# Microbiological food safety and storage life of Australian red meat

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# Research and development in the Australian red meat industry: its impact on food safety and shelf life

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## Acronyms

| | |
|---|---|
| AMPC | Australian Meat Processor Corporation |
| AMSA | American Meat Science Association |
| APC | Aerobic Plate Counts |
| AQIS | Australian Quarantine and Inspection Service (now DAWR) |
| B-VCBS | Beef and Veal Carcass Baseline Survey |
| C&A | conditioning and ageing |
| CBD | Central Business District |
| CMA | Carton Meat Assessment |
| CSIR | Council for Scientific and Industrial Research |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| DAWR | Department of Agriculture and Water Resources |
| EHEC | Enterohaemorrhagic *Escherichia coli* |
| ESAM | *E. coli* and *Salmonella* Monitoring (now NCMMP) |
| FSIS | Food Safety and Inspection Service |
| FMIA | Federal Meat Inspection Act |
| HACCP | Hazard Analysis and Critical Control Points |
| HBI | Hot Boning Index |
| HC | Haemorrhagic colitis |
| HUS | Haemolytic Uraemic Syndrome |
| ICMSF | International Commission on Microbiological Specifications for Foods |
| KPI | Key Performance Indicator |
| LAB | Lactic acid bacteria |
| MHA | Meat and Hygiene Assessment |
| MINTRAC | Meat Industry National Training Advisory Council |
| MIRINZ | Meat Industry Research Institute New Zealand |
| MLA | Meat and Livestock Australia |
| MRC | Meat Research Corporation |
| NCMMP | National Carcase Microbiological Monitoring Program |
| NSW | New South Wales |
| PHI | Product Hygiene Index |
| QA | Quality Assurance |
| RI | Refrigeration Index |
| RTE | Ready-to-eat |
| SARDI | South Australian Research and Development Institute |

| | |
|---|---|
| STEC | Shiga Toxin-producing *E. coli* |
| TVC | Total Viable Counts |
| UCFM | Uncooked Comminuted Fermented Meat |
| UTas | University of Tasmania |
| VP | Vacuum packed |

## Background to this Executive Summary

In 2017, the South Australian Research and Development Institute (SARDI) published *"Process Control Monitoring – Is there a better way?"* (AMPC Report 2017-1068) – a critical analysis of the *E. coli* and *Salmonella* Monitoring (ESAM), Product Hygiene Index (PHI) and Meat Hygiene Assessment (MHA) programs as currently operated by Australian meat export establishments.

The report made recommendations for improving the effectiveness of monitoring procedures required to be undertaken by the industry, some of which, during 2017-2018, were trialled at twelve establishments: *"Process Monitoring for the Australian meat industry – a comparative industry trial"* (AMPC Project 2018-1070).

During the course of AMPC Project 2017-1068, overwhelming objective evidence emerged that, globally, the hygiene status in terms of food safety and shelf life of Australian meat products is excellent. An application was made to AMPC for funding to gather, in one publication, objective evidence surrounding the hygiene status of Australian meat products, together with the research and development which has underpinned this status.

The findings and outcomes of this work are presented in a monograph as *"Research and development in the Australian red meat industry: its impact on food safety and shelf life"* (AMPC Project 2018-1086).

The monograph comes in two parts, for both non-technical and technical readers:

1. This Executive Summary is a snapshot of the current microbiological profile of Australian red meat highlighting comparisons with Australia's global competitors – it is written specifically for non-technical readers. The data speak for themselves – Australia exports meat of excellent microbiological quality and food safety.
2. The main part of the monograph is written in scientific format and charts the pivotal role played by research and development in underpinning Australia's current system. It begins with our first exports in 1880 and follows the scientific underpinning provided initially by scientists at the Council for Scientific and Industrial Research (CSIR), the forerunner of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), by CSIRO itself in very large measure, the universities and more recently, by a meat industry which has become adept at improving and monitoring its hygienic practices.

For many years, there has been anecdotal evidence through the international meat trade that Australian meat products are excellent in terms of food safety and shelf life.

In this Executive Summary, we present the headline evidence supporting both these contentions that underpin the international reputation of Australian meat.

# Executive Summary

The purpose of this summary is firstly to accumulate key indicators of the hygienic quality of Australian meat carcases, primal cuts and manufacturing meat and secondly, to make comparisons with the hygienic quality of similar products from other countries; details of each study examined are presented in Appendix 1.

We are aware that making such comparisons is difficult because of differences in methodology between different studies and, to minimise these effects, we have used data only from studies done since the introduction of Hazard Analysis and Critical Control Points (HACCP) principles to the meat industry in the late-1990s. A summary of the methodology of each study and its influence on microbiological counts is presented in Appendix 2.

Here we highlight the unique features of the Australian system of slaughter and dressing, how national baseline studies have prompted processing and infrastructure improvements leading to meat products of outstanding hygienic quality.

## The Australian system

The Australian red meat industry operates very differently from those in many other countries and a number of key factors underpin Australian production. These include:

### Livestock generally enter the slaughter facility in a clean condition

In Australia, cattle are predominantly grass-fed and, as shown by a Meat and Livestock Australia (MLA) commissioned survey, are less likely to carry mud and faeces (tag) as they enter the abattoir than are North American cattle (Figure S1). In the study, Jordan (2003) assessed the tag loadings on 400 cattle, a mixture of grass and grain-fed cows, bulls, steers and heifers slaughtered at three abattoirs in Eastern Australian. Using an identical rating system, the author was able to compare tag loadings on Australian cattle with those of predominantly grain-fed North American cattle, as described previously in Jordan (1999).

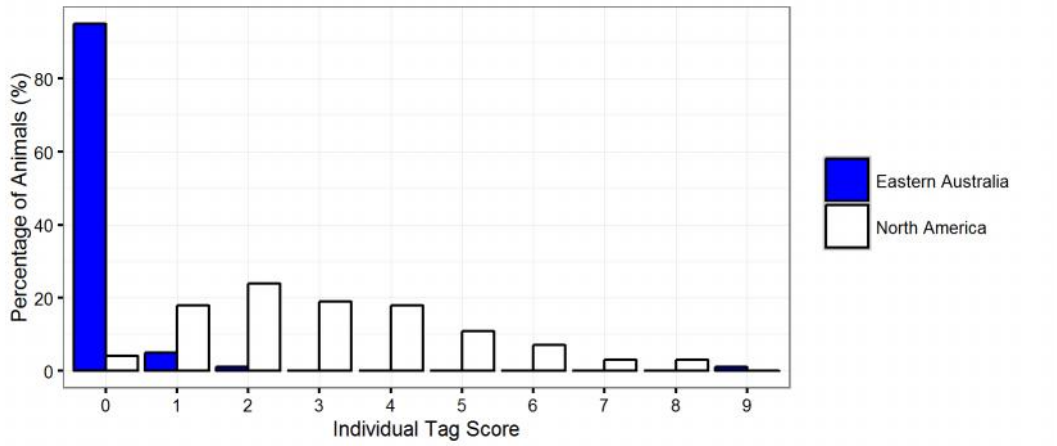


*Figure S1: Tag score cattle entering slaughter facilities in Australia and North America*

### Slaughter and dressing chain speeds are low

It is well known that the speed at which livestock are dressed can influence the bacteria transferred to the carcase surface by operators. Australian abattoirs generally slaughter around 70 cattle per hour with staffing levels around 25 operators. In contrast, the North American industry is based on high speed processing (>300 cattle/hour), which needs more operators: around 40 for hide removal and 55 for dressing and trimming (Anon. 2003).

### Improved unit operations for hide/pelt removal

In the southern hemisphere, the introduction of inverted dressing led to improvements in the hygiene of small stock carcases (Bell & Hathaway 1996; Biss & Hathaway 1995) while the beef slaughter floor saw a range of improved unit operations. For details of improvements in livestock cleanliness and handling, and in slaughter floor processing, see Kiermeier *et al*. (2006, 2007a) and Kiermeier & Sumner (2009).

### Well-trained operators and managers

In Australia, the level of operator training in the meat industry is comprehensive with the Meat Industry National Training Advisory Council (MINTRAC) charged with implementing formal training in the industry. All programs are endorsed by the Federal Government and have a strong food safety focus supported by rigorous assessment procedures.

On average, there are approximately 6,000 new commencements in endorsed training every year. Over 5,000 of these are in Certificates II or III in Meat Processing. In 2016, there were 11,721 employees undergoing training in meat processing qualifications, with around 30 moving to Diploma level and above (pers. comm. Jenny Kroonstuiver, MINTRAC).

### Establishments trim to a standard specification

Before leaving the slaughter floor, all Australian carcases receive a standard trim, removing organs, appendages, excess fat and visible contamination; some establishments also remove tissue around the Halal cut. The extent of trimming, and therefore removal of contaminated surface tissue, of Australian beef carcases far exceeds that done in North American abattoirs.

### Microbiological monitoring

The industry invests heavily in routine microbiological monitoring via the government-supervised *E. coli* and *Salmonella* Monitoring (ESAM) program (now incorporated in the National Carcase Microbiological Monitoring Program, NCMMP) and in national baseline surveys that are used to drive industry improvement.

As illustrated later in this summary and the main text, these factors result in Australian meat with lower bacterial loadings and likelihood of pathogens than its international competitors, with superior food safety and shelf life.

### Technical underpinning

In the main body of this monograph, we record the technical basis that underpins the ability of the Australian industry to produce meat products that are of consistent high microbiological quality. For almost a century, the industry has benefited from R&D, starting with the CSIR and the CSIRO, with its dedicated Meat Research Laboratory. More recently, the industry has invested in risk assessment and the building of predictive microbiology tools from scientists at CSIRO, the University of Tasmania (UTas) and the South Australian Research and Development Institute (SARDI).

### Likelihood of contamination

Given the several unique aspects of the Australian industry presented above, it would be expected that bacterial contamination in general, and of faecal organisms in particular, would be much lower on Australian carcases.

In 2013, the opportunity to assess this likelihood arose when the USA Food Safety and Inspection Service (FSIS) flagged the intention to undertake a Beef and Veal Carcass Baseline

Survey (B-VCBS). The study design involved sponging large areas of the carcase (4,000cm$^2$) at two stages in the slaughter and dressing process: immediately after hide removal and immediately prior to chilling.

A similar design was followed in an Australian survey, allowing a comparison with one of Australia's major markets. The results confirm great differences in the way opening cuts and hide removal are made between the two industries.

After removing the hide, carcases processed in USA plants were positive for the faecal indicator, *E. coli*, on 70% of occasions compared with 5% on Australian carcases (Figure S2). And while interventions in USA plants reduced the prevalence of *E. coli* significantly immediately pre-chill, it was still much higher than on Australian carcases (MLA 2017a).

Similarly, the prevalence of *Salmonella* on carcases was more than 10× higher immediately after hide removal (27.1%) and 6× higher pre-chill (3.6%) on USA carcases compared with the respective Australian prevalence of 2.09% and 0.56% (Figure S2).

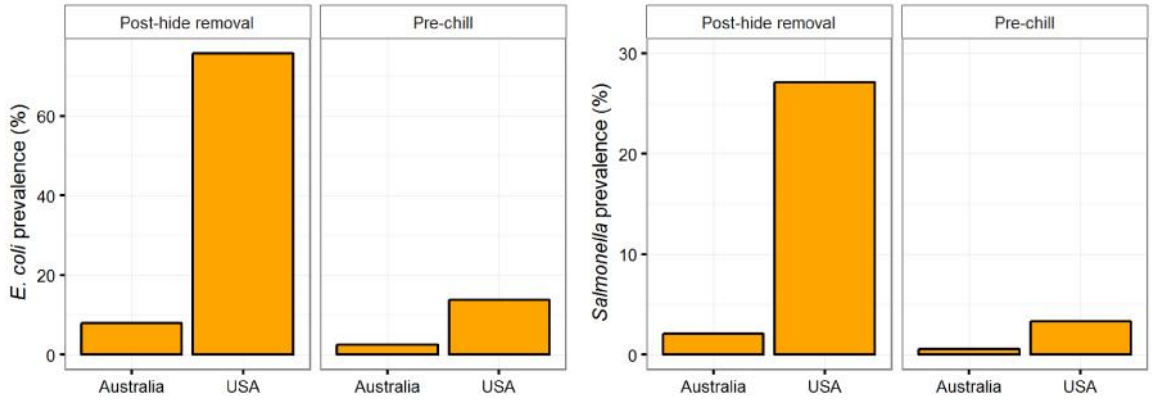


*Figure S2: Prevalence (%) of E. coli (left) and Salmonella (right) on Australian and USA carcases during dressing*

Since 1998, the ESAM program has generated more than 1,250,000 chilled carcase swab tests for indicator bacteria and 500,000 tests for *Salmonella*. Since 2007, the database has been 'active' with each export establishment receiving monthly summaries from SARDI comparing its own, with the national microbiological profile. In Figures S3 and S4 are 11-year retrospectives for Total Viable Count (TVC) and *E. coli* prevalence on beef and ovine (lamb and mutton) carcases.

## Testing and monitoring

For beef carcases, the mean TVC for carcases has generally cycled around 10 cfu/cm$^2$ (1.0 $\log_{10}$ cfu/cm$^2$) and for sheep carcases, around 30 cfu/cm$^2$ (1.5 $\log_{10}$ cfu/cm$^2$). Both species had higher bacterial loadings following the end of the Millennial Drought in 2011, with an increase from 2010-2013, when a number of extreme rain events occurred.

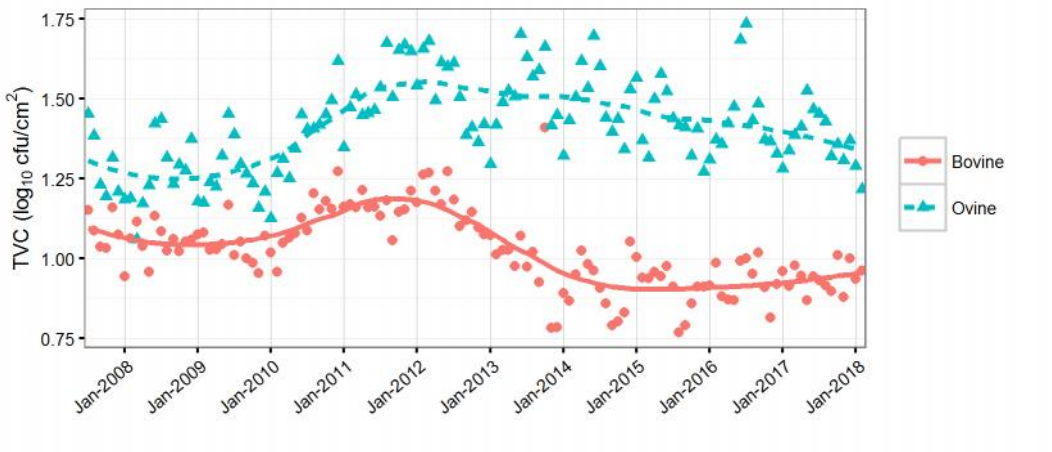


*Figure S3: Time-series plot of TVC concentration for bovine and ovine carcases; the solid lines indicate the smooth 'loess' trend.*

Prevalence of *E. coli* on beef carcases has cycled around 4%, and on sheep carcases around 15%, over the past decade with small stock being affected more by seasonal influences like rainfall and pasture growth (Figure S4).

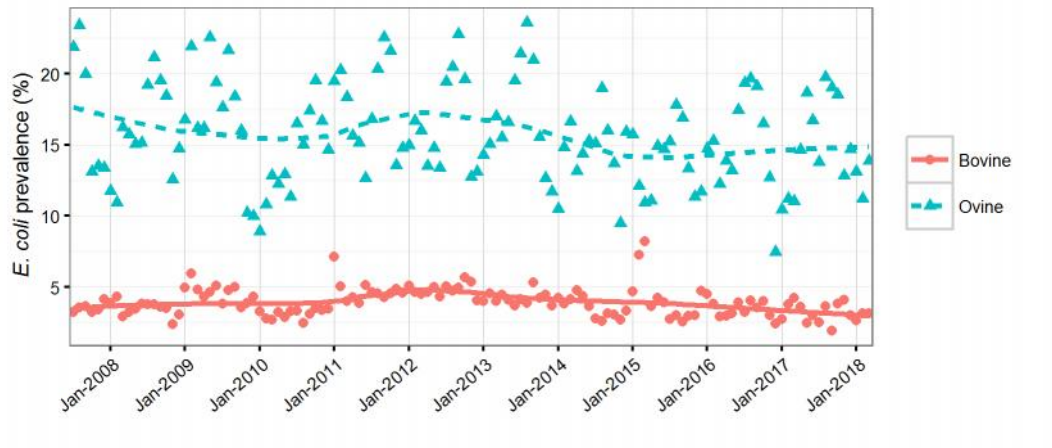


*Figure S4: Time-series plot of E. coli prevalence for bovine and ovine carcases; the solid lines indicate the smooth 'loess' trend.*

When the indicator bacterium *E. coli* is present, it is generally at a very low level, as can be judged from Figure S5, where levels cycle around 3/cm$^2$ on beef and around 5/cm$^2$ on sheep carcases; the large apparent peak was due to a single large *E. coli* detection.

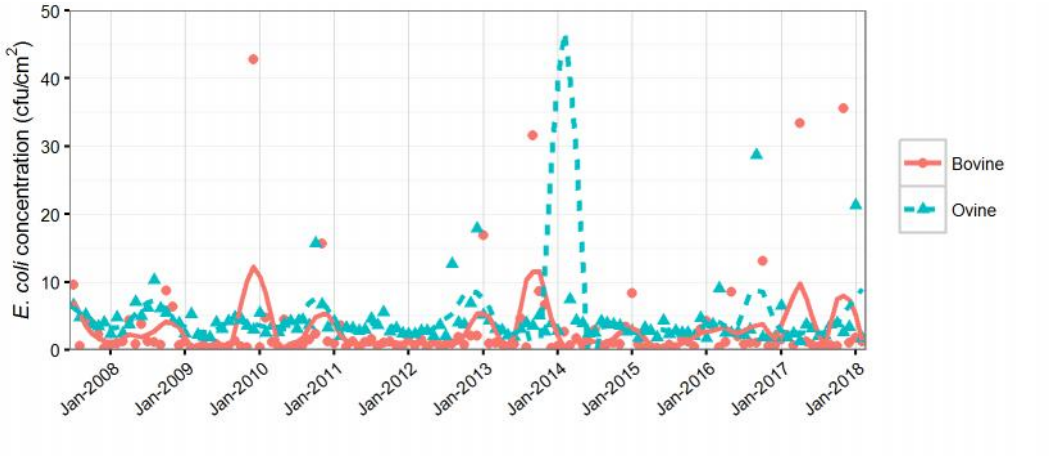


*Figure S5: Time-series plot of E. coli concentration (CFU/cm²) for bovine and ovine carcases; the solid lines indicate the smooth 'loess' trend.*

The ESAM program also monitors the presence of *Salmonella* on carcases, which generally cycles around 0.5% for beef and sheep carcases (Figure S6).

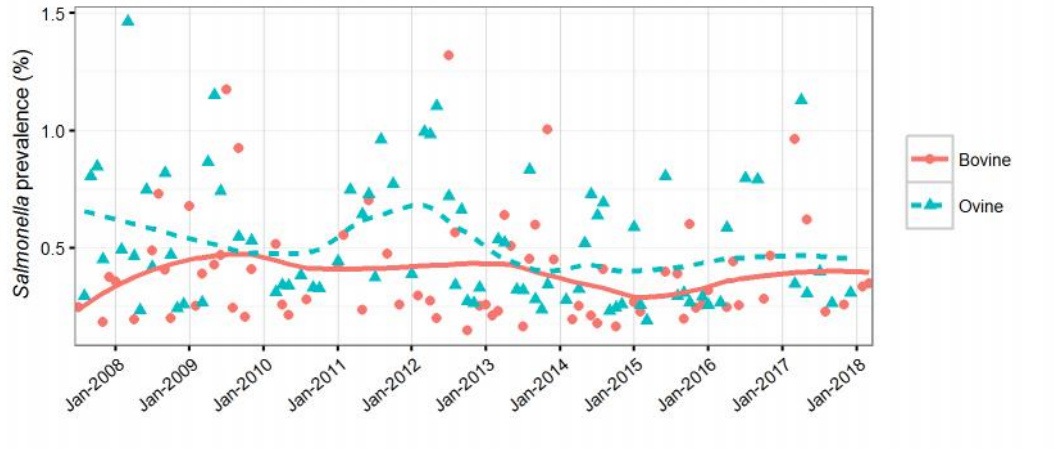


*Figure S6: Time-series plot of Salmonella prevalence for bovine and ovine carcases; the solid lines indicate the smooth 'loess' trend.*

## Carcase hygiene – how does Australia compare globally?

While sampling and testing methodologies differ, global studies indicate that the hygienic quality of Australian carcases compares favourably with those manufactured in other countries with bacterial loadings generally 90-99% (1-2 $\log_{10}$) lower than those produced in other countries (Appendix 1a, 1b and Figure S7). Note that the differences in bacterial loading are much greater than would be expected by slight differences in methodology (see Appendix 2 for details of all studies used and their methodology).

