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Megatrends, opportunities and challenges facing Australian livestock industries

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EXECUTIVE SUMMARY

As part of developing its *2020-25 Strategic Plan*, Animal Health Australia (AHA) has commissioned an independent report to provide insight and information about the drivers of opportunities and challenges faced by the Australian livestock sector over the next 10 years. This report outlines the key megatrends and commercial outlook that will shape the industries of the future.

Given the increased global demand for protein and bio-based materials, food and fibre production industries are rapidly evolving. Key issues driving this include food safety, product integrity and health benefits, corporate social responsibility, production systems and innovations, sustainability, and traceability.

Australian livestock farmers earn a price premium in international markets for producing safe, high-quality meat and fibre that is underpinned by our disease-free status. Prioritising animal health and biosecurity is therefore key in maintaining the future prosperity of the livestock sector if it is to take advantage of the opportunities afforded by the growing global demand for meat. This status is reliant on the strong biosecurity system that protects our agriculture industries, environment and community from pests and diseases. However, Australian livestock producers face a challenging future because maintaining our biosecurity status is not automatically guaranteed but requires collective committed vigilance and innovation.

(AHA) has commissioned an independent report to provide insight and information about the drivers of opportunities and challenges faced by the Australian livestock sector over the next 10 years.

The Australian livestock and aquaculture sectors face significant changes that are driven by various megatrends that relate to issues such as climate change, technological disruption, limiting resources, and changing consumer and market needs. The immediate key question that arises is: "How are these trends best dealt with, mitigated or taken advantage of?"

The key trends that are impacting the future of the Australian livestock sector include:

- **Climate change megatrends** are re-shaping terrestrial and aquatic animal production systems. The decline in ecosystem services (such as water quality and availability, soil health and biodiversity) is causing changes in the geographical ranges of animal and plant diseases, insect vectors and feral animal hosts which is increasing disease risk and is stretching surveillance capability and capacity.
- **Consumer megatrends** are creating increased global demand for meat as well as alternative, more sustainable choices for protein and fibre. Alternative products from plant and bio-industrial processes will likely coexist with traditional products for the foreseeable future, so there are great opportunities for synergies. Citizen-science and the rapid social dissemination of information (including misinformation and disinformation) by individuals, groups and communities will also impact animal production.
- **Technology megatrends** offer extensive opportunities to support the sustained prosperity of livestock industries. Innovative

tools for characterising new (previously unknown) diseases, or variants of existing diseases (including antibiotic-resistant microbes), should enable our growing 'omics' knowledge to predict the biology, host range and pathogenicity of new pathogens before they emerge and spread, allowing us to become increasingly proactive, rather than being reactive. Adoption of new technologies in biosensors, autonomous surveillance and diagnostics, and big data analysis will greatly improve biosecurity preparedness and response. Issues such as legislation in data protection and ownership, privacy, Freedom of Information and Right-to-Know in the face of accelerating data generation and predictive capacity will need to be considered.

- **Changes in Government resourcing** and shifts to user-pay systems exacerbates the need to achieve improvements in resource use efficiency.
- **The move to intensive and free-range production systems** will increase the pressure on antibiotic usage (accelerating anti-microbial resistance) and increase the risk of (animal and zoonotic) disease.

This report also reviewed the strategic plans and priorities of AHA industry members and identified several gaps and misalignments amongst them. These include:

- AHA Industry members have taken different timeframes for their strategic planning – most have taken a short-term approach (usually 3 years).
- While animal and plant (crop) health are key factors that determine productivity and competitiveness, some industries have not clearly highlighted or prioritised biosecurity issues that could affect their business.
- Gaps in capability and external investment associated with national priorities are often not clearly articulated.
- Lack of understanding, or appreciation of the sociological factors associated with the adoption of risk mitigation measures by industry stakeholders and the general public.
- Developing the knowledge base and protocols for managing the invasion risks in complex behavioural and social systems posed by one sector for stakeholders in a different sector. For example, a biosecurity incursion affecting one species (pest, weed or disease incursion that affects a fodder or feed grain crop) impacting on another species (animal or aquaculture).
- Mechanisms for cost-effectively demonstrating the absence of significant pests and diseases.
- Discussions, considerations and pathways associated with the adoption of new technologies to reduce biosecurity risks.

This report presents four scenarios that explore different possible future events for Australian livestock and aquaculture industries in the context of the described biosecurity-related megatrends and broader global market trends. These scenarios do not attempt to predict the future but rather present relevant available information and data to facilitate informed discussion and decisions on the future directions for animal health and biosecurity.

