trough space per head.”

7.5.8 Each Exporter must ensure that dead animals are removed from each feedlot paddock and pen each day in a manner that will minimise the possibility of disease spread, and that the carcasses are disposed of appropriately.

7.5.12 Each exporter must ensure, to minimise the risk of spreading disease, that:

(a) sheep and goats only leave an export feedlot for export, slaughter, relocation to

another quarantine area, or veterinary examination or treatment; and

(b) if carry-over animals are retained for a subsequent consignment, they are held in an area of the feedlot that is remote from the following consignment.”

7.5.13 Antimicrobial agents are only used during feedlotting under veterinary supervision

7.7.2 *(Best practice)* Sheep and goats should be held off water (but given dry feed) for at least twenty four (24) hours before transportation from the property of origin. This practice will minimise the risk of injury during transportation (because the floor of the stock crate will be drier) and ensure that animals are cleaner and easier to unload, whilst also minimising time-off-feed (which is an important risk factor for salmonellosis).

1. Background

The live sheep export industry makes a significant contribution to the Australian economy, and particularly to sheep producers in Western Australia, South Australia and Victoria. In 2001, over 6.5 million sheep were exported, including more than four million from Fremantle and one million each from Adelaide and Portland, with most destined for the Middle East (Norris & Norman, 2001a).

The live sheep export trade makes a significant contribution to the Australian economy

There has been a steady drop in mortality during export over the last decade, and the average sheep mortality of 1.26% for all sheep exported to the Middle East during 2001 was a new record low. Most deaths of sheep during export occur during the shipping phase, and are mainly the result of failure-to-eat (inanimation) and salmonellosis. These issues have been extensively researched by WA scientists during the 1980s and early 1990s.

The typical timing of the export process is presented in Figure 1. Due to problems of supply, some sheep are currently being held in feedlots for longer periods until sufficient numbers have been assembled.

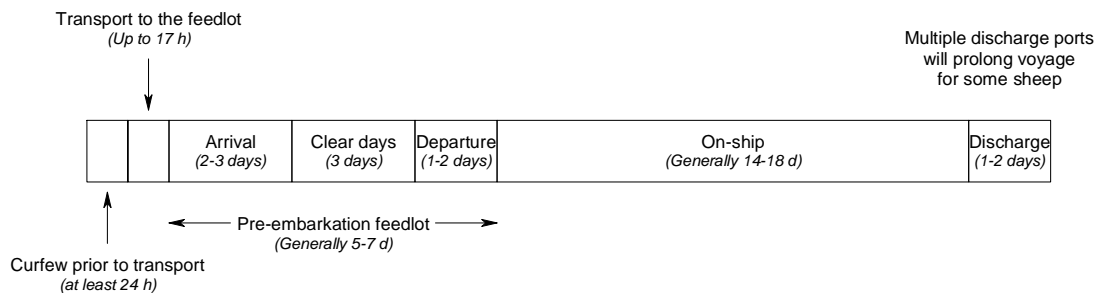


Figure 1. The timing of the export process.

The problem of salmonellosis during feedlotting is the subject of this report. Based on preliminary industry reports, there have been sporadic outbreaks of salmonellosis at some paddock-based feedlots, resulting in significant losses in affected groups. Anecdotal evidence indicates that sheep losses have continued after loading, and for a further 5-7 days at sea. The objectives and methodology for this report are presented in Appendix A3.

Salmonellosis during feedlotting, with possible spillover during the initial stages of a voyage, is believed to be an important cause of death in sheep that are held in paddock-based feedlots prior to embarkation

2. Current practice relating to live sheep export feedlots

2.1 An overview of current feedlotting practices

A detailed description of current practices at live sheep export feedlots is presented in the Appendix A4. These data were collected using the proforma presented in Appendix A5.

Live sheep export feedlotting is an important part of live sheep export. Its purpose is two-fold. Firstly, it enables large numbers of sheep to be assembled over a short period prior to export. Secondly, sheep have an opportunity to acclimatise to ship-like conditions of feeding and general management. In paddock-based feedlots, which are located in Victoria, South

Australia and Western Australia, sheep are held at high stocking density in a series of small paddocks. In shed-based feedlots, which are located only in Western Australia, sheep are held in large, covered sheds, each holding approximately 7,500 animals. The sheep are held on woven mesh, approximately 2 metres above the ground.

The standard of management at all the large feedlots is very high, and there are generally only subtle differences in current practices at each of the paddock-based feedlots. The management practices at shed-based feedlots are somewhat different, particularly in terms of feeding management.

Sheep in the major live sheep export feedlots in Australia are held in either paddock- or shed-based systems. In paddock-based feedlotting, animals are held at high density in a series of small paddocks. In shed-based feedlotting, animals are held off the ground in a series of large, covered sheds. In both systems, the standard of management is very high

2.2 Sheep ownership during feedlotting

There are two main models of sheep ownership during feedlotting:

- *The sheep are owned by the feedlot operator during feedlotting.* Therefore, all sheep losses during feedlotting are borne directly by the operator (or associated company)
- *The sheep are owned independently, with the feedlot operator being paid under contract to hold and feed the animals during feedlotting.* Under this arrangement, there is no direct cost to feedlot operators from sheep losses during feedlotting. However, significant or ongoing losses of sheep during feedlotting may lead to reduced demand for future services.

Regardless of whether sheep are owned by the feedlot operator or managed under contract, there are very strong incentives for operators to minimise sheep losses during feedlotting

3. Salmonellosis during feedlotting

3.1 A description of the problem

Within the live sheep export trade, concerns have been raised about outbreaks of salmonellosis among sheep during feedlotting, particularly in the intensive paddock-based feedlots in South Australia and Victoria. The current report has been developed in response to this concern.

This project was undertaken in response to industry concern about losses from salmonellosis during live sheep export feedlotting, particularly in paddock-based systems in Victoria and South Australia

During a normal feedlotting period, there are on average 6 to 7 'background' deaths per 10,000 sheep (0.067%). Similar death rates are reported by operators of both paddock-based and shed-based feedlot systems. In the paddock-based systems, operators generally attribute a number of these losses to salmonellosis.

In addition to these 'background' losses, feedlot operators describe worrying – but sporadic – outbreaks of salmonellosis, affecting approximately 20% of consignments. These outbreaks have mainly occurred since early 2000, and involve each of the large paddock-based feedlots in Victoria, South Australia and Western Australia. Similar outbreaks do not occur in the shed-based systems. During these outbreaks, there can be an additional overall mortality rate of approximately 100 deaths per 10,000 animals (1%), and a much higher rate in affected paddocks. Although the shed-based feedlots in Western Australia are able to hold up to 15,000 to 20,000 sheep in paddocks surrounding the sheds, there have been no reported outbreaks of salmonellosis in either the shed- or paddock-based animals at these feedlots.

Outbreaks of salmonellosis have occurred sporadically since early 2000 at each of the large paddock-based feedlots in Victoria, South Australia and Western Australia. Similar outbreaks have not been reported in the shed-based feedlots, nor have there been significant losses attributable to salmonellosis in animals held in paddocks surrounding these facilities

Information about the patterns of these outbreaks includes:

- *In time.* According to the feedlot operators, problems with salmonellosis were common in paddock-based feedlots throughout the 1980s, but not in the 1990s. The problems in the 1980s occurred at a time of high throughput. In the 1990s, there was a substantial drop in throughput at each of these facilities. The current losses in the feedlots in Victoria and South Australia coincide with substantially increased throughput of animals. In 2001, for example, over 1.2 million sheep were each exported through South Australia and Victoria (Norris & Norman, 2001a), a 373% and 174% increase in throughput from the year before (Norris & Norman, 2001b). In the last two years, the outbreaks have not been predictable, although operators suggest that up to 3 to 4 of the approximately 20 consignments each year have been affected during this period. Outbreaks appear to be more common between the autumn break and early summer. Outbreaks generally occur approximately five days after the sheep arrive at the feedlot.

Outbreaks of salmonellosis, which were a problem throughout the 1980s, have re-emerged during 2000-2002, and affect approximately 20% of consignments each year. All have occurred at a time of high feedlot throughput. Outbreaks are sporadic and unpredictable, but may be more common between the autumn break and early summer

- *In space.* The outbreaks are confined to one or a small number of non-contiguous paddocks/pens in affected consignments, and can result in the deaths of up to 50% of animals in these paddocks. These paddocks are not more likely to be affected in subsequent consignments.

In all outbreaks of salmonellosis during feedlotting, deaths have been highly clustered in a small number of non-contiguous paddocks. However, 'problem' paddocks have not persisted from one consignment to the next

- *Among animal factors.* When outbreaks occur in a particular paddock, a number of operators have suggested that deaths are more common in specific lines of sheep. Although not consistently affected, high-risk lines include young animals, animals in poor condition and long-haul and pastoral animals. Risk of disease is substantially higher if animals arrive when the weather is cold, windy and wet.

Although not consistently affected, high-risk lines include young animals, animals in poor condition and long-haul and pastoral animals. Risk of disease is substantially higher if animals arrive when the weather is cold, windy and wet

Diagnosis is mainly based on clinical findings, including severe diarrhoea, dysentery and debilitation, although some post-mortems have been conducted by veterinarians. Samples have been collected on several occasions from feedlots in Victoria, and *Salmonella typhimurium* and *S. bovis-morbificans* have consistently been isolated.

Salmonella typhimurium and S. bovis-morbificans are believed to be associated with most feedlot outbreaks

Based on industry experience, salmonellosis is a significant problem during the live export of goats. Goats are highly susceptible to salmonellosis.

Goats are highly susceptible to salmonellosis

In some of the paddock-based feedlots, the operators hold both sheep and cattle. At all feedlots, however, the different species are invariably held in different areas. An outbreak of salmonellosis in cattle has only occurred at a single feedlot, on a single occasion. In comparison to sheep, therefore, salmonellosis does not appear to be an important health problem in cattle during live export feedlotting.

Cattle and sheep are managed separately in the feedlots. Only a single outbreak of salmonellosis has been reported in cattle

3.2 Feedlot deaths in relation to other stages of the export process

3.2.1 Feedlot deaths as a contributor to deaths during export

Based on data presented in Table 1, the mortality rate during feedlotting has traditionally been lower than reported losses on-ship. After accounting for the sporadic nature of the current outbreaks of salmonellosis during feedlotting, losses during paddock-based feedlotting (at 24.8 deaths per 10,000 sheep) contributed between 15.0 and 27.3% of total losses experienced between the start of feedlotting and unloading at the first port of destination.

The losses during paddock-based feedlotting contribute between 15.0 and 27.3% of total losses experienced between the start of feedlotting and unloading at the first port of destination

Table 1. Documented mortality rates throughout the export process

Time period	Mortality rate (deaths per 10,000 sheep)			
	Trucking to the feedlot	Feedlotting	Loading	On-ship
During 1980s ¹	0.9	6.2		210.7
In 2001 ²				
Fremantle			1	65
Adelaide			3	111
Portland			4	136
In 2002 ³				
Shed-based feedlots		6.7		
Paddock-based feedlots		24.8		

1 Data from Norris et al. (1989)

2 Data from Norris and Norman (2002)

3 Based on anecdotal information from relevant feedlot operators. These data are based on the following:

- During feedlotting, most consignments experience approximately 6.7 deaths per 10,000 sheep. Some of these losses are attributed to salmonellosis
- During an outbreaks of salmonellosis, there may be an additional 100 deaths per 10,000 sheep over the feedlot period
- On average, sporadic outbreaks of salmonellosis occur in 4 of approximately 22 consignments each year

3.2.2 Does feedlotting increase mortality risks later in the export process?

In recent years, there has been a progressive reduction in the mortality rate during the shipboard phase (loading, voyage to the first port of unloading and discharge) for sheep loaded in Fremantle. In 2001, this mortality rate reached a record low of 0.96%, including 0.65% during the voyage. In contrast, this rate has steadily increased for sheep loaded in Portland and Adelaide (Figure 2). In 2001, the mortality rate during the shipboard phase was 2.1% for Portland-loaded sheep (including 1.36% during the voyage) and 1.48% for Adelaide-loaded sheep (including 1.11% during the voyage) (Norris & Norman, 2001a).

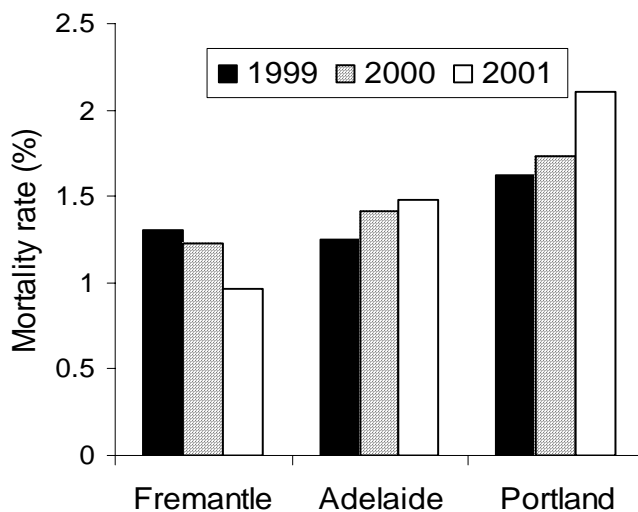


Figure 2. The mortality rate during the shipboard phase of live export for sheep loaded in Fremantle, Adelaide and Portland during 1999, 2000 and 2001

There has been a progressive decrease in the mortality rate during the shipboard phase for Fremantle-loaded sheep. In contrast, for Portland and Adelaide-loaded sheep, this rate has been both higher and progressively worsening in recent years

Although anecdotal, there has been some evidence in support of the hypothesis that feedlot-related salmonellosis may contribute to the increased losses experienced by sheep loaded in Portland and Adelaide in comparison to Fremantle. Firstly, it is biologically feasible that losses will be greater in animals that survive a feedlot-related outbreak of salmonellosis (as occurs at times during paddock-based feedlotting) in comparison to those that have not. Due to the nature of infection with *Salmonella spp* and the epidemiology of this disease in the feedlot, “outbreak survivors” are very likely to be passive, active and/or pre-incubatory carriers at the time of loading on-ship. As a consequence, they are also at increased risk of developing clinical disease on-ship following the imposition of stresses associated with transport from the feedlot, loading on-ship and/or the initially-unfamiliar shipboard environment. Secondly, salmonellosis has been consistently identified as the main cause of death during veterinary investigations of losses during the passage from Portland or Adelaide to Fremantle. It is important to note, however, that alternative points-of-view are also held. In particular, it has been suggested that the increased losses could be due to the increased length-of-voyage (and therefore the increased time-at-sea) for sheep loaded in Portland and Adelaide in comparison to Fremantle. Sheep age and weight are other confounding factors. There is a higher proportion of heavy, aged sheep exported from the eastern States than from Fremantle.

Based on detailed analysis of Voyage 1 in another LiveCorp-supported study (LIVE.212: Investigation of ventilation efficacy on live sheep vessels), solid evidence has now become available to test the above-mentioned hypothesis and determine the importance of voyage-length in losses at seas. During Voyage 1, approximately 45,000 sheep were loaded in Portland and 27,000 in Fremantle. The ship sailed to the Middle East during the northern summer. Figure 3 presents the number of deaths by day of voyage, whereas Figure 4 presents the number of deaths by day of loading. Deaths during the voyage included 269 (99.8 deaths per 10,000) Fremantle-loaded and 902 (200.3 per 10,000) Portland-loaded sheep.