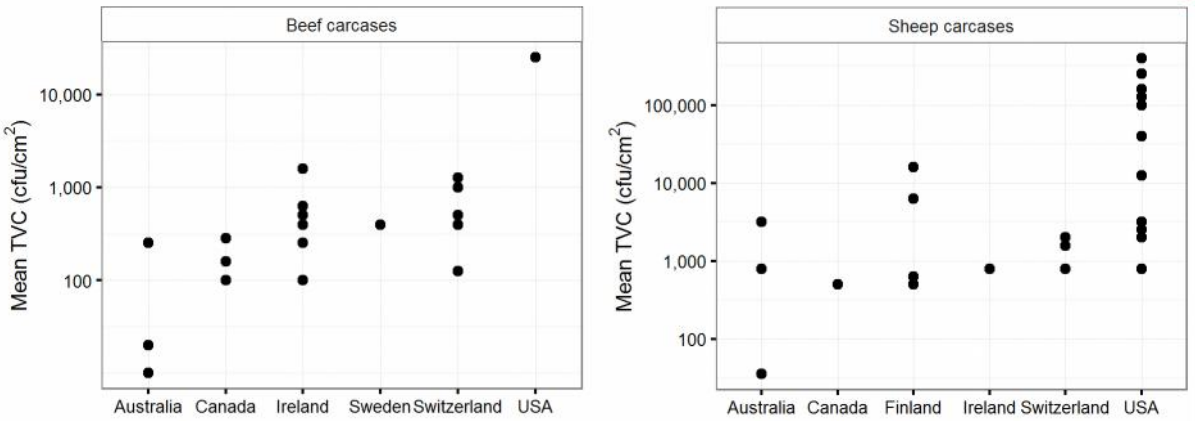


*Figure S7: Inter-country comparisons total bacterial loadings (TVC) on beef and sheep carcases*

## Final product hygiene - how does Australia compare globally?

In Australia, carcases are broken down into two main products: chilled, vacuum packed cuts and manufacturing meat which is then frozen in cartons. There is evidence that the hygienic quality of Australian carcases leads to loadings of indicator and pathogenic bacteria which compare favourably with those manufactured in other countries.

As shown in Appendix 1c and Figure S8, the scientific literature indicates that Australian beef cuts prepared for vacuum packaging have much lower bacterial loadings (90-99% in most cases) than those of other countries, which is not surprising since they are produced from carcases of high hygienic quality.

Data for lamb cuts at packaging in Australia are on average approximately 100 cfu/cm$^2$ or /g and are presented in Appendix 1d; we could find no international data for comparison.

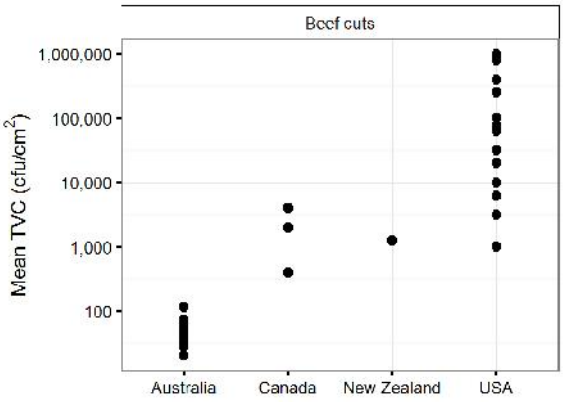


*Figure S8: Inter-country comparisons total bacterial loadings (TVC) on beef cuts*

## Food safety

In 1992-93, outbreaks involving more than 400 people in the western USA revealed the risk of *E. coli* O157 illness from consumption of undercooked hamburgers. Since this time, there have been numerous outbreaks from consumption of hamburgers in the USA, and the presence of Shiga Toxic *E. coli* (STECs) in meat destined for grinding remains the most pressing issue for the global beef industry.

In Figure S9 are presented data from the Department of Agriculture and Water Resources (DAWR) Product Hygiene Index (PHI) database for *E. coli* O157 isolations from Australia

manufactured meat destined for grinding in the USA, which averages between 0.1% and 0.2%, with a recent downward trend.

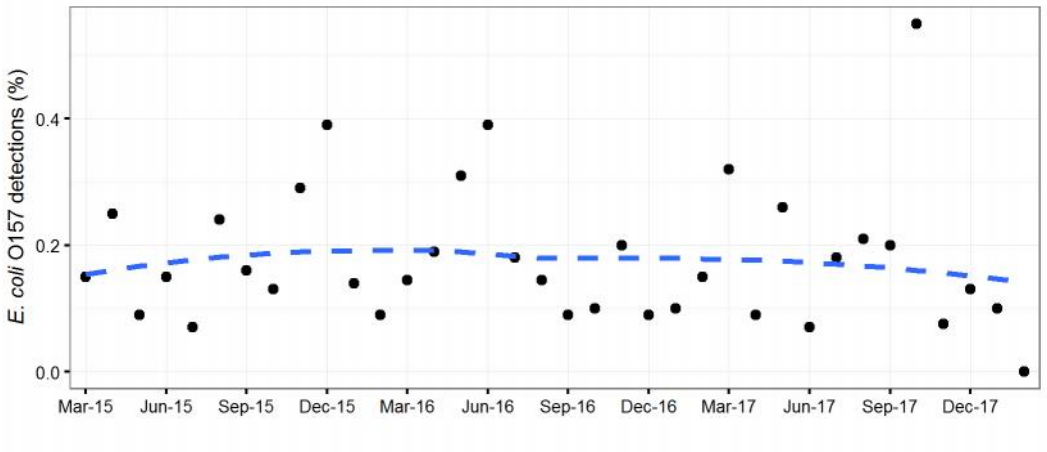


*Figure S9: Prevalence (%) of E. coli O157 on Australian manufacturing meat*

### Manufacturing meat – how does Australia compare globally?

The USA import large quantities of manufacturing meat for grinding and, in 2007, government researchers from the U.S. Department of Agriculture were tasked with evaluating the hygienic quality of imports. They tested beef trim from Australia, New Zealand, Uruguay, comparing the results with their own domestic product. They tested indicator organisms such as Total Bacteria, *Enterobacteriaceae*, Coliforms/*E. coli*, *Staphylococcus aureus* and pathogens: *Campylobacter*, *Listeria*, *Salmonella* and non-O157 STEC.

The microbiological status of Australian boneless beef was best in eight of the nine categories, shaded by New Zealand in the ninth. The USA researchers stated that the results revealed significant differences between samples *"with the lowest pathogen numbers in samples from AUS"* (Bosilevac *et al*. 2007).

The differences between USA and Australian contamination levels are still present, as shown by the recent carcase baseline studies done in both countries and illustrated in Figure S2 (MLA 2017a).

### Risk of STEC illness in "Aussie" hamburgers

Many of the problems surrounding meat destined for grinding in the USA revolve around the propensity of their consumers to prefer undercooked hamburgers. Since the Jack-in-the Box outbreaks of 1992-93, the major hamburger chains around the world have established thorough cooking regimes for hamburgers, with zero outbreaks resulting from the introduction of this Critical Control Point (CCP).

The prevalence and concentration of STEC in Australian manufacturing meat is extremely low and risk studies indicate that if all Australian trim exported to the USA was manufactured into "Aussie" hamburgers (no comingling with trim from other countries), they would cause less than 1 illness/decade in quick serve restaurants (Kiermeier *et al*. 2015a).

### Virulence of Australian STECs

CSIRO research comparing *E. coli* O157 isolates in Australia and the USA indicates Australian types have lower virulence than those in the USA (Mellor *et al.* 2013). The evolution of *E. coli* O157 has resulted in populations with differing potential to cause disease in humans as

there are some types of *E. coli* O157 that only appear to be associated with cattle and rarely cause disease in humans or cause only mild illness, while other types can cause severe disease in humans. These differences are related to the type of toxin the bacteria produce along with other factors that limit the ability of the bacteria to infect humans. *E. coli* O157 populations have diverged in different countries and those found in Australian cattle mostly belong to the types that rarely cause severe illness in humans. This is in contrast to other countries, such as the USA, where *E. coli* O157 populations circulating in cattle also contain those types associated with severe human disease. Australian manufacturing meat therefore now has one huge advantage in that Australian types of *E. coli* O157 are less likely to cause severe disease in humans than North American types.

### Comparison of STEC illness in Australia and other countries

According to a study commissioned by MLA, researchers based at the Australian National University have established that the risk of STEC illness from consumption of Australian meat was 0.4 cases/100,000 populations for STECs in general and 0.1/100,000 population for STEC O157 (Vally *et al*. 2012). As may be seen from Table S1, the risk of STEC infection in other countries is much higher than in Australia (Rivas *et al.* 2014).

*Table S1: Relative rates of STEC illness/100,000 population (after Rivas et al. 2014)*

| Country | STEC | O157 only |
|---|---|---|
| EU | 1.1 | 0.6 |
| Denmark | 3.5 | 0.7 |
| Austria | 1.5 | 0.2 |
| Belgium | 0.9 | 0.6 |
| Ireland | 9.0 | 4.3 |
| Sweden | 5.0 | 1.2 |
| Netherlands | 6.3 | 2.0 |
| New Zealand | 4.6 | 3.9 |
| Scotland | - | 1.4 |
| Canada | - | 1.4 |
| USA | 2.3 | 1.2 |
| UK | 2.2 | 2.1 |

The researchers also found that there had been only 11 outbreaks of STEC illness in Australia between 2000 and 2010 from all sources, none of which involved meat (Vally *et al*. 2012).

## Shelf life of vacuum packed cuts

During the late 1960s, because of advances in packaging films and technology, it became possible to supply distant markets with chilled primals and subprimals. Australian product quickly gained a reputation in the international trade for achieving shelf lives of up to 100 days at -1°C for beef primals.

In the ensuing three decades, anecdotal evidence suggested shelf lives longer than 100 days and recent studies have demonstrated shelf lives of 189-203 days (Small *et al.* 2012), 161-280 days (Tunnage 2018) for beef vacuum packed (VP) primals and 94-103 days for lamb VP primals (MLA 2017b).

Only one comparable overseas study could be found, that of Yousseff *et al*. (2014) where the shelf life of VP boneless beef butts boned in Canada from carcases which had received several decontamination interventions was 160 days at -1.5°C.

## Conclusions

The sum total of the findings reported in this summary and further detailed in the full monograph reflect the commissioning of meat industry R&D by various funding bodies over the past half century: the Australian Meat Research Committee (AMRC, 1966-85), the Australian Meat and Livestock Research Development Corporation (AMLRDC, 1985-91), the Meat Research Corporation (MRC, 1991-98), Meat and Livestock Australia (MLA, 1998-present), together with Australian Meat Processor Corporation (AMPC, 1998-present).

The result in 2017, is an Australian meat industry valued at almost AUD17 billion, comprising beef ($12.7 billion) and lamb/mutton ($3.9 billion) products, of which around 65% is exported, chilled and frozen, to more than 100 markets globally.

Frozen products underpin the Middle Eastern mutton and the North American hamburger markets. In 2015, for example, Australia exported the equivalent of 3.4 billion quarter-pounder hamburger patties to North America as manufacturing meat.

Australia exports around 3 million kg of vacuum packed meat of which the vast bulk (85%) is beef primals that will be further processed through the world's retail and food service chains.

The main body of this monograph follows how R&D has assisted the red meat industry to service more than one hundred markets with meat of high hygienic quality, giving long shelf life and low food safety risk.

# 1 Introduction: an industry is born

In 1788, the first European settlers landed at Sydney on an island continent with no meat animals. The eleven vessels of the First Fleet carried 7 cattle, 44 sheep, 19 goats, 32 pigs and various poultry all purchased at the last landfall in South Africa. Problems arose when two bulls and four cows wandered off into the bush, leaving only one cow to supply the 1,000 or so new Australians with dairy products. The escapees were not found for seven years, by which time they numbered 61, and in much better condition. From this beginning, the Australian livestock herd was steadily built with stock purchased from India and Asia.

Australia's meat industry was based on freshly killed game and salted pork imported from Norfolk Island where there was a large wild pig population. Tahiti, then regarded as a dependency of New South Wales (NSW), also supplied large quantities of salted pork. It was almost a quarter of a century before cattle numbers exceeded the needs of the colonists, and in 1813, there were suggestions for exporting salted beef in barrels to Britain for use by the navy.

A great deal is known about the early Australian meat industry thanks to three definitive texts: *A Settlement Amply Supplied* (Farrer 1980), *To Feed a Nation: A History of Australian Food Science and Technology* (Farrer 2005) and *Food Science and Technology in Australia* (Vickery 1990). Their work shows how techniques that stemmed from historical times (salting, boiling) were augmented by the 'new' global technologies: thermal processing and refrigeration.

## 1.1 Salting and boiling

In 1830, the industry experienced its first over-supply crisis when the price of livestock collapsed, stimulating an export trade in salted meat. Australia's next venture in meat processing was 'sheep boiling' to produce tallow. At the time, sheep sold for as little as six pence whereas rendering increased their value 10-fold.

Process development followed apace and by the mid-1840s, sheep were being processed into tallow, mutton hams, pig feed, meat meal and bone meal for fertiliser, glue, bone oil and portable soup (a dried bouillon cake).

## 1.2 Meat canning

In Europe, thermal processing and tinplate containers had been developed, allowing food to be put into 'metal boxes' and by 1850, canneries had sprung up all over Australia, canned meats achieving market domination for the next two decades.

## 1.3 Refrigeration

Mechanical refrigeration ('cold on demand') revolutionised the food industry, replacing an existing global trade in natural ice. For the Australian meat industry, refrigeration offered an alternative to canned meat and in 1873, the *SS Norfolk* was loaded with a trial shipment to England. The trial proved unsuccessful when the circulating brine system failed.

In 1879, the *SS Strathleven* was fitted with mechanical refrigeration and loaded with beef and mutton carcases in Sydney and Melbourne, which were then frozen on board. After a 60-day voyage, the SS *Strathleven* arrived in London with a 34-tonne cargo in excellent condition (Vickery 1979). More importantly, the venture was a commercial success stimulating a frozen meat trade that was to dominate beyond the middle of the 20th century. Australia continues to ship large quantities of frozen meat to many destinations – around one million tonnes in 2016.

## 1.4 The chilled meat trade

While the good news was that an export market had been opened, the cliché 'tyranny of distance' had its impact because South American countries such as Argentina and Paraguay were able to land chilled meat in London after a 14-day voyage. Their product was markedly superior to Australian frozen meat because there was no 'drip', and it attracted a price premium.

For the next 60 years, Australian research concentrated on trying to deliver chilled meat to distant markets. Various processes were investigated and scientists from the CSIR found that carbon dioxide atmospheres ultimately gave sufficient shelf life even after voyages of up to 60 days. The first trial shipment of chilled meat under carbon dioxide took place in 1933, with forequarters held in gas-tight cargo spaces. While the trial was successful and the effectiveness of modified atmospheres on meat spoilage organisms was validated, commercialisation did not take place until the advent of flexible packaging.

During the late 1960s, because of advances in packaging films and technology, it became possible to reach distant markets, particularly Japan, with chilled primals and subprimals. Vacuum packaging technology had progressed to the point where shelf lives up to 100 days at -1°C were regularly achieved. Nowadays, Australia ships vacuum packed primals and subprimals to many countries with over 300,000 tonnes of chilled beef, sheep, and goat meat exported in 2016.

# 2 Hygienic status of Australian red meat carcases

## 2.1 Early research

From 1880, and the voyage of the *SS Strathleven*, Australia sold meat in carcase form to the United Kingdom – the vast majority as frozen lamb and mutton carcases, plus a small volume of chilled beef in chambers containing an atmosphere of carbon dioxide. That trade continued virtually unchanged for more than seventy years, except for a hiatus for World War II, with few microbiological problems except for occasional 'black spot' moulding of frozen carcases. That problem was much more prevalent in New Zealand and research at the Meat Industry Research Institute New Zealand (MIRINZ) revealed that *Cladosporium* was capable of producing black spot on meat held as cold as -6°C (Gill *et al.* 1981; Gill & Lowry 1982).

Between the two world wars, scientists at the CSIR worked on preservation of foods, particularly meat, and began to piece together the critical factors which influence the microbiological condition of meat: the microbiology of the living animal at slaughter; the degree to which hide and gut removal transferred contamination to the meat surface; and temperature during chilling, storage and distribution.

Early work, on the influence of humidity on the growth of micro-organisms, was investigated at CSIR by W. J. Scott and co-workers who established that *Pseudomonas* and *Achromobacter* from raw beef were inhibited by drying of the carcase surface (Scott, 1936; 1937). Empey & Scott (1939) also found that psychrophiles could grow on meat at low temperatures; that animals from cooler parts of Australia had a higher proportion of these organisms; and that enclosing meat held at 5°C led to increases in bacterial count (Scott & Vickery, 1939) a finding which would become more relevant when packaging of meat allowed supermarkets to compete with high street butchers.

## 2.2 Meat safety and quality problems emerge

**Context – meat safety**

After World War II, a number of events concerning food safety and quality prompted major change. In terms of food safety, the Swedish salmonellosis outbreak in 1953 constituted the first large-scale, documented food poisoning incident involving meat. In all, more than 9,000 cases and at least 90 deaths were caused by *S*. Typhimurium, with bobby veal and pork slaughtered at a single abattoir implicated. There were several possible causes: a strike resulted in the build-up of livestock at the abattoir; several operators were confirmed as symptomless *Salmonella* carriers; ambient temperatures exceeded 30°C which, with increased kill rates when slaughtering recommenced after the strike, probably exceeded the establishment's refrigeration capacity (Lundbeck *et al*. 1955).

In Australia, research into carriage of *Salmonella* in livestock in the pre-slaughter phase became important as a way of preventing the hazard entering the slaughter floor in large numbers in the animal's gut, and this work will be followed later in this section.

In addition, the fact that the root cause of the outbreak involved line operators of whom 15% were *Salmonella* carriers initiated changes to on-line procedures to prevent carcase-to-carcase transmission of microorganisms, particularly by washing hands and cleaning knives between carcases. Over time, these aspects were refined, especially knife cleaning, with a 2-knife system introduced to allow the knife not in use to remain in the 'steriliser' at 82°C.

With rising energy costs, maintaining water at 82°C became problematic and when little scientific backing could be found for it (Midgley & Eustace 2003), MLA commissioned CSIRO to investigate whether alternative temperatures and times could achieve equivalent inactivation of bacteria remaining on the knife blade compared with the current system: washing the knife and then dipping in 82°C water. An industry trial was carried out where knives used at key points along the slaughter and dressing chain were monitored before and after cleaning, and a series of alternative temperature:time regimes were identified which gave equivalent inactivation to dipping in 82°C (Eustace *et al*. 2007; 2008).

Further industry trials using a 2-knife system were undertaken to 'validate' alternative procedures and the Meat Standards Committee approved a final report: *"Water at less than 82°C for sanitizing knives and equipment in abattoirs: a guide to gaining regulatory approval"* (MLA 2007).

**Context – meat quality**

The way animals were slaughtered and dressed also changed after World War II, with so-called 'solo butchering' (each animal processed by one operator) replaced by a moving chain where each operator performed a limited number of tasks.

Abattoir capacity increased in Australia and New Zealand with some plants processing more than 10,000 small stock per day, prompting the need for increased refrigeration capacity for active chilling and freezing of carcases. As blast chillers and freezers replaced chambers with overhead brine pipes, increased refrigeration capacity brought with it quality problems with reports from the United Kingdom of frozen lamb being tough.

Researchers at MIRINZ and CSIRO established that rapid freezing causing cold shortening was the cause of toughness, and the first response was to alter the rapid chilling and freezing cycle. Newly slaughtered lamb/mutton carcases were stored overnight around 15°C, so-called 'high temperature chilling' or 'conditioning and ageing' (C&A). While C&A substantially solved the tenderness problem, it also resulted in significant microbiological growth.

Studies in NZ, USA and Australia showed that altered posture hanging from the pelvis achieved more tender meat without microbiological problems (see Baxter *et al*. 1972). Later, electrical stimulation was introduced to prevent cold shortening, an advance which became important with the advent of hot boning. The review *"New Concepts in Meat Processing"* by Locker *et al*. (1975) describes how researchers in NZ and Australia responded to these early quality problems in their major distant markets.

# 3 Rapid increase in microbiological knowledge of carcases

**Context**

In the 1960s, microbiological testing at an abattoir was much more difficult than today, where a laboratory can be set up in the establishment's training room in minutes using off-the-shelf sterile equipment and media. In the early days, samples were taken on the slaughter line and transported as quickly as possible to a dedicated microbiology laboratory with autoclave, glass pipettes and Petri dishes.

'Abattoir microbiology' was in its infancy, with researchers at the fledgling CSIRO building on their knowledge that bacteria on the carcase immediately after hide removal were derived mainly from the hide/pelt and that some of them (psychrotrophs) were able to grow at refrigeration temperatures (Empey & Scott, 1939). That knowledge was expanded significantly over the next two decades by CSIRO researchers.

In 1969, the CSIR became the CSIRO with specialist laboratories servicing the dairy, seafood and meat industries. The Meat Research Laboratory at Cannon Hill in Brisbane was a multi-disciplinary unit with chemists, engineers and microbiologists working on a range of R&D projects to support the 'new' export industry – chilled meats.

An important development in the early 1960s was the creation of the International Commission on Microbiological Specifications for Foods (ICMSF), the initial work of which sought to standardise methods and sampling of foods in international trade. CSIRO microbiologists were active in the early ICMSF with Dr. John Christian (1971-1991) chairing its activities and Dr. Fred Grau (1985-1999) bringing specific meat expertise.

Not surprisingly, in the wake of the massive Swedish salmonellosis outbreak, control of this pathogen was a major task for the ICMSF, which characterized the hazard in chilled or frozen carcase meat as *"serious and incapacitating but not usually life threatening".* The ICMSF noted that it is expected that meat will be consumed cooked and in the sampling plan of the day, of five samples (n=5), no more than one sample was allowed to contain *Salmonella*. The ICMSF also placed before the industry the aspiration that improvements in hygienic processing could, over time, lead to no sample containing the pathogen.