These scenarios are:

1. **The triple whammy**
   Australia experiences simultaneous outbreaks of three of the biggest threats to the livestock industries: foot-and-mouth disease, African swine fever and avian influenza, which would potentially bring the entire sector to a standstill and likely place our biosecurity and emergency response systems under enormous stress.
2. **Embracing the Agricultural 4.0 Revolution**
   We describe how the adoption of new digital and biological technologies can provide innovative solutions that enable farmers and food producers to better manage key animal health challenges and improve biosecurity preparedness and outbreak responsiveness.
3. **Industry practices are influenced by consumer demands and Government policy**
   This scenario considers several factors that will influence and shape future livestock production systems such as consumer demands and expectations over food choices; increased scrutiny over production practices in the face of declining natural resources and stronger focus on animal welfare; competition from alternative protein products; the growing threat of antimicrobial resistance (AMR); and Government policies on trade and sustainability.

4. **Climate-driven changes to ecosystem services impact livestock production and biosecurity risks**
   We describe how a series of complex interactions involving concurrent biosecurity breaches of plant diseases and environmental pests could severely impact the livestock sector. A combination of Karnal bunt fungus decimating livestock feed availability; Xylella fastidiosa virus destroying native plant species in grazing ecosystems; Red Imported Fire Ants blocking the use of pastural land across the country; and aquatic biosecurity incursions destroying aquaculture and fishery ecosystems and blocking water supplies would have broad and profound consequences.

An AHA workshop was conducted on 26 November 2019 to present information to its members and to stimulate discussion amongst stakeholder participants around what the future of Australia's livestock health and biosecurity may look like in the context of these scenarios. Importantly, it posed key questions to the participants and facilitated an informed dialogue around future challenges and opportunities faced by the livestock sector. The four scenarios were presented to stimulate discussion and participants were then asked to respond to questions of what AHA should continue doing, or do differently, and how it could assist members to respond to the scenarios.

Several key issues were identified and discussed at the workshop community. These include:

- increasing appreciation of the complexity of animal health and biosecurity – the compounding effects of disease and pest threats across the plant, environment and invasive species domains and declining availability of ecosystem services due to climate change has the potential to result in biosecurity "shock" or breakdown
- need for a more holistic approach to a National Biosecurity Strategy that embraces a One Health view – it starts with on-farm biosecurity
- need for broader coordination, collaboration and information sharing – while new technologies for data generation and analysis are seen as valuable, issues of data ownership and privacy need to be addressed
- need for additional funding for biosecurity resources and transparency of its expenditure.

This report has identified a number of additional issues, gaps and opportunities that we anticipate will provoke further discussion and consideration amongst the animal industries community. These include:

- Opportunities for adoption of digital and bio-technology interfaces to demonstrate and support animal industry best practices, sustainable production and traceability.
- Need for clear articulation of changing risk profiles arising from shifts to intensive production systems and opportunities to increase capacity and capabilities in order to deal with them.
- Threat of emerging peri-urban and free-range production systems presenting increased risks for the transmission of infectious animal and zoonotic diseases and exacerbating AMR issues.
- Shifting social dynamics and opportunities to engage with consumers in order to demonstrate industry's corporate social responsibility credentials.
- The need for Government, as a custodian and significant investor in biosecurity, to respond to consumer and business sentiment.

The immediate key question that arises is: "how are these trends best dealt with, mitigated or taken advantage of?" and answering this demands a more holistic, far-sighted and collaborative approach to future AHA strategy and activities. The consensus at the workshop amongst participants was that AHA plays a valuable role as a relationship manager, trusted advisor and network builder and is therefore well placed to help navigate the livestock sector into the future.

1

BIOSECURITY MEGATRENDS AND IMPLICATIONS

Biosecurity refers to actions and measures that are implemented to prevent and control the introduction and spread of infectious diseases, pests and invasive species. For the successful performance of any animal production system the implementation of a good biosecurity system is absolutely critical.[1] Today's global marketplace gives more access than ever before to agricultural commodities from around the world. It also requires greater vigilance to ensure that imports and exports comply with international standards for trade.

Recent years have seen a range of biosecurity problems which are notable for their high costs and public profile.[2] An outbreak of Classical Swine Fever in 1997 cost The Netherlands approximately €2.4 billion[3] whereas a foot-and-mouth disease (FMD) outbreak in 2001 cost the UK £7 billion.[4] In addition, approximately US$3-4 billion was lost in trade revenue due to appearance of Bovine Spongiform Encephalopathy (BSE) in Canada and the USA in 2003.[5] Interestingly, Avian Influenza (AI) had previously been considered an animal disease, but in 2003 a devastating outbreak occurred in humans in The Netherlands and a series of outbreaks began in Asia which have continued and spread

For the successful performance of any animal production system the implementation of a good biosecurity system is absolutely critical.