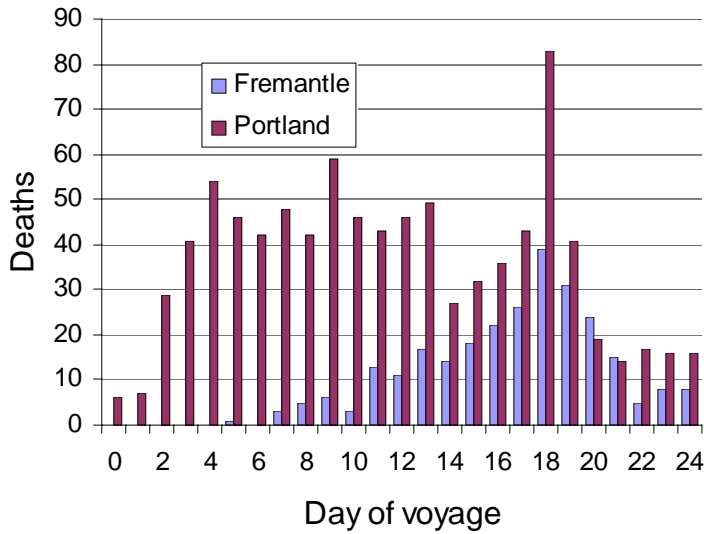


Figure 3. The number of deaths by day of voyage and port of loading for sheep travelling on Voyage 1 of the LIVE.212 project

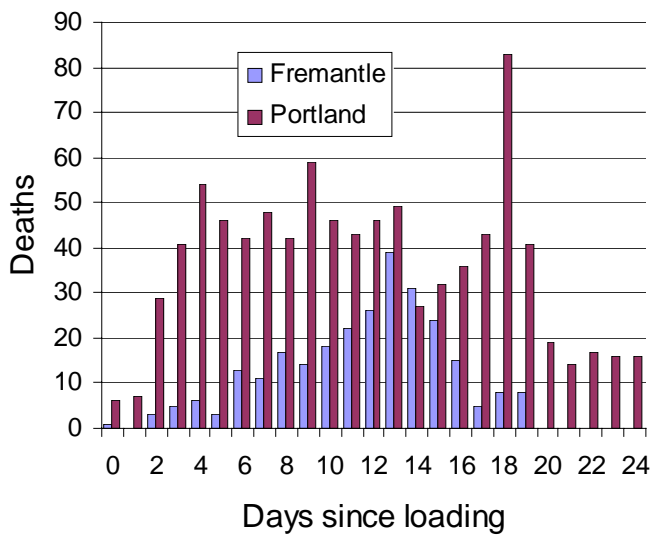


Figure 4. The number of deaths by day since loading and port of loading for sheep travelling on Voyage 1 of the LIVE.212 project

Based on the information presented in Figure 4, there are substantially more deaths during the first 12 days since loading for sheep loaded in Portland in comparison with Fremantle. Indeed, during this period, Portland and Fremantle sheep experienced mortality rates of 51.6 and 113.1 per 10,000, respectively, which is a difference of 61.5 deaths per 10,000 animals. If this voyage is representative of others, it is clear that the varying losses between ports of loading are due to differences between Portland and Fremantle rather than the length of voyage. These findings support anecdotal evidence from a number of voyages. Outbreaks of salmonellosis could be an important contributor to this problem (noting that these sheep were held in a paddock-based feedlot in Portland and a shed-based feedlot in Fremantle), although other factors could include the type of sheep and method of handling. It is important to note

that the mortality rate during Voyage 1 is slightly greater than the average mortality rates reported for sheep loaded in Portland and Fremantle during 2001.

Based on results from Voyage 1 of the LIVE.212 project, and supporting anecdotal evidence from a number of voyages, length of voyage is not an important contributor to the increasing losses experienced during shipping in sheep loaded in Portland and Adelaide in comparison to Fremantle. Feedlot-related salmonellosis may be an important contributor to these problems, although other factors that differ between the eastern and western ports of loading may also be important

4. Why the problem is occurring

4.1 General principles of disease causation

As indicated in the accompanying literature review, most diseases are 'multifactorial', or caused by a number of 'causal factors' acting together. Given its complexity, disease causation is often presented as a 'causal web', to represent each of the causal factors and the relationship between them. An understanding of disease causation is important, both in terms of understanding why a disease occurs, and also to enable effective control measures to be put in place.

An understanding of disease causation is important, both to understand why a disease occurs and to enable effective control measures to be put in place

4.2 Two different syndromes of salmonellosis in the export trade

A key outcome of this report is the recognition of two different syndromes of salmonellosis in the live sheep export trade. Although both syndromes result in similar clinical signs in affected sheep, the causes of each syndrome are somewhat different. Under such circumstances, as mentioned above, effective control measures will be different for each syndrome.

These two syndromes are:

- *Salmonellosis related to intensive feedlotting (feedlot-related salmonellosis).* The pattern of losses at each of the paddock-based feedlots is highly suggestive of more 'classical' salmonellosis, which is an increasingly problematic syndrome associated with animal industry intensification. In these situations, clinical disease develops after stressed animals are exposed to a heavy challenge with *Salmonella* organisms. In the live sheep export trade, feedlot-related salmonellosis mainly occurs during feedlotting, although it may also contribute to increased mortality during the first 5-7 days on-ship.
- *Salmonellosis as part of the persistent inappetence – salmonellosis – inanition complex.* The persistent inappetence – salmonellosis – inanition (PSI) complex is an important cause of death of sheep during live export. Based on detailed research conducted by scientists from Agriculture WA, there is a variable, but generally small, percentage of exported sheep that refuse to eat at any stage after leaving the farm-of-origin. These animals eventually die from inanition, unless they first succumb to salmonellosis. Deaths associated with the PSI complex mainly occur during the voyage between Australia and the port of destination.

There are two different syndromes of salmonellosis in the live sheep export trade. The current problems in paddock-based feedlots are due to feedlot-related salmonellosis

The relationship between these syndromes is illustrated diagrammatically in Figure 5. Detailed information about these two syndromes is presented in the Appendix A6.

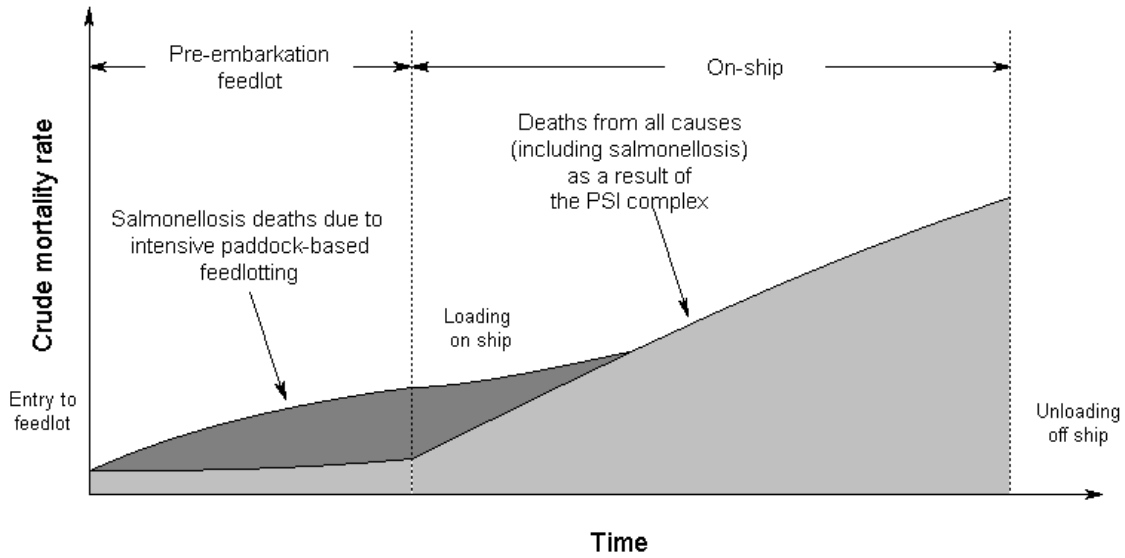


Figure 5. A stylised representation of the temporal pattern of salmonellosis as part of the PSI complex, and as a result of intensive paddock-based feedlotting. Based on anecdotal evidence, there have been occasions where there has been a 'spillover' of problems from feedlot to ship. In other words, salmonellosis problems during feedlotting at Portland and Adelaide are associated with higher-than-normal mortality rates due to salmonellosis for up to a week after embarkation

4.3 The ecology of *Salmonella* spp. in paddock-based live sheep export feedlots in Australia

The following section describes best-known information about the ecology of the organism in live sheep export feedlots in Australia. These conclusions were developed following a visit to each of the large industry feedlots, and have been underpinned by a detailed understanding of international literature and expert opinion. The ecology of salmonellae in paddock-based feedlots during live goat export is likely to be similar. Although outside the scope of this current report, our understanding of these issues would be improved if experimental field work were undertaken at representative feedlot(s).

Although sampling has been occasional and opportunistic, it is likely that *S. typhimurium* and *S. bovis-morbificans* are the main serotypes involved in these outbreaks. These serotypes are carried by a wide variety of animal species.

Based on published findings, the prevalence of active *Salmonella* infection (that is, with organisms being shed in faeces) is generally very low, particularly in sheep at pasture. For several reasons, however, the prevalence of infection will increase during transit to the feedlot and significant numbers of sheep will be shedding *Salmonella* spp. at the time of entry. Sheep will become infected as the organism spreads rapidly between infected and uninfected animals during the close contact of transit. Also, latent carrier animals which normally shed the organism intermittently will frequently become continuous shedders under conditions of stress, such as long-distance trucking. As a consequence of these events, and after accounting for the high throughput of sheep at each feedlot and the multitude of properties-of-

origin involved, there is little doubt that introduced sheep are the initial source of the organism in the feedlot environment.

Some sheep will be shedding the organism on entry to the feedlot

Once placed in a feedlot paddock/pen the feedlot environment becomes rapidly and highly contaminated with *Salmonella* organisms. Factors contributing to the level of contamination include:

- *The length of time since the last consignment of sheep.* Although influenced by a range of environmental factors, the absolute number of *Salmonella* organisms will generally decay rapidly with time. Although the organism can persist for months or years, the level of environmental contamination will generally be very low after a 3-4 week spell.
- *The number of infected sheep.* Following introduction, spread among sheep is very rapid, due to the close contact with other sheep (with stocking rates of approximately 1000 sheep per hectare) and as a result of an increasingly contaminated feedlot environment. Shedding of organisms is greatest from clinical cases of disease, which can produce 10^9 salmonellae per gram of faeces. This means that one sick sheep can shed enough organisms to infect more than 1,000 additional sheep each day
- *Factors contributing to the survival and proliferation of the organism in the feedlot environment.* The organism will rapidly proliferate under favourable conditions of warmth and moisture, and in the presence of suitable nutrients. Conversely, survival is least likely under hot and dry conditions. A range of management practices, including the use of open ground-based troughs for pellet feeding, are certain to influence the pattern of environmental contamination. During warm but inclement weather, organisms are likely to proliferate in these pellets, which have been contaminated by faeces and spoiled by rain. Because survival and proliferation is affected by climatic factors at the micro-level, the level of environmental contamination may be very variable throughout a feedlot paddock.

The feedlot environment rapidly becomes heavily contaminated with Salmonella organisms from resident sheep. However, the level of environmental contamination may be very variable throughout a feedlot paddock, and will be influenced by a range of management and microclimatic factors

Salmonella organisms spread via the faecal-oral route, either directly as a result of close contact between animals, or indirectly from a contaminated environment or via contaminated feed and/or water. Within the live sheep export trade, there is little doubt that sheep-to-sheep spread is important during transit. During this time, animals are in close contact for significant periods. However, once sheep arrive at the feedlot, the dominant challenge of *Salmonella* organisms is likely to come from an environment that has been contaminated by resident sheep.

After arrival at a feedlot, the main challenge of Salmonella organisms comes from the contaminated feedlot environment

There is no evidence that feed or water played any role as a source of infection at any feedlot. At the feedlots, water was sourced either from bores or town supply. Although feed was certain to come from a wide variety of sources, the feedstuffs had not been grown under conditions where contamination was likely (such as irrigation with waste or effluent water). Because drainage at all feedlots was excellent, with little build-up of surface water, there will be minimal movement of salmonellae between paddocks.

Rodents, birds and most other animal species do not appear to play a significant role in the source or spread of *Salmonella* organisms at any of the visited feedlots. In comparison to sheep, challenge from these sources would be very small. Furthermore, all feedlots have a program of rodent control. The role of cattle could be potentially important, given their large daily faecal output. However, at all industry feedlots, these animals are managed separately from sheep, and there is no apparent opportunity for cross-contamination.

4.4 The causes of feedlot-related salmonellosis

4.4.1 General comments

Feedlot-related salmonellosis is a disease of intensification. As indicated in the accompanying literature review, and in common with similar syndromes in a range of animal-based industries throughout the world, the two broad causal factors of feedlot-related salmonellosis include reduced host resistance and increased challenge from *Salmonella* organisms. The size of the *Salmonella* challenge, the level of host resistance and the virulence of the serotype involved each play a key role in determining the outcome after exposure to *Salmonellae* (Figure 6).

The outcome following Salmonella challenge is affected by the size of the Salmonella challenge, the level of host resistance and the virulence of the serovar involved

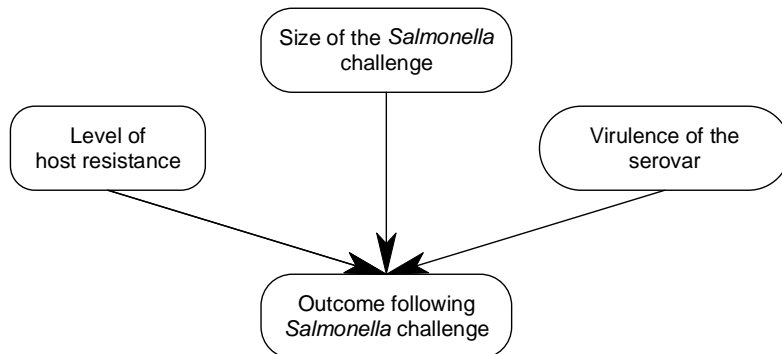


Figure 6. Factors affecting the outcome following exposure to *Salmonellae*

As discussed in detail in the accompanying literature review, the likelihood of clinical disease following challenge is closely dose-related. As illustrated in Figure 7, if the level of challenge is low, animals will not become sick, but may become passive carriers. With increasing challenge, there is increasing likelihood of animals becoming active carriers or, at high challenge, developing clinical disease.

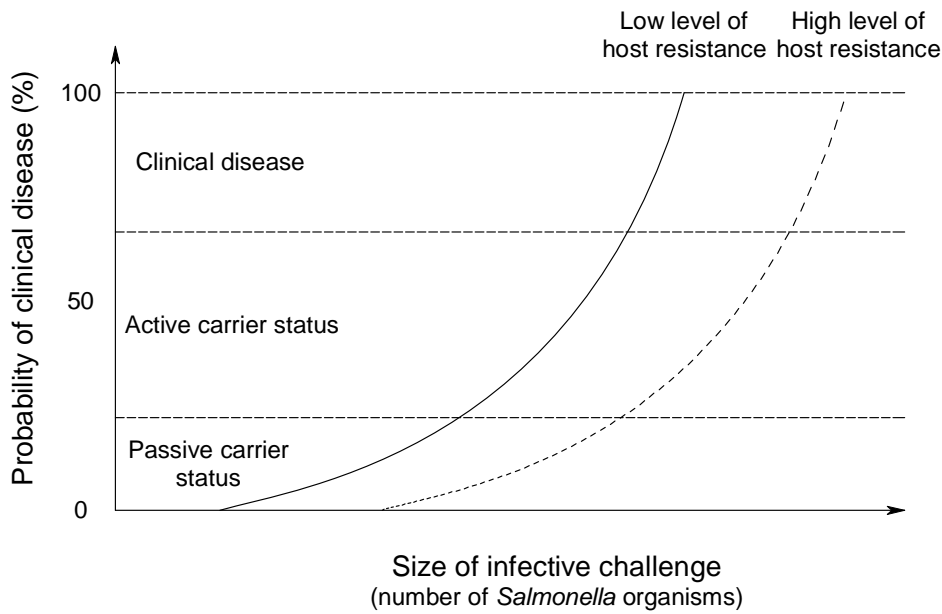


Figure 7. A stylised representation of the dose-response relationship between the size of the infective challenge and the probability of clinical disease. As host resistance is reduced, a much smaller challenge of *Salmonella* organisms is needed to produce clinical disease

When host resistance is compromised, however, clinical disease will develop following a much lower challenge. In healthy animals the infectious dose of *Salmonella* organisms is at least 10^9 organisms. However, in animals with reduced host resistance, only 400 organisms may be needed to produce clinical disease.

There is a dose-response relationship between Salmonella challenge and clinical disease. As host resistance is reduced, a much smaller challenge of Salmonella organisms is needed to produce clinical disease

4.4.2. The importance of reduced host resistance in outbreaks of salmonellosis

As indicated previously, many aspects of salmonellosis do not appear consistent. For example, a wide range of sheep types are involved, and outbreaks may occur in a number of different months each year. However, as illustrated in Figure 8, the operators' description of some aspects of each outbreak is extremely consistent:

- Although the location of each outbreaks is not predictable, all outbreaks are highly clustered (affecting only one or a small number of generally non-contiguous paddocks in any particular consignment); and
- Problem paddocks do not persist from one consignment to the next.