CSIRO researchers established the link between *Salmonella* prevalence in the gut during transport and holding of livestock immediately prior to slaughter. If a small number (a few hundred) salmonellae were transferred by tube into the animal's rumen, the population decreased over 24-48 hours due to the production of volatile fatty acids such as acetic acid. However, if animals were held for more than 48 hours off feed, when feed was again made available, *Salmonella* numbers quickly exceeded 100,000,000/g of faeces (Grau *et al.* 1969; Grau *et al*. 1974; Brownlie & Grau, 1976).

More recently, Pointon *et al.* (2012) found the effect of pre-slaughter feed withholding (curfew) on *E. coli* O157 / STEC were not as large as on *Salmonella*, leading the authors to conclude: *"… that animals should be fasted before loading only enough to allow sufficient faecal expulsion i.e. ≤24 h to maintain 'clean' livestock after transport. Adverse food borne microbial growth can be minimised by not exceeding 48h for time off feed before slaughter."*

In 1979, Grau published *Fresh meats: Bacterial association,* a summary of global knowledge of meat microbiology and processing based on work in Australia, Europe and New Zealand. Microbiologists had explored bacterial loadings on beef and ovine carcases, finding considerable variability on different regions of the carcases. A survey quoted by Grau (1979)

showed Aerobic Plate Counts (APC) on mutton carcases ranged between 2.8 $\log_{10}$ cfu/cm$^2$ (630 cfu/cm$^2$) at the shoulder to 3.8 $\log_{10}$ cfu/cm$^2$ (6310 cfu/cm$^2$) at the brisket. However, based on *E. coli* contamination, the sacral area was most contaminated (1.6 $\log_{10}$ cfu/cm$^2$, 40 cfu/cm$^2$) and the hindlegs the least (0.5 $\log_{10}$ cfu/cm$^2$, 3 cfu/cm$^2$). Empey & Scott (1939) had shown that most bacteria on the carcases immediately after hide removal were derived from the hide and the current work cited by Grau confirmed this, adding that evisceration was the primary source of *E. coli*.

While Grau (1979) found no correlation between APC and *E. coli* counts, there seemed some relationship between the latter and presence of *Salmonella*. On mutton carcases, evisceration led to a 100-fold increase in *E. coli* concentration, and *Salmonella* was found on 26% of eviscerated carcases compared with 4% prior to evisceration. Similarly, on beef carcases, when *Salmonella* was isolated (mainly from the perianal region) *E. coli* was also present at concentrations up to 1800 cfu/cm$^2$. It should be stressed though, that in modern slaughter and dressing systems, any correlation between prevalence of *E. coli* and of *Salmonella* is at best weak.

# 4 The modern Australian slaughter and dressing system

**Context**

Over the past four decades, there have been radical changes to the unit operations in beef and sheep slaughter and dressing, to the hygiene status of the abattoir environment and to implementation of food safety systems to control hazards.

Factors underpinning production of Australian meat of high hygienic quality are presented below.

## 4.1 Livestock generally enter the slaughter facility in a clean condition

In Australia, cattle are predominantly grass-fed and, as shown by a MLA-commissioned survey, are less likely to carry mud and faeces (tag) as they enter the abattoir than are North American cattle (Figure 1). In the study, Jordan (2003) assessed the tag loadings on 400 cattle, a mixture of grass and grain-fed cows, bulls, steers and heifers slaughtered at three abattoirs in Eastern Australian. Using an identical rating system, the author was able to compare tag loadings on Australian cattle with those of predominantly grain-fed North American cattle as described in Jordan (1999).

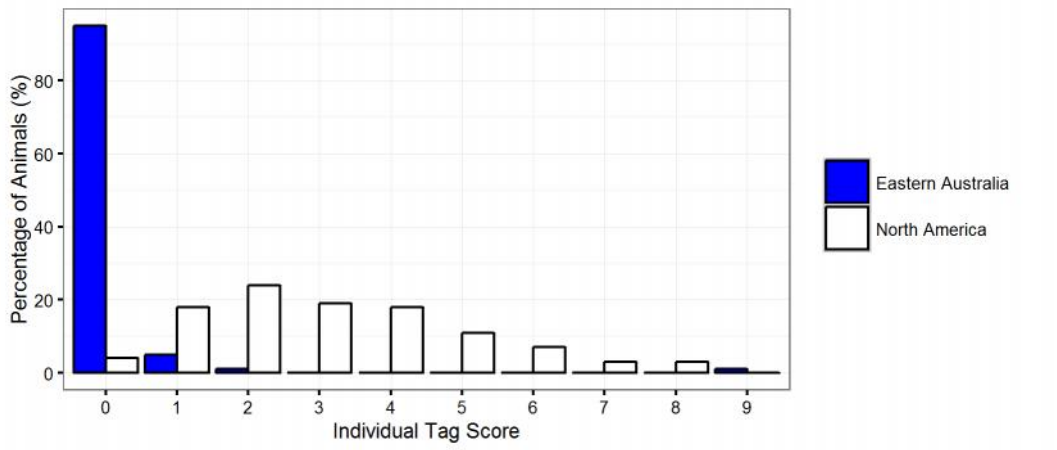


*Figure 1: Tag score cattle entering slaughter facilities in Australia and North America*

## 4.2 Slaughter and dressing chain speeds are low

It is well known that the speed at which livestock are dressed can influence bacterial transfer to the carcase surface by operators. Australian abattoirs generally slaughter around 70 cattle per hour with staffing levels around 25 operators. In contrast, the North American industry is based on high speed processing (>300 cattle/hour), which needs more operators: around 40 for hide removal and 55 for dressing and trimming (Anon. 2003).

## 4.3 Improved unit operations for hide/pelt removal

In the southern hemisphere, the introduction of inverted dressing led to improvements in the hygiene of small stock carcases (Bell & Hathaway 1996; Biss & Hathaway 1995) while the beef slaughter floor saw a range of improved unit operations. For details of improvements in livestock cleanliness and handling, and in slaughter floor processing, see Kiermeier *et al*. (2006, 2007a) and Kiermeier & Sumner (2009).

## 4.4 Well-trained operators and managers

In Australia, the level of operator training in the meat industry is comprehensive with the Meat Industry National Training Advisory Council (MINTRAC) charged with implementing formal training in the industry. All programs are endorsed by the Federal Government and have a strong food safety focus supported by rigorous assessment procedures.

On average, there are approximately 6,000 new commencements in endorsed training every year. Over 5,000 of these are in Certificates II or III in Meat Processing. In 2016, there were 11,721 employees undertaking training in meat processing qualifications, with around 30 moving to Diploma level and above (pers. comm. Jenny Kroonstuiver, MINTRAC).

## 4.5 Establishments trim to a standard AUS-MEAT specification

Before leaving the slaughter floor, all Australian carcases receive a standard trim, removing organs, appendages, excess fat and visible contamination; some establishments also remove tissue around the Halal cut. The extent of trimming, and therefore removal of contaminated surface tissue, of Australian beef carcases far exceeds that done in North American abattoirs.

## 4.6 Process monitoring

The industry invests heavily in routine microbiological monitoring via the government-supervised *E. coli* and *Salmonella* Monitoring (ESAM) program and in national baseline surveys which are used to drive industry improvement.

As illustrated later, these factors result in Australian meat with lower bacterial loadings and likelihood of pathogens than its international competitors, leading to superior food safety and shelf life.

# 5 Process evaluation and improvement

**Context**

With many changes to unit operations on the slaughter floor being implemented, the question arose: what are their effects on food safety? MLA commissioned CSIRO and Primary Industry and Resources Victoria to assess abattoir operations and SARDI to evaluate their findings.

In 2006, Kiermeier *et al*. reported on a survey of fifteen export beef abattoirs and grouped variables influencing contamination based on each establishment's *E. coli* prevalence and concentration under two categories: contamination on incoming livestock (Problem variables) together with the ability of the plant's process to deal with such contamination (Process variables).

The analysis had three main findings. Firstly, some plants managed their incoming problem to ensure their process could cope, for example, by limiting the length of wool and by shearing the peri-anal area (crutching) of all sheep. Secondly, plants with a large incoming problem with livestock (long haul, high tag score and proportion of cows/bulls slaughtered) plus 'poor' processes had higher than average *E. coli* prevalence. Thirdly, plants with hot water decontamination systems had low *E. coli* prevalence even when there was a substantial incoming problem with livestock, such as a relatively high proportion of cows/bulls.

The concept of aligning an establishment's incoming livestock problems with its ability to manage those problems was developed into spreadsheet tools to facilitate the establishment in improving its operations: for beef (Kiermeier *et al*. 2006, 2007a) and sheep processing (Kiermeier & Sumner 2009).

Many establishments undertake simple testing of process and product hygiene. To facilitate improvements in experimental design and reporting, MLA commissioned SARDI to undertake national workshops in 2012, 2013 and 2016 and to collate experiments undertaken by industry (Jolley *et al.* 2018a). The *Processor's guide to improving microbiological quality and shelf life of meat*, now in its third edition, lists more than sixty investigations undertaken by establishments (MLA 2017c).

# 6 Microbiological quality of Australian carcases, then and now

**Context**

A retrospective of the microbiology of Australian carcases spanning more than half a century can be determined thanks to early CSIRO studies, to the foresight of Program Managers at MRC and MLA who planned national baseline studies, and to the industry which saw the advantages of knowing its status and of publishing internationally.

Taken together, the changes over the past four decades have resulted in significant microbiological improvements in carcases, particularly in levels of the faecal indicator *E. coli*. Resulting from work carried out by CSIRO on the microbiology of beef carcases, it is possible to construct a time profile by utilising data from Grau (1979) plus three national baseline studies and a recent industry survey (Table 1). It should be emphasised that the data for 1964 and 1978 were gathered at a single abattoir whereas baseline and ESAM data (see Section 7) are industry-wide.

*Table 1: Beef carcase contamination in Australia 1964 to 2018*

| | Number of samples | Mean $\log_{10}$ TVC (cfu/cm$^2$) | *E. coli* prevalence (% >10 cfu/cm$^2$) | Reference |
|---|---|---|---|---|
| 1964 | 70 | 3.9 | 22.5 | Grau (1979) |
| 1978 | 86 | 2.7 | 15.6 | Grau (1979) |
| 1994 | 1063 | 3.2 | 9.2 | Vanderlinde *et al*. 1999a |
| 1998 | 1268 | 2.4 | 2.4 | Phillips *et al.* 2001a |
| 2004 | 1147 | 1.3 | 0.2 | Phillips *et al.* 2006a |
| 2008 | 4374 | 1.0 | 0.0 | Jolley *et al.* 2018b |

Similar data for sheep carcase hygiene are presented in Table 2, again with the caveat that the 1978 data were gathered from a single abattoir, whereas baseline and survey data are national.

*Table 2: Sheep carcase contamination in Australia 1978 to 2018*

| | Number of samples | Mean $\log_{10}$ TVC (cfu/cm$^2$) | *E. coli* prevalence (% >10 cfu/cm$^2$) | Reference |
|---|---|---|---|---|
| 1979 | - | 3.2 | 63.6 | Grau, 1979 |
| 1994 | 470 | 3.9 | 55.5 | Vanderlinde *et al*. 1999b |
| 1998 | 917 | 3.5 | 4.2 | Phillips *et al.* 2001b |
| 2004 | 1117 | 2.3 | 4.8 | Phillips *et al.* 2006b |
| 2018 | 2508 | 1.6 | 1.0 | Jolley *et al.* 2018b |

The progressive reduction in bacterial loading in general, and in *E. coli* in particular, are concurrent with the radical changes which the industry underwent beginning with the introduction of HACCP-based Quality Assurance (QA) systems in the mid-1990s.

# 7 The National Carcase Microbiological Monitoring Program

**Context**

Australian abattoirs exporting to the USA are required to monitor bacterial numbers on carcases according to the Pathogen Reduction – HACCP final Rule (FSIS 1996). To this end, the ESAM program was implemented in 1998, and has accumulated a database comprising more than 1,200,000 beef and sheep carcase swab tests for indicator bacteria and 500,000 tests for *Salmonella*, making it by far the largest national database. Since 2007, the database has been 'active' with each export establishment receiving monthly summaries from SARDI comparing its own, with the national, microbiological profile.

Below are 11-year retrospectives for Total Viable Count (TVC) and *E. coli* prevalence on beef and ovine (lamb and mutton) carcases. For beef carcases the mean TVC has generally cycled around 1.0 $\log_{10}$ cfu/cm$^2$ and for sheep carcases around 1.5 $\log_{10}$ cfu/cm$^2$ (Figure 2).

Both species had higher bacterial loadings following the end of the Millennial Drought in 2011, with an increase from 2010-2013, when a number of extreme rain events occurred, the full extent of which are reported in Anon. (2011) and Comrie (2011).

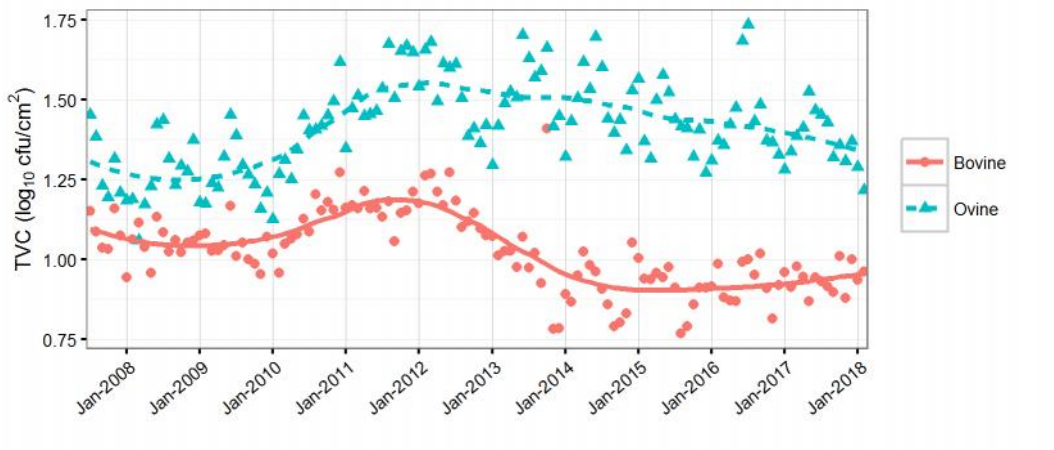


*Figure 2: Time-series plot of TVC concentration for bovine and ovine carcases; the solid lines indicate the smooth 'loess' trend.*

Prevalence of *E. coli* on beef carcases has cycled around 4%, and on sheep carcases around 15%, over the past decade with small stock being affected more by seasonal influences like rainfall and pasture growth (Figure 3).

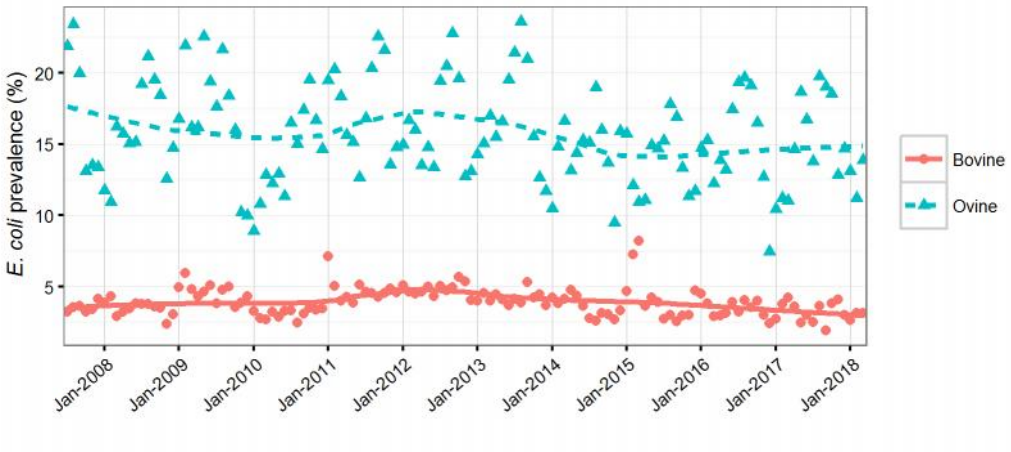


*Figure 3: Time-series plot of E. coli prevalence for bovine and ovine carcases; the solid lines indicate the smooth 'loess' trend.*

When the indicator bacterium *E. coli* is present, it is generally at a very low level, as can be judged from Figure 4, where levels cycle around 3 cfu/cm$^2$ on beef and around 5 cfu/cm$^2$ on sheep carcases; the large apparent peak was due to a single large *E. coli* detection.

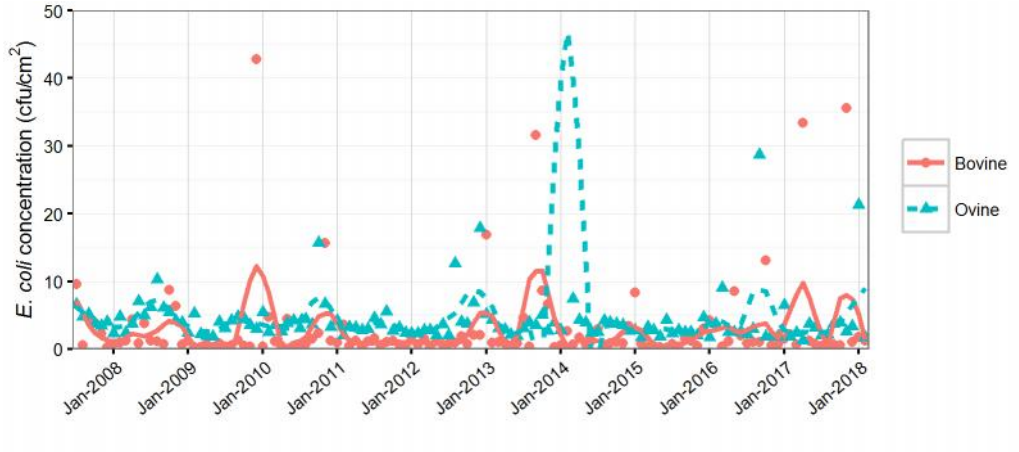


*Figure 4: Time-series plot of E. coli concentration (CFU/cm$^2$) for bovine and ovine carcases; the solid lines indicate the smooth 'loess' trend.*

The ESAM program also monitors the presence of *Salmonella* on carcases, which generally cycles around 0.5% for beef and sheep carcases (Figure 5).

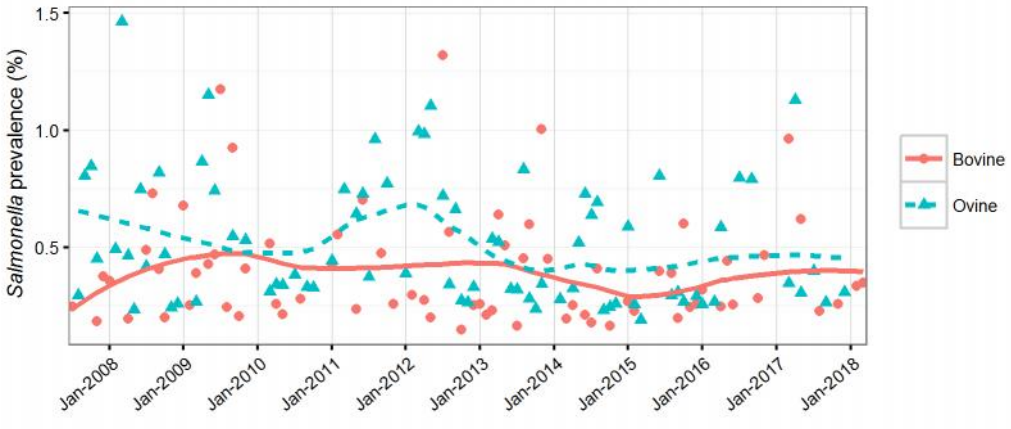


*Figure 5: Time-series plot of Salmonella prevalence for bovine and ovine carcases; the solid lines indicate the smooth 'loess' trend.*

# 8 How does Australia compare globally?

**Context**

It is acknowledged that surveys are essentially snapshots at a specific time and, in making the comparison presented here, we have used surveys from the time HACCP principles had been implemented by the global meat industry. We have also selected surveys in which swab sampling (generally) and excision sampling (rarely) were used to remove indicator bacteria from chilled carcases. In Appendices 1 and 2 are presented full details of each survey of beef and sheep carcases.

Global studies of chilled carcases indicate that the hygienic quality of Australian carcases compares favourably with those manufactured in other countries with bacterial loadings generally 90-99% (1-2 $\log_{10}$) lower than those produced in other countries (Appendix 1a, 1b and Figure 6).

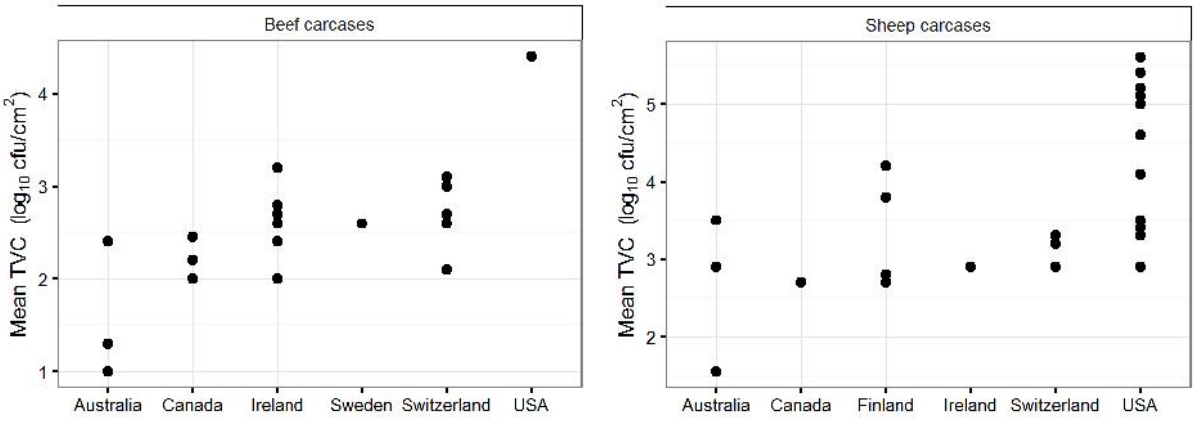


*Figure 6: Inter-country comparisons total bacterial loadings (TVC) on beef and sheep carcases*

There is an element of subjectivity in the sponging/swabbing of meat. Seager *et al.* (2010) monitored ten experienced operators working at five Australian abattoirs, finding a wide variation of recovery among operators: 2.3 - 93.1% of the total bacteria at the carcase site. The temperature at which chilled carcase samples are incubated also affects the total bacterial count, as shown by Simmons *et al*. (2007), with higher counts being obtained after incubating at 25°C/96h, compared with 30°C and 37°C for 48h.