to other regions.[6] Due to the explosive growth of aquaculture and mariculture worldwide, the spread of many serious diseases and parasites of fish and shrimp is now very common.[7] Increased global interconnectedness has led to human-assisted movement of pests and pathogens and is now a major cause of animal biosecurity problems. In addition, climate change has been cited as the primary reason for the geographical spread of livestock diseases. One example is Bluetongue disease of sheep in Europe as it appears to be directly related to climatic changes that have extended the range of its culicoid vectors.[8] These examples of agricultural biosecurity threats illustrates their diversity and considerable potential to impact the Australian livestock sector. It also illustrates the urgency to consider what scenarios might present in terms of biosecurity and health threats and how animal industries, and more broadly Australia, can be prepared for any potential

1 Scott, A.B. et al.,'Biosecurity practices on Australian commercial layer and meat chicken farms: Performance and perceptions of farmers', PLoS ONE, vol. 13, no. 4, 2018, e0195582. https://doi.org/10.1371/journal.pone.0195582

2 Waage, J.K. and Mumford, J.D., 'Agricultural biosecurity', *Phil. Trans. R. Soc. B.*, vol. 363. doi: 10.1098/rstb.2007.2188.

3 Whiting, T.L., 'Foreign animal disease outbreaks, the animal welfare implications for Canada: risks apparent from international experience - Special report', *Can. Vet. J.*, vol. 44, 2003, pp.805-815. PMC340296/

4 Thompson, D. et al., 'Economic costs of the foot and mouth disease outbreak in the United Kingdom in 2001', *Revue Scientifique et Tecnique*, Office International des Epizooties, vol. 21, 2002, pp.675-687.

5 Anon, 'Cow with BSE likely to be one infected animal in the herd', *J. Am. Vet. Med. Assoc.*, vol. 224, no. 4, 2004, pp.489-90.

6 Harder, T. C. and Werner, O., 'Avian influenza' in *Influenza Report*, B.S. Kamps, C. Hoffmann and W. Preiser (eds)., Flying Publisher, 2006. http://www.influenzareport.com/ir/ai.htm.

7 Lafferty, K.D. et.al., 'Infectious Diseases Affect Marine Fisheries and Aquaculture Economics', *Ann. Rev. Marine Science*, vol. 7, 2015, pp.471-496. https://doi.org/10.1146/annurev-marine-010814-015646

8 Department for Environment, Food and Rural Affairs (UK), *Bluetongue disease control strategy for the United Kingdom*, London, UK, DEFRA, 2002. https://webarchive.nationalarchives.gov.uk/20061027120000/http:/www.defra.gov.uk/animalh/diseases/notifiable/disease/bluetongue_control_strategy.pdf.

incursions of pests and diseases threatening the sector.

One way to predict the future growth and sustainability of any industry is through the identification and impact of megatrends. Megatrends are major shifts in environmental, social and economic conditions occurring at the intersection of many trends.[9] Megatrends have the potential to irreversibly change the way we live and challenge the models we use to organise our societies.[10] A range of authors and organisations around the world have undertaken studies to identify megatrends (Appendix A Megatrend Review).[11,12,13,14,15,16] While the names and classifications of megatrends can differ, common themes have emerged across the literature, each with the potential to significantly influence Australia's biosecurity future.[17]

We have identified the following five megatrends that are highly relevant to livestock health and biosecurity.

1.1 Climate change and environmental sustainability

Climate change has resulted in the gradual global warming of land and water and altered weather patterns, in particular rainfall, and is critically impacting on environmental conditions worldwide. The concept of environmental sustainability, i.e. the ability to maintain the quality and reproducibility of natural resources, is therefore becoming increasingly

9 Hajkowicz, S., *Global Megatrends: Seven Patterns of Change Shaping Our Future*, Canberra, CSIRO Publishing, 2015.

10 Hajkowicz, S. and Eady, S., *Rural Industry Futures: Megatrends impacting Australian agriculture over the coming twenty years*, Australia, CSIRO and RIRDC, 2015.

11 EY, *Megatrends 2015: Making sense of a world in motion*, EYGM Limited, 2015. https://www.ey.com/Publication/vwLUAssets/ey-megatrends-report-2015/$FILE/ey-megatrends-report-2015.pdf

12 CSIRO Futures, *Food and Agribusiness: A Roadmap for unlocking value-adding growth opportunities for Australia*, Australia, CSIRO, 2017. https://www.csiro.au/en/Do-business/Futures/Reports/Food-and-Agribusiness-Roadmap

13 National Farmers' Federation, *Roadmap 2030: Australian Agriculture's Plan for a $100 Billion Industry*, NFF, 2018. https://www.nff.org.au/read/6187/nff-releases-2030-roadmap-guide-industry.html

14 PWC (UK), *Megatrends: Shift in Global economic power, PWC UK*, 2019, UK. https://www.pwc.co.uk/issues/megatrends/shift-in-global-economic-power.html.

