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

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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.

Introduction

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).

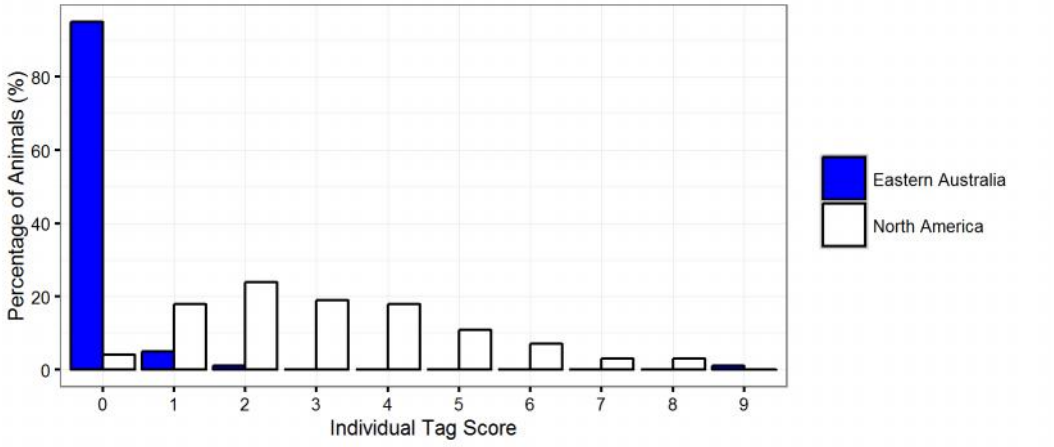

Figure S1: Tag score cattle entering slaughter facilities in Australia and North America

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, 2017b).

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).

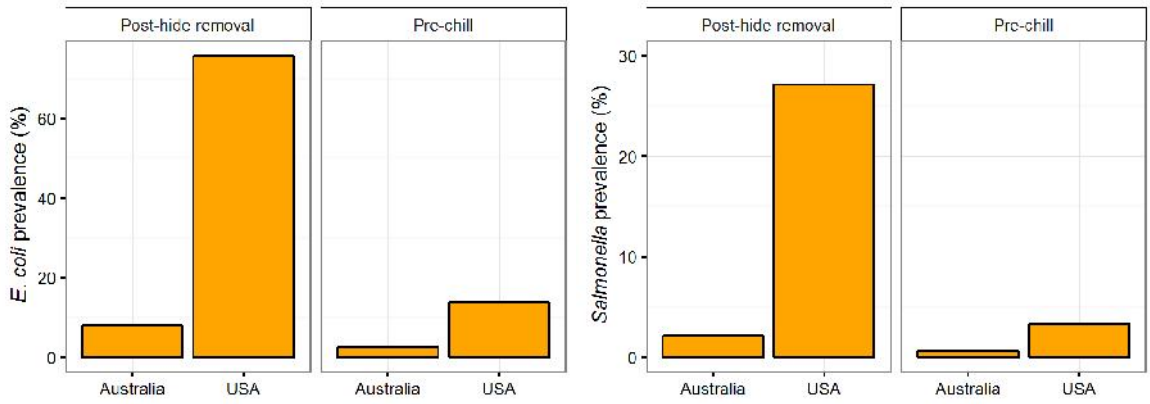

Figure S2: Prevalence (%) of E. coli (left) and Salmonella (right) on Australian and USA carcases during dressing

Testing and monitoring

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.

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.