Comparisons of studies on the microbiology of meat are difficult because of differences in final product (frozen versus chilled) and in methodology. However, researchers from the US Department of Agriculture were able to compare the microbiology of beef destined for grinding from Australia, New Zealand and Uruguay with that of domestic product (Bosilevac *et al.* 2007).

As may be seen from Table 3, indicator bacteria were isolated much less frequently and at lower concentration from meat manufactured in Australia and New Zealand than that from Uruguay or the USA, as were pathogenic bacteria (Table 4). Of particular reference was the non-isolation of *Salmonella* and non-O157 STECs associated with HUS in meat manufactured in Australia.

*Table 3: Prevalence and concentration of indicator bacteria in boneless beef destined for grinding*

| Country | Mean cfu/g | % Prevalence (Mean cfu/g) | | | |
|---|---|---|---|---|---|
| | APC | *Enterobacteriaceae* | *E. coli* | Coliforms | *S. aureus* |
| Australia | 40 | 8.2 (25) | 1.0 (16) | 4.5 (25) | 4.0 (13) |
| NZ | 158 | 9.0 (32) | 0.5 (10) | 4.6 (32) | 8.2 (20) |
| Uruguay | 631 | 31.3 (100) | 9.5 (63) | 26.1 (100) | 29.5 (40) |
| USA | 316 | 37.8 (32) | 7.2 (16) | 25.5 (40) | 4.2 (25) |

*Table 4: Prevalence and concentration of pathogenic bacteria in boneless beef destined for grinding*

| Country | Positive/Number of samples (%) | | | |
|---|---|---|---|---|
| | *Salmonella* | *Campylobacter* | *L. monocytogenes* | HUS-related non-O157 STECs |
| Australia | 0/220 | 0/151 | 4/198 (2.0) | 0 |
| NZ | 1/223 (0.4) | 1/216 (0.5) | 5/219 (2.3) | 2 |
| Uruguay | 1/256 (0.4) | 1/250 (0.4) | 53/226 (24.0) | 6 |
| USA | 4/487 (0.8) | 5/593 (1.3) | 17/341 (5.0) | 5 |

The USA researchers stated that the results revealed significant differences between samples *"with the lowest pathogen numbers in samples from AUS"* (Bosilevac *et al*. 2007).

We note that the differences between USA and Australian contamination levels are still present, as shown by the recent carcase baseline studies done in both countries (Figure 7; MLA, 2017b).

# 9 The impact of the Australian system on carcase contamination

**Context**

Over many years, there have been numerous developments in preventing contamination when the hide/pelt is incised with opening cuts, then removed at the hide/pelt puller. Given the factors underpinning the Australian system of slaughter and dressing as set out in section 4 above, it might be expected that faecal organisms on the freshly-exposed carcase will be lower on Australian carcases than on those processed in other countries.

In 2013, the opportunity to assess the Australian system arose when the USA FSIS flagged the intention to undertake a Beef and Veal Carcass Baseline Survey (B-VCBS; FSIS 2017). The study design involved sponging large areas of the carcase (4,000cm$^2$) at two stages in the slaughter and dressing process: immediately after hide removal and immediately prior to chilling; 5400 carcase samples were collected.

A similar design was followed in an Australian survey, comprising 5290 samples, allowing a comparison with one of Australia's major markets. The results point to great differences in the way opening cuts and hide removal are made between the two industries.

After removing the hide, carcases processed in USA plants were positive for the faecal indicator, *E. coli*, on 70% of occasions compared with 5% on Australian carcases (Figure 7; left). And while interventions in USA plants reduced the prevalence of *E. coli* significantly on pre-chill carcases, it was still much higher than on Australian carcases (MLA 2017a).

Similarly, the prevalence of *Salmonella* on carcases was more than 10 times higher immediately after hide removal (27.1%) and 6 times higher pre-chill (3.6%) on USA carcases compared with the respective Australian prevalence of 2.09% and 0.56% (Figure 7; right).

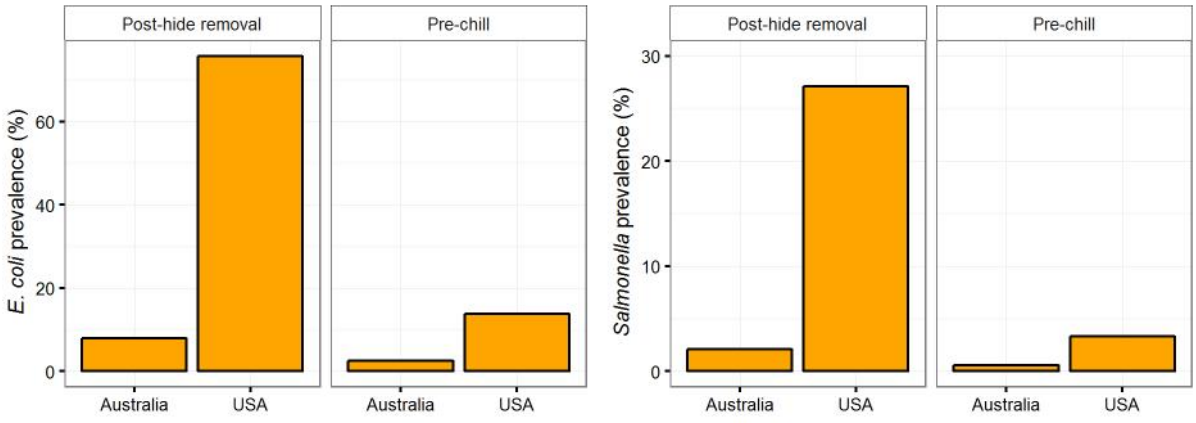


*Figure 7: Prevalence of E. coli (left) and Salmonella (right) on Australian and USA carcases during dressing*

# 10 Interventions to decontaminate the carcase

**Context**

Following the Jack-in-the Box outbreak in the USA, it became customary for abattoirs in North America to install one or more unit operations to reduce contamination on carcases. McDowell *et al*. (2005) list typical decontamination steps used on the slaughter floor under the heading *"Intervention HACCP"*. The importance of interventions as a means of removing contamination introduced during hide removal to the North American industry may be gauged from the fact that, in addition to Sheridan's paper, three further chapters are devoted to this topic in John Sofos' tome: *Improving the safety of fresh meat* (Sofos 2005).

In Australia, until recently, it was usual to adopt the approach that *"If we don't put contamination on the carcase, there's no need for an intervention to take it off"*. However, as is shown later in this section, several Australian establishments now utilise a hot water decontamination step as a hurdle to prevent faecal pathogens being isolated from manufacturing meat intended for grinding in the USA.

In this section, we follow the role played by CSIRO researchers in validating the effect of hot water and organic acid in carcase decontamination before citing more recent work and then commenting on whether these interventions are effective as a CCP.

## 10.1 Early work by CSIRO

While it might be tempting to think of interventions as a 21st century food safety invention to eliminate enteric pathogens in general and STECs in particular, CSIRO were working on interventions in the 1970s. Smith & Graham (1974, 1978) reported on experiments where meat was subjected to hot water and steam (with unreliable results) and to a naked flame (melted fat causing poor appearance and no significant bacterial reduction).

By 1978, the same authors were able to report trials where mutton carcases were immersed in a vat of water at 80°C for 10 seconds, leading to 99% reduction in coliforms and 96% reduction in total aerobic bacteria. The authors concluded that hot water should *"substantially reduce Salmonella contamination on the meat and may improve shelf life"* but also acknowledged potential problems with using immersion in a vat.

Soon after, Graham *et al.* (1978) reported on *An enclosed hot water spray cabinet for improved hygiene of carcass meat*, foreshadowing by almost a quarter of a century, the intervention which has become commonplace in those establishments which supply meat for grinding in the USA.

Another 'modern' intervention is the use of organic acids to eliminate Gram-negative, enteric pathogens, with the use of lactic and peracetic acid at several points in the dressing and boning processes in North American plants (described by Yang *et al*. 2012). However, some thirty years earlier, CSIRO had already reported on the use of acetic acid to extend the shelf life of vacuum-packed lamb carcases (Eustace *et al.* 1979; Eustace 1981).

CSIRO Meat Research Laboratory was also active in the 'new' area of predictive modelling, with a series of publications surrounding the effect of temperature and water activity on the growth of *E. coli* (Davey 1989a; 1991) and its thermal death in hot water cabinets (Davey 1989b; 1990; Davey & Smith 1989; Smith & Davey 1990).

## 10.2 USA and interventions

In the USA, the FSIS mandated that a CCP for enteric pathogens such as *E. coli* O157 must be operated on the slaughter floor, prompting processors to install one or more interventions. A wide range of interventions is used in series including hide sanitisation, acid rinsing of carcases and pieces of meat, plus thermal pasteurisation of carcases; Yang *et al*. (2012) provides a detailed list of where and how hot water and chemical interventions are operated in North American plants.

The additive effect of such a sequence of interventions should be sufficient to constitute a CCP for *E. coli* O157 by eliminating it from the boned (fabricated) meat. However, recalls of large quantities of meat continue to occur in North America and are sometimes associated with illness and death among consumers.

The website of the Marler law firm (www.marlerblog.com) records meat-related outbreaks and recalls and has accumulated a comprehensive database. One case history states: "*Since 1993,* (Company A, name withheld here) *has been the source of contaminated meat implicated in at least 10 major outbreaks … and 347 illnesses"*; eight of the outbreaks were due to pathogenic enteric microorganisms in red meat products and involved the recall of 2.27 million kilograms (Marler 2011).

The outbreaks quoted on the Marler website provide unequivocal evidence that a reliable CCP for *E. coli* O157 or *Salmonella* does not exist in meat slaughter facilities. It may be that interventions are not capable of reliably delivering the claimed inactivation of *E. coli* O157 or are not always operating according to their design. It is also possible that the incoming load of *E. coli* O157 in the faeces of so-called super-shedders (Arthur *et al*. 2010) overwhelms the effectiveness of the interventions.

## 10.3 Australia and interventions

In Australia, it has long been known that the hide is the major source of carcase contamination (Empey & Scott 1939; Grau 1979) though contamination of the hide can be minimised by reducing stress during transport, by sourcing clean cattle and by managing contamination of hides pre-slaughter.

On the slaughter floor, transfer of microorganisms from the hide to carcase can be minimised by using double knife sanitising systems (one knife is held in water at a minimum of 82°C, while the other is being used by the operator), spear cuts through the hide/pelt, paper to prevent hide/pelt roll back, downward hide pullers and trained operators. Contamination of carcases from the gastrointestinal tract is minimised by oesophagus tying immediately after bleeding, sealing the bung during separation of the rectum and reducing rumen volume by ensuring sufficient time off feed prior to slaughter. Fuller accounts of important unit operations in beef and sheep processing are contained in Kiermeier *et al*. (2007) and Kiermeier & Sumner (2009), respectively.

There is evidence that freezing and frozen storage inactivates *E. coli* which, considering Australian boxed beef remains frozen for 3-4 months prior to grinding in the USA, constitutes an intervention. Inactivation of *E. coli* O157 in meat due to freezing has been studied by Ansay *et al.* (1999), Sage & Ingham (1998) and Dykes (2000). Work by CSIRO and University of Tasmania (UTas) scientists predicted inactivation of between 0-3 $\log_{10}$ cfu/g of *E. coli* O157 may result from freezing and frozen storage of manufacturing meat (Anon. 2003).

Since Australian systems for slaughter and dressing differ radically from those in North America (see Section 4), microbial loadings on Australian carcases have traditionally been lower (see Section 8). Australian processors have typically claimed *"If we don't put it (contamination) on the carcase, we don't need to take it off"*, removing the need for hot water or chemical interventions.

However, such are the financial and regulatory impacts of detecting *E. coli* O157 or one of the 'Big Six' STECs (serogroups O26, O45, O103, O111, O121 and O145) in a container of meat, either prior to shipment or at Point of Entry in the USA that some Australian establishments have investigated the effectiveness of chemical or hot water interventions as described in *Processor's Guide to Improving Microbiological Quality and Shelf Life of Meat* (MLA 2017c).

In Table 5 are presented a comparison of Australian plants participating in the Australian survey analogous to the B-VCBS either just trimmed to AUS-MEAT specifications, or amalgamating trimming with an intervention (MLA 2017a). Overall, the prevalence of *E. coli* immediately pre-chill was 11.4% (n=2108) though, as may be seen from Table 5, there appears to be a trend towards lower *E. coli* prevalence in plants with an intervention.

*Table 5: Effect of interventions on prevalence of E. coli on Australian carcases*

| Plant | *E. coli* prevalence (%) | Treatment |
|---|---|---|
| A | 4.0 | Trim + Hot Water |
| B | 5.2 | Trim + Hot Water |
| C | 6.2 | Trim + Hot Water |
| D | 6.7 | Trim + Lactic Acid |
| E | 7.7 | Trim + Steam Vacuum |
| F | 7.7 | Trim |
| G | 8.6 | Trim |
| H | 9.0 | Trim + Hot Water |
| I | 11.8 | Trim + Hot Water |
| J | 11.9 | Trim |
| K | 13.1 | Trim |
| L | 14.1 | Trim |
| M | 27.4 | Trim |

Not all studies show that interventions lead to carcases with improved microbiological quality. For instance, Gill & Baker (1988) and Gill & Landers (2003) did not find significant reductions in *E. coli* populations on red meat carcases following steam vacuuming or washing with organic acid. However, the evidence supporting the effectiveness of thermal pasteurisation of carcase sides with hot water around 85°C or steam is generally accepted to result in an approximate 2 $\log_{10}$ reduction of *E. coli* (see Gill *et al.* 1999 as an example). For a fuller consideration of the effectiveness of interventions, see Greig *et al.* (2012).

A recent approach to identifying intervention strategies widened the scope from the abattoir to the paddock/feedlot and the transport phases. Brookes *et al*. (2015) used global sensitivity analysis to model a range of interventions, concluding that while the unit operations listed by Kiermeier *et al*. (2006) to prevent contamination of the carcase from the hide or gut were effective interventions, the most effective combination was improved abattoir hygiene linked with vaccination of young cattle against STECs.

Interventions were implemented primarily to reduce STECs to below the level of detection. The emergence of STECs as a pathogen reasonably likely to occur in comminuted meats has had significant consequences for meat establishments supplying manufacturing meat for

grinding to the USA. The steps which the Australian industry has taken to minimise presence of the pathogen (and by extension *Salmonella*) are documented in the next section.

# 11 The Shiga toxin-producing *E. coli* (STEC) problem

**Context**

As a commodity, manufacturing meat destined for grinding in the USA came under close focus because of contamination with enteric pathogens, particularly *E. coli* O157. The first documented outbreak involved hamburgers in Oregon and Michigan in 1982 with the report citing *"a rare E. coli serotype O157:H7"* (Wells *et al.* 1983). Then in 1992-93, outbreaks involved more than 400 people in the western United States and revealed the risk of *E. coli* O157 illness from consumption of undercooked hamburgers (CDC 1983). In the ensuing decades, there have been numerous outbreaks from consumption of hamburgers, some of which are summarised by Rangel *et al*. (2005).

Over the same period, there have been a series of regulatory changes by the FSIS aimed at enhancing control of pathogenic *E. coli* in meat used for grinding and in ground beef, most notable of which are:

- Declaration of *E. coli* O157 as an adulterant
- Requirement to test meat destined for grinding
- N60 ("robust") testing
- Increased attention on non-O157 serotypes (Big Six testing) and their declaration as adulterants

## 11.1 Testing of lots for STECs

For more than four decades, Australia has been a major exporter to the USA of manufacturing beef for grinding into hamburger patties. According to MLA statistics, in 2015, Australia supplied 328,830t of frozen beef meat in 60lb (27.2kg) cartons to the USA, equivalent to 2,500,000,000 quarter-pounder patties, or approximately 10% of hamburgers consumed in the USA.

The declaration of *E. coli* O157 and the Big Six as adulterants in ground beef in 1994 and 2012, respectively, and the consequent zero tolerance policy, has resulted in the need for testing of manufacturing beef for their presence. Such testing has become a significant aspect of the control of STECs in the beef supply chain with a company's testing program becoming a *de facto* disposition CCP under which a specific lot of production is not released to the trade unless and until there is confirmation that the pathogen has not been detected in the corresponding sample. Together with the adoption of a zero-tolerance policy came the codifying of testing programs designed to support the concepts of 'adulterant' and 'zero tolerance'.

Early sampling in Australia (so-called 'Burger King' testing) involved either a sponge sample ($100cm^2$) or a single meat sample of 25g. Later plans involved accruing small pieces of meat during boning to give a sample size of 25g (5×5g samples) per lot of production. Since late 2007, the collection of 60 surface slices from the external carcase surface has been mandated, so-called N60 or 'robust' testing. Samples are drawn from 12 cartons selected at random, consisting of a total of 375g (12×5 = 60 samples each of 6.25g), from the lot, and test results are provided to DAWR for entry into the NCMMP; the Department also performs verification testing on random lots prior to the establishment's release of the product.

## 11.2 Testing frequencies – are they fit for purpose?

Soon after FSIS imposed testing criteria for *E. coli* O157, criticism followed that testing is not effective in detecting lots that contain the microorganism of concern when its prevalence is low. The declaration came from thirty-five international experts assembled by the American Meat Science Association (AMSA) who pointed out that, if *E. coli* O157 were present at 0.1% prevalence, the number of samples from a contaminated lot needed to detect the pathogen with probabilities of 0.90, 0.95 and 0.99 were 2,303, 2,996 and 4,605, respectively (AMSA 1999). Due to their low prevalence and non-random distribution, the AMSA consensus also counselled against pathogen testing *per se* to assess process control.

A subsequent gathering of meat safety experts, under the *aegis* of the International Livestock Congress, concurred with the AMSA findings and concluded that testing programs should focus on enumerating indicator organisms, particularly when pathogens are likely to be present at low concentrations (Brown *et al*. 2000).

Despite the advice from these two expert panels, pathogen testing has remained at the forefront of process control monitoring for the USA industry and for all other industries supplying into that market, to the extent that detection of STEC has become a disposition CCP. The current moving window approach, for indicators and pathogens, spreads sample collection over time, but the trade-off is that this approach gives a slower signal for 'out-of-control' (FAO 2016). With respect to microbiological test results, finding a root cause in such situations is especially difficult as many days may have passed before loss of process control has been noticed.

## 11.3 Australia's regulatory testing response

In 1998, the Australian Quarantine and Inspection Service (AQIS) implemented the ESAM program. The program is performed by all export establishments, which are required to take action on results considered unacceptable, based on three-class sampling plans with values for sample size (n), acceptance number (c), marginal limit (m) and unacceptable limit (M), together with a moving window and Alert system (AQIS 2003).

The values were based on an examination of ESAM data from January 2000 to June 2001, and calculated values with which a high proportion (approximately 95%) of carcases in each category would conform; the aspiration was that establishments regularly in the bottom 5% would improve their processes (Vanderlinde *et al*. 2005). The authors counselled that it was important to reassess performance standards over time and in their paper *Performance Standards and Meat Safety – developments and direction*, Jenson & Sumner (2012) questioned whether the future will retain current performance standards which Gill (2005) describes as based on *"…. subjective judgments and adherence to hygienically irrelevant procedural details?"* or will regulators set performance standards within a risk-based framework, to ensure that they will contribute in a cost-effective way to achieving public health outcomes? For a fuller exposition of the argument against the regulatory imposition of finished product microbiological standards in favour of demonstrated process control see Jenson *et al.* (2014).

In 2010, the ESAM program was incorporated into the Product Hygiene Index (PHI) system by which each establishment is required to forward data monthly to the DAWR, including:

- ESAM data
- Carton meat microbiology
- Contact surface microbiology
- Personal hygiene microbiology

- Meat Hygiene Assessment (MHA) data recording visual defects on product on the slaughter floor and in the offal and boning rooms (AQIS 2002)
- Carton Meat Assessment (CMA) data recording visual defects in packed product (AQIS 2002).

Based on data submitted to the DAWR, each establishment is assessed according to Key Performance Indicators (KPIs) and compared with the national performance criteria.

## 11.4 *E. coli* O157 and STEC in Australian cattle

In the mid 1990s, Enterohaemorrhagic *Escherichia coli* (EHEC) became important as a result of incidents of foodborne illness both in Australia and overseas. In USA, more than 400 individuals, predominantly children, contracted haemorrhagic colitis (HC) and Haemolytic Uraemic Syndrome (HUS) after consuming hamburgers contaminated with *E coli* O157:H7 and four died (CDC 1993). In 1995, there were more than 20 cases of HC and HUS in South Australia following consumption of mettwurst contaminated with *E. coli* O111 (Paton *et al*. 1996). Soon after, there were EHEC food poisonings acquired from non-meat sources such as radish sprouts (Itoh *et al*. 1998), apple juice and salads (Tarr *et al*. 1997) with, in each case, the original source judged to be contamination of the product with faeces containing EHEC.