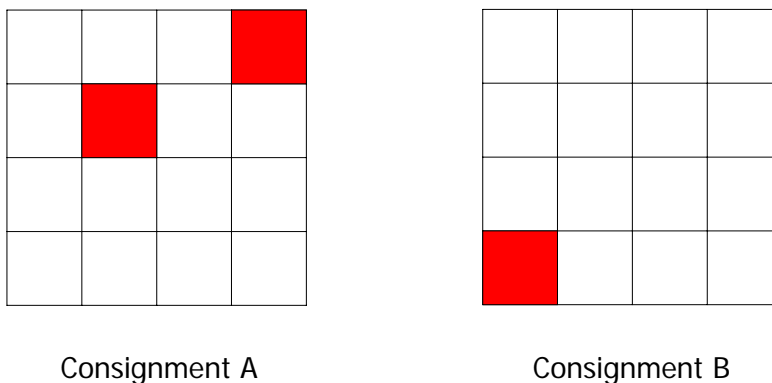


Figure 8. A stylised representation of the spatial pattern of outbreaks in two consecutive consignments. In both consignments, the outbreaks affect only one or a small number of generally non-contiguous paddocks. Furthermore, 'problem paddocks' in one consignment do not persist to later consignments

These patterns in disease presentation, which were consistent at all paddock-based feedlots, can be used to assess the relative the relative importance of *Salmonella* challenge (paddock factors) and host resistance (host factors) in these outbreaks. It is well-recognised among epidemiologists that the pattern of disease outbreaks (in time, in space and among different animal factors) can provide clues about why they occur.

- *If paddock conditions (affecting Salmonella challenge) were more important*, outbreaks would be more likely in particular paddocks, where microclimatic conditions consistently tend to favour *Salmonella* proliferation and survival, and where high levels of environmental contamination (as would occur during an outbreak) would likely affect future consignments.
- *If host factors (affecting host resistance) were more important*, outbreaks would not be associated with particular paddocks.

Based on the patterns seen:

- Reduced host resistance is critical to the development of outbreaks during feedlotting. Although *Salmonella* challenge is likely to be high throughout a paddock-based feedlot, outbreaks occur in only a limited number of non-contiguous paddocks, and appear to affect specific lines of sheep. Furthermore, the high *Salmonella* load in affected pens does not, on its own, lead to further outbreaks in later consignments
- However, high *Salmonella* challenge also plays an important role in the development of outbreaks. In particular, high *Salmonella* load from a small

number of clinically-affected animals appears sufficient to trigger a propagating epidemic among other sheep in the paddock.

On balance, therefore, although reduced host resistance and high *Salmonella* challenge are both important causes of outbreaks of salmonellosis during feedlotting, the former causal factor is likely to be the more influential of the two.

Although reduced host resistance and Salmonella challenge are both important causes of outbreaks of salmonellosis during feedlotting, the former causal factor is likely to be the more influential of the two

5. Feedlot management in the face of an outbreak

Based on experiences in the industry, outbreaks of salmonellosis are generally isolated to one or a small number of paddocks. In affected paddocks, morbidity (illness) and mortality (death) rates can be substantial, particularly in common lines of sheep.

Based on current understanding, appropriate feedlot management in the face of an outbreak should include:

- *Observe reasonable standards of hygiene.* Based on available evidence, paddock-to-paddock spread rarely occurs. Therefore, barrier hygiene is likely of little benefit. Nonetheless, carcasses will be heavily contaminated, and it is advisable that these should be collected and removed in a vehicle that is dedicated for this purpose and then disposed of in a manner that prevents any possible exposure of other sheep
- *Provide high-quality feed and water.* Stressful conditions are certain to increase the morbidity and mortality rates during an outbreak. Stress will be minimised by providing high-quality feed and water and reasonable shelter, and leaving the animals alone.
- *Minimise stress if live animals are to be moved from the affected paddock.* The movement of live sheep from affected paddocks should only be considered if animals can be moved with minimal stress, if suitable empty paddocks (with little contamination) are located nearby, and if sheep from non-affected paddocks are not put at risk. If these criteria cannot be met, it is advisable that sheep remain in the affected paddock(s). It is important to note that infection spreads quickly during an outbreak. Therefore, most clinically-normal animals will rapidly become heavy faecal shedders of *Salmonella* organisms (either as active carriers or as animals soon to develop clinical disease). Clinical disease and further paddock contamination will occur if stress is imposed on animals that have or are incubating clinical disease.
- *Do not use antimicrobial agents therapeutically.* As indicated in the accompanying literature review, there is much debate about the use of antimicrobial agents to treat clinical salmonellosis in a range of animal species. In the live sheep export trade, there are a number of reasons why antimicrobial agents should not be used therapeutically (to treat clinically-affected animals):
 - Antimicrobial agents are generally only helpful if used in association with rigorous and appropriate intravenous fluid therapy. Such therapy is not possible within the industry
 - Because clinically-affected animals are inappetent, and also because of logistic difficulties with other routes of administration, antimicrobial agents

must be given in the water. However, the administration of these products by mouth is certain to disrupt the normal bacterial flora in the digestive tract, which play a critical role in the animal's natural defences against salmonellosis

- There is widespread antimicrobial resistance against the two products (sulphadimidine, oxytetracycline) that are available for administration through water. If these agents are used in the presence of resistant *Salmonella spp.*, the disruption to normal bacterial flora will occur simultaneously with unchecked proliferation of *Salmonella spp.*
- Regular use of these antimicrobial agents will result in selection of resistant strains of *Salmonella spp.* Given the potential for salmonellae to persist in the environment, it is likely that resistance will re-emerge in subsequent consignments
- *Undertake ground maintenance and spell paddock for 1 month.* After the removal of animals, organism survival (and proliferation) is affected by microclimatic factors including moisture, heat and the availability of nutrients. Operators should seek to limit survival of salmonellae by improving paddock drainage, preventing the pooling of surface water and disrupting the build-up of faecal material. It would also be valuable to apply lime to the paddock after the sheep have been removed. Although salmonellae can survive for long periods, the majority of the organisms will die rapidly. Therefore, the paddock should be spelled for at least one month, thereby limiting *Salmonella* challenge for the next consignment.

In the face of an outbreak, sheep in affected paddock(s) should only be moved if this can be done with minimal stress, if suitable empty paddocks are located nearby, and if sheep from non-affected paddocks are not put at-risk. The sheep should be given high-quality feed and water. Antimicrobial agents should not be used therapeutically (to treat clinically-affected animals). After the affected consignment has been removed, ground maintenance should be undertaken to limit survival of the organism, and the paddock should be spelled for at least one month

6. Long-term control of feedlot-related salmonellosis

6.1. The strategic use of sheds in paddock-based feedlots

6.1.1 Introduction

As indicated previously, the control of feedlot-related salmonellosis will depend on strategies to increase host resistance and reduce *Salmonella* challenge. Of all the control measures available, the strategic use of sheds in paddock-based systems is likely to be most-effective means in reducing this problem. The potential advantages and concerns of this issue are discussed, and a detailed economic benefit-cost analysis is presented.

6.1.2 Potential advantages associated with shedding

According to industry sources, there have been no significant outbreaks of salmonellosis in any of the shed-based feedlots. Moreover, there have not been any recent outbreaks in sheep held in paddocks surrounding these sheds.

Based on the experience of the shed-based feedlots in Western Australia, sheds offer a wide range of advantages, including:

- *Increased flexibility in sheep selection.* In shed-based feedlots, operators have considerable flexibility both in the selection of sheep for purchase and in subsequent management decisions. Woolly sheep can be handled and shorn without concerns of current weather or subsequent hypothermia, thereby potentially decreasing the current serious supply problems. Recently-shorn sheep are also reported to travel better during the hot, humid conditions in the Middle East summer months. In paddock-based feedlots, however, woolly sheep can only be purchased in small numbers, shearing is limited to favourable weather, and animals post-shearing must be managed with care. Substantial losses from hypothermia were experienced at a paddock-based feedlot on one occasion some years ago.
- *Increased flexibility in sheep management.* There would be considerable theoretical advantages associated with the shedding of lines considered at high-risk of salmonellosis. In a shedded environment, the risk of disease in high-risk lines would be substantially reduced. As a cautionary note, this benefit will be difficult to exploit in practice because there is an incomplete understanding of the characteristics that place particular sheep lines at higher risk of disease. Despite these difficulties, however, several operators believe that they are able to identify some high-risk lines, based on their appearance and events that occurred during transport.
- *Reduction (and potential elimination) of outbreaks of salmonellosis.* There is compelling theoretical evidence in support of reduced feedlot-related salmonellosis in shedded sheep. Shedded sheep are at decreased risk of salmonellosis as a result of increased host resistance and reduced *Salmonella* challenge. Shedded sheep have increased host resistance because they are sheltered from inclement weather and have access to a consistent supply of high-quality feed and water. Sheep held on raised mesh floors will also have reduced *Salmonella* challenge, because the opportunity for faecal-oral cycling will be substantially reduced. This theoretical evidence is supported by practical findings, with no reported outbreaks of salmonellosis in shedded animals within the live export trade.
- *Reduced labour costs.* Based on the experience of shed-based operators, daily labour requirements are substantially lower in shed-based as compared to paddock-based systems. In shed-based feedlots, feeding and watering of 12,000 sheep can be undertaken by two people in 30 minutes. Equivalent tasks in a paddock-based system take four hours (eight times as long). Labour costs associated with maintenance such as fencing and yard repairs are likely to be similar in both systems.
- *Income from sale of manure.* The sale of manure is a substantial source of income at each of the shed-based feedlots. The manure is sold *in situ* at the feedlot for A\$24-25 per m³, and is mainly destined for use in home gardens. The shed-based feedlots are all located on the fringes of the greater Perth area. At this point, it is difficult to predict whether similar prices could be achieved if sheds were built in the South Australia (one hour by road from Adelaide) and Victorian (four hours from Melbourne) feedlots.
- *Reduced environmental concerns.* Sheds would address many of the current environmental concerns associated with paddock-based systems, including soil erosion, vegetative loss, groundwater contamination and loss of visual amenity. In Western Australia, the use of sheds has helped to allay many of the environmental concerns associated with intensive feedlotting. These shed-

based feedlots are located on the fringes of the greater Perth area in an area where local aquifers are replenished by groundwater. The sheds were built to comply with strict Environmental Protection Authority guidelines, including the installation of complex draining aprons.

Sheds offer a range of advantages during feedlotting, including increased flexibility in sheep selection, increased flexibility in sheep management, reduction (and potential elimination) of outbreaks of salmonellosis, reduced labour costs, income from the sale of manure and reduced environmental concerns.

6.1.3 Concerns associated with shedding

At this point, it is also important to highlight a number of concerns associated with the potential introduction of sheds into paddock-based systems:

- *The capital cost is very high.* Based on available information, the cost to build a shed to hold 7,500 sheep ranges from \$50 to \$100/head, depending on the design of the floor.
- *The choice of floor design is not clear.* Two general floor designs are possible, including raised (mesh/slatted) floors and non-raised (concrete/earthen) floors. All Australian shed-based systems currently use a raised floor. From a theoretical perspective, a raised floor is preferred because it addresses each of the controllable risk factors for salmonellosis, namely increasing host resistance and decreasing *Salmonella* challenge. In contrast, although a shed with non-raised flooring is likely to lead to improved host resistance (considered the more important of the two key risk factors), the impact on faecal-oral cycling and subsequent *Salmonella* challenge may be minimal. Reduced *Salmonella* challenge will be greatest if feed and water troughs are raised, thereby minimising faecal contamination. In both floor types, host resistance is heavily influenced by shed design and will be greatest if sheep are comfortable and sheltered from wind and rain, and with ready access to feed and water. Although raised floors offer theoretical advantages, there are also several significant concerns with respect to these facilities. Firstly, sheds with raised floors are approximately twice the cost of sheds without raised floors. Secondly, many sheep in eastern states would not be able to tolerate raised floors, as a result of 'soft' feet. Therefore, although raised floors may be preferable in theory, they may not be as practical in eastern states. Because knowledge is limited, rigorous testing needs to be undertaken to rigorously assess the effectiveness of sheds without raised floors in the control of salmonellosis during feedlotting.
- *The management of sheep in a partially-shedded feedlot may prove problematic.* In the current shed-based systems, shedding capacity is very high and most animals are held within a shedded environment. As a consequence, all animals are shedded except for those (such as heavy wethers) that will not tolerate shedding. If shedding were to be introduced into the current paddock-based systems, shedding capacity is certain to be limited. As a consequence, decisions will need to be made to determine the appropriate mix of animals in the sheds and paddocks. Due to current limitations in knowledge, it is generally not possible to identify animals that are at higher disease risk. Therefore, in terms of a strategy for disease control, sheds may be of limited advantage.

There are a number of concerns relating to the introduction of sheds, including the high capital cost, concerns about the most appropriate floor design and potential concerns with sheep management in a partially-shedded feedlot.

6.1.4 An economic analysis

a. Obstacles to shed construction

Before looking in detail at the cost of shedding, it is necessary to acknowledge the obstacles to shed construction, particularly in eastern states:

- *Market risk.* The live sheep export trade is completely reliant on the Middle East as an outlet. Ongoing access to this outlet is dependent on political and economic factors, making it rational for operators to minimise the sunk capital that they are prepared to place at-risk.
- *Location risk.* The location of preference for sourcing sheep is Western Australia (due to its relative proximity to the Middle East). Only when sheep are in short supply do operators pull significant numbers of sheep from eastern Australia.
- *Cost.* In light of the above risks, the capital cost of constructing holding sheds is significant. This cost, however, needs to be balanced against the long life of sheds, the high throughput that is possible, the ease of manure collection and sale from sheds and the avoidance of losses due to reduced salmonella mortalities relative to open paddocks.

Obstacles to shed construction include market risk, location risk and cost

b. Vertically-integrated operations

A detailed economic analysis has been undertaken to present the expected benefits and costs of introducing some shedding capacity into a vertically-integrated paddock-based feedlots which can capture all of the expected benefits. The relevant MS Excel file is available from the author on request. The results of these analyses were generated using a spreadsheet run over 15 years. This analysis was conducted based on the following assumptions and relevant data sources:

- *Shed capacity.* In shed-based feedlots, sheds currently hold 7,500 sheep.
- *Cost of shed.* Based on advice from feedlot operators, sheds with and without raised floors would cost approximately \$90 and 50/head, respectively
- *Annual maintenance.* Based on advice from feedlot operators, \$5,000 is a reasonable estimate of annual costs to enable long-term shed maintenance
- *Average sheep value.* Sheep currently cost approximately \$60/head
- *Consignments per year.* A total of 16 consignments represents a conservative estimate of throughput in eastern states in recent years
- *Background feedlot mortality rate.* As illustrated earlier, the average feedlot mortality rate in recent years has been approximately 7 deaths per 10,000 animals
- *Number of outbreaks of salmonellosis in paddock-based consignments.* Based on data collected during this study, in recent years paddock-based feedlots have experienced outbreaks in an average of 4 consignments per year

- *Number of outbreaks of salmonellosis in shed-based consignments.* Based on data collected during this study, there have been no outbreaks of salmonellosis in shed-based feedlots in recent years
- *Feedlot mortality during outbreaks of salmonellosis.* As illustrated earlier, the average mortality rate during outbreaks of salmonellosis is approximately 100 deaths per 10,000 animals
- *Additional mortality at sea following an outbreak of salmonellosis during feedlotting.* Based on data collected during Voyage 1 of the LIVE.212 study, during the first 12 days following loading there were an additional 61.5 deaths per 10,000 animals in sheep loaded in Portland as compared to Fremantle. In the base scenario, it is assumed that half of these losses can be attributed to feedlot-related salmonellosis in the live export feedlot.
- *Average time in sheds.* In the base scenario, animals spend an average of 5 days in sheds before loading
- *Value of manure.* Given the distance of most paddock-based feedlots from large centres and the increased difficulty in retrieving manure from sheds without raised floors, the base scenario uses a conservative estimate of \$18/m³

An economic analysis was undertaken by considering the expected benefits and likely costs associated with the strategic use of sheds in vertically-integrated, paddock-based feedlots.

b. Operations that are not vertically-integrated

The above-mentioned economic analysis is only relevant to vertically-integrated operations, because it is these operations that will capture all the benefits and incur all of the costs listed previously. In operations that are not vertically-integrated, the issue arises as to how the shed owner might justify the shed investment under circumstances when most the gains are revealed through superior sheep performance. Clearly the shed operator will want to pass-on the additional costs implicit in offering shed accommodation relative to paddock accommodation. Two situations are possible:

- *Situations where third-party owners can be convinced of the benefits of shedding.* Under these circumstances, and particularly given current circumstances where feedlotting options are limited, third-party owners are likely to agree to higher charges for shed accommodation. It is hoped that excerpts from this research would help to clearly convey the potential benefits associated with the use of sheds during feedlotting.
- *Situations where third-party owners cannot be convinced of the benefits of sheds.* Under these circumstances, and particularly if shed throughput were comprised for this or other reasons, it would clearly be a risky strategy to build a shed on the presumption that the higher costs could be passed-on to independent operators. This risk would be only partly offset by the financial benefits of shed ownership, including the money generated from manure sales. This broad issue is unlikely to be important for vertically integrated operators, particularly if they are able to achieve maximum shed throughput without relying on business from third-party owners.