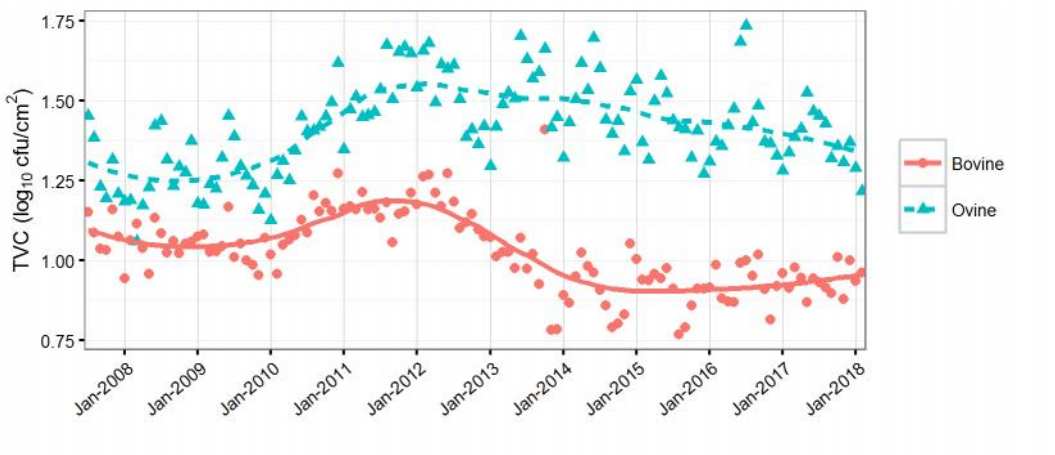

Figure S3: Time-series plot of TVC concentration for bovine and ovine carcases; the solid lines indicate the smooth 'loess' trend.

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).

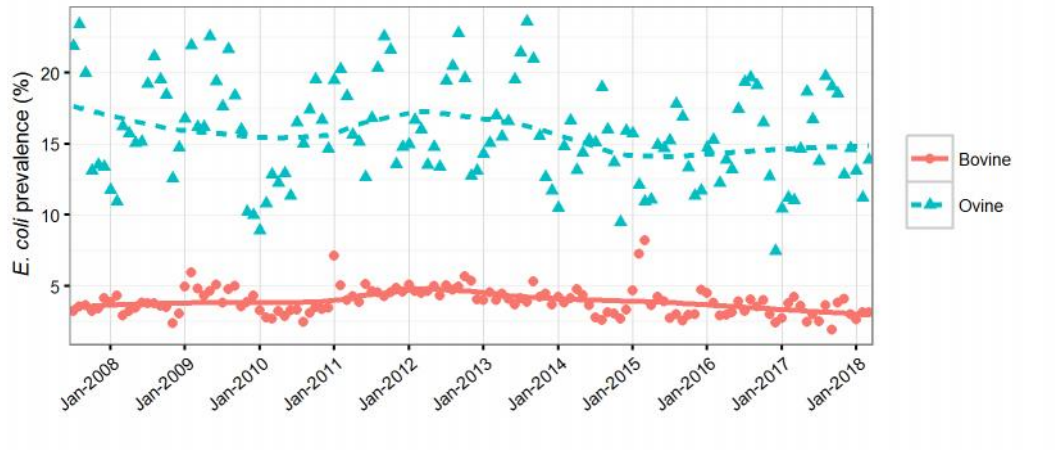

Figure S4: Time-series plot of E. coli prevalence for bovine and ovine carcases; the solid lines indicate the smooth 'loess' trend.

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.

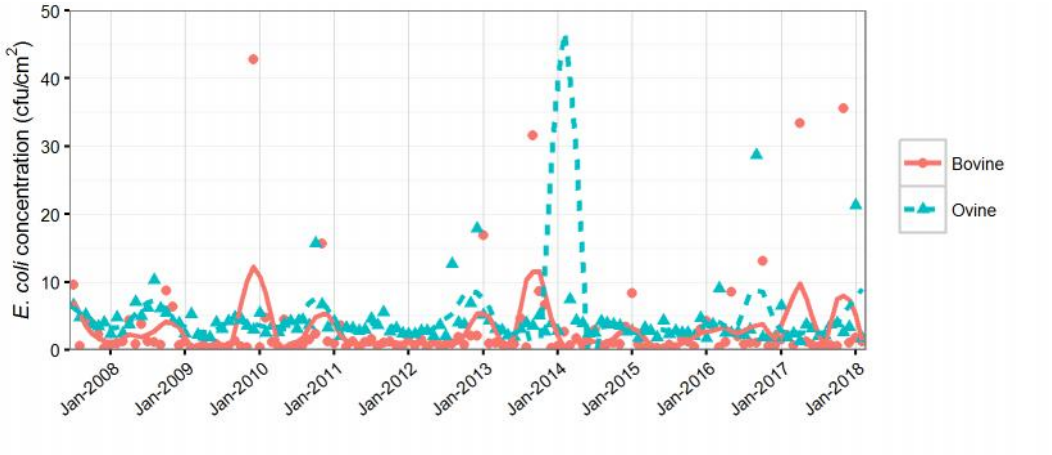

Figure S5: Time-series plot of E. coli concentration (CFU/cm²) for bovine and ovine carcases; the solid lines indicate the smooth 'loess' trend.