Early suggestions were that *E. coli* O157 was associated with dairy cattle (Wells *et al*. 1991) and, in Australia, an estimate of the prevalence of the pathogen was undertaken by surveying faecal samples from 505 dairy cattle from more than 200 herds in the Goulburn valley of northern Victoria (Hallaran & Sumner 2001). The survey found *E. coli* O157 in 1/505 (0.2%) of faecal samples, a level lower than those from surveys of North American and European cattle using similar methodology.

Midgley *et al.* (1999) showed that *E. coli* O157, when it was present in the faeces of cattle, usually comprised only a small proportion of the total population of *E. coli*, though numbers ranged up to 23,980 MPN/g.

Fegan *et al.* (2004a) determined the prevalence and concentration of *E. coli* O157 in the faeces of cattle at slaughter from different production systems, finding no significant differences between grass-fed and grain-fed animals. Though most samples of faeces positive for *E. coli* O157 had a low concentration (<10 MPN/g), one sample was >100,000 MPN/g; Arthur *et al*. (2010) defined 'super-shedding' as >10,000 cfu/g.

Midgley & Desmarchelier (2001) found that shedding of STECs in feedlot cattle occurred with intermittent peaks, a finding confirmed by Williams *et al*. (2015a) in a grass-fed dairy herd, where shedding of *E. coli* O157 was not only intermittent, but could be transient and also consistent. The extremes of variability in shedding were demonstrated by a heifer from which no *E. coli* O157 could be detected in the faeces one day, was shedding >10,000 cfu/g the next day and was shedding >100 cfu/g the following day.

In 2012, monitoring of manufacturing meat for grinding was extended to include other STECs which have caused illness in the USA, the so-called 'Big Six'. CSIRO undertook a study of the prevalence of EHEC in the faeces of beef cattle i.e. of *E. coli* that had the virulence factors which allow the pathogen to colonise the intestine of the host (*eae*) and also to produce Shiga toxin ($stx_1$ and/or $stx_2$). Of the 300 faecal samples tested, the researchers only isolated five *E. coli* O157, one *E. coli* O91 and one *E. coli* O26 which contained EHEC virulence markers leading them to conclude that the prevalence of EHEC in Australian beef cattle is very low (Barlow & Mellor 2010).

In a subsequent study, CSIRO researchers analysed 1500 faecal samples collected at slaughter from adult (n=628) and young beef cattle (n=286), from adult (n=128) and young

dairy cattle (n=143) and from veal calves (n=315) across 31 Australian export-registered processing establishments. There was a higher prevalence of pathogenic STEC (pSTEC) in younger animals: veal (12.7%), young beef (9.8%) and young dairy (7.0%) than in adult animals: adult beef (5.1%) and adult dairy (3.9%). *E. coli* O157 was isolated from 6.7% of samples, O26 from 1% and O11 from 0.3%; serotypes O45, O103, O121 and O145 were not isolated (Mellor *et al*. 2016).

Williams *et al*. (2015b) undertook a longitudinal study of dairy heifers, swabbing faeces and recto-anal mucosae detecting *E. coli* O157 in 416/933 (44.6%) of samples with 32 (3.4%) samples enumerated at >10,000 cfu/g. The same authors determined a range of factors influencing shedding: higher temperature, rainfall, relative humidity, pasture growth and body score, with higher rainfall, hide contamination and increased faecal consistency being positively associated with super-shedding.

Lammers *et al*. (2015) studied shedding in a grass-fed beef herd over a 9-month period, finding *E. coli* O157 varied on any given day from 0% to 57%. Predictors of shedding were occurrence of rainfall, silage feeding and lactating; moving cattle to a new paddock had a negative effect on shedding.

Seen as a whole, these studies illustrate that abattoirs face the seemingly intractable problem of intermittent shedding, coupled with a small proportion, but significant number, of super-shedders, which cannot be distinguished from non-shedding animals.

## 11.5 STEC in Australian sheep

Fegan & Desmarchelier (1999) surveyed sheep and lambs at 15 properties, isolating STEC from 45% of sheep faeces collected on farms and from 36% of lamb faeces in abattoir yards. STECs were also isolated from the faeces of lamb and mutton on 90% of 40 properties by Djordjevic *et al*. (2001) although only 0.1% of animals were positive when presented for slaughter.

## 11.6 *E. coli* O157 on Australian beef and sheep carcases

Much of our knowledge of STECs on beef and lamb carcases stems from a continuum of work by CSIRO scientists, some of which is summarised by Desmarchelier *et al*. (2007). The CSIRO team mapped contamination of *E. coli* O157 on the hides and in the oral cavities, rumens and faeces of 100 cattle as they passed through the slaughter and chilling process (Fegan *et al*. 2005a). The work was performed on groups of 25 consecutively slaughtered animals and isolated *E. coli* O157 from 24% of oral cavity samples, 44% of hides, 10% of faecal samples (collected post evisceration), and 6% of pre-chill carcase swabs; the pathogen could not be isolated from any of 100 rumen or post-chill samples. Of the six positive pre-chill samples, four were from consecutive carcases (#92-95) as were carcases (#99 and #100). In the faeces of animal #93, the concentration of *E. coli* O157 was 750,000 MPN/g, a super-shedder, with which the abattoir's dressing processes apparently coped, the concentration on the pre-chill carcase being <0.1 MPN/cm$^2$.

## 11.7 *E. coli* O157 in Australian manufacturing meat

From the preceding section it can be seen that pathogens, while present on cattle hides and in the oral and rectal cavities, are generally controlled by the hygienic processing typically followed in Australian abattoirs. The study also established that occasionally super-shedders enter the slaughter floor with high concentrations (>100,000/g) of *E. coli* O157 in their faeces and the extent to which this pathogen is still present in manufacturing meat destined for grinding in the USA.

In Figure 8 are presented data from the DAWR Product Hygiene Index (PHI) database for *E. coli* O157 isolations from Australia manufacturing meat destined for grinding in the USA, which averages between 0.1% and 0.2%, and a recent downward trend.

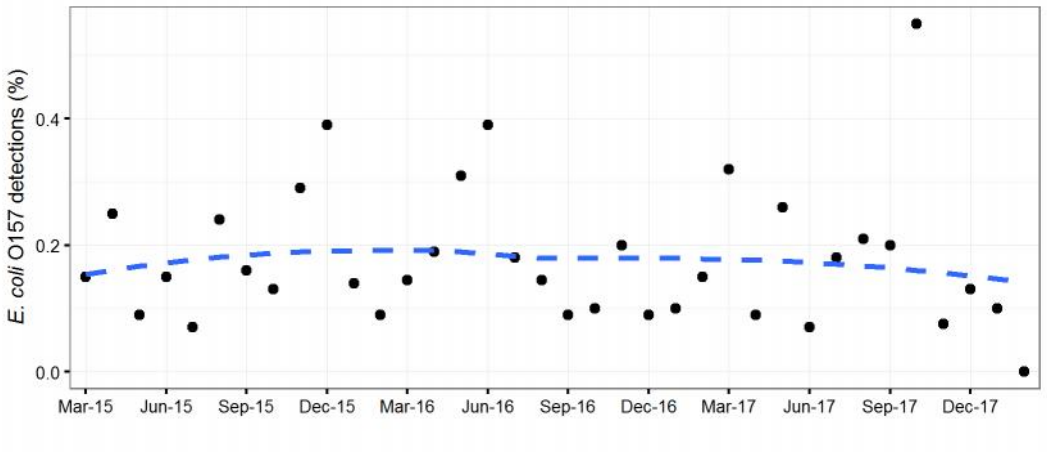


*Figure 8: Prevalence of E. coli O157 on Australian manufacturing meat*

Several of Australia's national baseline surveys have also monitored presence of *E. coli* O157 in frozen boneless beef and sheep (Table 6) with generally low prevalence in beef (Vanderlinde *et al*. 1999a; Phillips *et al*. 2001a, 2006a) and slightly higher in sheep meat (Vanderlinde *et al*. 1999b; Phillips *et al*. 2001b, 2006b).

*Table 6: Prevalence of E. coli O157 in frozen boneless beef and sheep meat*

| Positive/total samples (%) | | |
|---|---|---|
| Frozen boneless beef | Frozen boneless sheep meat | |
| 4/1057 (0.38) | 0/470 | Vanderlinde *et al*. 1999a, b |
| 0/990 | 6/470 (1.3) | Phillips *et al*. 2001a, b |
| 0/1082 | 6/1117 (0.6) | Phillips *et al*. 2006a, b |

## 11.8 *E. coli* O157 on Australian meat at retail

A national survey of retail meat from high street butcher shops and supermarkets was undertaken by Phillips *et al*. (2008a) based on products which were likely to have received maximum processing either in-store or at a central packing facility: ground beef and diced lamb. *E. coli* O157 was recovered from 1/357 (0.3%) of ground beef samples.

A one-year study of STECs in retail ground beef and lamb cuts by Barlow *et al*. (2006) isolated STEC on 46/285 (16%) of ground beef and on 111/275 (40%) of lamb samples and, while some isolates possessed either or both Shiga toxin genes ($stx_1$ and $stx_2$), none had the attaching and effacing gene (*eae*); *E. coli* O157 was not detected in the survey.

In New Zealand, a survey of retail meats (minced or diced samples) tested beef, bobby veal and lamb/mutton finding *E. coli* O157 in 0/233 beef samples, in 1/183 (0.5%) of bobby veal and 3/231 (1.3%) of lamb/mutton samples (Wong *et al*. 2006).

## 11.9 Comparison of STEC disease in Australia and other countries

In a study commissioned by MLA, researchers based at the Australian National University established that the risk of STEC illness from consumption of Australian meat was 0.4 cases/100,000 population for STECs in general and 0.1/100,000 population for STEC O157, much lower than other countries, as indicated in Table 7 (Rivas *et al.* 2014).

*Table 7: Relative rates of STEC and E. coli O157 illness/100,000 population (after Rivas et al. 2014)*

| Country | STEC | O157 only |
|---|---|---|
| EU | 1.1 | 0.6 |
| Denmark | 3.5 | 0.7 |
| Austria | 1.5 | 0.2 |
| Belgium | 0.9 | 0.6 |
| Ireland | 9.0 | 4.3 |
| Sweden | 5.0 | 1.2 |
| Netherlands | 6.3 | 2.0 |
| New Zealand | 4.6 | 3.9 |
| Scotland | - | 1.4 |
| Canada | - | 1.4 |
| USA | 2.3 | 1.2 |
| UK | 2.2 | 2.1 |

In addition, Vally *et al.* (2012) found that out of 11 outbreaks of STEC illness in Australia between 2000 and 2010, two were possibly food-related and neither involved meat.

## 11.10 Virulence of Australian STECs

The evolution of *E. coli* O157 has resulted in populations with differing potential to cause disease in humans as there are some types of *E. coli* O157 that only appear to be associated with cattle and rarely cause disease in humans or cause only mild illness, while other types can cause severe disease in humans (Mellor *et al.* 2013). These differences are related to the type of toxin the bacteria produce along with other factors that limit the ability of the bacteria to infect humans. *E. coli* O157 populations have diverged in different countries and those found in Australian cattle mostly belong to the types that rarely cause severe illness in humans. This is in contrast to other countries, such as the USA, where *E. coli* O157 populations circulating in cattle also contain those types which are associated with severe human disease. Australian manufacturing meat therefore now has one huge advantage in that Australian types of *E. coli* O157 are less likely to cause severe disease in humans than North American types.

# 12 Risk of illness from meat consumption

**Context**

In the mid-1990s, following major illnesses due to *E. coli* O157 in the USA, risk assessment came to the fore. It soon became apparent that risk assessments can be expensive in terms of resources required, and may also take several years to complete and, in the early 2000s, Risk Profiling emerged as a useful preliminary tool. Defined as '*a description of a food safety problem and its context*' (CAC 2003), risk profiling involves collecting information needed to make a decision on what will be done next, and where resources should be allocated to provide the detail necessary to undertake a more robust scientific assessment.

## 12.1 STECs in Australian hamburger meat

In 1996, MRC commissioned Health Canada and CSIRO to undertake risk assessments of STEC and *E. coli* O157 in hamburgers consumed in Australia and the USA. For STEC in hamburgers consumed in Australia, the authors stated: "*…. the probability of illness extends over a wide range of values, with the distribution centered around a probability of* $10^{-11}$*"* indicating that the risk was very low, even though the assumption was made that Australians undercook their burgers as do a proportion of North Americans. For *E. coli* O157 in hamburgers made solely from Australian beef trimmings and consumed in North America, the authors calculated the same probability of illness, again indicating the low risk of Australian beef trimmings (Lammerding *et al*. 1999a, b).

## 12.2 *Salmonella* on Australian carcases and retail meat

Fegan (2004b) monitored *Salmonella* prevalence in the faeces of grass- and grain-fed cattle at slaughter finding the pathogen in 6.8% of samples, with no significant difference between the two production systems. Concentration in positive samples was low with a few samples ranging up to 3 MPN/g, leading the researchers to state that beef cattle did not appear to be a major source of entry of *Salmonella* into the human food chain.

In a through-chain study of similar design to the STEC study described in Section 11 (Fegan *et al*. 2005a), the CSIRO team also monitored *Salmonella* presence and concentration, isolating the pathogen from 29% of oral cavity samples, 68% of hides, 25% of rumen contents, 16% of faecal samples (collected post evisceration) from 2% of pre-chill and 3% of post-chill carcases on which the maximum count was 0.31 MPN/cm$^2$ (Fegan *et al.* 2005b). The researchers concluded that, though hides had a high prevalence, carcases were infrequently contaminated with *Salmonella*, indicating the effectiveness of slaughter and chilling processes. This conclusion is borne out by carcase monitoring data included in the NCMMP where prevalence generally cycles around 0.5% for beef and sheep carcases (see Figure 5).

In a national survey of retail meat from high street butcher shops and supermarkets undertaken by Phillips *et al*. (2008a) of ground beef and diced lamb, *Salmonella* was recovered from 4/360 (1.1%) of ground beef and 2/360 (0.6%) of diced lamb samples.

By comparison, in a New Zealand survey of retail meats, *Salmonella* was detected in 3/230 (1.3%) lamb/mutton samples, 1/232 (0.4%) of beef samples and 1/183 (0.5%) veal samples (Wong *et al*. 2007).

While the likelihood that *Salmonella* will be present in finished products, numerous outbreaks of salmonellosis from meat-based foods occurred in the 1990s with several associated with fermented meats in South Australia (Baldwin *et al*. 1992). And in 1997,

Victoria recorded some 944 *Salmonella* notifications in the first four months, surpassing the 1996 total of 915; at least 750 notifications were traced to consumption of cured meats, including pork products (leg ham, Virginia ham and pork rolls) and corned silverside were incriminated (Lester *et al.* 1997). It should be emphasised that all these outbreaks were caused by ineffective processing which allowed replication of *Salmonella* to levels capable of causing illness.

A study of salmonellosis in Australia linked with serovar matching led Sumner *et al*. (2003a) to attribute 31% of cases to *Salmonella* emanating from meats (red meats and pork). The same authors (Sumner *et al.* 2003b) also studied salmonellosis in Australia before and after the implementation of outcomes-based regulations finding that case rates had not fallen and the same serovars were prominent among the top 10 isolates from meat both before and after regulation, and there was little linkage with human salmonellosis.

## 12.3 Australia's national risk assessment

In 2002-03, risk profiles of all raw meat products across the supply continuum for microbial, chemical and physical hazards were undertaken in Australia. This was done to assist public health and industry risk managers to prioritise strategic food safety issues for protection of consumers, both domestically and in Australia's international red meat markets. To aid in the prioritising of hazards investigated under the risk profile, risk ratings were generated using a qualitative framework based on ICMSF (2002) and Food Science Australia (2000), together with a semi-quantitative spreadsheet tool, Risk Ranger (Ross & Sumner 2002). The whole-of-industry risk profile was published in three parts: approach and management (Pointon *et al.* 2006); hazard identification (Sumner *et al.* 2005a) and risk profiles of hazard:product pairings (Sumner *et al.* 2005b).

Information on prevalence of pathogens in raw meats was available from national baseline surveys of beef (Vanderlinde *et al*. 1999a; Phillips *et al.* 2001a) and sheep meat (Vanderlinde *et al*. 1999b; Phillips *et al*. 2001b). Consumption data were available from national surveys (ABS 1999) and data on prevalence of *L. monocytogenes* in processed meats were gathered as part of a quantitative risk assessment on *L. monocytogenes* in smallgoods (Ross *et al*. 2004). Using the qualitative risk rating tool, a wide range of hazard–product pairings were screened and, for a number of pairings, semi-quantitative risk ratings (0–100) were also obtained (Table 8).

For red meat cuts, the qualitative estimate of risk of human illness for a range of Gram-negative and Gram-positive pathogens was assessed as low. An estimate using Risk Ranger was not made in cases where the final cooking step was considered sufficient to inactivate all pathogens. Of meats where the site of microbiological concern was not at the surface (fresh sausages and hamburgers), the risk was considered low because, commercially at least, they undergo a heat process which is adequate for the destruction of target (Gram-negative) pathogens. Doner kebabs were estimated to be of medium risk, a rating supported by anecdotal linkages between salmonellosis and doner kebab consumption in Australia.

The industry's first risk assessments brought focus on product:pathogen pairings which required further investigation to provide sufficient data for quantitative risk assessment (QRA): *L. monocytogenes* in ready-to-eat (RTE) meats, STEC in domestically consumed ground beef, and *E. coli* O157 in beef trimmings exported to the USA (Lammerding *et al*. 1999a, b). Due to its export focus, we elaborate on the latter in this section but, for completeness, we reference here the work of University of Tasmania and their associates with respect to *L. monocytogenes* in RTE meats (Ross *et al.* 2004; Jenson *et al.* 2009; Ross *et al.* 2009a, b).

When a risk rating was generated in 2002-03 for illness in the USA due to EHEC contamination of undercooked hamburgers manufactured solely from Australian meat (Table 9), it became clear that potential risks from this product:pathogen pairing should be studied further.

*Table 8: Microbiological hazard risk rating for meat and meat products in Australia (after Sumner et al. 2005b)*

| Product | Identified Hazard | Risk Rating | |
|---|---|---|---|
| | | Qualitative | Risk Ranger[a] |
| **Red meat entire cuts (steaks, chops etc)** | *Listeria monocytogenes* | Low | Not done |
| | *Staphylococcus aureus* | Low | Not done |
| | *Aeromonas* | Low | Not done |
| | *Mycobacterium paratuberculosis* | Low | Not done |
| | *Bacillus* | Low | Not done |
| | *Yersinia enterocolitica* | Low | Not done |
| | *Enterohaemorrhagic E. coli* | Low | Not done |
| | *L. monocytogenes* | Low | 11 (Low) |
| **Processed meats** | | | |
| Cured cooked sausages, not requiring further cooking | *L. monocytogenes* | Low | 25 (Low) |
| UCFM | *Salmonella* | Medium | 33 (Medium) |
| | *EHEC* | Medium | 33 (Medium) |
| Deli meats | *L. monocytogenes* | Medium | 36 (Medium) |
| | *L. monocytogenes* | Medium | 32 (Medium) |
| **Meat products eaten cooked** | | | |
| Fresh sausages | | | |
| Hamburgers | *Enterohaemorrhagic E. coli* | Low | 0 |
| Doner Kebabs | *Salmonella* | Medium | 40 (Medium) |

[a] *Arbitrary aggregation of Risk Ranger ratings are: 'Low' (25 or less), 'Medium' (26-40), 'High' (>40). Note that a change in risk rating of '6' is equivalent to an order of magnitude change in relative risk as defined in Ross & Sumner (2002)*

*Table 9: Risk Rating EHEC contamination in undercooked hamburgers in USA (after Sumner et al. 2005b)*

| | | |
|---|---|---|
| 1. | Hazard severity | Moderate |
| 2. | Population susceptibility | General |
| 3. | Frequency of consumption | Few times a year |
| 4. | Proportion consuming (%) | Most (75%) |
| 5. | Total population | 270 million |
| 6. | Proportion (%) of raw product contaminated (concentration) | 0.01% (0.1/g, 10/serve) |
| 7. | Effect of processing on hazard | No effect |
| 8. | Post processing contamination rate (%) | Nil |
| 9. | Post processing control | No increase |
| 10. | Increase required to cause infection | 100x |
| 11. | Effects of preparation before eating on hazard | 90% reduction |
| Predicted cases per annum | | 61 |
| Risk Rating | | 36 |

## 12.4 The effect of changes to testing for *E. coli* O157 in manufacturing meat

In Australian boning (fabrication) rooms over the period 1998-2007, sampling involved accumulating small pieces of trim during the period when a lot was produced, from which a sample was taken for testing for *E. coli* O157. Initially, a 25g sample was tested, then at the requirement of the FSIS, five 65g samples from pieces of trimmings were amalgamated into a 325g sample for microbiological testing for *E. coli* O157:H7.

In anticipation of further changes to the sampling and testing requirements for *E. coli* O157, Kiermeier *et al*. (2007b) assessed the effect of the change from sampling small pieces of trimmings to surface slices, using generic *E. coli* as a surrogate for *E. coli* O157. Fifty cartons of beef trim were sampled by taking 'portion' samples and surface slices, and for both sample types, approximate surface area:mass calculations were performed and compared. For portion samples, 48 (96%) were positive, while 45 (90%) of surface slice samples were positive (P-value = 0.37). Surface slices had greater surface area to mass ratio only when slices were less than about 3 mm in thickness, which proved difficult to achieve by use of a knife and hook/tongs for sampling. The authors concluded that: *"Taking surface slices instead of portion samples does not appear to increase the isolation of E. coli, at least not at the concentrations present in this work and at a surface slice thickness of 0.5-1.0 cm."*

In 2007, FSIS further refined sampling of lots of manufacturing meat by introducing N60 testing in which 375g of meat comprising 60 samples (5 from each of 12 randomly selected cartons) is enriched and tested for the presence of *E. coli* O157. While the initial requirements were for the collection of surface slices, the work of Kiermeier *et al.* (2007b) resulted in small grab samples becoming a permitted alternative. Lots are released into the marketplace only when *E. coli* O157 is not detected in the 375g sample which, in the case of many Australian processors is taken from around 700 cartons (each of 27.2 kg), comprising a full container.