To assist with decision-making, an economic analysis has been conducted to determine the additional charge (as c/head for the full feedlotting period) that would be required to enable a non vertically-integrated operation to recover shed construction costs plus a margin of 25%. These additional charges are presented in Tables 2 and 3 under the same scenarios as previously, but only take account of the capital cost of the shed, the yearly maintenance costs, the annual returns from manure and the throughput of animals each year over a 15

year period. For each scenario the percentage increase in the overall charges for contract feedlotting, based on current charges of 30c/head/day, has also been estimated.

An economic analysis was also undertaken to determine the additional charge required to enable a non vertically-integrated operation to cover shed construction costs plus a margin of 25% in paddock-based feedlots

c. Results

As illustrated in Table 2 and with reference to a vertically-integrated operation, the base scenario includes assumptions that are generally considered conservative, but indicate an internal rate of return (IRR) of only 1.7%, which is too low to attract investment. In addition to the 'base case', Table 2 also presents the sensitivity of returns to positive movement in a number of key variables; thereby testing scenarios including increased sheep value, increased feedlot throughput, increased number of outbreaks in paddock-based consignments, increased additional mortality at seas following feedlot outbreaks, increased time in sheds and increased value of manure. In S1 to S6, one variable is changed while all others remain unchanged as per the 'base case'. A number of variables are not changed in any scenario, and are generally accepted figures by industry. The column headed 'SB' combines all the 'best case' circumstances that could be reasonably expected.

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Table 2. Comparison of benefits and costs of introducing sheds to paddock-based feedlots, including the sensitivity of returns to a number of positive scenarios

Assumption	Base case	Scenarios ^a						SB ^b
		S1	S2	S3	S4	S5	S6	
In vertically-integrated operations								
Shed capacity (sheep)	7,500							7,500
Cost of shed (per sheep place)	\$50							\$50
Annual maintenance	\$5,000							\$5,000
Average value of sheep	\$60	\$70						\$70
Consignments per year	16		20					20
Background feedlot mortality rate (%)	.0007							.0007
Number of outbreaks in paddock-based consignments	4			6				6
Number of outbreaks in shed-based consignments	0							0
Feedlot mortality during salmonella outbreaks (%)	.01							.01
Additional mortality at sea following salmonella outbreak in feedlot (%)	.0031				.0062			.0062
Av. Time in shed (days)	5					7		7
Value of manure (\$/m ³)	18						20	20
Internal rate of return (%)	1.7	3.7	3.2	7.4	4.6	4	2.4	19.1
In operations that are not vertically-integrated								
Additional charge to cover shed costs (c/hd) ^c	20	20	13.8	20	20	15.5	18.8	7.5
Percentage increase in feedlotting charges ^d	13.3	13.3	9.2	13.3	13.3	7.4	12.5	3.6

a. Scenarios include:

- S1. An increase in sheep value
- S2. An increase in feedlot throughput
- S3. An increase in the number of outbreaks in paddock-based consignments
- S4. An increase in the additional mortality rate at sea following feedlot outbreaks
- S5. An increase in time in sheds
- S6. An increase in value of manure

b. Selected best case

c. The additional charge (as c/hd) to enable an operation that is not vertically-integrated to cover shed construction costs plus a margin of 25%. This calculation takes account of the capital cost of the shed, the yearly maintenance costs, the annual returns from manure and the throughput of animals each year over a 15 year period

d. Based on current charges for contract feedlotting of 30c/hd/day

In vertically-integrated operations, the internal rate of return (IRR) using conservative assumptions is 1.7%. If conditions are favourable, and particularly if the incidence and severity of outbreaks of feedlot-related salmonellosis were to increase, this figure could increase to 19.1%

In operations that are not vertically-integrated and using conservative assumptions, an additional 20c per head during the feedlotting period would need to be charged over 15 years to cover shed construction costs plus a margin of 25%. If conditions are particularly favourable, this figure could reduce to 7.5c/hd. The addition of 20c/hd during the feedlotting period will increase the overall charge for feedlot contracting by 13.3%, based on current charges of 30c/hd/d for 5 days

Table 3 is similar to Table 2, except that it shows the result of outcomes worse than the base case.

Table 3. Comparison of benefits and costs of introducing sheds to paddock-based feedlots, including the sensitivity of returns to a number of negative scenarios

Assumption	Base case	Scenarios ^a			SW ^b
		S7	S8	S9	
In vertically-integrated operations					
Shed capacity (sheep)	7,500				7,500
Cost of shed (per sheep place)	\$50	\$90			\$90
Annual maintenance	\$5,000				\$5,000
Average value of sheep	\$60				\$60
Consignments per year	16				16
Background feedlot mortality rate (%)	.0007				.0007
Number of outbreaks in paddock-based consignments	4		3		3
Number of outbreaks in shed-based consignments	0				0
Feedlot mortality during salmonella outbreaks (%)	.01				.01
Additional mortality at sea following salmonella outbreak in feedlot (%)	.0031			.0016	.0016
Av. Time in shed (days)	5				5
Value of manure (\$/m ³)	18				18
Internal rate of return (%)	1.7	-6	-1.4	0.2	-8.9
In operations that are not vertically-integrated					
Additional charge to cover shed costs (c/hd) ^c	20	40.9	20	20	40.9
Percentage increase in feedlotting charges ^d	13.3	27.3	13.3	13.3	27.3

a. Scenarios include:

- S7. An increase in shed establishment cost, as would occur if a raised-floor design were used
- S8. A reduction in the number of outbreaks in paddock-based consignments, as might occur if there were effective adoption of other control strategies
- S9. A reduction in the additional mortality at sea following feedlot outbreaks, as might occur if there were effective adoption of other control strategies

b. Selected worst case

c. The additional charge (as c/hd) to enable an operation that is not vertically-integrated to cover shed construction costs plus a margin of 25%. This calculation takes account of the capital cost of the shed, the yearly maintenance costs, the annual returns from manure and the throughput of animals each year over a 15 year period

d. Based on current charges for contract feedlotting of 30c/hd/day

The overall establishment cost, which is greatly influenced by the flooring used during construction, is particularly influential in the long-term benefit-cost of shedding

The results from both tables indicate the following:

- The variable that seems to have the greatest impact on expected returns is the incidence of salmonella that can be avoided by not having to hold the sheep in open paddocks. If the number of shipments per year (out of open paddocks) that suffers a salmonella outbreak goes from four up to six, the expected IRR (due to shedding) in vertically-integrated operations would rise from 1.7% to 7.4%. This result suggests that if the incidence of salmonella outbreaks in open paddocks were to rise, removal of this problem alone would go close to justifying a move to sheds.
- If there were gains across all the key variables (resulting in a 'best case' outcome) as shown in column SB (Table 2), the expected IRR in vertically-integrated operations would be quite attractive at 19.1%. While some combination of favourable movements is not beyond the bounds of possibility, operators need to make their own judgement about the likelihood of this happening in practice.
- The base case assumes a concrete floor shed. When the cost per sheep place is raised from \$50 to \$90 (as might occur if raised sheds were built), the IRR in vertically-integrated operations drops considerably – to minus 6%. Clearly the economics of the proposed conversion depend very much on the capital cost per sheep space of constructing a shed. When the three unfavourable scenarios are combined (a more-costly shed, a drop in the number of mortalities in paddock-based consignments and a decrease in the additional mortality at sea) (resulting in a worst case scenario denoted SW in Table 3), the expected IRR would fall to minus 8.9%. In operations without vertical-integration, the additional charge to cover shed construction costs plus a margin of 25% would need to rise from 20 to 40.9c/head if all three unfavourable scenarios were to occur simultaneously

In vertically-integrated operations, the analysis provides an estimate of the likely benefit-cost of shedding, based on a number of possible scenarios. Although the internal rate of return for the 'best case' scenario is favourable, operators will need to make their own judgment regarding the likelihood that this scenario might occur. A similar proviso is relevant to operations without vertical integration

These tables relate specifically to the direct economic benefits relating to the use of sheds, in comparison to open paddocks, during live sheep export. It is important to note that there are other less-tangible benefits associated with the use of sheds. These benefits may not be directly captured by the operator but could be highly valued by the community at large, including:

- *Reduced environmental impacts.* Confinement of sheep in sheds is likely to bring a number of environmental benefits as mentioned previously, including

reduced soil erosion, vegetative loss, groundwater contamination and visual amenity.

- *Animal welfare.* Exposure to severe weather combined with greater mortalities from salmonella and degraded amenity values makes the open paddocks vulnerable to accusation of sub-standard animal welfare.

Additional less-tangible benefits associated with the introduction of sheds include reduced environmental impacts and improved animal welfare

6.1.5 Conclusions and recommendations

Three key factors have driven the current debate concerning the need for superior feedlot accommodation for export sheep, including:

- Concern regarding feedlot-related salmonellosis, and key risk factors for this condition associated with paddock-based feedlotting;
- The link, now increasingly certain, between the standard of accommodation during feedlotting and the level of mortalities subsequently during the sea voyage;
- A marked increase in both the demand for and unit-price of live export sheep in the past few years; and
- The consequent need to draw increasingly on sheep populations from eastern Australia.

As illustrated throughout this report, the strategic use of sheds in paddock-based feedlots is likely to be the most effective strategy for industry in the control of feedlot-related salmonellosis. Although their advantages are clear, there are complex issues associated with adoption of shed accommodation. First, the cost of shed construction is highly dependent on the type of flooring that is installed. Secondly, the economics of moving to shed accommodation are not strong when subject to 'most likely' assumptions. Thirdly, the trade is vulnerable to underlying risks that might reasonably cause operators to discount the value of any large capital investment in infrastructure – such as accommodation. Hence it is necessary (as has been done in the above sensitivity analyses in Tables 2 and 3) to consider the impact of under-performance by some variables. Under favourable circumstances, however, the expected returns from investing in superior accommodation appear quite attractive. Operators who judge these circumstances (see Table 2) to be achievable in practice should be encouraged to implement shed accommodation without delay.

After consideration of all the technical and economic issues the following recommendations are offered:

- If sheds are to be constructed, it is critical that they are carefully planned to maximise host resistance and minimise *Salmonella* challenge. Sheds will be most effective if shedded sheep are comfortable, protected from wind and rain, and fed and watered using systems that maximise consistent feed intake and minimise faecal contamination;
- Providing the economic fundamentals underlying the trade at this time remain in place, a policy of moving paddock-based systems to at least partial shed accommodation should be adopted; and

- Further research should be undertaken to identify the relative merits of raised and concrete flooring. An assessment of rumen health, *Salmonella* ecology, general animal health (particularly relating to the epidemiology of salmonellosis) and economics should be included in any such investigation.

The following recommendations are made regarding the strategic use of sheds in paddock-based feedlots:

- (1) If sheds are to be constructed, it is critical that they are carefully planned to maximise host resistance and minimise Salmonella challenge. Sheds will be most effective if they enable shedded sheep to be comfortable, protected from wind and rain, and fed and watered using systems that maximise consistent feed intake and minimise faecal contamination;*
- (2) Providing the economic fundamentals underlying the trade at this time remain in place, a policy of moving paddock-based systems to at least partial shed accommodation should be adopted; and*
- (3) Further research should be undertaken to assess the relative merits of raised and concrete flooring. An assessment of rumen health, Salmonella ecology, general animal health (particularly relating to the epidemiology of salmonellosis) and economics should be included in any such investigation.*

In the Australian Livestock Export Standards (March 2001), there is currently no mention of the use of shedding during feedlotting. After preliminary consideration of the potential role of shedding during feedlotting, an industry review meeting in Adelaide on 13 August 2002 suggested that no change to these standards be made.

6.2 Additional strategies to increase the level of host resistance

6.2.1 General comments

As indicated above, the level of host resistance is likely to be more important than the size of the *Salmonella* challenge in determining whether an outbreak of feedlot-related salmonellosis will occur. Consequently, control of this problem will be most effective if particular emphasis is placed on efforts to increase the level of host resistance during feedlotting.

Control of feedlot-related salmonellosis should mainly focus on efforts to increase the level of host resistance

The current standard of management in feedlots is high, and further progress is likely to be incremental. Given the nature of the problem, and the multifactorial basis of salmonellosis, each of the recommendation given below (with the possible exception of sheds) is unlikely, on its own, to have a measurable impact. Together, however, these recommendations should contribute to reduced problems.

The current standard of management in feedlots is high, and further progress is likely to be incremental

As indicated in the accompanying literature review, consistent feed intake is probably the most critical host factor in enabling sheep to withstand substantial *Salmonella* challenge. When sheep are appetent, high concentrations of ruminal volatile fatty acids (VFAs) are produced, making conditions unfavourable for *Salmonella* growth. During inappetence, however, there is a drop in ruminal VFA concentration and an increase in pH which allows salmonellae to proliferate.

Consistent feed intake is critical to the prevention of feedlot-related salmonellosis

6.2.2 A role for vaccination?

Vaccination against salmonellosis is currently not a viable control option for industry. There are several reasons for this, including:

- *Reasons relating to vaccine efficacy.* The production and testing of *Salmonella* vaccines is currently an area of considerable international effort. At this stage, however, there is no product available of proven efficacy that would be suitable for use within the industry.
- *Logistic reasons.* To be effective, animals would need to derive immunological benefit from the vaccine prior to transport to the live sheep export feedlot. Because high-risk lines cannot be reliably identified, all animals would need to be vaccinated using the recommended vaccination protocol prior to leaving the property-of-origin. Vaccination of animals at the time of arrival at the feedlot is likely to be ineffective.
- *Economic reasons.* Based on currently-available figures (see Table 1, on page 16), the average loss rate suffered in paddock-based feedlots is approximately 24.8 sheep per 10,000 sheep exported or 12.4 cents per sheep, given a value of A\$50 per head. This loss figure, which currently cost industry approximately A\$7,440 per consignment (60,000 sheep per consignment at 12.4 cents per head), derives mostly from sporadic outbreaks associated with feedlot-related salmonellosis. Although vaccination might reduce these losses, the value of losses is only 6.2% of vaccine costs (estimated at A\$120,000 per consignment, based on an estimated vaccination cost of A\$2, including 11.4 cents per dose¹, a total cost of vaccine and administration of A\$1², and a 2-dose protocol). Additional costs will be incurred with administration of the vaccine on the farm-of-origin prior to transport.

Vaccination is not yet a viable control option

¹ This cost is an estimate only, and based on the current price of CSL 5-in-1 vaccine (Primac Elders catalogue 2002, 500 dose pack). The likely cost of *Salmonella* vaccines for sheep in Australia is speculative at this stage

² Within the industry, the current cost to exporters for the second scabby mouth vaccine is \$1, which includes vaccine cost and administration charges

6.2.3 Immediate opportunities based on existing knowledge

Based on current knowledge and in addition to the strategic use of sheds, there are a number of immediate opportunities relating to increased host resistance, which would assist to control feedlot-related salmonellosis. There remain some areas of uncertainty, however, and these are listed in section 7. There may be significant industry benefit in further focused research (see section 8) to address these issues.

Prior to raising these opportunities, the current relationship between industry and relevant government regulatory bodies does not appear to be based on a cooperative partnership. Consequently, significant constraints are in-place to prevent a genuine and open culture within industry of continuous improvement at all levels and at all stages of the export process. As an example, current rules regarding regulatory involvement (including “regulatory triggers” when the feedlot mortality rate exceeds 0.5% in any one day or the voyage mortality rate exceeds 2% whilst at-sea) do not appear to encourage open communications or stimulate efforts for ongoing industry improvement. The development of a constructive and sustainable partnership between industry and government would assist with efforts to develop a culture of continuous improvement within industry.

The development of a constructive and sustainable partnership between industry and relevant government regulatory bodies would assist with efforts to develop a culture of continuous improvement within industry

a. Modification of curfews prior to long-haul transport

As indicated previously, under current curfew arrangements many long-haul sheep will be off feed and water for more than two days prior to arrival at the feedlot. Although curfews are effective in limiting injury during transport, prolonged periods off-feed will also make sheep more susceptible to developing clinical salmonellosis following challenge.