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

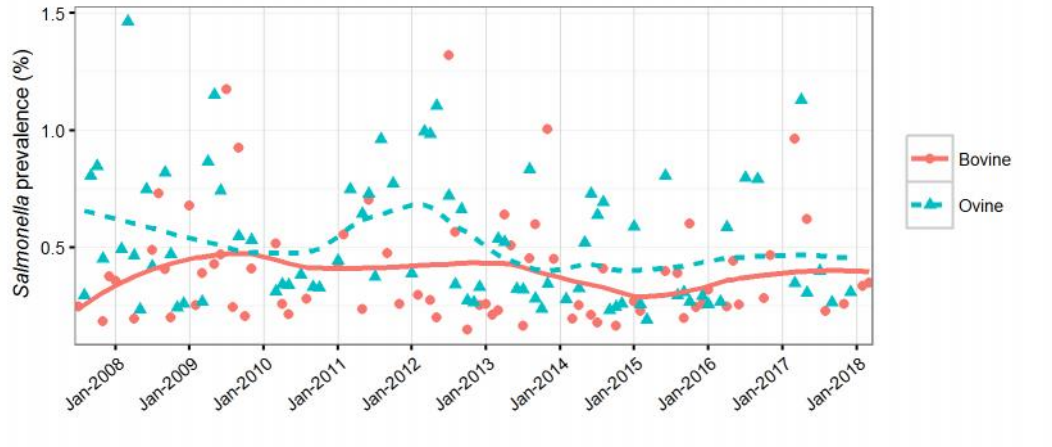

Figure S6: Time-series plot of Salmonella prevalence for bovine and ovine carcases; the solid lines indicate the smooth 'loess' trend.

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).

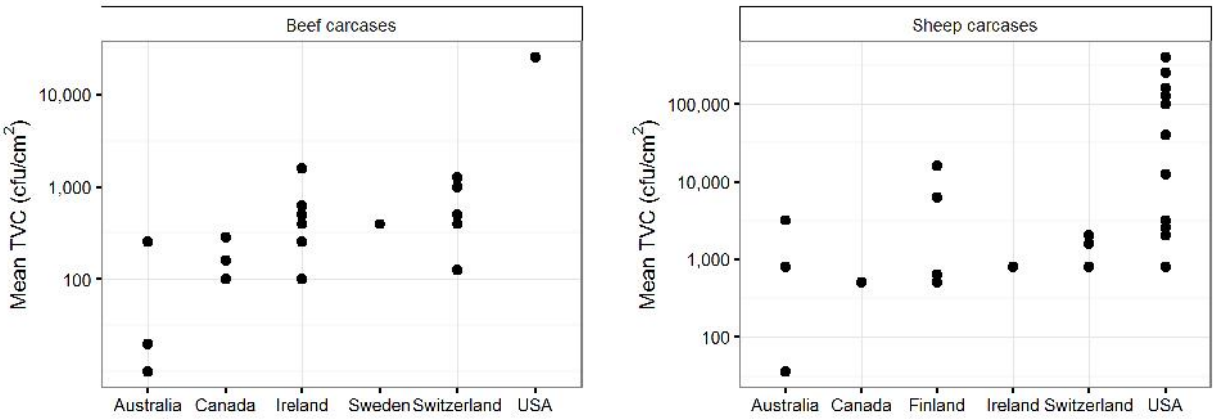

Figure S7: Inter-country comparisons total bacterial loadings (TVC) on beef and sheep carcases

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.