## 12.5 Intensive sampling of 'failed' lots

On rare occasions, a container lot of manufacturing meat fails to meet Australian requirements for export to the USA because *E. coli* O157 is detected in the N60 test. At its basis, this indicates that at least one cell of the pathogen was present on at least one of the 60 surface slices taken from the 12 cartons tested. To gain a better understanding of the level of contamination in those lots in which *E. coli* O157 had been detected, it was decided to submit the twelve cartons used for testing for more intensive analysis; in total, 60 cartons, each weighing 27.2kg, from five lots positive for *E. coli* O157 were obtained from establishments.

CSIRO scientists undertook intensive sampling by first thawing each carton, then (aseptically) removing each meat piece, estimating its external surface area and then taking 75 surface slice samples (each of 5g / 10cm$^2$) from pieces with external surfaces. The number of pieces removed was roughly proportional to their contribution of the total external surface area in the carton. In total, 900 samples were removed from each lot for microbiological testing to determine presence/absence of *E. coli* O157. The scale of the intensive sampling is impressive: 1,794 meat pieces with external surface were tested, comprising a surface area of 585,694cm$^2$. Statisticians from the SARDI were able to estimate the Most Probable Number of *E. coli* O157 cells in each carton (Kiermeier *et al.* 2011). In Table 10 are presented the results of the intensive sampling.

*Table 10: Results of sampling and testing lots of manufacturing beef for the presence and concentration of E. coli O157 (after Kiermeier et al. 2011)*

| Lot | No. samples in which O157 was detected/no. tested | No. pieces (cartons) from which O157 was detected | O157 concentration (MPN/cm$^2$) |
|---|---|---|---|
| A | 0/283 | 0 | <0.0013 |
| B | 0/597 | 0 | <0.0013 |
| C | 0/253 | 0 | <0.0013 |
| D | 2/382 | 1 (1) | 0.0014 |
| E | 74/279 | 27 (2) | 0.019, 0.093 |
| Total | 76/1,794 | 28 (3) | |

Since the total surface area had also been estimated for each carton, the researchers were able to estimate the total number of *E. coli* O157 cells in each carton. For those cartons from which *E. coli* O157 could not be isolated again, it was estimated that there were less than 12 cells present, while in the most contaminated carton (in Lot E), the total number of *E. coli* O157 cells was estimated to be approximately 800.

## 12.6 USA focus – how much illness would our meat account for?

In 2011, Scallan *et al*. estimated that there were 63,000 food illnesses/annum from *E. coli* O157 in USA resulting in more than 20 deaths, an estimate which, together with the link between illness and consumption of undercooked ground beef in USA made by Rangel *et al*. (2005) was of obvious concern to Australian processors. Australian meat for grinding in the USA typically has a low fat content (80-95%) that allows it to be mixed (co-mingled) with meat from feedlot cattle (around 50% chemical lean).

While national baseline studies provide estimates of the prevalence of *E. coli* O157 in frozen ground beef exported to the USA (Phillips *et al*. 2001a, 2006a, 2012a), previous risk assessments (Lammerding 1999a, b) had been able to give only broad estimates of the extent to which 'Australian' hamburgers might cause illness among US consumers. A novel approach to the problem was made by Kiermeier *et al*. (2015a) using data generated from work done on lots of Australian meat in which *E. coli* O157 had been detected (see previous section) and which had been withdrawn from the food chain (Kiermeier *et al.* 2011). Using these data, the researchers were able to estimate the risk of *E. coli* O157 illness from lots of Australian beef if purely Australian beef burgers were consumed in the United States, and particularly, how many illnesses might be expected per lot. The results of the risk assessment were that if, in 2012, all the 155,000t of Australian manufacturing beef exported to USA had been made into almost 2.5 billion 'Australian' burgers, there would be less than 1 illness per decade in quick serve restaurants (Kiermeier *et al*. 2015a). The risk of 49 illnesses per year was considerably higher for hamburgers consumed in the home due to undercooking. The work also confirmed that 99.9% of USA illnesses are likely to occur in the home but that, if hamburgers were cooked to an internal temperature of 68°C, expected illnesses would fall to about one per century (Kiermeier *et al*. 2015a).

The Australian estimates were very low compared with similar risk assessments in Canada (Cassin *et al.* 1998; Smith *et al.* 2013), the United States (Ebel *et al*. 2004), Ireland (Duffy *et al*. 2006), France (Delignette-Muller & Cornu 2008), Argentina (Signori & Tarbala 2009) and the United Kingdom (Kosmider *et al.* 2010) where, perhaps unsurprisingly given different conditions of livestock-raising, meat-processing, and consumption patterns, estimates of illness vary widely from 1/10,000,000 servings (Ebel *et al*. 2004) to 800/10,000,000 servings (Kosmider *et al.* 2010).

The fragility of risk assessments in general, and of the dose-response relationship in particular, are the basis for *The role of meat in foodborne disease: Is there a coming revolution in risk assessment and management* (Fegan & Jenson 2018) in which the authors identify a range of new technologies which may revolutionise risk assessment and management.

## 12.7 Would increased sampling be useful in excluding contaminated lots?

Although USA authorities had progressively increased the stringency of sampling of lots of manufacturing meat (see Section 12.4) to N60 testing of 375g, suggestions were made for increased sampling rates (USDA 2011; Ferrier & Buzby 2013). As a result of previous work on contaminated lots, Australian researchers were able to determine the impact of such increases on *E. coli* O157 food-borne illness in the USA caused by 'Australian' burgers.

In Table 11 are presented estimates for likely illnesses caused in the USA from 'Australian' hamburgers with different sampling plans instituted (Kiermeier *et al*. 2015b).

*Table 11: Summary of sampling plans and expected number of illnesses from consumption of 'Australian' hamburgers in the USA (after Kiermeier et al. 2015b)*

| Sampling plan | No. cartons sampled | Sample size (g) (n = 5 samples per carton) | Total meat mass tested (g) | Expected number *E. coli* O157 illnesses/annum |
|---|---|---|---|---|
| No sampling | None | 0 | 0 | 55.2 |
| N60 | 12 | 6.25 | 375 | 50.2 |
| N90 | 18 | 6.25 | 562.5 | 49.6 |
| N120 | 24 | 6.25 | 750 | 48.4 |
| 'ICMSF N60' | 12 | 25 | 1,500 | 47.4 |

Only small reductions in illness were estimated if other, more intensive, sampling plans were used. The researchers also found that while the current and suggested sampling plans were more likely to detect highly contaminated lots, they did not always do so, confirming that sampling and testing cannot be relied upon as a food safety measure.

The work also confirmed that 99.9% of USA illnesses are likely to occur in the home but that, if hamburgers were cooked to an internal temperature of 68°C, expected illnesses would fall to about one per century (Kiermeier *et al*. 2015a).

# 13 Chilled meat to distant markets – flexible packing and modified gas atmospheres

**Context**

After 80 years of shipping frozen meat carcases, mainly to the United Kingdom, and having to sell at a discount to the price of chilled meat from South America, the advent of flexible packaging in the 1960s offered the potential for Australia to supply chilled, vacuum packed (VP) cuts to distant markets.

Technical information on vacuum packaging films and packaging technologies in the early days of VP chilled meats reflects a technology in its infancy: impermeable films are described without any reference to oxygen transmission rates, and packaging technologies are broadly assigned to either *Evacuation and Sealing Without a Chamber*, or *Vacuum Sealed in a Chamber* (Anon. 1970).

An early edition of CSIRO's Meat Research News Letter (Anon. 1971) describes the first steps in the export of chilled beef cuts, citing the advantages of refrigerated containers and concluding: *"Vacuum packs in air-impermeable films extend the storage life by about two and a half times the period possible in air. They have the advantage of minimising weight loss while allowing ageing during this safe distribution life."*

## 13.1 R&D to facilitate export of chilled meat

As suppliers to distant markets, the technology presented obvious commercial opportunities to Australia and New Zealand, and R&D proceeded in both countries led by scientists at CSIRO and MIRINZ. In the early 1970s, a shelf life of 10-12 weeks at 0°C allowed export of VP beef to the Japanese market but with little knowledge of what was happening to the microbiology of the product.

The selective effect of carbon dioxide against Gram-negative aerobes commonly found on meat, *Pseudomonas* and *Achromobacter,* was established in the 1930s by scientists at the Low Temperature Research Station, University of Cambridge (Haines 1933). Further work at CSIRO in Brisbane showed inhibition of the growth of organisms on ox-muscle at -1°C in an atmosphere of $CO_2$ (Empey & Scott 1939*).* The first practical use of modified atmospheres containing elevated levels of $CO_2$ as a preservative in the handling of fresh meat was in the shipment of whole chilled beef carcases from Australia and New Zealand to Britain in the 1930s (Lawrie 1974).

The next advance also involved scientists at the Cambridge Low Temperature Research Station via a symposium on *The Effect of the Newer Forms of Packaging on the Microbiological and Storage Life of Various Foods*, where a paper by Ingram (1962) on *Microbiological Principles in Prepacking Meats* heralded the appearance of flexible packaging films.

In Australia, CSIRO discovered that the organisms dominating the microflora of VP meat were predominantly lactic acid bacteria (LAB), particularly species of *Lactobacillus*. However, there were numerous reports (e.g. Hitchener *et al*. 1982) of 'unusual lactobacilli' from VP meat which were unable to grow on acetate agar and, on the basis of biochemical, physiological and chemical criteria, Collins *et al*. (1987) ascribed several atypical lactobacilli to a new genus, *Carnobacterium*.

The final step in the early science behind vacuum packing was the discovery that when beef of normal pH (5.4-5.8) was packed in a film of low oxygen permeability (<100cm$^3$/m$^2$/day at 25°C) with an atmosphere of 20% carbon dioxide and <1% oxygen, LAB would grow to be the dominant flora at the time of spoilage (Egan 1983).

## 13.2 Early microbial problems

Soon after exports for VP beef began, three major problems occurred in the marketplace. Firstly, it was commonplace for an obnoxious odour, caused by microbial by-products accumulating in the headspace around the meat to accompany opening of the vacuum bag. Fortunately, this 'confinement odour' dissipated within minutes, the meat was suitable for consumption and the problem was solved by education of consumers.

The second problem occurred in shipments to Japan when meat with a pH >6 underwent greening and developed a strong odour. Scientists at the CSIRO Meat Research Laboratory in Brisbane determined the cause – sulphmyoglobin produced by *Pseudomonas* – and concluded their paper: *"To avoid this green discolouration under low $O_2$ tensions (in gas-impermeable packages or controlled atmospheres), meat of a high ultimate pH should not be used, since these conditions may allow bacterial $H_2S$ production and subsequent suphmyoglobin formation"* (Nicol *et al*. 1970).

The third problem occurred when meat spoiled well before its expected shelf life because of unacceptable dairy-like odours caused by acetic, isobutyric and isovaleric acids. The cause of the problem was *Brochothrix thermosphacta* (then known as *Microbacterium thermosphactum*), which was capable of growth on high pH meat or on normal pH meat if the $CO_2$:$O_2$ ratio was reduced (Campbell *et al.* 1979; Grau 1980).

## 13.3 Process parameters established

CSIRO researchers identified the prerequisites needed to optimise the shelf life of VP meats (Egan *et al.* 1988) as:

- An initial count no more than 2-3 $\log_{10}$ cfu/cm$^2$
- Packaging film with low oxygen permeability
- Good control of temperature throughout the storage period

If these pre-requisites were met, it was predicted that shelf lives for VP lamb and beef stored at 0°C would be 42-56 days and 70-84 days, respectively. However, shelf lives tended to the shorter end of the range because initial counts were often higher than 2-3 $\log_{10}$ cfu/cm$^2$ and temperature control could not be guaranteed.

At the same time, researchers at MIRINZ defined the optimum temperature for storage of VP primals as -1.5±0.5°C (Gill *et al.* 1988a). The same workers also established that small rises in temperature reduce shelf life significantly – at temperatures of 0, 2 or 5°C, the storage life was reduced by about 30, 50 or 70%, respectively, compared with storage at -1.5°C (Gill *et al.* 1988b). One effect of a slightly warmer storage temperature (around 4-5°C) was that pseudomonads were favoured, particularly if the pH was 6.0 or above, a pH which also favoured growth of *B. thermosphacta.*

Growth of LAB in VP meat was demonstrated by Egan (1983) with a typical sigmoid growth curve observed in VP primals stored at 0°C where the population of LAB increased to a maximum of 7-8 $\log_{10}$ cfu/cm$^2$ after around 10 weeks. The LAB comprised a small

proportion of the Total Viable Count initially but dominated it within the first few weeks. Shelf life was considered over after around 14 weeks due to persistent off odours when packs were opened.

These early studies indicated that a very high microbial count *per se* did not equate with end of sensory shelf life, rather it was the composition of the bacterial population and the build-up of metabolic end products which were critical in determining shelf life.

More recently, this has been demonstrated by shelf life studies at CSIRO, SARDI and UTas in which total bacterial counts reached a maximum well before the end of sensory shelf life (Small *et al.* 2009; Kiermeier *et al*. 2013; Kaur *et al*. 2017a).

Using modern microbiological techniques such as terminal restriction fragment length polymorphism and clone library analyses of RNA (16S rRNA), Kiermeier *et al*. (2013) and Kaur *et al*. (2017b) have also more clearly defined the bacterial communities which dominate in VP beef and lamb, with *Carnobacterium* being prominent. However, storage temperature has a marked effect on microbial populations; on VP lamb shanks stored at -1.2°C, *Carnobacterium*, *Yersinia* and *Clostridium* dominated, while at 8°C *Hafnia*, *Lactococcus* and *Providencia* were also present (Kaur *et al*. 2017a).

## 13.4 Chilled lamb carcases to the Middle East

During the 1980s, chilled lamb carcases were air freighted into Middle Eastern markets but this became prohibitively expensive, stimulating research into machines and packaging capable of extending shelf life to allow sea freight. In New Zealand and Australia, 'snorkel' machines were developed which removed air, replacing it with a carbon dioxide atmosphere around carcases packed in impermeable film in large cartons ('coffins').

Static trials in Australia by CSIRO established that carcases were acceptable after 12 weeks storage at 0°C and that the meat boned from them could be retailed over three days (Bill & Shay 1993). This finding led to commercial trials of lamb carcases under carbon dioxide atmospheres, carried out between 1987 and 1990 by MIRINZ and the Saudi Arabian Standards Organisation. The trials involved sea freight and road transport in-country and ascertained that carcases had a maximum shelf life of 95 days at -0.5 to +1°C. While the trials revealed problems with maintaining the cold chain through sea and road freight, the commercial potential for moving lamb carcases was established (Garout *et al.* 1989; Bell & Garout 1991).

In the ensuing decades, air-freight has become sufficiently affordable to allow carcases to be exported to Middle Eastern destinations packed only in stockingette. Arrival 2-3 days after slaughter allows marketing in those countries which require more than 50% of the shelf life from the date of slaughter to be available (Sumner 2016).

## 13.5 Major Australian markets for VP meats

Transmission rates for films routinely used for vacuum-packaging have improved from 30-40 $cm^3/m^2$/day at 25°C in 1985 (Gill & Penney 1985) to 18.6 $cm^3/m^2$/day at 23°C in recent years (Kiermeier *et al.* 2013). The multilayer structure of packaging materials has become more robust, and tailoring to fit specific cuts reduces the likelihood of air entrapment or the development of leaks. Vacuum machines have also evolved, allowing rapid sealing (about 25 products/minute) and form/fill machines are increasingly giving abattoirs the ability to manufacture retail-ready products in addition to the traditional primal/ subprimal in a vacuum bag.

Thus, meat in vacuum packs today is encased in superior packaging films with lower oxygen transmission, reducing the chance of leakage and oxygen entrapment, and contributing to

greatly reduce the opportunity for those microbes requiring oxygen or lower carbon dioxide concentration to grow and spoil product.

Australia currently supplies around 380,000t of VP meat to many destinations, with VP beef to Japan, USA and Korea and VP lamb to the Middle East and USA comprising the major markets (Table 12).

*Table 12: Major markets for Australian VP meats (after MLA data for 2016)*

| | Shipped tonnes | | | |
|---|---|---|---|---|
| | Beef | Lamb | Mutton | Offal |
| Europe | 21,266 | 6,597 | 95 | 1 |
| China | 14,888 | 677 | - | 207 |
| Japan | 116,657 | 5,241 | 48 | 5,652 |
| Korea | 36,641 | 1,769 | 1 | 1,452 |
| Middle East | 11,662 | 52,053 | 7,197 | 978 |
| North America | 63,494 | 32,102 | 11 | 180 |
| Total | 264,608 | 98,439 | 7,352 | 8,471 |

## 13.6 Global comparison – beef cuts

In Australia, carcases are broken down into two main products: chilled, VP cuts and manufacturing meat, which is frozen in cartons. There is evidence that the hygienic quality of Australian carcases leads to loadings of indicator and pathogenic bacteria which compare favourably with those manufactured in other countries.

As shown in Figure 9, the scientific literature indicates that Australian cuts prepared for vacuum packaging have much lower bacterial loadings than those of other countries, which is not surprising since they are produced from carcases of high hygienic quality (see also Figure 6). A full listing of the cuts tested in each country is provided in Appendices 1 and 2.

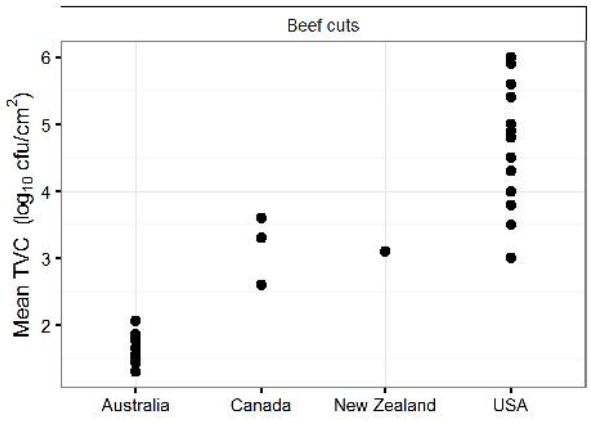


*Figure 9: Inter-country comparisons total bacterial loadings (TVC) on beef cuts*

# 14 Shelf life of Australian VP chilled meats

**Context**

An early Meat Research News Letter described the shelf life of VP beef primals as 2.5 times longer than that of primals packed in aerobic film, allowing sufficient time for export to Japan, plus marketing through their supermarket chains. By the 1980s, shelf life of VP beef and sheep primals was around 84 days and 60 days, respectively (Egan & Shay 1988). In international trade, there was anecdotal evidence that Australian VP beef had a longer shelf life than that of its competitors, with the claim of 100 days at -1°C. More recently, further anecdotal evidence suggested even longer shelf lives for both beef and sheep VP primals and there have been several studies of Australian products to quantify the shelf life more closely. Egan *et al*. (1988) identified the pre-requisites needed to optimise the shelf life of vacuum-packed meats as:

- A low initial count
- Packaging film with low oxygen permeability
- Good control of temperature throughout the storage period

The MLA publication *Shelf life of Australian red meat* (MLA 2016), now in its second edition, covers these prerequisites in great detail – accordingly, this monograph will cover only recent studies which describe the shelf life of VP beef and sheep primals.

## 14.1 Bacterial levels at packaging

As seen from Figure 9 (above) and Appendices 1c and 1d, TVCs of primal cuts immediately before vacuum packing in Australia are low, especially when compared with those of cuts in overseas countries. More importantly, the LAB which will become the dominant microflora during VP storage, are often below the limit of detection (0.5 $\log_{10}$ cfu/cm$^2$) at packing (Sumner & Jenson 2011). The result is that the dominant microflora takes longer to develop, resulting not only in extended shelf lives but also in the requirement for researchers to lay down sufficient packs to be able to monitor shelf life. In some recent studies the researchers underestimated the expected shelf life and ran out of packs while product was still acceptable to taste panels. In the study of Small *et al*. (2009), beef striploins and cube rolls were still acceptable at 160 days and in that of Kiermeier *et al*. (2013), lamb shoulders were still acceptable at 84 days.

## 14.2 Recent Australian and overseas shelf life studies

Subsequent studies by Small *et al.* (2012), MLA (2017c) and Tunnage (2018) have demonstrated extremely long shelf lives for beef and lamb VP primals (Table 13). Only one comparable overseas study could be found, that of Yousseff *et al*. (2014) in Canada where a shelf life of VP boneless beef butts boned from carcases which had received decontamination interventions was 160 days at -1.5°C.