The use of water-only curfews prior to long-haul transport would seem an effective means of balancing competing animal welfare and health concerns. According to industry sources, problems of slipping during transport are mainly due to urine rather than faeces. If producers were to withhold water but not dry feed for 24 hours prior to loading, urine output (and associated slipping) during transport would be minimal. Although feed intake in the absence of water will progressively decrease, the period off-feed will be significantly less than is currently the case.

The industry should consider the use of curfews where producers withhold water but continue to provide dry feed to sheep

In the Australian Livestock Export Standards (March 2001), the standards for Land Transportation do not reflect the importance of ‘time-off-feed’ as a risk factor for salmonellosis. After considering the above recommendation, an industry review meeting in Adelaide on 13 August 2002 suggested the following revision to the Best Practice statement following 7.7.2:

“Sheep and goats should be held off water (but given dry feed) for at least twenty four (24) hours before transportation from the property of origin. This practice will minimise the risk of injury during transportation (because the floor of the stock crate will be drier) and ensure that animals are cleaner and easier to unload, whilst also minimising time-off-feed (which is an important risk factor for salmonellosis).”

b. Practices to maintain consistent feed intake

As presented in the literature review (particularly Figures 3 to 5), and in comparison to south-western Western Australia, the eastern feedlots (and particularly those at Portland) experience colder and wetter weather for longer periods each winter. In addition, rain at Portland is less intensive but more frequent than Fremantle during autumn to spring (comparing monthly average rainfall and rain days at each site).

Given this background, operators of eastern feedlots will find it difficult to achieve consistent feed intake during inclement weather if pellets are fed in open troughs. Under these conditions, and to prevent water spoilage, pellets are generally withheld and hay re-introduced. Consequently, if weather is changeable, sheep may be shifted between hay and pellet rations on several occasions during the feedlotting stage.

As illustrated below, several systems of pellet feeding are used in feedlots. However, the self-feeding system (Figure 9; on the right) is the only system in current use where pellet feeding can continue during wet weather. It is also the only available system where animals can be fed *ad lib*. Because consistent feed intake is known to be so critical to effective salmonellosis control, as indicated in the literature review, there is a compelling argument for the use of similar feeding systems in all eastern feedlots. To minimise risk factors associated with feeding, feedlot feeding systems should keep pellets dry and (as illustrated in 6.6.2.a) minimise opportunities for faecal contamination. Although further confirmatory work is needed, based on an understanding of first principles, risks associated with salmonellosis may also be reduced if animals are fed *ad lib*. Due to ongoing improvement in pellet formulation (and also because cereal grains comprise no greater than 30% of the pellet in eastern states), there is no danger of grain overload during *ad lib* or self feeding. If self-feeding systems were used, based on industry experience, approximately three feeders (each costing \$2000) would be needed for every 1000 sheep spaces.

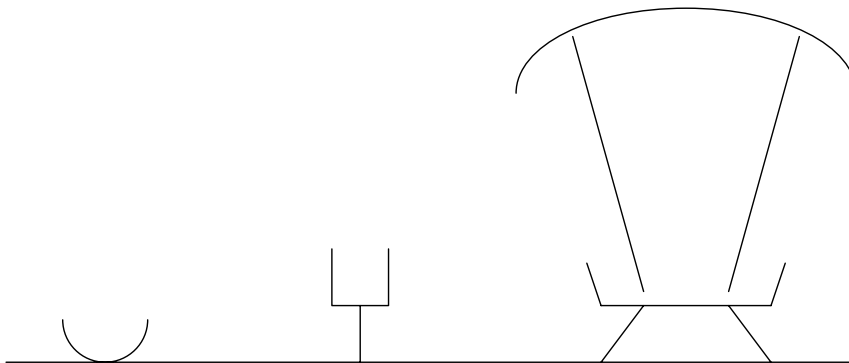


Figure 9. Diagrammatic representation of current systems for pellet feeding in paddock-based feedlots. The self-feeding system (on the right) is the only one where pellet feeding can continue during wet weather

The industry should use feeding systems that enable feed to remain dry, and with minimal faecal contamination, throughout the feedlot period

A number of feeding systems could be used to achieve the previous recommendation. For simplicity, however, only the economics of self-feeders are considered here. The economics of replacing open troughs with covered self-feeders can be assessed in terms of expected

differences in costs and benefits. The cost side of the calculation must account for the additional cost per feeding space and the throughput of the feeder system while the expected benefits will stem from feed and labour savings and more significantly, reduced sheep losses. As indicated above, the new cost of a covered self feeder is A\$6 per sheep place. If the cost of an open trough place was (say) A\$2, then the net additional cost of the covered self feeder would be only A\$4. Once this cost is spread across its life, in terms of sheep throughput, and account is taken of any feed and labour savings, we have the unit cost that can be compared to benefits stemming from the sheep receiving a dry and consistent feed throughout the feedlotting period. While it has not been possible to quantify this benefit, a fraction of a cent improvement in performance would clearly exceed the additional cost at stake. In light of this reasoning, it is recommended that a staged program of replacing open troughs with closed self feeders, be implemented.

In the Australian Livestock Export Standards (March 2001), the standards do not specify feeding systems or practices to ensure consistent feed intake, particularly during inclement weather. Furthermore (as mentioned in 6.1.3. f. of this report), there is no mention of the need for animals to have access to feed as soon as practical following arrival. After considering the above recommendation, an industry review meeting in Adelaide on 13 August 2002 suggested the following revision to 7.5.7:

“Each Exporter must ensure that:

- (a) all sheep and goats are provided with sufficient, suitable feed, as soon as practical following entry and throughout the feedlotting period;
- (b) all sheep and goats are fed to meet at least maintenance energy requirements during the feedlotting period;
- (c) sheep and goats with four (4) or less permanent incisor teeth are provided with sufficient, suitable feed for continued growth;
- (d) feed troughs and self-feeders are designed so as to minimise faecal contamination and injuries, and to prevent pellets from being spoiled by water during inclement weather ; and
- (e) if feed is not provided ad-libitum, there is at least five (5) centimetres of trough space per head.”

c. Holding sheep in paddock-based feedlots for the shortest time possible

Paddock-based feedlots provide conditions that are often well-suited to the development of feedlot-related salmonellosis, including animals with low host resistance and an environment of high *Salmonella* challenge. Therefore, a useful strategy to limit outbreaks of salmonellosis would be to hold sheep in paddock-based feedlotting systems for as short a time as possible.

The industry should hold sheep in paddock-based feedlots for the shortest time possible before loading on-ship

The Australian Livestock Export Standards (March 2001) provide a clear statement of Best Practice (following 7.3.3) regarding the need to minimise the time between farm to loading. After considering the above recommendation, an industry review meeting in Adelaide on 13 August 2002 agreed that no revision is needed.

d. Maintenance of sheep quality

There has been an ongoing decrease in the Australian sheep flock size over the last decade. Consequently, the export industry is facing substantial supply problems, and many ships are

proving difficult, if not impossible, to fill with suitable sheep. It is likely that supply problems will continue for some years.

Given this environment, it is understandable that there has been some reduction in the quality of some exported sheep. Although the quality of most sheep has been maintained, there is a perception among some in the industry that this drop is reflected in a larger tail of poor-quality sheep in recent consignments. This may have some implications for control of salmonellosis. Poorer quality sheep will be at increased risk of salmonellosis if suffering from pre-existing disease, but not if these sheep are of poorer quality due to a marginal reduction in age. Younger sheep have a stronger appetite drive and may achieve a consistent feed intake under feedlot conditions.

Within most sections of industry, considerable effort is being made to maintain high standards during the selection of sheep for export. These efforts are strongly applauded, and should be continued.

The Australian Livestock Export Standards (March 2001) provide clear standards in section 7.1 for the selection of suitable sheep for export. No revision is needed.

e. Practices to get sheep quickly onto feed

Throughout the industry, there is a high level of general feeding management. In particular, feedlot operators take considerable care in seeking to get sheep onto feed as quickly as possible after arrival at the feedlot. A range of strategies are used, including rapid processing, attention to feed quality, preferential treatment to lines considered at 'high-risk', and the feeding of hay to animals on arrival. At all feedlots, lines considered at 'high-risk' are handled preferentially, and may be given more or higher quality hay, or hay in an area of the paddock away from general traffic, immediately following arrival and during inclement weather. Furthermore, molasses and/or cereal grain (such as barley) are added to pellets in some feedlots to improve palatability.

These strategies specifically seek to target those sheep that find it difficult to adapt to feedlot conditions. They will have limited impact on the persistently-inappetent animals that eventually die as a result of the PSI complex.

The industry is strongly encouraged, in combination with the other listed recommendations, to continue those practices that have been found to be most effective in getting sheep quickly onto feed. At this stage, the consultants have no knowledge of methods, additional to those currently used in the industry, to more effectively get sheep onto feed.

The Australian Livestock Export Standards (March 2001) provide clear standards and statements of best practice for the general handling of sheep following entry into the feedlot. However, no mention is made of the need for animals to have access to feed as soon as practical following arrival. This issue is addressed in section 6.1.3.b. (above) of this report.

6.3 Additional strategies to reduce the size of the Salmonella challenge

6.3.1 General comments

As indicated previously, host resistance may be more influential than *Salmonella* challenge as a cause of outbreaks of salmonellosis. Consequently, efforts to reduce the size of the *Salmonella* challenge, while important, may have less impact than efforts to increase host resistance.

Efforts to reduce the size of the Salmonella challenge will play an important role in controlling feedlot-related salmonellosis

As indicated earlier, in the feedlot environment sheep are challenged with *Salmonella* spp. from a number of different sources. The most important include the general feedlot environment and clinically-affected animals. There is no evidence that contaminated feedstuffs, contaminated drinking water, or wild animal or bird populations play an important role in the epidemiology of feedlot-related salmonellosis. Similarly, carcasses are generally disposed of off-site, and thus would not pose a risk to other feedlot animals following removal.

6.3.2. Immediate opportunities based on existing knowledge

Based on current knowledge and in addition to the strategic use of sheds, there are a number of immediate opportunities relating to reduced *Salmonella* challenge, which would assist to control feedlot-related salmonellosis. There remain some areas of uncertainty, however, and these are listed in section 7. There may be significant industry benefit in further focused research (in section 8) to address these issues.

a. Practices to minimise contamination of pellets

Various systems are used to feed pellets to sheep during feedlotting (Figure 9), ranging from open troughs to self-feeding systems. The pellets may play an important role in *Salmonella* challenge, either directly following faecal contamination, or following proliferation of the organism after faecally-contaminated pellets have been moistened and warmed during warm inclement weather. In either case, contamination of the trough and surrounding ground area may be very high.

Of all systems currently in use, the self-feeding system is the preferred method of pellet feeding, because pellet spillage is minimal and rain-spoilage is eliminated. Using this system, there would be minimal contamination of both the trough and surrounding ground, and (as indicated previously) consistent feed intake will maximise host resistance.

Of the other two systems, open troughs raised above the ground are preferred to those sitting on the ground, although both would contribute to significant *Salmonella* challenge during warm, wet periods when proliferation is possible. This problem can be minimised, as occurs in one paddock-based feedlot, where raised troughs are situated adjacent to, but just outside, the paddock fence.

The industry should use feeding systems that enable feed to remain dry, and with minimal faecal contamination, throughout the feedlot period

The economic principles associated with replacing open troughs with self-feeders were discussed on page 39 and apply equally to the situation above.

Implications for the Australian Livestock Export Standards (March 2001) have been raised previously.

b. Specific practices to minimise paddock contamination

A number of practices have been used, by feedlot operators and in similar industries, to limit the survival of salmonellae in soil. The application of lime is an example of this, and works by increasing pH (increasing alkalinity) and making microclimatic conditions unfavourable for bacterial survival. Whilst effective at achieving this, it is of limited value as a one-off treatment during a consignment will be rapidly negated (within 1-2 days) as a result of ongoing faecal contamination. Regular liming of feedlots is not recommended because of the workload involved, the predominant importance of host resistance, and the need for repeated applications.

However, there are a number of simple practices that could be used to limit paddock contamination, including:

- *Paddock drainage.* The existing paddock-based feedlots are all sited on well-drained soil, which undoubtedly assists in limiting *Salmonella* problems. Nonetheless, it would be of benefit to conduct further earthwork, if needed, to improve drainage in any paddocks where pooling of groundwater is a problem. Furthermore, work following each consignment to disrupt surface faecal material (using rotary hoes or similar equipment) is recommended in areas where surface build-up is preventing soil from draining freely.
- *Water trough maintenance.* Salmonellae are potentially able to proliferate in the environment under warm and wet conditions. Therefore, leaking water troughs could play a key role in heavy environmental challenge to resident sheep. It is critical that leakage from water troughs are minimised.

The industry should take steps to ensure that paddock drainage remains high and ground water does not pool. Similarly, water trough need to be maintained to prevent any water leakage

The Australian Livestock Export Standards (March 2001) provide clear standards in section 7.6.1 concerning the drainage of paddocks. After considering the above recommendation, an industry review meeting in Adelaide on 13 August 2002 agreed that revision is needed.

c. Appropriate management of newly-introduced animals

Due to current supply problems, some sheep are being held in feedlots for extended periods, pending shipment. As a result, there have been situations where newly-introduced sheep have been placed with lines that have been present in the feedlot for some time. In many situations, outbreaks of salmonellosis have occurred in these animals approximately five days after introduction.

These outbreaks are not surprising given our understanding of the epidemiology of feedlot-related salmonellosis. In the days following the introduction of sheep into a feedlot paddock, there is a steady increase in host resistance (as animals come onto feed) and a progressive increase in environmental contamination. Because these factors each occur concurrently, disease is rarely precipitated. When newly-introduced sheep are introduced into an established flock, however, clinical disease is a logical outcome, given the low level of host resistance in these animals in association with a very high level of paddock contamination.

It is critical that new sheep are not added to paddocks where longer-duration sheep have been held for some days. If mixing is unavoidable, the risk could be reduced (but not eliminated) by moving newly-introduced and longer-duration sheep to a paddock that has not held sheep for some weeks.

The industry should not add new sheep to paddocks where longer-duration sheep have been held for some days

In the Australian Livestock Export Standards (March 2001), the need to segregate newly-arrived animals from longer-duration sheep is not specified. After considering the above recommendation, an industry review meeting in Adelaide on 13 August 2002 suggested the following changes to the Best Practice statement following 7.5.2:

“Sheep and goats should be inspected on arrival at the feedlot. They should be kept in mobs with other animals of a similar age, weight and duration since arrival at the feedlot. Where possible, sheep and goats should be retained in mobs with other animals of a similar origin.

After sheep and goats have been placed in their paddock or shed, they should be disturbed as little as possible whilst in the feedlot. All inspections and other management procedures should be done with the minimum possible disturbance to the sheep or goats.”

d. Using an all-in-all-out approach to feedlot management

The strategy for managing carry-over animals differs substantially between feedlots. Some operators remove all sheep from a feedlot within a short period (generally 24-48 hours) after a ship has been loaded. In effect, this strategy is similar to the *all-in-all-out approach* used within many intensive animal industries, including chickens and pigs. In contrast, other operators maintain a carry-over flock between consignments, and retain all carry-over animals that are likely to meet export criteria within the subsequent 1 to 2 months.

Within the industry, there is some concern that the ‘carry-over’ flock, associated with the latter strategy, may be an important contributor to feedlot-related salmonellosis. This concern is valid, because *Salmonella* organisms will be shed from a significant proportion of the carry-over mob throughout feedlotting. Because the carry-over animals are generally managed as a number of different groups, they may cause significant and ongoing environmental contamination.

The industry should adopt an all-in-all-out approach to feedlot management. Any carry-over animals that are retained for a subsequent consignment should be held in an area of the feedlot that is remote from the following consignment

In the Australian Livestock Export Standards (March 2001), the need to adopt an all-in-all-out approach to feedlot management is not specified. After considering the above recommendation, an industry review meeting in Adelaide on 13 August 2002 suggested the following changes to standard 7.5.12:

“Each exporter must ensure, to minimise the risk of spreading disease, that:

(a) sheep and goats only leave an export feedlot for export, slaughter, relocation to another quarantine area, or veterinary examination or treatment; and

(b) if carry-over animals are to be retained for a subsequent consignment, they will be held in an area of the feedlot that is remote from the following consignment.”

e. Appropriate use of antimicrobial agents

As indicated in the accompanying literature review, antimicrobial agents should not be used prophylactically (as preventative measures in apparently-healthy animals). The use of antimicrobial agents for prophylaxis is unlikely to provide any benefit, and may precipitate an outbreak of salmonellosis as well as increased antimicrobial resistance.