15 Butler, J.R.A. et al., *Australia-Indonesia Centre Megatrends: Agriculture and Food*, Report prepared for the Australia-Indonesia Centre, Monash University, CSIRO, Australia, 2015. https://publications.csiro.au/rpr/download?pid=csiro:EP158473&dsid=DS3

16 Food and Agriculture Organization of the United Nations, *The Future of Food and Agriculture: Trends and Challenges*, Rome, FAO, 2017. http://www.fao.org/3/a-i6583e.pdf

17 Simpson, M. and Srinivasan, V., *Australia's Biosecurity Future: Preparing for future biological challenges*, Canberra, CSIRO, 2014. https://www.csiro.au/en/Research/BF/Areas/Our-impact-strategy/Biosecurity-Future-Report

Megatrends have the potential to irreversibly change the way we live and challenge the models we use to organise our societies.

important. Globally there is an increased focus on the sustainability of food production, with people beginning to pay attention to topics such as the environmental impact of meat production, food miles[18], and alternative sources of protein[19]. The serious water stress that impacts many areas of the planet, the generation of energy that depends on fossil fuels, and the serious risk of biodiversity loss are some of the factors that are raising serious concerns over the consumption of non-renewable resources.

These changes are directly impacting the health and biosecurity risks of livestock and aquaculture production systems in several ways including susceptibility to pathogen transmission, vector prevalence, and the re-distribution of feral intermediate hosts.

The combination of the global increase in consumer demand for animal meat (particularly in developing regions), declining environmental resources (land, water) and trends in sustainable farming, is driving the shift to large-scale intensive farming of livestock and aquaculture. This is increasing the risk and impact of major disease outbreaks that are difficult to predict and control and is likely to drive the increased use of antibiotics, further exacerbating issues associated with antimicrobial resistance (AMR). Globally, AMR is rising to dangerously high levels, leading to increased medical costs, prolonged hospital stays, and increased mortality.[20] AMR is driven by antibiotic misuse and the subsequent spread of resistant organisms between humans and animals and the wider environment and is therefore best addressed by a One Health approach.[21] Antibiotic consumption is projected to double in

18 Oxford University Press,'food mile', *Oxford Advanced Learner's Dictionaries*, 2019, https://www.oxfordlearnersdictionaries.com/definition/english/food-mile, (accessed 23 October 2019).

19 Crabbe, M., Moriarty, S., and Lieberman, G., *Mintel Global Consumer Trends*, 2018. http://www.mintel.com/mintel-reports, (accessed 23 October 2019).

20 Gelband, H. et al., *The State of the World's Antibiotics*, 2015; Washington D.C., Centre for Disease Dynamics, Economics and Policy, 2015. https://cddep.org/wp-content/uploads/2017/06/swa_edits_9.16.pdf

21 Department of Health and Department of Agriculture, 'Antimicrobial resistance', *Australian Government* [website], https://www.amr.gov.au/, (accessed 23 October 2019).

countries that are major producers and consumers of meat and fish (Brazil, Russia, India and China).[22] Consequently, importation of agricultural products from these regions pose significant risks for the introduction and spread of AMR, similar to the risks associated with emergency animal disease incursions.

Australian livestock industries are under constant threat from the potential risks of disease transmission by feral animals. Multiple species of animals have been introduced to Australia over time which has resulted in the establishment of numerous feral species across large geographic ranges. Many of these species are posing increasing biosecurity risks for the spread of diseases to livestock due to climate-induced environmental changes increasing their abundance and expanding ranges into urban and livestock production regions. Deer are closely related to cattle, sheep and goats, and thereby share many pathogens, including several of major agricultural importance including FMD, Bluetongue, anthrax, and ticks that may be capable of transmitting African swine fever (ASF).[23] Australia has approximately 1.2 million feral camels with a rangeland across half of Australia and are potential carriers of bovine tuberculosis and anthrax.[24] Middle East Respiratory Syndrome (MERS) is a zoonotic viral respiratory disease that is endemic in overseas camel populations. Humans can become infected following contact with camels or their products, followed by spread by human to human contact. MERS is untreatable and continues to be a serious emerging disease problem with 2,470 cases of infection being reported worldwide, resulting in 851 deaths since 2012.[25] Australia has a population of 24 million feral pigs that pose a significant biosecurity risk of transmitting diseases such as ASF, FMD, Swine Flu to domestic pigs, with catastrophic consequences. Another example is the re-distribution of bat colonies due to habitat loss caused by deforestation, unprecedented bushfires and severe droughts resulting in increased risk of zoonotic diseases such as Hendra and Nipah viruses being transmitted to horses and pigs and then to humans.[26] In addition, Australia has growing populations of feral buffalo, cattle, goats, sheep, horses and fish. Furthermore, climate-driven changes in biosecurity risks for plant pests and pathogens pose key risks to feed supply for the animal, aquaculture and fisheries sectors.