*Table 13: Shelf lives of Australian VP beef and lamb primals*

| Product | Mean storage temperature (°C) | Shelf life (days) | |
|---|---|---|---|
| **Beef** | | | |
| Striploin | -0.5 | 189-203* | Small *et al.* 2012 |
| Cube roll | -0.5 | 189-203* | Small *et al.* 2012 |
| Bolar blade | -1 | 210-252** | Tunnage 2018 |
| Short loin | -1 | 161 | Tunnage 2018 |
| Cube Roll | -1 | 266 | Tunnage 2018 |
| NE Brisket | -1 | 259 | Tunnage 2018 |
| Outside Flat | -1 | 231 | Tunnage 2018 |
| PE Brisket | -1 | 168-196** | Tunnage 2018 |
| Short Rib | -1 | 210-252** | Tunnage 2018 |
| Striploin | -1 | 280 | Tunnage 2018 |
| **Lamb** | | | |
| Bone-in shoulder | -0.3 | 84+ | Kiermeier *et al*. 2013 |
| Boneless shoulder | -0.3 | 84+ | Kiermeier *et al*. 2013 |
| Boneless leg | 0 | 103 | MLA 2017b |
| Bone-in leg | 0 | 97 | MLA 2017b |
| Rack | 0 | 94 | MLA 2017b |

* Variation between different abattoirs
** One of three replicate packs failed at the earlier date; it was not a leaker

## 14.3 Temperature control from Australia to distant markets

Australia exports VP meat cuts to more than 100 countries, relying on the cold chain during the air or sea voyage to get product to market. An AMPC project followed 200 consignments to Australia's major markets, monitoring temperatures every step of the journey and calculating shelf life remaining for the importer (Sumner 2016). The study was undertaken because of two 'new' factors: the implementation of slow steaming to optimise fuel use, extending voyages by up to 20% (Mills *et al*. 2014), together with perceived cold chain difficulties in some countries.

Data downloaded from loggers inserted in cartons of product indicated that almost all consignments arrived at the importer's cold store with good temperature control during the voyage, whether by sea or air freight (Table 14). The study found that though sea voyages have increased voyage times, the main impediments to prompt delivery were extended delays during trans-shipping in Asia, and in the USA during a protracted longshoremens' strike.

*Table 14: Summary temperature statistics for containers monitored in the study (after Sumner 2016)*

| | Temperature during voyage (°C) | |
|---|---|---|
| | Air freight | Sea freight |
| Mean | 0.6 | -0.2 |
| Standard error | 1.9 | 0.7 |
| Minimum | -4.7 | -1.8 |
| Maximum | 6.2 | 1.9 |

The study made special reference to the (then) emerging Chinese market, where a shelf life of 120 days is required for beef, irrespective of temperature at which the product is held during the marketing chain in that country. The effect of relatively small rises in temperature

during storage can shorten the shelf life dramatically. For VP lamb shanks stored at -1.2°C the shelf life was 124 days, compared with 13 days at 8°C (Kaur *et al*. 2017a).

In a series of AMPC/MLA workshops in China, McLellan (2016) documented potential problems with maintaining cold chain integrity including non-palletised deliveries, lack of loading/unloading docks, traffic congestion in CBDs causing delays in delivery, regulations restricting truck capacity in CBDs, costly maintenance of reefer units and limited skilled labour resources.

# 15 Meat regulation and quality systems

**Context**

Meat and milk have traditionally been targeted as products posing risks to human health, and therefore in need of government intervention by way of regulation. In the late 19th century, abattoir operations were a cause for concern, both in terms of workplace safety and of product hygiene. The British medical journal, The Lancet, commissioned a report on sanitary conditions of the world's largest meat operation, Packing Town in Chicago. The reviewer (Smith 1905) wrote of the construction which allowed *".... blood, the splashing of offal and the sputum of tuberculous workers (to) accumulate for weeks, months and years".* Meat was often contaminated with rat faeces and workers ate amid the general filth. The reviewer noted that *"Close at hand are closets and they are in some places only a few feet from the food."*

In 1905, Upton Sinclair took a commission from the socialist weekly, *The Appeal to Reason*, to investigate the Chicago meat industry. Posing as a meat worker, Sinclair infiltrated the Chicago plants, where a largely immigrant workforce slaughtered and dressed animals. His seminal publication, *The Jungle* (Sinclair 1905), although intended primarily as an exposé of corporate greed and worker exploitation, achieved instant impact in the area of meat safety with the passing of the Federal Meat Inspection Act (FMIA) Act 1906 regulating four major areas: livestock (ante mortem) inspection, post mortem inspection, sanitary standards for meat premises and on-plant inspection and monitoring by the US Department of Agriculture.

## 15.1 The way we were – the value of traditional meat inspection questioned

More than a century later, the FMIA retains the same basic elements, which are replicated by meat authorities of all countries involved in the global meat trade: animals presented for slaughter are inspected for a number of conditions which may be detected either at *ante-mortem* and/or at *post-mortem* inspection.

In the 1970s, a new paradigm in hazard management, HACCP, became available to the food industry, prompting questions of whether traditional veterinary inspection of meat animals was fit for purpose. In New Zealand, a chair in Veterinary Public Health and Meat Hygiene at Massey University was set up and challenges to the role of meat inspection were published: *A new approach to meat inspection* (Blackmore 1983) and *Postmortem Meat Inspection Programs; Separating Science and Tradition* (Hathaway & McKenzie 1991).

In Australia, the process of uncoupling the nexus between veterinary meat inspection and perceived food safety began in 1990 when then-Treasurer, the Hon. Paul Keating, instituted a user pays policy for meat inspection. For the first time, establishments were required to meet full cost recovery of veterinary meat inspection provided by governments, State, Territory and Federal. The costs were onerous and representations by industry led to the setting up of a trial to assess whether government meat inspectors could be replaced by company meat inspectors.

The trial was facilitated by the MRC at three domestic establishments in Victoria, Tasmania and New South Wales and was overseen by veterinarians from AQIS and representatives of the unions representing meat inspectors. The experimental work which underpinned the decision to allow company-based meat inspection involved monitoring government *versus*

company inspection systems for the presence of pathology in inspected carcases, and for microbiological quality of carcases; full details are presented in Sumner (1994, 1996), Fabiansson & Sumner (1997) and Sumner & Herd (1999).

## 15.2 The way we are – risk-based QA systems

By the mid-1990s, it was commonplace for domestic establishments to have company-employed meat inspectors as part of the QA team. Later, as company inspection gained acceptance by overseas jurisdictions, so-called Tier 1 establishments were able to export to certain markets.

In 1995, AQIS began the process of attempting to replicate the changes to company-based inspection which had taken place in the domestic industry. After almost twenty years of negotiating with major overseas jurisdictions such USA and European Union, a hybrid system, the Australian Export Meat Inspection Service was accepted in which post-mortem inspection may be carried out by company employees under the overall supervision of a government veterinarian.

In the early 1990s, two food poisoning incidents changed the face of meat regulation in Australia (see also Section 11). As a major supplier of manufacturing meat for grinding in the USA, Australia was required to respond to increased regulation following a large outbreak in the North-western United States when more than 400 became ill and four children died of HUS following consumption of undercooked hamburgers from a chain of restaurants (Bell *et al.* 1994).

Then, in 1995, Australia endured its worst meat-based food poisoning outbreak when more than 150 consumers of an uncooked, comminuted, fermented meat were hospitalised with illnesses caused by *E. coli* O111; in twenty-two cases (mostly young children) their illnesses progressed to the more serious HUS and one child died (Cameron *et al*. 1995).

The latter outbreak galvanised State and Federal regulators who all agreed on the need for change in food safety and for the introduction of HACCP-based food safety plans. A Meat Standards Committee was formed which developed an outcomes based Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption, the most recent version of which is AS 4696:2007 (Anon. 2007).

Under the Standard, establishments are able to negotiate an Approved Arrangement with their regulator, with the export sector implementing Meat Safety and Quality Assurance programs, in which a HACCP plan is operated based on Good Manufacturing Practices and Standard Sanitation Operating Procedures.

The industry responded to a changed regulatory climate by adopting a number of innovative approaches such as the use of predictive microbiology to develop software tools, plus the use of national baseline surveys to monitor industry performance.

# 16 Predictive microbiology

**Context**

In *Shelf life of Australian red meat* (MLA 2016) Dr Tom Ross introduces the section on Predictive Microbiology by stating: *"The behaviour of spoilage bacteria is predictable, which serves as the foundation of a field of food microbiology called Predictive Microbiology. In this research discipline, predictive tools (models) are produced by measuring and understanding how quickly bacteria grow (or die) in different food environments. Once understood, the data are converted into mathematical equations, which are then translated into software tools that help food companies manage the growth or death of bacteria in food processing systems and supply chains. The benefits of validated tools include reduced reliance on microbiological tests and greater flexibility in meeting performance standards."*

In Australia, predictive microbiology had its foundation in modelling at CSIRO to predict spoilage of fish in the early-1970s (Olley & Ratkowsky 1973a, b). CSIRO also used predictive microbiology in the 1980s to describe the effect of temperature and water activity on growth of *E. coli* and its thermal death in hot water cabinets (see also Section 10).

Work on modelling growth of *E. coli* and *Salmonella* in meat processing followed, using CSIRO studies (Grau 1983; Smith 1985; 1987). In the 1990s, MRC began funding the development of models at UTas, a process continued by MLA, which has led to tools which are used regularly in the red meat and RTE meat sectors.

By the late-1980s, UTas and CSIRO collaboration led to models for the dairy and seafood industries and publication of *Predictive microbiology: theory and application* (McMeekin *et al*. 1993).

In 2000, at the 3rd International Conference on Predictive Modelling in Foods, use of modelling and software tools in Australia was described by Sumner & Krist (2002), revealing the various tools under development which were to become pivotal for regulating the meat industry in Australia.

Commissioned by the MRC, UTas began applying the work of a generation of post-graduate students to the meat industry including Presser *et al*. (1997, 1998); Krist *et al*. (1998); Salter *et al*. (1998a, b, c); Shadbolt *et al*. (1999, 2001) and Mellefont (2001). Major reviews followed the uptake of predictive microbiological models (Ross 1996, 1999; Ross & Nichols 2000; Ross *et al*. 2000, 2003; McMeekin *et al*. 2002, 2008; McQuestin *et al.* 2009; Sumner *et al*. 2012).

Understanding the microbial ecology of *E. coli* in meat systems was a priority, particularly in predicting how the organism would react during chilling, especially of hot boned meat, and during fermentation, and to develop a range of predictive microbiology tools/computer software.

## 16.1 The salami predictor

The monograph *Predicting E. coli inactivation in uncooked comminuted fermented meat products (UCFM)* by Ross & Shadbolt (2001) came at an important time for the sector, which, in the aftermath of the Garibaldi outbreak, had been charged with demonstrating that its processes would inactivate at least 99.9% of *E. coli* which might be present in each gram of in-going raw meat, the so-called '3-log kill'.

It soon became clear that this would be very expensive for companies both large and small since, for each product type, the process would need to undergo challenge testing. Not many microbiological laboratories were capable of doing challenge testing, not to mention the fear of fermentation and maturation in-plant, using sausages which had been inoculated with a large number of pathogens.

In 2001, the UTas team developed the *E. coli* Inactivation Predictor tool which rendered challenge testing redundant and which required monitoring of only two parameters in the UCFM process: temperature and time. The tool was, and still is, used extensively by establishments and regulators in a cooperative manner to verify the extent that each UCFM process can inactivate *E. coli*.

## 16.2 The Refrigeration Index (RI) predictor

In 1999, freezing of meat in cartons became a regulatory problem with some hot boning establishments unable to meet the 15 hour time limit specified to reach 7°C at the slowest cooling point (centre) of the carton, an outcome predicted by Spooncer (1993): "*For meat boned straight off the slaughter floor, the cooling rates that apply to hot-boned meat cannot be achieved with conventional packing and freezing techniques*".

An approach was made to the regulator to allow an industry trial of an approach similar to that used in New Zealand whereby the growth of *E. coli* would be monitored by microbiological testing and then compared with estimates using a predictive model developed by UTas.

The criteria for assessing chilling regimes were regulated as a Hot Boning Index (HBI) in Meat Notice 2001/20 (AQIS 2001) according to predicted growth of *E. coli*:

- Average HBI of no more than 1.5 log
- 80% of the HBIs must be no more than 2.0 log
- Upper target HBI of no more than 2.5 log

The UTas model was evaluated and found to predict growth more accurately than existing predictive models (Mellefont *et al.* 2003). The HBI was later subsumed within a regime for all meat establishments, the Refrigeration Index (RI). The model contained factors for pH, water activity and lactate within a simple spreadsheet tool into which QA staff were required to paste only temperature:time data.

The process of developing a validated tool was facilitated using data obtained by CSIRO which compared predicted *E. coli* growth with actual observed growth (Herbert & Smith 1980) as well as equations derived by Smith (1985).

The RI has proved an everyday, robust tool which removed the expense of verifying chilling by microbiological testing; it has also been used to evaluate potential growth of *E. coli* during protracted loss of refrigeration such as when extreme weather events cause loss of power.

## 16.3 The Listeria predictor

In the late 1990s, there were large outbreaks of listeriosis globally with a range of foods implicated, including RTE meats. MLA commissioned UTas to undertake a range of studies on *Listeria monocytogenes* in RTE meats, including the effect of adding organic acids in the formulation to prevent growth, together with a quantitative risk assessment.

The UTas team also cooperated in a global project led by Danish researchers to develop a spreadsheet tool to predict growth of *L. monocytogenes* in RTE meats (Mejlholm *et al*. 2010). The tool led to regulation in Australia being amended to distinguish between

products which could or could not support growth of *L. monocytogenes* during refrigerated storage.

## 16.4 The shelf life predictor

In MLA's *Shelf life of Australian red meat products*, UTas describes the development of a tool to predict shelf life of VP beef and sheep meats. The establishment needs only know the Total Bacterial Count on primals as they are packed, together with the temperature:time history and the tool will predict remaining shelf life. The model has been validated by industry trials.

The tool can be used for various 'what-if' scenarios e.g. what if the count is higher – how much shelf life will I lose? Or, what if I modify the storage temperature, how will the shelf life be impacted? It has also proved extremely useful in advising establishments of how much shelf life remains when refrigeration has been compromised.

# 17 National baseline surveys

**Context**

It was against the background of two large outbreaks of illness caused by consumption of hamburgers in the USA containing *E. coli* O157 that, in 1993-94, the Australian meat industry commissioned its first baseline study of the microbiological quality of Australian meat. The logistics of such surveys are daunting: samples from export and domestic abattoirs in every State in Australia must be transported to the laboratory with strict temperature and time limits for acceptance.

The intentions behind the national survey included benchmarking against product from other countries; informing abattoirs of their performance as compared with the national average; pinpointing areas for improvement, and assessing macro changes which occurred in the industry implementation of quality systems and improvements to infrastructure.

The industry has invested in numerous large surveys for beef and sheep meats: carcases, boneless meat and primals, and has published the results in the peer-reviewed international literature. The results for indicator organisms on frozen boneless meat are summarised in Table 15 and Table 16; generally, pathogens such as *Salmonella*, *E. coli* O157 were either absent or were isolated at very low frequency.

Since there are differences in methodology, limits of detection and the influence of the Millennial Drought which occurred for the early years of the 21st century, it is prudent to make only generalised comments on the continuum for the hygiene status of boneless frozen meats as set out in Table 15 and Table 16. The overwhelming aspect for both beef and sheep meats is the reduction in prevalence of *E. coli* over the period 1993-2011; further detail for each baseline study are provided below.

*Table 15: National baseline surveys of frozen boneless beef in Australia 1993 to 2011*

| | Number of samples | TVC ($log_{10}$ cfu/g) | *E. coli* prevalence (%) |
|---|---|---|---|
| 1993 | 929 | 2.8 | 16.7 |
| 1998 | 987 | 2.5 | 5.3 |
| 2004 | 1082 | 1.2 | 1.1 |
| 2011 | 1165 | 2.2 | 2.1 |

*Table 16: National baseline surveys of frozen boneless sheep meat in Australia 1993 to 2011*

| | Number of samples | TVC ($log_{10}$ cfu/g) | *E. coli* prevalence (%) |
|---|---|---|---|
| 1993 | 415 | 3.5 | 47.7 |
| 1998 | 467 | 3.3 | 24.5 |
| 2004 | 560 | 1.8 | 4.3 |
| 2011 | 551 | 2.8 | 12.5 |

## 17.1 Baseline *survey 1: 1992-93*

As well as accumulating and analysing a large amount of data for the first time in Australia, the survey (Vanderlinde *et al.* 1999a, b) also focused on contemporary aspects of interest:

differences between export and domestically-manufactured meats and between meat manufactured at plants with/without QA systems.

Counts of indicator organisms were found to be generally lower on meat at export establishments, with the practice of loading carcases offsite to independent boning rooms in the domestic sector pinpointed as a likely cause of higher counts.

There was little difference between counts of indicator organisms in domestic plants irrespective of whether they operated QA systems or were under the jurisdiction of the government regulator.

Two aspects emerged as important: firstly, weekend chilling, which led to higher counts and secondly, the high prevalence (27%) of *S. aureus* on beef carcases. The latter was investigated further by CSIRO at three abattoirs with Desmarchelier *et al*. (1999) following the prevalence and concentration on cattle hides immediately after slaughter and at key points through the process. After weekend chilling, the prevalence of the pathogen was 83%, 70% and 47%, respectively at abattoirs A, B and C. The researchers also isolated *S. aureus* from the hands of operators, which were shown by Vanderlinde *et al*. (1999c) to be identical with those on the beef carcase.

## 17.2 Baseline survey 2: 1998-99

The survey (Phillips *et al*. 2001a, b) involved 37 export, 18 domestic and 37 very small plants (defined as slaughtering less than 150 cattle equivalents/week) and a comparison of indicator organisms on beef and sheep carcases produced by each sector is presented in Table 17.

*Table 17: Indicator organisms and S. aureus on beef and sheep carcases produced at export, domestic and very small plants in Australia (after Phillips et al. 2001a, b)*

| | Export | Domestic | Very small plants |
|---|---|---|---|
| **Beef carcases** | | | |
| No. establishments | 21 | 7 | 31 |
| Mean log TVC/cm$^2$ | 2.2 | 2.6 | 3.1 |
| Mean *E. coli* (%) | 11.3 | 8.8 | 7.9 |
| Mean *S. aureus* (%) | 24 | 27.8 | 20.5 |
| **Sheep carcases** | | | |
| No. establishments | 7 | 8 | 31 |
| Mean log TVC/cm$^2$ | 2.9 | 3.8 | 3.9 |
| Mean *E. coli* (%) | 35.2 | 32.7 | 21.4 |
| Mean *S. aureus* (%) | 12.2 | 34 | 24.6 |

As well as adding to the body of knowledge of Australian meat, especially of prevalence of pathogens, which was again very low, with the exception of *S. aureus*, the survey showed broad differences between meat produced in the three sectors. However, when individual plant data were assessed, it became clear that, within each sector, there were broad differences in TVC and *E. coli* prevalence, with some domestic and very small plants having lower counts and prevalence than some export plants.

The ability of domestic and very small plants to manufacture meat of acceptable microbiological quality was evaluated by two Australian State regulators, South Australia and New South Wales. Both jurisdictions allow establishments to employ qualified meat inspectors, which they register or approve. Termed “co-regulation”, companies are regulated via auditors or auditing agents, responsible to the Controlling Authority.

In the South Australian survey (Sumner *et al*. 2003c), mean log TVCs on beef and sheep carcases were similar at both medium and very small plants, though prevalence of *E. coli* was much lower on carcases produced at very small plants, similar to the findings of Phillips *et al*. (2001 a, b).

In NSW, HACCP was introduced in 1997, since which time, plants have been required to undertake microbiological monitoring. In 2006, the NSW Food Authority undertook a comprehensive survey of the red meat industry in the State in which levels of indicator bacteria on carcases processed via the co-regulatory system were found to be similar to those established in surveys of abattoirs that operate the traditional system overseen by government inspectors (Bass *et al*. 2011).

## 17.3 Baseline survey 3: 2004

In this survey (Phillips *et al*. 2006a, b), samples of chilled beef carcases and frozen boneless beef were collected from processors accounting for approximately 75% of Australia's throughput and samples of chilled sheep carcases and frozen boneless sheep meat were collected from processors accounting for approximately 78% of Australia's throughput. The number of samples collected from each processor was proportional to their estimated processing volume.

As may be seen from Table 15 and Table 16 above, total bacterial loadings and prevalence of *E. coli* in boneless beef and sheep meat were lower than both the previous and the subsequent baseline studies, which may reflect the influence of the Millennial Drought; *S. aureus* however, was isolated from 20.1% and 15.9% of beef and sheep carcases, respectively.

## 17.4 Retail survey: 2005

In 2005, MLA commissioned a national baseline study of retail ground beef and diced lamb in Australia (Phillips *et al*. 2008a). The study design involved sampling meat in Melbourne, Sydney and Brisbane from retail outlets (supermarkets and butcher shops) selected from telephone listings to ensure a broad coverage of socioeconomic regions within the three cities.

For both products, the mean APC was 5.7 $\log_{10}$ cfu/g, with *E. coli* 17.2%, while prevalence of *S. aureus* was 28% and 22% for ground beef and diced lamb, respectively. *Salmonella* was recovered from 4/360 (1.1%) of ground beef and 2/360 (0.6%) of diced lamb samples while *E. coli* O157 was recovered from 1/357 (0.3%) of ground beef samples; *Campylobacter* and *Clostridium perfringens* were not recovered from any of the 91 and 94 samples tested, respectively.

Following the finding in Baseline 3 and the retail survey of continued high levels of *S. aureus* on meat carcases and retail meats, an investigation was undertaken in 2006 at five abattoirs in which observations were made of operator handling practices, and microbiological samples taken (Phillips *et al*. 2008b). Prevalence of *S. aureus* in this survey were compared with that established during Baseline 3 and are presented in Table 18.