The use of antimicrobial agents in the face of an outbreak was discussed previously in this report.

The industry should not use oral antimicrobial agents prophylactically (as a preventative measure to apparently-healthy animals)

The use of antibiotics, either therapeutically or prophylactically during feedlotting, is not raised in the Australian Livestock Export Standards (March 2001). After considering the above recommendation, an industry review meeting in Adelaide on 13 August 2002 suggested the following inclusion at 7.5.13:

|| “Antimicrobial agents should only be used during feedlotting under veterinary supervision.”

f. General hygiene, including the handling of carcasses

When the feedlot is near-capacity with no apparent disease, and particularly when all lines have been in the feedlot for similar durations, it is likely that paddocks will each be carrying similar levels of *Salmonella* contamination. Under such circumstances, the transfer of organisms between paddocks is of little epidemiological significance. During and following outbreaks, however, the level of contamination in affected paddocks will increase substantially as a result of the high rates of *Salmonella* shedding from clinically-affected animals. Therefore, feedlot operators should employ high standards of hygiene during outbreaks to prevent cross-contamination from affected to unaffected paddocks, including the cleaning of boots and vehicle tyres. The employees should also pay attention to personal hygiene in such circumstances, to prevent human cases of the disease from developing.

To limit contamination of other sheep, and to minimise risk to feedlot employees, carcasses need to be handled with care. Carcasses should not be removed using the feed-transport vehicle. In addition, feedlot employees should maintain high levels of personal hygiene prior to eating or drinking. Retrieving carcasses from affected paddocks in a manner to minimise disease spread. Feed-transport vehicles should not be used for this purpose

The industry should ensure that carcasses are retrieved from paddocks in a manner that will minimise the possibility of disease spread. Feed-transport vehicles should not be used for this purpose. Relevant employees should maintain high levels of personal hygiene during outbreaks

The appropriate retrieval of dead animals is not addressed in the Australian Livestock Export Standards (March 2001). After considering the above recommendation, an industry review meeting in Adelaide on 13 August 2002 suggested the following inclusion to 7.5.8:

|| “Each Exporter must ensure that dead animals are removed from each feedlot paddock and pen each day in a manner that will minimise the possibility of disease spread, and that the carcasses are disposed of appropriately.”

g. The strategic use of sheds for high-risk groups

As indicated previously, sheds with raised mesh or slatted floors are effective in eliminating significant *Salmonella* challenge. In association with their positive effect on host resistance, the strategic use of sheds would be of particular value with lines considered at high-risk of developing salmonellosis.

h. Practices to minimise contamination of hay

At all feedlots, hay is fed to all sheep for a variable, but generally limited period after arrival at the feedlot. At most feedlots, the hay is fed on the ground. Hay racks are rarely used.

Hay-racks offer several advantages over on-the-ground feeding, including reduced hay spoilage and reduced *Salmonella* challenge. When hay is fed on the ground, sheep are continually moving over the hay-feeding area, thereby damaging hay and facilitating faecal-oral cycling of *Salmonella* organisms. However, hay-racks also contribute a number of problems, including a significant increase in pink-eye problems as well as increased labour demands.

Because the benefits from hay-racks do not clearly outweigh the disadvantages, any costs associated with the introduction of hay-racks cannot be recommended at this time.

i. Effective rodent control

At this stage, there is no evidence to suggest that rodents are significantly involved in the epidemiology of salmonellosis at any of the feedlots. Furthermore, effective control programs are in place at all feedlots.

7. Gaps in current understanding

There remain a number of key gaps in understanding. Many of the gaps relate to current sources of information, which include best-available information from the international literature and anecdotal information from industry. There is little rigorous and current data from feedlots or on-ship relating to this problem.

Current gaps in understanding include the following:

- Knowledge of the ecology of *Salmonella spp.* and the epidemiology of salmonellosis in paddock-based sheep feedlots. Particular issues include:
 - The ecology of the organism in Australian live sheep export feedlots
 - The serotypes involved
 - The level of feedlot contamination over time, including the influence of different feedlot practices
 - Patterns of antimicrobial resistance
 - The epidemiology of the disease
 - The actual importance of salmonellosis as a cause of death (noting that it is opportunistic and is frequently a secondary cause of death)
 - Patterns of death in time, in space and among different types of animals
 - Animals that are at highest-risk of feedlot-related salmonellosis
 - The importance of pre-existing conditions, including internal parasitism and trace element deficiencies, on the development of this condition
- The impact of various feedlot-related practices on rumen function
- The importance of feedlot-related salmonellosis after loading; the contribution of this condition on higher-than-average voyage mortalities on ships from Portland and Adelaide
- The efficacy and cost-effectiveness of a range of currently-used products, including Bio-Start and Maxi-Min Export

- A possible role for new/emerging products, including genetically-modified vaccines, probiotics, antimicrobial-like compounds and rumen modifiers

8. Opportunities for further focused research

As indicated previously, there remain some gaps in the current understanding of salmonellosis. As a consequence, further focused research would assist to fill gaps in existing knowledge and may help to provide practical solutions for industry. The topics are listed in order of priority.

8.1 Improved understanding of the reasons for increased sheep losses during voyages from Adelaide and Portland in comparison to Fremantle

Background

Over the last 10 years, there has been a steady drop in the mortality rate of sheep during live export. The current industry-wide cumulative mortality rates of 1.26% during loading, voyage and discharge after arrival at the first port represents a record low for the industry. Although there has been a steady drop in these annual figures for sheep exported from Fremantle, this is not the case for sheep from Portland and Adelaide. Indeed, since 1998 there has been a steady increase in the reported mortality rate from these latter ports, particularly relating to the phases of voyage and discharge.

It is well-recognised that most of the losses during voyage, particularly in sheep from Fremantle, are related to the persistent inappetence-salmonellosis-inanition (PSI) syndrome. An underlying mortality rate of approximately 0.60-0.65% during voyage can be attributed to this condition. However, the reasons for higher losses in shipments from Portland and Adelaide during this period are not yet been conclusively determined. Based on recent LIVE.212 results, the increased voyage length from these ports in comparison to Fremantle is unlikely to be an important contributor. Therefore, the differing mortality rates are due to specific port-related differences, which could include the type of sheep, the method of feedlotting and the long-term impact of feedlot-related salmonellosis on shipboard health.

Methodology for such as study will rely on linkage between feedlot- and ship-related data. To achieve this, there will be a need for an intensive, but time-limited, period of data collection from defined feedlots and ships. Laboratory back-up will be needed to support the feedlot and shipboard work.

Objectives

To determine the causes of increased losses of sheep during voyages from Adelaide and Portland in comparison to Fremantle, and the contribution of feedlot-related issues to these losses

To identify practical solutions to this problem

Assessment criteria

Cost	Depending on methodology, cost will be moderate to high
Time-to-completion	Estimate 12 months. Progress would be enhanced if linked with 8.2 (below)
Risk	Depending on methodology, understanding of issues may be incremental. An understanding of cause may occur more quickly than an understanding of practical solutions. May be considerable logistic difficulties associated with required laboratory back-up. The study outcomes are very dependent on the quality of data collection by relevant industry people.
Industry benefit	Potential for significant contribution to the industry, particularly in eastern Australia

8.2 Improved understanding of the ecology of *Salmonella* spp. and the epidemiology of salmonellosis during feedlotting

Background

The current report about feedlot-related salmonellosis is based on best-available information obtained from the international literature and from industry. No rigorous scientific work has been conducted in live sheep export feedlots in Australia for 10-15 years. Because feedlot-related salmonellosis and the PSI complex were not well-differentiated in earlier Australian feedlot studies, there are aspects of the condition that remain uncertain. Furthermore, there remain some gaps in understanding regarding the differences between sheds and paddocks and between raised and non-raised floor sheds in terms of the ecology of the organism and of the epidemiology of the disease. With this knowledge, it is likely that further options will emerge concerning the sustainable control of this condition in live sheep export feedlots.

Objectives

To gain a clear understanding of the ecology of *Salmonella* spp. in live sheep export feedlots in eastern Australia, including:

- *Salmonella* serotypes involved
- Sources involved
- Levels of environmental contamination over time, and with different practices
- Patterns of antimicrobial resistance over time

To gain a clear understanding of the epidemiology of salmonellosis in live sheep export feedlots in eastern Australia, including:

- Causes of death during feedlotting
- Clear characterisation of the role of salmonellosis in these deaths, and the patterns of *Salmonella*-related deaths in time, in space and among various animal factors
- Identification of characteristics of high-risk lines of sheep
- The role of other predisposing factors, including internal parasites and various trace elements (particularly selenium, copper and cobalt)

To gain an understanding of differences between sheds and paddocks and between sheds with raised and non-raised floors in terms of the ecology of the organism and the epidemiology of the disease

Assessment criteria

Cost	Likely to be high. The cost could be offset, to some extent, by using this work as the basis of a Masters study. Supervision could be provided by Dr John House (an international <i>Salmonella</i> expert based at the School of Veterinary Science, University of Sydney)
Time-to-completion	Estimate 24 months
Risk	Relatively-low risk provided a suitable post-graduate student were found. The risk associated with confirmation of existing information would be minimised by undertaking these investigations in a number of settings, including paddocks, raised sheds and sheds without raised floors
Industry benefit	Potential for significant contribution to whole industry, and particularly in eastern states

8.3 Improved understanding of rumen function during feedlotting

Background

Inconsistent feed intake, leading to rumen dysfunction, is probably the most important risk factor for feedlot-related salmonellosis. Therefore, studies to more-clearly understand rumen function in live sheep export feedlots, and the impact of potential solutions on this function, should contribute to practical efforts to limit losses from salmonellosis in the industry. It would be considerable practical benefit to test the effect of ad lib versus non ad lib feeding on rumen function.

Objectives

To gain an understanding of the impact of current industry practices on rumen function during live sheep export feedlotting

To identify practices, relevant to and practical within the industry, that would minimise rumen dysfunction during this period

Assessment criteria

Cost	Likely to be moderate
Time-to-completion	Estimate 12 months. Would be appropriate to link to 8.2, and to incorporate into a postgraduate study program
Risk	Will prove much less risky than studies about outbreaks of salmonellosis, which are both rare and unpredictable. There is international literature on this subject, which will be of considerable assistance to the researchers. The research would be less-risky if at least-part were undertaken in a controlled environment (as well as in a feedlot)
Industry benefit	Potential for significant contribution to whole industry

8.4 Assessment of the efficacy and cost-effectiveness of existing and emerging feedlot products

Background

A range of existing products are currently being used within the live sheep export industry. Examples include Bio-Start³ (Bio-Start Ltd, Auckland, New Zealand), Maxi-Min Export⁴ (Maxi-Minerals Pty Ltd, Dandenong South), a range of electrolytes and antimicrobials. Although these products may be of benefit, their efficacy under industry conditions is currently unproven, and their cost is high. In addition, there is or may soon be a role for some emerging products in live sheep export. Potential products include:

- *Competitive exclusion.* This approach depends on inoculation of 'favourable' *Salmonella spp.* in the ruminant digestive system. Following establishment, these organisms may be effective in competitively excluding 'unfavourable' *Salmonella spp.* that the animal subsequently encounters. Competitive exclusion may be achievable by administering modified live vaccine to sheep in drinking water at the time of arrival at the feedlot
- *The use of probiotics.* Probiotics can be considered hypothetical substances in the alimentary tract that aid in establishing the best balance of microorganisms⁵. Examples in human medicine include *Acidophilus* and *Bifidus* dietary supplements. Similar to the novel use of *Salmonella* inoculums, probiotics may assist in competitively excluding 'unfavourable' *Salmonella spp.*
- *The use of antimicrobial-like agents.* Although there are significant disadvantages with the use of antimicrobial agents, some (such as capsaicin and dihydrocapsaicin from capsicum and extracts from raspberry juice) have been identified which have mild antimicrobial-like actions against *Salmonella spp.*
- *The use of rumen modifiers.* Rumen modifying products, such as monensin (Rumensin®, Elanco), are widely used by beef and dairy producers. They are effective growth promotants in ruminants, and may assist with consistent feed intake during feedlotting

Determining the efficacy and cost-effectiveness of any of all of these products can be achieved by undertaking a rigorous field trial. However, given the number of potential candidates for such work, it is important that industry critically evaluate the likelihood that any such work will succeed.

Objectives

To assess the efficacy and cost-effectiveness of a range of existing and emerging products to improve the performance of sheep during live sheep export feedlotting

Assessment criteria

Cost	Low to moderate
Time-to-completion	Estimate 3 months for each product
Risk	Difficult to assess. Given the range of products that could be tested, there could be little return for the cost involved. To maximise industry benefit, it is critical that the study is focused on industry-relevant outcomes, including mortality and weight change
Industry benefit	Potential for moderate to significant industry benefit

³ According to the manufacturer, this product is a non-viable blend of naturally-occurring digestive enzymes, bacteriocins and metabolites derived from the biological fermentation process, and provides benefit to ruminants by increasing digestive efficiency, stimulating appetite, and reducing stresses associated with weaning and feed changes Anon. (2002). Bio-Start Ruminant: enzyme feed additive. Product description. Accessed at <http://www.bio-start.co.nz/> on 18 June 2002.

⁴ According to the manufacturer, this product is a chelated trace element and amino acid drench, feed and water additive for cattle and sheep, and provides benefit to livestock by increasing dietary intake of certain trace elements where intake may be low (Allan Giffard, personal communications)

⁵ Blood, D. C. & Studdert, V. P. (1988). *Baillière's comprehensive veterinary dictionary*. Baillière Tindall, London.

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APPENDICES

A1. Abbreviations

AMSA	Australian Marine Safety Authority
AQIS	Australian Quarantine and Inspection Service
CSL	Commonwealth Serum Laboratories
LEAP	Live Export Accreditation Program
MLA	Meat and Livestock Australia
pH	The negative log of the hydrogen ion concentration (a measure of acidity/alkalinity)
PSI complex	Persistent inappetence-salmonellosis-inanition complex
VFAs	Volatile fatty acids

A2. Glossary

Active carriers	Animals that show no signs of disease but excrete <i>Salmonella</i> organisms for months or years
Antimicrobial agent	An agent with the capacity to kill or inhibit the growth of micro-organisms
Carrier animal	An animal which harbours a disease organism in its body without manifest signs, thus acting as a carrier or distributor of infection
Causal factor	A cause of a disease event
Causal web	A diagrammatic representation of the factors, and their interrelationship, that cause a disease event
Cause	A factor that is responsible for bringing about an effect
Curfew	Holding animals off feed and water for a period prior to transport
Latent carriers	Animals that have <i>Salmonella</i> organisms in their tissues but not in their faeces
Morbidity	Illness
Mortality	Death
Multifactorial	Arising from the action of many factors
Prophylactic	A preventative measure to apparently-healthy animals
Spread	The movement of disease from one animal cluster to another
Syndrome	A combination of clinical signs resulting from a specific cause and presenting with a distinct clinical picture
Therapeutic	Treatment of clinically-affected animals
Transmission	The movement of disease within a cluster of animals

A3. Objectives and methodology

The objectives of this report are to:

- Develop for live sheep export feedlots, a set of current best-practices in feedlot management, with emphasis on control of salmonellosis, which can be incorporated into the Livestock Export Accreditation Program (LEAP)
- Prepare a best-practice manual in hard copy, CD and internet format
- Where recommended best-practice differs from actual practice, present a simple economic analysis comparing the differences in management
- Identify gaps in best-practice and where further research could be undertaken

The consultancy has been based on the following methodologies:

- A review of literature relating to best-practice in sheep feedlot management has been conducted, with particular reference to management of salmonellosis
- Contact has been made with key relevant technical experts and providers, including vaccine companies, industry representatives and Salmonella experts in Australia and New Zealand
- Each of the main live sheep export feedlots, in Victoria, South Australia and Western Australia, has been visited to gain an understanding of current feedlot practice. In addition, and in collaboration with each feedlot operator, the consultants have sought to identify workable solutions to the salmonellosis problem at points of leverage
- A manual of best-practice has been developed, with particular emphasis to salmonellosis during feedlotting. Furthermore, simple economic analyses have been used at points where actual and current best-practice differ, and potential areas for further research have also been identified

A4. Current practices at live sheep export feedlots

A4.1 Paddock-based feedlots

Paddock-based feedlots are located in Victoria, South Australia and Western Australia. Most of these feedlots also have limited shedding space to handle recently-shorn (or otherwise high-risk) sheep.