Biosecurity implications

- Mass disruption of natural habitats and changing climatic conditions will cause significant changes in disease vector and feral animal distribution and proximity to farmed animals, thereby increasing biosecurity risks to animal and aquaculture health.
- Changes in climatic conditions increases the risk of incursion, the subsequent establishment of new disease vectors and the re-distribution of feral animal intermediate hosts, increasing the pressure on our biosecurity system, in particular national border control and surveillance.
- The increasing trend to intensive livestock and aquaculture farming increases the consequences of disease outbreaks and associated AMR issues.
- A rapidly changing climate is causing major shifts in ecosystem diversity, some of which is linked to human activity (e.g. land clearing, spread of invasive species), consequently reducing the resilience of our natural environment to pests and diseases.
- The increased appreciation of the complexity of climate and environmental interactions is driving the need for new approaches to food safety risk assessments, AMR and safeguarding livestock and aquaculture health which will inform biosecurity risk management, including policymaking and decision-making.[27]

A rapidly changing climate is causing major shifts in ecosystem diversity...

22 Van Boeckel, T.P. et al., 'Global trends in antimicrobial use in food animals', *Proc. Natl. Acad. Sci. USA*, vol. 112, 2015, pp.5649–5654.

23 Cripps, J. K. et al., 'Introduced deer and their potential role in disease transmission to livestock in Australia', *Mam. Rev.*, vol. 49, 2019, pp.60-77.

24 Invasive Animals Ltd, 'Camel Scan', *FeralScan* [website], 2019, https://www.feralscan.org.au/camelscan/pagecontent.aspx?page=camel_largepopulations, (accessed 22 October 2019).

25 World Health Organization, 'Middle East respiratory syndrome coronavirus (MERS-CoV) - The United Arab Emirates', *WHO* [website], 31 October 2019, https://www.who.int/csr/don/31-october-2019-mers-the-united-arab-emirates/en/, (accessed 2 November 2019).

26 Grenfell, R. and Drew, T., 'The link between climate change and disease', *CSIROscope* [web blog], 31 July 2019, https://blog.csiro.au/link-between-climate-change-disease/, (accessed 22 October 2019).

27 Melba, G. et al., *Climate change-driven hazards on food safety and aquatic animal health*, FAO Fisheries and Aquaculture Technical Paper No. 627, 2019, pp.517-34.

1.2 Global interconnectedness and trade intensification

The increase in global travel and trade is leading to increases in the incidence of zoonotic diseases with wildlife and livestock being a key link in the spread of disease to humans.[28] There is a growing risk of a pandemic that could affect not only the health of animals but also people world-wide. Over the past three decades there has been a rise in the incidence of emerging infectious diseases (EIDs) in humans, with around 70 5 being zoonotic in nature – that is they can be passed from animals to people. Examples of high-mortality EIDs, for which there are limited or no treatments, include highly pathogenic avian influenza (HPAI), MERS, Nipah and Hendra.

In 1997, human infections with the HPAI (H5N1) virus were reported during an outbreak in poultry in Hong Kong. Since 2003, this avian virus has spread from Asia to Europe and Africa, and has become endemic in poultry populations in some countries. Outbreaks have resulted in hundreds of millions of poultry deaths, several hundred human cases, and many human deaths. The outbreaks in poultry have seriously impacted livelihoods, the economy and international trade in affected countries. In 2013, human infections with HPAI (H7N9) virus were reported for the first time in China. Since then, the virus has spread throughout the poultry population across the country and resulted in over 1500 reported human cases and hundreds of human deaths.[29]

Several factors have contributed to this increased incidence of EID outbreaks. The recent growth and geographic expansion of human populations, trade movement and increased tourism has resulted in a greater risk of EIDs being transmitted to people from wildlife and domesticated animals. Moreover, increased global travel means there is a greater likelihood that these new infectious agents can rapidly spread among the human population.[30] The threat of bioterrorism is also now a real concern voiced by many biosecurity experts. Intentional introduction of animal diseases is not common, but livestock have been targets of biological warfare or bioterrorism incidents[31] and countries are required to maintain a heightened alert to avoid any incursions especially at the point of entries such as airport and shipping terminals. Australia for the first time executed its new Biosecurity laws to deport international passengers for failing to declare food in their luggage. Testing of the intercepted pork products showed the presence of ASF virus.[32]

Biosecurity implications

- With the increased number of international visitors and rising trade movement, Australia is at a greater risk of incursion of infectious animal diseases such as ASF, FMD and HPAI, plant diseases (viruses, fungi) and environmental pests.
- It is imperative that we maintain our "disease free" status in order to retain our competitive advantage in international export markets for our livestock industries (meat, fibre, live-export).
- With the growth in online retailing and increased numbers of international travellers creating greater opportunities for the introduction of pests and diseases through illegal importation of food, increased funding and adoption of new detection technologies for our biosecurity system is vital.
- Maintaining high vigilance and developing and maintaining effective contingency plans is required to counteract the ever increasing threat of bioterrorism.
- Increasing strategic biosecurity investment in pre-border facilities in China, SE Asia and India, with whom Australia has maximum trade, is needed to strengthen our biosecurity preparedness.