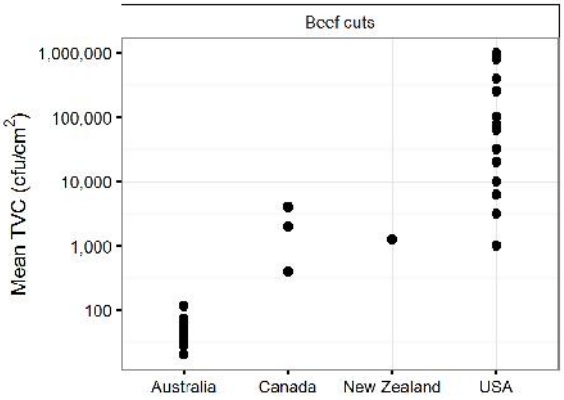

Figure S8: Inter-country comparisons total bacterial loadings (TVC) on beef cuts

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.

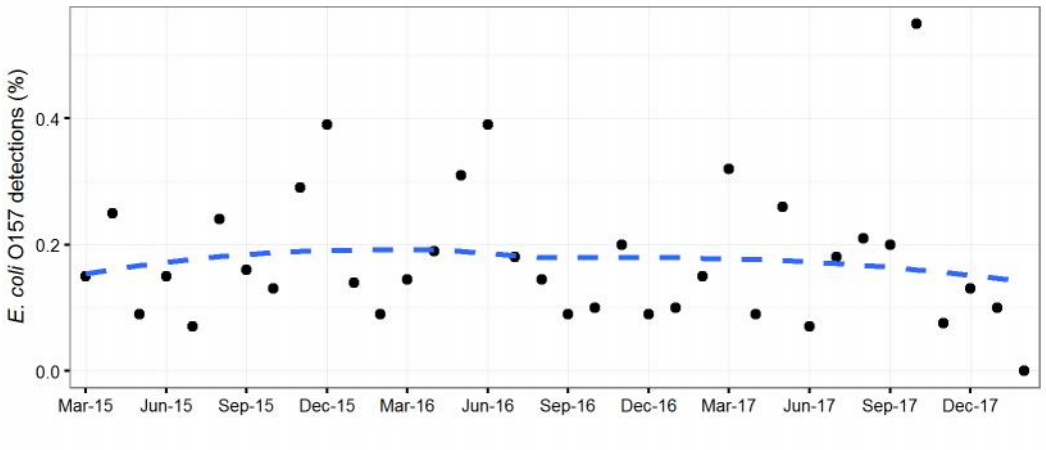

Figure S9: Prevalence (%) of E. coli O157 on Australian manufacturing meat

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.

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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
Australia	Cube Roll	3	2.4	Tunnage 2018

Country	Cut	Samples	log_{10} TVC/cm^2 or /g	Reference
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 = 300cm^2 Flank, leg, breast	Chilled	35/48	Petrifilm	TVC/cm^2	
Pearce & Bolton 2005	Sponge 100cm^2	Pre-chill	25/48	Plate Count agar	TVC/cm^2	
Zweifel & Stephan 2003	Sponge 40 cm^2 at ten sites = 400cm^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 = 400cm^2	Pre-chill	30/72	Plate Count agar	TVC/cm^2	
Phillips *et al.* 2001b	Sponge 5 x5 cm at three sites = 75cm^2 Midloin, flank, brisket	Chilled	25/96	Plate Count agar	TVC/cm^2	
Phillips *et al.* 2006b	Sponge 5 x5 cm at three sites = 75cm^2 Midloin, flank, brisket	Chilled	25/96	Plate Count agar	TVC/cm^2	
Jolley *et al.* 2018	Sponge 5 x5 cm at three sites = 75cm^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 = 100cm^2	Prior to packaging	25/72	Tryptone soy fast green agar	TVC/cm^2	
Ware *et al.* 2001	Sponge 100cm^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 300cm^2	Prior to packaging	25/96	Petrifilm	TVC/cm^2	
Jolley *et al.* 2018	Sponge 100cm^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 = 100cm^2	Prior to packaging	25/96	Petrifilm	TVC/cm^2
Sumner & Kiermeier 2015	Sponge 20x10 = 200cm^2	Prior to packaging	25/96	Petrifilm	TVC/cm^2
Jolley *et al*. 2018	Sponge 100 = 100cm^2	Prior to packaging	37/48	Petrifilm	TVC/cm^2
MLA 2017b	Sponge 20x10 = 200cm^2	Prior to packaging	25/96	Petrifilm	TVC/cm^2