A4.1.1 Ownership of sheep during the feedlotting process

There are several possibilities regarding ownership of sheep during feedlotting:

- Integration of exporting process (from delivery at feedlot through feedlotting and on-ship). The integrated exporter suffers a financial penalty for sheep deaths during feedlotting
- Contract buyers (taking ownership from delivery at feedlot until delivery at port), with feedlot operators being paid to manage sheep during feedlotting. In this situation, the feedlot operator does not suffer a financial penalty for sheep deaths during feedlotting

A4.1.2 Sourcing sheep

There have been ongoing problems in all states in sourcing sufficient and suitable sheep, as a general consequence of the reduced size of the Australian sheep flock. As a consequence, supply has been unable to meet demand, and increasing numbers of long-haul and pastoral sheep are being drawn from increasingly distant areas. The maximum-known trucking distance is 17 h (southern Queensland to Adelaide).

There is generally little predelivery preparation (grain-feeding, drenching etc) of sheep by producers, although a 24-36 hour curfew (period off feed and water prior to loading) are increasingly being adopted in eastern states to prevent injury during transport.

Sheep must meet strict specifications at purchase relating to weight, wool length, age and health status, and producers are not paid for animals that fail to meet the specifications. One feedlot indicated that they will not buy specific lines of sheep, if past problems have been identified.

Each shipment contains sheep from a large number of properties-of-origin

A4.1.3 Transport

Transporting standards are high, and there are very few losses or injury during transport.

There are significant transporting differences between eastern states and Western Australia.

In eastern states, there are two important features of sheep transport:

- *Curfewing of sheep is common.* In eastern states, sheep are invariably carried in multi-purpose vehicles (which can be converted to carry either sheep or cattle). The floors in these vehicles are made from plate metal and overlaid with weld mesh. Because slipping (due to accumulated faeces and urine) can lead to serious injury on these surfaces, curfews are frequently imposed, with animals held off feed and water for a variable period (generally 24 h or more) prior to transport. Curfews have proved very effective in eliminating the problem of downer animals.
- *Long-distance transport is common.* Although sheep have traditionally come from regions surrounding south-eastern South Australia and western Victoria, due to the increasing difficulties in sourcing sheep, long-distance transport of sheep is increasingly common. Journeys of 12 hours are now routine, and longer journeys (for example, 17 hours from Goondiwindi to Adelaide) are increasingly common. In all cases, sheep are shipped in a single stage (with approx. 400 sheep/B-double)

In Western Australia, the key features of transport include:

- *Purpose-built trucks are used.* In Western Australia, most sheep are carried in purpose-built trailers. These trailers have a false or double floor, which allows the faeces and urine to accumulate and drain in a section below where the sheep are standing. Therefore, curfewing is unnecessary and rarely used..
- *Most sheep are transported over short distances.* The majority of live-export sheep are transported for 3-4 hours between farm-of-origin and live sheep export feedlot. A small percentage of export sheep are sourced from pastoral areas, such as the Gascoyne, and transported for much longer distances.

A4.1.4 On-arrival

General

At all feedlots, arrivals can only be processed during fixed hours, thereby ensuring that animals are processed rapidly. Processing takes approximately one hour and includes:

- Counting exact numbers in each consignment

- Identifying rejections (generally rare due to financial penalty imposed on producers for sheep that do not meet specifications)
- Drafting on weight into A, B, C lines

Specific animal health procedures (such as drenching) are rarely undertaken.

All feedlots provide higher levels of care to lines considered at high-risk (such as long-haulage, pastoral and/or young animals). These animals are given additional hay, hay for a longer period and/or the use of Bio-Start in the water.

Shearing

Using one feedlot as an example, 3000 sheep in a single consignment can be safely shorn. At this feedlot, there is sufficient accommodation in a shed and in very sheltered paddocks for 1000 and 2000 sheep, respectively. Substantial losses from hypothermia have occurred in one paddock-based feedlot some years ago, but all feedlots are now able to safely manage shearing, and losses from hypothermia are now insignificant. Shearing is not conducted in winter.

A4.1.5 Feedlotting

Trucks generally bring sheep in to the feedlot over three days; all animals are held in the feedlot for three clear days; and there are two days when the sheep are transported from feedlot to port.

Infrastructure and topography

- In Victoria, two feedlots are located on an exposed peninsula at Portland within 1 km of the ocean. In South Australia, two large feedlots are located approx. one hour north of Adelaide. In Western Australia, a single large feedlot is located approximately four hours south of Perth.
- The topography at the feedlot varies between feedlots from undulating to flat
- All feedlots comprise a variable number of paddocks holding approximately 1200 sheep, with a stocking density between 400-600 sheep/acre.
- All feedlots are located on very well drained soils (such as limestone country), and drainage is excellent. There is little to no run-off following storms
- Various forms of shelter are available, including man-made shelters and trees (either within or beside each paddock)
- Several feedlots now handle cattle as well as sheep. The cattle are generally held in cattle-only areas of the feedlot, and there appears to be no movement of surface water from cattle to sheep pens

Feed and feeding management

- Feeding hay
 - Hay is of relatively-low nutritive value (energy little greater than 8 MJ/kg) is provided to sheep on arrival at the feedlot with the aim to provide a familiar feedstuff while they become accustomed to pellets. However, all feedlot operators seek to introduce sheep to pellets as quickly as possible. The quality of hay is closely monitored, and mouldy hay is not used.
 - A full hay ration is generally given for the first 1-2 days, then replacing with pellets over next 3 days. Unless there is inclement weather, animals are on full pellets by day six
 - Hay is fed either on-the-ground (most feedlots) or in hay racks
 - Hay is fed for a longer period to high-risk lines. Because rain spoils pellets, hay is also fed (in place of pellets) during rainy or generally-inclement weather
 - There is ongoing monitoring of sheep (and particularly sheep behaviour and faecal consistency) to determine the appropriate hay/pellet mix
- Feeding pellets

- In the eastern states, the pellets are based on cereal grain (approximately 30%), roughage (hay, rice hulls etc) and some salt and bentonite. No other additives (such as monensin) are used. In Western Australia, lupins form the basis of the pellet. In all cases, the pellets meet accepted industry standards.
- There are several different suppliers, some of whom are aligned to specific exporting companies
- Pellets are fed in troughs on a daily basis at the rate of approximately 1.2-1.5 kg/animal/day. Some troughs are on the ground, some are approx. 30 mm off the ground
- Troughs are cleaned out between shipments. If required, they are also cleaned on a daily basis
- The pellets are not necessarily the same as those fed on-ship

Providing water

- Good quality water is available to all feedlots, either as bore or town water
- In each feedlot paddock, there is one or more water trough
- Several feedlots add nothing to the water throughout the feedlotting period, but several add Bio-Start to high-risk lines for 1-2 days after arrival
- Several feedlots have a worker stationed at troughs to ensure that sheep do not over-drink on arrival at the feedlot

General hygiene and management of the feedlot environment

- Water and feed troughs are cleaned out between consignments. These may also be cleaned daily, as required, when sheep are held
- At one feedlot, stocking density is high-than-average to enable paddocks to be spelled and used on every second shipment
- In one feedlot, any wet areas have been fenced off
- Dead sheep are picked up daily, and generally disposed off-site. At one feedlot, the same vehicle is used to feed out hay and carry carcasses

Managing shy-feeders

- A range of different management methods are used for shy-feeders, including:
 - Placing feeding trough in middle of paddock
 - Providing oats on top of hay to young sheep to encourage feeding
 - Feeding lambs ad lib (up to 1.6 kg/animal/day), using self-feeders

Managing outbreaks of salmonellosis

- All feedlots seek to minimise stress and increase access to hay
- Drafting off tail etc is impractical, and will contribute further deaths
- Antibiotics (Terramycin® in drinking water) are used at times to medicate affected paddocks
- At all feedlots, the affected paddocks are spelled for a variable period (often 3-6 w, and are empty for 1 or 2 consignments). At some feedlots, lime is applied in high-use areas in the paddock (around feed troughs, on sheep camps), and rotary hoeing may be used to mix faecal material and improve drainage

Handling of rejects

Several strategies are used to handle animals considered unsuitable for shipping.

- At some feedlots, all reject animals are removed within 24 hours of clearing the feedlot (feedlot essentially operated on an all-in, all-out system)
- At some feedlots, some rejects (those which could meet specifications within 1-2 months with additional care) are retained. Therefore, a 'resident' population of sheep remains in the feedlot between shipments

A4.2 Shed-based feedlots

Large shed-based feedlots are only found in Western Australia, and are generally surrounded by a number of paddocks for paddock-based feedlotting. Most aspects of management are similar, and only substantial differences from the paddock-based feedlots are listed here.

A4.2.1 Ownership of sheep during the feedlotting process

The feedlots are generally run as part of a large integrated operation. Therefore, all feedlot losses are borne by the owners. In some cases, however (and particularly in recent months), some of the sheep consignments are managed on behalf of other companies. In this latter arrangement, all losses during feedlotting are borne by the owner (and not the feedlot).

A4.2.2 Feedlotting

The sheds were purpose-build 10-15 y ago, each holds approximately 7,500 sheep, and the operators estimate that they would cost A\$350,000-400,000 to replace. The sheds are raised off the ground to enable the build-up of pellets to be cleaned easily using a bobcat. The flooring, which is a woven mesh grid, is the major capital cost in the shed and costs approximately \$200,000 per shed.

At each of the two shed-based feedlots, the sheds are located around a central holding/drafting yard. Each shed consists of a series of large yards, and is bisected by a long series of self-feeding units down the centre of the shed. Self-filling water troughs are located along the sides of the shed. Operators indicated very few problems with these sheds, and would make few changes if they were to be replaced or more sheds were built. Sheep tolerate the flooring well, provided they are not too heavy. Heavy wethers are generally held in the paddocks surrounding the sheds.

A5. Data collection during visits to live sheep export feedlots

A5.1 Background

General information

- Ownership during feedlotting
 - Payment for feedlotting services
 - Premiums, incentives from buyers
 - Is there a need/opportunity for an incentive-driven system?
 - Would change be driven by incentives or improved knowledge?
- Throughput
 - Long-term trends
 - Recent events
- Sources of sheep
 - Long-term trends
 - Recent events
- Changes to feedlot infrastructure
 - Long-term trends
 - Recent events

Information about salmonellosis

- History
 - Long-term trends (duration, magnitude)
 - Recent events (duration, magnitude)
- Presenting clinical signs
- Key epidemiological features

- Morbidity/mortality rates, case-fatality rates
- Patterns in time
 - Long-term: patterns over last 1/2/10/25 y, key industry events and their relationship with long-term patterns
 - Yearly: effect of season and climate
 - Within each shipment: period of highest risk
- Patterns in space (are there 'high-risk' paddocks, 'problem paddocks' that persist over several shipments)
- Patterns relevant to animal groups (age, sex, breed, origin, trucking distance)
- Is there a link with events after loading?

Interventions/practices to this point

- In the face of an outbreak
 - Procedure(s)
 - Effect/impact
- To prevent further outbreaks
 - Procedure(s)
 - Effect/Impact

Believed cause/contributors to problem

Access to daily mortality data

- Purpose
 - Long-term patterns – relationship with climate, season and industry trends
 - Short-term patterns – relationship with time since entry (class, origin?)
 - Linking of feedlot and ship data – evidence for salmonellosis spillover during the first week at sea

A5.2 Reducing the size of the Salmonella challenge

Prior to entry to the feedlot

Assembly points whilst in-transit

- Route(s) of travel, frequency of staged travel
- % of sheep where travel may have been staged
- Potential contribution to *Salmonella* challenge

During feedlotting

General feedlot environment

- General topography, soil type
- Drainage
 - Problems, long- and short-term efforts to improve
- Use of feedlot for other species (cattle)
- Changes to feedlot environment
 - Long-term
 - Recent events

Paddock contamination

- Management of paddocks during consignments
- Management of paddocks between consignments
 - Management of accumulated sheep manure
 - Frequency, methods, sites
- Procedures attempted to limit paddock contamination
 - Methods, monitoring methods, level of success
- Further/practical opportunities to limit contamination

Feeds

- Potential for contamination of hay and/or pellets at source
- Stock feeding facilities and procedures
 - Potential for contamination in paddocks
 - Cleaning/disinfection
 - Use of feed-out equipment for other purposes
- Opportunities/need for improvement

Drinking water

- Increasing pressures on water usage?
- Potential for contamination at source
- Stock watering facilities and procedures
 - Potential for contamination in paddocks
 - Cleaning/disinfection
- Opportunities/need for improvement

Waste water

- Method of disposal
- Opportunities/need for improvement

Rodent and wild bird populations

- Problems (size of populations, species involved)
- Control efforts (methods, level of success)

Procedures in the face of an outbreak

- Use of quarantine measures
 - Measures to limit spread
 - Movement of staff
 - Movement of equipment
- Other measures
 - Antibiotic usage (therapeutic, prophylactic)
- Disposal of carcasses (method, site, equipment used)
 - Entry of rendering trucks?

Discussion about sheds

- Current facilities
- Perceived advantages: salmonellosis, hypothermia
 - Approach to shearing
 - Scope of problems with hypothermia (frequency and magnitude of occurrence)
- Disadvantages: cost, intermittent trade
- Would further information assist with decision-making?
 - Cost-benefit from WA experience
 - Visit by WA operator(s)

Possible future work

- Willingness to participate in longitudinal studies/intervention trials

A5.3 Increasing the level of host resistance

Sourcing of sheep

- Current situation
- Short- and long-term trends
 - Pastoral sheep
 - Long-distance transport

- Two-stage selling

Transport to the feedlot

- Current transport arrangements
 - Pastoral sheep
 - Long-haul sheep
- Opportunities for improvement
 - Streamlining of arrangements
 - Need for changes to best-practice?

Processing on-arrival

- Current procedures
- Opportunities/need for improvement

Maximising feed and water intake on arrival and during feedlotting

- Current procedures
 - Feeding hay
 - Source, long- and short-term trends in source
 - Hay quality/palatability
 - Opportunities/need for improvement
 - Feeding pellets
 - Source, long- and short-term trends in source
 - Providing water
 - Source, presentation
 - Problems of shy drinkers
 - Opportunities/need for improvement

Medication/supplements on entry to the feedlot

- Current practices
- Perceived benefit
- Information sources

Coping with inclement weather whilst at the feedlot

- Policy in face of approaching weather
- Current approaches/infrastructure changes
- Opportunities/need for improvement

A6. Two different syndromes of salmonellosis

There is evidence to support the hypothesis that salmonellosis occurs within the export trade under two different circumstances:

- As part of the persistent inappetence – salmonellosis – inanition (PSI) complex;
and
- As a consequence of intensive paddock-based feedlotting.

Although the presentation of clinical disease is identical under both of these circumstances, as indicated in the following sections, the underlying web of causal factors is different. This has important implications in terms of effective disease control.

A6.1 Salmonellosis as part of the persistent inappetence – salmonellosis – inanition complex

A6.1.1 The PSI complex

Detailed information about the persistent inappetence – salmonellosis – inanition (PSI) complex is presented in the accompanying literature review. Based on work by scientists of Agriculture WA, Figure A6.1 provides an accurate summary of the causal web for this complex. As illustrated, salmonellosis is integral to this web, and an important outcome for sheep that refuse to eat from the time of leaving the farm-of-origin and for a variable period during the export process.