28 Layton, D.S., Choudhary, A. and Bean, A.G.D., 'Breaking the chain of zoonoses through biosecurity in livestock', *Vaccine*, vol. 35, No. 44, 2017, pp.5967-5973.

29 World Health Organization (WHO), 'Newsroom – Fact Sheets – Detail – Avian and other zoonotic', *WHO* [website], 30 November 2018, https://www.who.int/news-room/fact-sheets/detail/influenza-(avian-and-other-zoonotic), (accessed 22 October 2019).

30 CSIRO, 'Animal and Human Health', *CSIRO – AAHL* [website], 7 December 2018, https://www.csiro.au/en/Research/Facilities/AAHL/Animal-and-human-health, (accessed 22 October 2019).

31 Elbers, A.R.W. and Knutsson, R., 'Agroterrorism Targeting Livestock: A Review with a Focus on Early Detection Systems', *Biosecurity and Bioterrorism: Biodefense Strategy, Practice, and Science*, vol. 11, no. S1, 2013, S25-S35. doi.org/10.1089/bsp.2012.0068

32 Sullivan. K., 'Sydney deports second tourist carrying pork in mooncakes amid fears of spreading deadly pig disease', *ABC News* [website], 4 November 2019, https://www.abc.net.au/news/2019-11-04/pork-filled-moon-cakes-turned-away-amid-fears-of-swine-fever/11668730, (accessed 8 November 2019).

1.3 Increased consumer expectations

The expectations of the modern consumer are changing - locally and globally. Consumers are now expecting environmentally-friendly and sustainable production with more information about the provenance of their food and fibre. This is causing agriculture, including the animal industry, to embrace new (increasingly digital) supply chain models, which creates a more direct connection to a product's point of origin.[33] Consumers are also embracing new food sources, such as free-range production and organic farming - a trend which is driving a dramatic reshaping of Australia's production systems.[34]

Besides being increasingly focussed on where their food and fibre come from and how they're produced, customers are showing greater interests in characteristics like nutritional profile, animal welfare, sustainability, safety, GM-free status, Fair Trade and Child Labour free products. This means farmers cannot be solely motivated by productivity and must therefore develop strategies to meet their customer's ethical, environmental and nutritional requirements.[35] Also, due to increased number of online marketplaces, just in 2014–15 alone, Australians spent an estimated $38 billion online to order more than 50 million international mail parcels. Because of that huge volume of goods coming into the country, it is vital that shopping websites are aware of and support Australia's biosecurity requirements to minimise the risk posed by goods sold online.[36] Moreover, communities in Australia and globally are also concerned about the risks of disease emergence, particularly associated with epidemics and pandemics (e.g. HPAI), and other major public health risks (e.g. Hendra virus).[37]

Increasing cultural diversity in Australia will drive demand for a number of new and imported food products. The recent census data reveals there are increasingly more Australians who were born in

33 PMG, *Talking 2030: Growing agriculture into a $100 billion industry*, KPMG, 2018, https://assets.kpmg.com/content/dam/kpmg/au/pdf/2018/talking-2030-growing-australian-agriculture.pdf, (accessed 22 October 2019).

34 Ridoutt, B. et al., 'Changes in Food Intake in Australia: Comparing the 1995 and 2011 National Nutrition Survey Results Disaggregated into Basic Foods', *Foods*, vol. 5, no. 2, 2016, p.40. doi:10.3390/foods5020040.

35 CSIRO, 'Mapping out Australia's Food Future', *CSIRO* [website], 17 July 2017, https://www.csiro.au/en/News/News-releases/2017/Mapping-out-Australias-food-future, (accessed 22 October 2019).

36 DAWR, 'Managing biosecurity and imported food risk', *Department of Agriculture* [website], 2019, http://www.agriculture.gov.au/about/reporting/annualreport/2015-16/part-2/managing-biosecurity-imported-food-risk, (accessed 22 October 2019).