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*Table 18: Prevalence of S. aureus on chilled carcases at Plants A-E (after Phillips et al. 2008b)*

| | Baseline 3 | | Phillips *et al.* 2008b | |
|---|---|---|---|---|
| Plant | n | Prevalence (%) | n | Prevalence (%) |
| **Beef** | | | | |
| A | 41 | 58.5 | 25 | 0 |
| B | 32 | 51.6 | 25 | 0 |
| **Sheep** | | | | |
| C | 71 | 17.0 | 25 | 80 |
| D | 30 | 63.3 | 25 | 32 |
| E | 30 | 43.0 | 25 | 20 |

At both beef plants, disposable gloves had been introduced and were being worn by all operators at the time of sampling. At sheep plants D and E, disposable gloves were optional and were worn by a majority of operators, and this may be responsible for the reduction in prevalence and concentration of *S. aureus* in the present study, compared with Baseline 3. At plant C, gloves were worn by all slaughter floor operators except by those who freed the fleece by manual punching, and by final government inspection, which involved extensive handling of the rump and hind legs as the carcase was held, turned and palpated.

Another observation when comparing Baseline 3 (Phillips *et al*. 2006a, b) with the retail survey (Phillips *et al*. 2008b) was the disparity in APCs, with mean APCs of ground beef at retail being 4 $\log_{10}$ cfu/g higher than that of meat packed at the abattoir. An investigation of ground beef production at large and small central production facilities and at supermarket and butcher shops revealed the causes to be the extensive use of VP beef primals stored for 2-3 weeks, together with incorporation of bench trim which may have been stored for 5-6 days prior to grinding (Sumner *et al*. 2011).

## 17.5 Baseline survey 4: 2011

In this survey, samples of frozen boxed beef and sheep meat and beef and sheep primals were collected from meat processing establishments selected on the basis that they collectively accounted for at least 80% of either beef or sheep meat processed in Australia; product from 29 beef and 12 sheep establishments was sampled (Phillips *et al.* 2012a, b).

As in previous surveys, the prevalence of pathogens and indicators was low, though total bacterial counts and prevalence of *E. coli* were higher than in the previous survey (Table 15 and Table 16). From interrogation of the Bureau of Meteorology data, SARDI noted that during the first sampling period (January-March, 2011) rainfall was much higher than normal in northern, eastern and southern Australia due to cyclonic conditions.

By contrast, prevalence of *S. aureus* was much lower than in previous abattoir and retail baselines probably due to the almost universal use of gloves by operators on slaughter floors and in boning rooms as established by Phillips *et al*. (2008b).

# 18 Conclusions

The sum total of the findings reported in this monograph reflect the commissioning of meat industry R&D by various funding bodies over the past half century: AMRC (1966-85), AMLRDC (1985-91), MRC (1991-98), MLA (1988-present) and AMPC (1998-present).

The result is, in 2017, an Australian meat industry valued at almost AUD17 billion, comprising beef ($12.7 billion) and lamb/mutton ($3.9 billion) products, of which around 65% is exported, chilled and frozen, to more than 100 markets globally.

Frozen products underpin the Middle Eastern mutton and the North American hamburger markets. In 2015, for example, Australia exported the equivalent of 3.4 billion quarter-pounder hamburger patties to North America as manufacturing meat.

Australia exports around 3 million kg of vacuum packed meat of which the vast bulk (85%) is beef primals which will be further processed through the world's retail and food service chains.

For many years, there has been anecdotal evidence through the international meat trade that Australian meat products are consistently outstanding in terms of food safety and shelf life.

This monograph outlines how R&D has assisted the red meat industry to service more than one hundred markets with meat of high hygienic quality, giving long shelf life and low food safety risk.

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# Appendix 1

## Appendix 1a: Studies on the microbiology of chilled beef carcases

| Country | Samples | $log_{10}$ TVC/$cm^2$ or /g | Reference |
|---|---|---|---|
| Canada | 1036 | 2.5 | Bohaychuck *et al.* 2011 |
| Canada | 25 | 2.0 | Gill & Jones 2000 |
| Canada | 25 | 2.2 | Gill & Jones 2000 |
| USA | 96 | 4.4 | Ware *et al.* 2001 |
| Ireland | 30 | 2.0 | Pearce & Bolton 2005 |
| Ireland | 60 | 2.6 | Murray *et al.* 2001 |
| Ireland | 60 | 2.4 | Murray *et al.* 2001 |
| Ireland | 60 | 2.7 | Murray *et al.* 2001 |
| Ireland | 60 | 2.8 | Murray *et al.* 2001 |
| Ireland | 60 | 3.2 | Murray *et al.* 2001 |
| Ireland | 60 | 3.2 | Murray *et al.* 2001 |
| Ireland | 60 | 2.7 | Murray *et al.* 2001 |
| Switzerland | 200 | 3.0 | Zweifel *et al.* 2005 |
| Switzerland | 150 | 2.7 | Zweifel *et al.* 2005 |
| Switzerland | 150 | 2.6 | Zweifel *et al.* 2005 |
| Switzerland | 150 | 3.1 | Zweifel *et al.* 2005 |
| Switzerland | 150 | 2.1 | Zweifel *et al.* 2005 |
| Sweden | 100 | 2.6 | Hansson 2001 |
| Australia | 1268 | 2.4 | Phillips *et al.* 2001a |
| Australia | 1147 | 1.3 | Phillips *et al.* 2006a |
| Australia | 4374 | 1.0 | Jolley *et al.* 2018 |

## Appendix 1b: Studies on the microbiology of chilled lamb carcases

| Country | Samples | $\log_{10}$ TVC/cm$^2$ or /g | Reference |
|---|---|---|---|
| Canada | 25 | 2.7 | Gill & Jones 1997 |
| USA | 420 | 5.2 | Duffy *et al.* 2001 |
| USA | 420 | 5.1 | Duffy *et al.* 2001 |
| USA | 420 | 4.1 | Duffy *et al.* 2001 |
| USA | 420 | 5.4 | Duffy *et al.* 2001 |
| USA | 421 | 5.0 | Duffy *et al.* 2001 |
| USA | 421 | 2.9 | Duffy *et al.* 2001 |
| USA | 420 | 3.5 | Duffy *et al.* 2001 |
| USA | 420 | 5.2 | Duffy *et al.* 2001 |
| USA | 420 | 3.4 | Duffy *et al.* 2001 |
| USA | 420 | 5.6 | Duffy *et al.* 2001 |
| USA | 420 | 4.6 | Duffy *et al.* 2001 |
| USA | 420 | 3.3 | Duffy *et al.* 2001 |
| Ireland | 30 | 2.9 | Pearce & Bolton 2005 |
| Switzerland | 147 | 2.9 | Zweifel & Stephan 2003 |
| Switzerland | 318 | 3.2 | Zweifel & Stephan 2003 |
| Switzerland | 115 | 3.3 | Zweifel & Stephan 2003 |
| Finland | 16 | 2.7 | Salmela *et al*. 2013 |
| Finland | 15 | 3.8 | Salmela *et al*. 2013 |
| Finland | 3 | 4.2 | Salmela *et al*. 2013 |
| Finland | 15 | 2.8 | Salmela *et al*. 2013 |
| Australia | 917 | 3.5 | Phillips *et al.* 2001b |
| Australia | 1117 | 2.9 | Phillips *et al.* 2006b |
| Australia | 2508 | 1.6 | Jolley *et al.* 2018 |

## Appendix 1c: Studies on the microbiology of chilled beef cuts at packaging

| Country | Cut | Samples | $log_{10}$ TVC/$cm^2$ or /g | Reference |
|---|---|---|---|---|
| New Zealand | Striploins | 3 | 3.1 | Penney *et al.* 1998 |
| Canada | Striploins | 3 | 3.3 | Yousseff *et al.* 2014 |
| Canada | Striploins | 25 | 3.6 | Gill *et al.* 2001 |
| Canada | Striploins | 25 | 2.6 | Gill *et al.* 2001 |
| USA | Chuck tenders | 50 | 4.8 | Kennedy *et al.* 2006 |
| USA | Chuck tenders | 50 | 3.8 | Kennedy *et al.* 2006 |
| USA | Bottom round flat | 50 | 5.9 | Kennedy *et al.* 2006 |
| USA | Bottom round flat | 50 | 5.4 | Kennedy *et al.* 2006 |
| USA | Cap-off insides | 50 | 3.5 | Kennedy *et al.* 2006 |
| USA | Cap-off insides | 50 | 3 | Kennedy *et al.* 2006 |
| USA | Clod, fat | 48 | 6 | Ware *et al.* 2001 |
| USA | Clod, lean | 48 | 3.8 | Ware *et al.* 2001 |
| USA | Top butt, fat | 36 | 4.5 | Ware *et al.* 2001 |
| USA | Top butt, lean | 36 | 4.9 | Ware *et al.* 2001 |
| USA | Striploins | 52 | 5.9 | Stopforth *et al.* 2006 |
| USA | Top sirloin butt | 113 | 5.9 | Stopforth *et al.* 2006 |
| USA | Bottom sirloin butt | 35 | 5.6 | Stopforth *et al.* 2006 |
| USA | Shoulder clod | 117 | 5 | Stopforth *et al.* 2006 |
| USA | Short loins | 238 | 5 | Stopforth *et al.* 2006 |
| USA | Clod, top blade | 57 | 4.3 | Stopforth *et al.* 2006 |
| USA | Rib eye roll | 133 | 4 | Stopforth *et al.* 2006 |
| USA | Butt | 94 | 4 | Stopforth *et al.* 2006 |
| USA | Miscellaneous | 123 | 5.4 | Stopforth *et al.* 2006 |
| Australia | Striploins | 572 | 1.3 | Phillips *et al.* 2012a |
| Australia | Silversides | 572 | 1.5 | Phillips *et al.* 2012a |
| Australia | Blade | 39 | 2.1 | Jolley *et al.* 2018 |
| Australia | Chuck | 39 | 1.6 | Jolley *et al.* 2018 |
| Australia | Chuck tenders | 28 | 1.7 | Jolley *et al.* 2018 |
| Australia | Cube Roll | 45 | 1.6 | Jolley *et al.* 2018 |
| Australia | Eye Rounds | 28 | 1.6 | Jolley *et al.* 2018 |
| Australia | Knuckle | 55 | 1.8 | Jolley *et al.* 2018 |
| Australia | Navel End Brisket | 33 | 1.7 | Jolley *et al.* 2018 |
| Australia | Outside Flats | 36 | 1.8 | Jolley *et al.* 2018 |
| Australia | Point End Brisket | 33 | 1.9 | Jolley *et al.* 2018 |
| Australia | Rump | 37 | 1.8 | Jolley *et al.* 2018 |
| Australia | Shank | 11 | 1.5 | Jolley *et al.* 2018 |
| Australia | Short Rib | 6 | 1.4 | Jolley *et al.* 2018 |
| Australia | Striploins | 43 | 1.6 | Jolley *et al.* 2018 |
| Australia | Tenderloin | 41 | 1.5 | Jolley *et al.* 2018 |
| Australia | Topside | 38 | 1.7 | Jolley *et al.* 2018 |
| Australia | Bolar blade | 3 | 2.1 | Tunnage 2018 |
| Australia | Short loin | 3 | 2.2 | Tunnage 2018 |

| Country | Cut | Samples | $\log_{10}$ TVC/cm$^2$ or /g | Reference |
|---|---|---|---|---|
| Australia | Cube Roll | 3 | 2.4 | Tunnage 2018 |
| Australia | NE Brisket | 3 | 2.5 | Tunnage 2018 |
| Australia | Outside Flat | 3 | 2.9 | Tunnage 2018 |
| Australia | PE Brisket | 3 | 2.9 | Tunnage 2018 |
| Australia | Short Rib | 3 | 2.4 | Tunnage 2018 |
| Australia | Striploins | 3 | 2.3 | Tunnage 2018 |

## Appendix 1d: Studies on the microbiology of chilled lamb cuts at packaging

| Country | Cut | Samples | $log_{10}$ TVC/$cm^2$ or /g | Reference |
|---|---|---|---|---|
| Australia | Bone-in legs | 8 | 2.1 | MLA 2017b |
| Australia | Boneless legs | 8 | 2.2 | MLA 2017b |
| Australia | Bone-in shoulder | 8 | 2.0 | MLA 2017b |
| Australia | Boneless shoulder | 8 | 1.9 | MLA 2017b |
| Australia | Racks Frenched | 8 | 1.4 | MLA 2017b |
| Australia | Breast/flap | 8 | 2.3 | MLA 2017b |
| Australia | Short loin | 8 | 2.6 | MLA 2017b |
| Australia | Bone-in legs | 10 | 1.8 | Sumner & Kiermeier 2015 |
| Australia | Boneless legs | 10 | 2.0 | Sumner & Kiermeier 2015 |
| Australia | Bone-in shoulder | 10 | 2.5 | Sumner & Kiermeier 2015 |
| Australia | Boneless shoulder | 10 | 2.4 | Sumner & Kiermeier 2015 |
| Australia | Racks | 10 | 1.9 | Sumner & Kiermeier 2015 |
| Australia | Racks, fat removed | 10 | 1.8 | Sumner & Kiermeier 2015 |
| Australia | Boneless shoulder | 25 | 2.3 | Sumner & Jenson 2011 |
| Australia | Boneless shoulder | 25 | 1.4 | Sumner & Jenson 2011 |
| Australia | Boneless shoulder | 25 | 1.8 | Sumner & Jenson 2011 |
| Australia | Boneless shoulder | 25 | 1.8 | Sumner & Jenson 2011 |
| Australia | Bone-in shoulder | 4 | 3.4 | Kiermeier *et al.* 2013 |
| Australia | Boneless shoulder | 4 | 3.4 | Kiermeier *et al.* 2013 |
| Australia | Breast and flap | 3 | 1.4 | Jolley *et al.* 2018 |
| Australia | Foreshank | 2 | 2.6 | Jolley *et al.* 2018 |
| Australia | Full carcase cuts | 4 | 2.9 | Jolley *et al.* 2018 |
| Australia | Bone-in leg | 45 | 1.8 | Jolley *et al.* 2018 |
| Australia | Boneless leg | 38 | 1.9 | Jolley *et al.* 2018 |
| Australia | Loin | 14 | 1.5 | Jolley *et al.* 2018 |
| Australia | Bone-in loin | 9 | 2.2 | Jolley *et al.* 2018 |
| Australia | Boneless loin | 14 | 2.0 | Jolley *et al.* 2018 |
| Australia | Neck | 2 | 2.3 | Jolley *et al.* 2018 |
| Australia | Rack | 43 | 1.9 | Jolley *et al.* 2018 |
| Australia | Rack (Cap off) | 2 | 1.2 | Jolley *et al.* 2018 |
| Australia | Rack (Cap on) | 14 | 2.3 | Jolley *et al.* 2018 |
| Australia | Rack (Frenched) | 15 | 1.6 | Jolley *et al.* 2018 |
| Australia | Shank | 22 | 1.9 | Jolley *et al.* 2018 |
| Australia | Short loins | 24 | 1.7 | Jolley *et al.* 2018 |
| Australia | Shoulder – Square Cut | 36 | 1.7 | Jolley *et al.* 2018 |
| Australia | Bone-in shoulder | 16 | 2.5 | Jolley *et al.* 2018 |
| Australia | Boneless shoulder | 10 | 2.1 | Jolley *et al.* 2018 |
| Australia | Tenderloin | 16 | 1.6 | Jolley *et al.* 2018 |

# Appendix 2

## Appendix 2a: Study parameters that may affect Total Viable Count – beef carcases

| Study | Sponge/excision | Sampling stage | Incubation | | Counts |
|---|---|---|---|---|---|
| | | | Temperature (°C)/time (h) | Medium | |
| Bohaychuck *et al.* 2011 | Sponge 10 x10 cm at three sites = 300cm$^2$ Round, flank, brisket | Chilled | 35/48 | Plate Count agar | TVC/cm$^2$ |
| Gill & Jones 2000 | Sponge 10 x10 cm at four random sites = 400cm$^2$ | Chilled | 25/72 | Tryptone soy fast green agar | TVC/cm$^2$ |
| Ware *et al.* 2001 | Sponge 10 x10 cm at three sites = 300cm$^2$ Round, flank, brisket | Chilled | 25/72 | Standard Methods agar | TVC/cm$^2$ |
| Pearce & Bolton 2005 | Sponge 100cm$^2$ | Pre-chill | 25/48 | Plate Count agar | TVC/cm$^2$ |
| Murray *et al.* 2001 | Sponge 50 x 20 cm = 1000 cm$^2$ Brisket | Chilled | 22/48 | Nutrient agar | TVC/cm$^2$ |
| Hansson 2001 | Swab 10 x10 cm at two sites = 200 cm$^2$ Loin and sternum | Pre-chill | 30/72 | Plate Count agar | TVC/cm$^2$ |
| Zweifel *et al.* 2004 | Swab 10 x10 cm at four sites = 400 cm$^2$ Neck, brisket, flank, rump | ? Probably pre-chill | 30/72 | Plate Count agar | TVC/cm$^2$ |
| Phillips *et al.* 2001a | Sponge 10 x10 cm at three sites = 300cm$^2$ Butt, flank, brisket | Chilled | 25/96 | Plate Count agar | TVC/cm$^2$ |
| Phillips *et al.* 2006a | Sponge 10 x10 cm at three sites = 300cm$^2$ Butt, flank, brisket | Chilled | 25/96 | Plate Count agar | TVC/cm$^2$ |
| Jolley *et al.* 2018 | Sponge 10 x10 cm at three sites = 300cm$^2$ Butt, flank, brisket | Chilled | 35/48 | Petrifilm | TVC/cm$^2$ |

## Appendix 2b: Study parameters that may affect Total Viable Count – lamb carcases

| Study | Sponge/excision | Sampling stage | Incubation | | Counts | Comment |
|---|---|---|---|---|---|---|
| | | | Temperature (°C)/Time (h) | Time | | |
| Gill & Jones 1997 | Swab 10 x10 cm = 100 $cm^2$ Random site | Chilled | 25/48 | Plate Count agar | TVC/$cm^2$ | |
| Duffy *et al.* 2001 | Sponge 10 x10 cm at three sites = 300$cm^2$ Flank, leg, breast | Chilled | 35/48 | Petrifilm | TVC/$cm^2$ | |
| Pearce & Bolton 2005 | Sponge 100$cm^2$ | Pre-chill | 25/48 | Plate Count agar | TVC/$cm^2$ | |
| Zweifel & Stephan 2003 | Sponge 40 $cm^2$ at ten sites = 400$cm^2$ | Partial chill | 30/48 | Plate Count agar | TVC/$cm^2$ | Estimated from bar chart |
| Salmela *et al.* 2013 | Sponge 40 $cm^2$ at ten sites = 400$cm^2$ | Pre-chill | 30/72 | Plate Count agar | TVC/$cm^2$ | |
| Phillips *et al.* 2001b | Sponge 5 x5 cm at three sites = 75$cm^2$ Midloin, flank, brisket | Chilled | 25/96 | Plate Count agar | TVC/$cm^2$ | |
| Phillips *et al.* 2006b | Sponge 5 x5 cm at three sites = 75$cm^2$ Midloin, flank, brisket | Chilled | 25/96 | Plate Count agar | TVC/$cm^2$ | |
| Jolley *et al.* 2018 | Sponge 5 x5 cm at three sites = 75$cm^2$ Midloin, flank, brisket | Chilled | 35/48 | Petrifilm | TVC/$cm^2$ | |

## Appendix 2c: Study parameters that may affect Total Viable Count – beef cuts

| Study | Sponge/excision | Sampling stage | Incubation | | Counts | Comment |
|---|---|---|---|---|---|---|
| | | | Temp (°C) /Time (h) | Medium | | |
| Penney *et al.* 1998 | Swab 5 $cm^2$ lean surface | After vacuum packing | 25/72 | Plate Count agar | TVC/$cm^2$ | |
| Yousseff *et al.* 2014 | Massage entire surface | After vacuum packing | 25/72 | Tryptose soy agar | TVC/$cm^2$ | Decontaminated carcases were used |
| Gill *et al.* 2001 | Sponge 10x10 = 100$cm^2$ | Prior to packaging | 25/72 | Tryptone soy fast green agar | TVC/$cm^2$ | |
| Ware *et al.* 2001 | Sponge 100$cm^2$ Fat and lean sides separately | Prior to packaging | 25/72 | Standard Methods agar | TVC/$cm^2$ | |
| Stopforth *et al.* 2006 | Excision | Prior to packaging | 37/48 | Petrifilm | TVC/g | |
| Phillips *et al.* 2012 | Sponge 300$cm^2$ | Prior to packaging | 25/96 | Petrifilm | TVC/$cm^2$ | |
| Jolley *et al.* 2018 | Sponge 100$cm^2$ | Prior to packaging | 37/48 | Petrifilm | TVC/$cm^2$ | |
| Tunnage, 2018 | Massage whole surface | Prior to packaging | 25/96 | Petrifilm | TVC/$cm^2$ | |

## Appendix 2d: Study aspects that may affect Total Viable Count – lamb cuts

| Study | Sponge/excision | Sampling stage | Incubation | | Counts |
|---|---|---|---|---|---|
| | | | Temp (°C) /Time (h) | Medium | |
| Kiermeier *et al*. 2013 | Excision | Prior to packaging | 25/96 | Petrifilm | TVC/$cm^2$ |
| Sumner & Jenson 2011 | Sponge 10x10 = 100$cm^2$ | Prior to packaging | 25/96 | Petrifilm | TVC/$cm^2$ |
| Sumner & Kiermeier 2015 | Sponge 20x10 = 200$cm^2$ | Prior to packaging | 25/96 | Petrifilm | TVC/$cm^2$ |
| Jolley *et al*. 2018 | Sponge 100 = 100$cm^2$ | Prior to packaging | 37/48 | Petrifilm | TVC/$cm^2$ |
| MLA 2017b | Sponge 20x10 = 200$cm^2$ | Prior to packaging | 25/96 | Petrifilm | TVC/$cm^2$ |