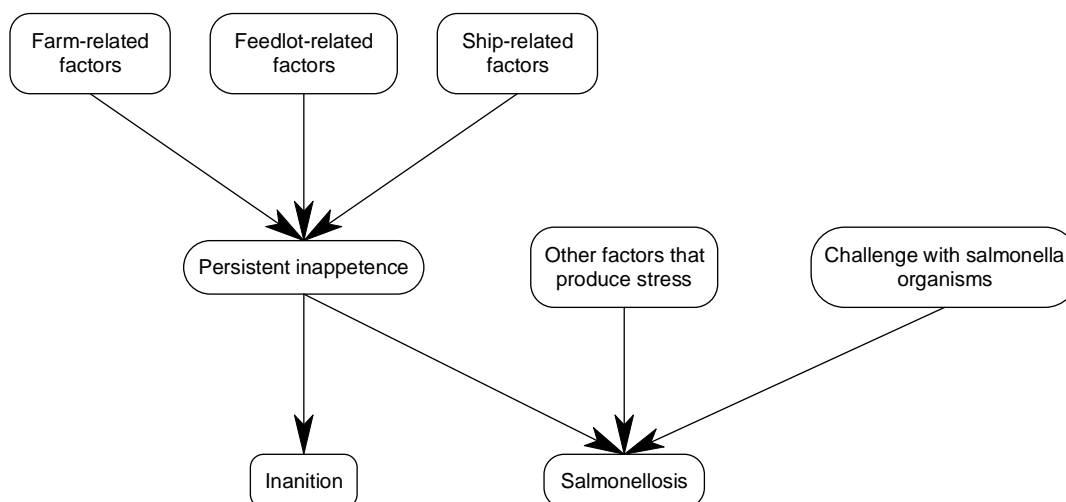


Figure A6.1 The causal web for the persistent inappetence – salmonellosis – inanition (PSI) complex in sheep during live export

The key issues relating to this causal web include the following:

- Persistent inappetence is the main 'driver' in this causal web. Animals that do not eat during feedlotting, particularly if inappetence continues on-ship, are at substantially-increased risk of dying from inanition or salmonellosis than their appetent pen-mates. Furthermore, persistently inappetent animals account for most of the deaths on-ship
- Although many factors contribute to the issue of persistent inappetence, the condition is mainly a problem in a small number of lines of sheep. Why some farms and lines are at increased risk of inappetence during export is not well understood, and some as-yet-unrecognised farm-level factors are certain to be important. Nonetheless, age, adiposity (condition score) and season of export each alter the risk associated with individual sheep lines, as a result of the underlying seasonality of appetite drive and fat metabolism in sheep.
- Salmonellosis is essentially a 'spillover' disease; persistently inappetent sheep will invariably die from inanition unless salmonellosis occurs first. Therefore, although stress and challenge with salmonella organisms are important, salmonellosis on-ship is most unlikely unless animals are also persistently (and chronically) inappetent.

A6.1.2 Features of salmonellosis as part of the PSI complex

Failure to eat is a common problem throughout the export process. At arrival to the feedlot, a variable but frequently high percentage of sheep do not eat. This percentage decreases with time, and most animals are eating at the time of loading on ships. The physical process of loading is effective in reducing this figure further, and whilst on-ship there is a small but relatively-constant percentage of sheep that refuse to eat. These latter animals have not eaten since leaving the farm-of-origin some 3-4 weeks earlier.

As part of the PSI complex, animals at greatest risk of dying from salmonellosis are the relatively small number of sheep that are persistently inappetent in the feedlot, and remain so after being loaded on-ship (as circled in Figure A6.2). Consequently, most losses from salmonellosis as part of the PSI complex occur whilst on-ship. Although salmonellosis as part of the PSI complex also occurs during feedlotting, mortality rates throughout the feedlot period are generally 30-fold less than similar rates whilst at-sea (Norris et al., 1989; Richards et al., 1989). Further detailed information about persistent inappetence is available in the literature review.

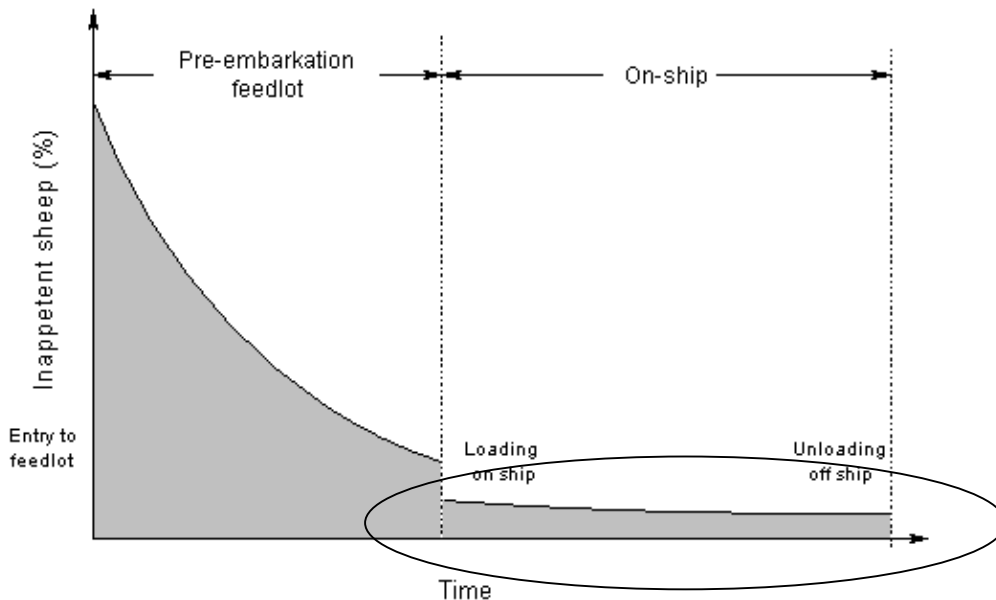


Figure A6.2 Inappetence in sheep during live export. Death as part of the persistent inappetence – salmonellosis – inanition (PSI) complex is mainly confined to those sheep that remain persistently inappetent after loading on-ship (circled).

A6.1.3 Impact of ongoing industry improvements

There have been ongoing improvements in many processes and practices associated with live sheep export during the late 1980s and 1990s, including substantial changes to live sheep export feedlots in Western Australia and ongoing general improvement to ship design. These changes, in association with increased market-driven demand for younger sheep, have contributed to a steady drop in crude sheep mortality over the last ten years. As indicated earlier, the crude sheep mortality during shipping and disembarkation in 2001 represents a record low of 1.26%. In consignments from Fremantle during this period, loading, voyage and discharge mortalities were 0.01%, 0.65% and 0.29%, respectively (Norris & Norman, 2001a).

Based on current knowledge, the majority of on-ship deaths in consignments from Western Australian feedlots are related to the PSI complex. Therefore, without specific efforts to further address the problem of persistent inappetence, it is likely that 0.65% (the crude mortality rate

during voyages from Fremantle to the first port of unloading during 2001) is approaching the lowest mortality rate achievable under current industry best practice. On-ship death rates in ships from Portland (at 1.36% in 2001) and Adelaide (1.11%) have been consistently higher than those from Fremantle, which will reflect, in part at least, the increased duration of voyage from Victoria and South Australia, as well as problems associated with intensive paddock-based feedlotting of sheep at Adelaide and Portland.

A6.1.4 Strategies to limit PSI-related salmonellosis

Several strategies have been identified to reduce deaths as part of the persistent inappetence – salmonellosis – inanition complex, based on a sound understanding of known contributors to the development of persistent inappetence in sheep during live export. These strategies, which each seek to reduce the number of persistently inappetent sheep on any shipment, include:

- The selection of low-risk sheep, including young animals or older during periods when mortality risk is low;
- The identification and culling of persistently inappetent sheep during feedlotting;
- The exclusion of sheep from high risk properties coupled with research to identify means whereby this risk could be reduced; and
- The exclusion of sheep from high risk regions.

Although these strategies are well-known to industry, they have generally been considered unworkable due to commercial, logistic and political constraints. Although some of these strategies would be more-easily implemented with the recent introduction of National Livestock Identification Scheme for Australian sheep flocks, this will not remove the most important constraints to change. Given these circumstances, the PSI complex will continue as a significant cause of on-ship mortality in the live sheep export trade for the foreseeable future.

A6.2 Salmonellosis as a consequence of intensive paddock-based feedlotting

A6.2.1 Salmonellosis in paddock-based feedlots

Salmonellosis during feedlotting has been identified as an important, if sporadic, problem in paddock-based feedlots in Victoria, South Australia and Western Australia. Similar problems have not been reported in the shed-based feedlots in Western Australia. The problems at the paddock-based feedlots, at least at Portland, have been present since the mid-1980s, based on detailed work by Kelly (1996). Descriptions of the disease presentation are typical of salmonellosis, including high attack and case-fatality rates in affected pens⁶, affected animals showing clinical signs consistent with acute enteritis (profuse, fluid diarrhoea, high fever) and septicaemia (depression, recumbency, fever), and the consistent isolation of *Salmonella typhimurium* and/or *S. bovis-morbificans* from those cases where samples have been collected.

A6.2.2 Support for a differing web of causation

Although the disease presentation in the paddock-based feedlots is identical to that described as part of the PSI complex, there is good epidemiological evidence indicating that the underlying web of causation is subtly different. This conclusion is based on some measured data but mainly anecdotal but well-informed information and feedback from industry sources.

⁶ A substantial proportion of the pen becomes sick (high attack rate), with a high percentage of these animals subsequently dying (high case-fatality rate)

Given our understanding of disease in human and animal populations, it is not surprising that we might get the same disease from two slightly-differing sets of circumstances.

The evidence in support of a differing causal web includes a range of features relating to the presentation of salmonellosis during paddock-based feedlotting. These features, and subtle differences with PSI-related salmonellosis, are listed below:

- In the paddock-based feedlots, salmonellosis has been a particular problem throughout the feedlot period. Based on anecdotal evidence, losses occur most frequently 5-7 days after entry, but may present at any time during feedlotting. According to Kelly (1996), losses at Portland during the 1980s peaked 10 days after entry. Furthermore, these losses are believed to precede increased losses in sheep during the first week or so after loading (Figure 5, on page 20). *This evidence is in contrast to what would be expected if the underlying causal web of the PSI complex were involved, where deaths from salmonellosis tend to increase with time, and are of greatest concern on-ship.*
- In the paddock-based feedlots, salmonellosis has been a particular problem during periods when feedlot usage has been high. To illustrate, salmonellosis at Portland and Adelaide was a concern throughout the 1980s, as documented by Kelly (1996), when throughput was high. Several operators have suggested that inferior pellet quality may have precipitated some of these outbreaks. During the 1990s, however, and coinciding with a substantial drop in throughput, salmonellosis was rarely seen. The drop in throughput coincided with a substantial reduction in sheep export numbers, with most Australian sheep being exported through Fremantle. Since early 2000, however, the disease has re-emerged as a problem at Adelaide and Portland, and again coincides with increasing throughput, following the re-entry of Saudi Arabia into the Australian live sheep export trade. In addition, due to low overall sheep numbers in Australia, an increased proportion of sheep of long-haul and/or pastoral origins have been sourced for the trade. *This evidence is in contrast to what would be expected if the underlying causal web of the PSI complex were involved. If these outbreaks were part of the PSI complex, we would expect Salmonella challenge to be of lesser importance than persistent inappetence. Consequently, deaths relating to the PSI-complex are relatively constant, regardless of feedlot throughput, and are mainly affected by factors that drive persistent inappetence (including season, age, adiposity and, more broadly, property/region-of-origin).*
- Based on anecdotal evidence, it is difficult to identify consistent host characteristics associated with affected sheep. Although quantitative information is not available, attending veterinarians and feedlot operators describe problems of salmonellosis in a wide variety of sheep from many different areas. *This evidence is in contrast to what would be expected if the underlying causal web of the PSI complex were involved. If these outbreaks were part of the PSI complex, we would expect deaths most commonly in older sheep, and particularly those in good body condition.*
- Based on anecdotal evidence, salmonellosis in paddock-based feedlots may not be more common during the second half of the year. Indeed, of the four consignments studied by Kelly in 1989 (Kelly, 1996), the salmonellosis-specific mortality rate was high in May and August, but low in September and November. Based on recent experiences, the disease may be more common in spring and autumn (D. Hayes, personal communication), although it is possible that no pattern exists (T. Brightling, personal communication). *This evidence is in contrast to what would be expected if the underlying causal web of the PSI complex were involved. If these outbreaks were part of the PSI complex, we*

would expect deaths most commonly during the second half of the year, when seasonal effects (known as homeorhesis) result in suppression of appetite and mechanisms of fat metabolism. These seasonal effects will influence all sheep from southern Australia, regardless of their state-of-origin.

In addition to each of the previous points, it is not surprising that salmonellosis has emerged in the intensive paddock-based feedlot environment of Portland and Adelaide, where highly-stressed animals are held in conditions that favour substantial challenge with *Salmonella* organisms. These *Salmonella* problems are very similar to those faced wherever there has been intensification of livestock industries.

A6.2.3 The web of causation

The causal web for salmonellosis, as it relates to intensive paddock-based feedlotting, is presented in Figure 6 (on page 22). This web is based on the causal factors most commonly associated with salmonellosis under conditions of intensive animal husbandry. The key causal factors include:

- 'Factors that reduce host resistance', referring to the basket of factors that increase stress⁷ and reduce host resistance to infection in animals at entry and/or during feedlotting, including long-distance transport, climatic stress and inappetence;
- 'Challenge with *Salmonella* organisms', which is a necessary – and critical – cause of salmonellosis during intensive feedlotting; and
- The virulence of the *Salmonella* serotype involved.

Differences between the two webs are subtler than initially apparent, and relate entirely to the issue of persistent inappetence:

- *In the PSI complex* (as presented in Figure A6.1 on page 61), persistent inappetence is central, and animals at-risk of dying as part of the PSI complex are those that are persistently inappetent during export. With increasing duration of persistent inappetence, there is a concomitant increase in mortality risk. As mentioned previously, minimisation of the PSI complex will require strategies that minimise the number of persistently inappetent sheep within the trade.
- *With intensive feedlotting* (as presented in Figure 6 on page 22), however, inappetence is only one of a number of stress-related factors that contribute to salmonellosis during intensive feedlotting. Furthermore, as illustrated in Figure A6.3, animals at greatest risk of developing salmonellosis due to intensive feedlotting are those that fail-to-eat at entry and throughout the feedlotting period. This will include, but not be limited to, the persistent inappetent animals (those sheep that refuse to eat throughout the entire export process) that form the basis of the PSI complex.

⁷ The sum of the biological reactions to any adverse stimulus (either physical, mental or emotional, internal or external) that tends to disturb the homeostasis of an organism Blood, D. C. & Studdert, V. P. (1988). *Baillière's comprehensive veterinary dictionary*. Baillière Tindall, London.

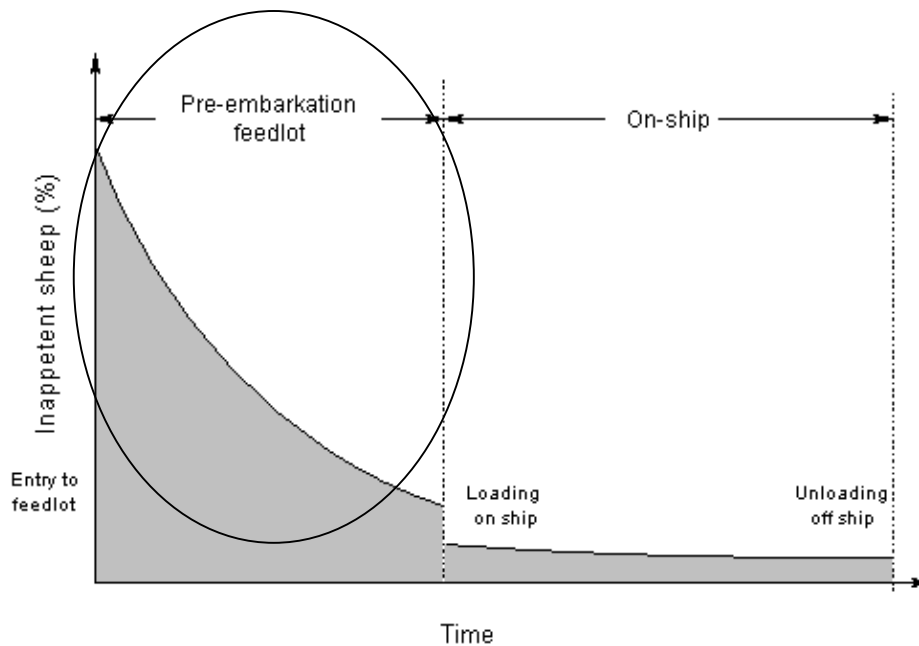


Figure A6.3 Inappetence in sheep during live export. Death from salmonellosis relating to intensive paddock-based feedlotting mainly affects those sheep that do not eat on-entry and during feedlotting (circled).

A6.2.4 Strategies to limit salmonellosis during intensive paddock-based feedlotting

In situations of intensive husbandry, such as intensive paddock-based feedlotting, there are three major factors which determine whether animals develop salmonellosis following exposure to *Salmonella* organisms, namely host resistance, the size of exposure and the virulence of the serovar (House & Smith, 2000). Because the latter factor cannot be easily-manipulated, strategies to effectively limit salmonellosis rely entirely on efforts:

- To minimise challenge of *Salmonella* organisms; and/or
- To maximise host resistance in the face of this challenge.

These strategies are considered in detail in the report proper.

A7. People contacted during the preparation of this report

- Rick Beasley, national manager, National Livestock Identification Scheme
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- Barry Richards, veterinary pathologist, Agriculture WA
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