37 Rowland, D., *Animal Biosecurity National Research, Development and Extension Strategy 2014: National Primary Industries Research, Development and Extension Framework*, Animal Health Australia 2014, ISBN 978-1-921958-20-5. https://www.npirdef.org/content/23/7c8dc80c/Animal-Biosecurity-RDE-Strategy.pdf

Asia and other parts of the world: first generation Australians now constitute 27% of the population. Australia's increasingly ethnic demographic is diversifying demand for a wider food range, including imported and processed meat products, halal-certified goods and alternate cuts of meat. This trend is likely to increase as food traditions pass through to future generations of ethnic Australians to 2050.[38,39]

Interestingly, some consumers are also looking for alternatives to traditional meat protein. The number of Australians taking up vegetarian diet is up 30% in the past four years and this trend is being compounded by government policies and dietary guidelines encouraging a shift to plant-based proteins in Australia and other countries. Globally, plant-based proteins are forecast to make up 33% of the protein market by 2054 up from a current market share of less than 5% by value (a 660% increase) and may act as a direct competitor to the meat industry in the coming years.[40] Both meat and alternative based proteins will clearly have a critical role to play in filling the dietary needs of 2 billion extra people over the next three decades, but our farming systems also need to dramatically evolve to produce more food using less land and resources, while maintaining a disease-free status.[41,42] Examples of novel products include uses of bio-preparations with microelements such as copper, iron, zinc and magnesium to produce a new generation of functional food and the use of biofortified milk and cheese to prevent micronutrient deficiencies.[43] In addition, Vitamin D deficiency is a major health concern, particularly in Europe and northern latitudes where sufficient synthesis of vitamin D through sunlight is limited. Biofortification of meat could contribute up to 25% of an individual's average requirement for vitamin D.[44]

Another key driver for this megatrend in Australia is the supermarket dynamics which are highly relevant to the red meat, dairy and egg industries. Their strategy of hard-nosed negotiations with suppliers and aggressive price discounting, has led to discontent amongst farmers and financial distress[45] causing many to leave the business, hence creating knowledge gaps around implementation of farm biosecurity management plans. In particular, supermarkets are driving demand for free-range poultry and pig production, which increases the risk of disease transmission from environmental and wildlife interactions.

Biosecurity implications

- Increased biosecurity risks in operating free-range systems due to supermarket and consumer demand. As an example, poultry will be exposed to potential sources of disease such as AI due to direct contact with wild birds, animals and insects.[46] Furthermore, increased exposure to food safety pathogens will increase antibiotic usage which will further impact AMR.
- With increased demand for provenance, stricter traceability and labelling laws may be imposed and improved data collection and analysis capability will be needed.
- Evolution of peri-urban production to cater for niche markets, may act as infection sinks and increase disease outbreak risks, without proper adoption of biosecurity practices.
- Due to financial stress caused by supermarket dynamics, loss of farmer knowledge of farm biosecurity practices and a lack of younger talent to fill these gaps created, will diminish industry capabilities to prevent and respond to biosecurity incidents.

38 Hogan, L., *Food demand in Australia: Trends and issues 2018*, ABARES Research Report 18, Canberra, 2018.

39 Hogan, L., 'Food demand in Australia: Trends and issues 2018', Department of Agriculture - *ABARES* [website], http://www.agriculture.gov.au/abares/research-topics/food-demand/trends-and-issues-2018#food-demand-2018-data-visualisation, (accessed 22 October 2019).

40 Lux Research, 'Alternative proteins to claim a third of the market by 2054', *Lux Research* [website], 24 February 2015, https://www.luxresearchinc.com/press-releases/alternative-proteins-to-claim-a-third-of-the-market-by-2054, (accessed 22 October 2019).

41 KPMG, *Talking 2030: Growing agriculture into a $100 billion industry*, KPMG, 2018. https://assets.kpmg.com/content/dam/kpmg/au/pdf/2018/talking-2030-growing-australian-agriculture.pdf, (accessed 22 October 2019).

42 FAO, *How to feed the world in 2050*, Food and Agriculture Organisation, n.d., http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf, (accessed 22 October 2019).

43 Witkowska, Z. et al., 'Biofortification of milk and cheese with microelements by dietary feed bio-preparations', *J.Food Sci Technol.*, vol. 52, no. 10, 2015, pp.6484-6492. doi:10.1007/s13197-014-1696-99.

44 Sarah, K. et al., 'Vitamin D-biofortified beef: A comparison of cholecalciferol with synthetic versus UVB-mushroom-derived ergosterol as feed source', *Food Chemistry*, vol. 256, 2018, pp.18-24.

45 McKinna et al., *Future Scan* [website], 2nd edn, Australia Meat Processor Corporation, 2015. https://www.ampc.com.au/uploads/pdf/strategic-plans/McKinna-Future-Scan-Final-Low-Res.pdf, (accessed 22 October 2019).

46 Business Queensland, 'Biosecurity and free range poultry farming', *Queensland Government* [website], 2019, https://www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/livestock/poultry/biosecurity-for-poultry-producers/biosecurity-free-range-poultry#targetText=There%20are%20increased%20biosecurity%20risks,animals%2C%20rodents%20and%20airborne%20infection, (accessed on 22 October 2019).

- Competition from non-traditional sources such as alternative food (protein) and fibres will see greater investment in R&D in the "alternate protein" sector, which may divert funding away from developing technological solutions to address current and future animal biosecurity challenges.

1.4 Technology accelerates

This megatrend directly impacts all other megatrends considered in this report. Technology development in robotics and automation are directly applicable to farming operations e.g. animal feed industry and dairy industry,[47] changing the efficiency and productivity of animal production and surveillance systems. Others, while not yet applied to farming systems, create new capabilities that will provide novel opportunities for changes in the way agricultural operations are executed. Wi-Fi and broadband technology have already transformed some farming operations; greater spatial data coverage and reliability is a critical feature underpinning the continued expansion of many aspects of precision technology and the on-farm use of extensive, integrated datasets.[48] A recent Agrifutures report[49] (*See Appendix A Megatrend Review*) has identified disruptive technologies in Australia. Some of the key technologies identified that may affect animal biosecurity include:

- The Internet of Things (IoT)
- Gene Editing (as distinct from GMO)
- DNA sequencing
- Synthetic biology
- Surveillance technologies.

IoT is linked to other applications including remote sensing for disease surveillance, big data analysis and sharing, robotics/artificial intelligence for diagnostics and risk-mapping for emergency disease management (preparedness, response, eradication and proof of disease absence).

Gene editing technologies allow small and precise heritable changes to the genome of animals and plants. It can replicate changes that occur in the natural processes of genetic variation in living organisms and take advantage of mutations that already occur in nature. Gene editing has already created improvements such as polled cattle, in-egg sex identification for poultry, and generatrion of virus-resistant pigs.[50] However, gene editing has a risk of being negatively perceived by consumers, largely because it may be seen to be associated with GMOs. Gene editing is distinct from GMO approaches as it does not incorporate foreign genes or gene fragments into the genome. As development and commercialisation of gene editing progresses, it is critical that the lessons from GMO cases be learned to ensure adoption of this technology for the benefit of Australian agriculture.

Regulatory approval of gene editing has recently been reviewed in Australia by the Office of the Gene Technology Regulator (OGTR). The OGTR has determined that genetic edits (that involve the deletion of one or a few nucleotides) are no different to changes that already occur in nature, and therefore do not pose an additional risk to the environment or human safety and health. Updated regulations that are now in effect, allowing the use of certain genome-editing techniques in plants and animals without the need for government approval.[51]

Synthetic biology uses knowledge and understanding of living organisms at a molecular level to (re)design existing biological systems. The products that can be developed using this technology range from food and fibre (e.g. synthetic meat and clothing) to biochemicals and biofuels, to high value pharmaceuticals.[52]

Lastly, animal health programmes need to be underpinned by efficient surveillance systems

47 Calleija, M., 'Implications of robotics and autonomous vehicles for the grain industry', *Australian Government – GRDC* [website], https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2018/02/implications-of-robotics-and-autonomous-vehicles, (accessed 22 October 2019).

48 Australian Academy of Sciences, Decadal Plan for Australian Agricultural Sciences 2017-26, *AAS* [website], November 2016, https://www.science.org.au/files/userfiles/support/reports-and-plans/in-progress-decadal-plans/decadal-plan-agricultural-sciences-final-draft-nov16.pdf, (accessed 22 October 2019).

49 GHD and Agthentic, *Emerging agricultural technologies*: Consumer perceptions around emerging agtech, Publication No. 18/048 Project No. PRJ-011141, Agrifutures Australia, 2018, https://www.agrifutures.com.au/wp-content/uploads/2019/01/18-048.pdf, (accessed 22 October 2019).

50 Tait-Burkard, C. et al., 'Livestock 2.0 – genome editing for fitter, healthier, and more productive farmed animals', *Genome Biology*, vol. 19, no. 204, 2018.

51 'Australian gene-editing rules adopt 'middle ground'', *Nature*, 2019, https://www.nature.com/articles/d41586-019-01282-8, (accessed 23 October 2019).

52 Rural Industries & Development Corporation, *National Rural Issues: Transformative technologies - Synthetic biology*, RIRDC publication no. 16/035, 2016, https://www.agrifutures.com.au/wp-content/uploads/publications/16-035.pdf, (accessed 22 October 2019).

which accurately and quickly detect and report disease occurrence patterns and guide activities to targeted regions so that timely interventions can yield desirable outcomes. New surveillance systems based on latest sensing technologies, big data analysis and citizen science methods should improve the identification and distribution of infectious diseases. Furthermore, these systems will improve the management of emergency responsiveness by employing real-time disease outbreak forecasting to generate dynamic risk maps.

Biosecurity implications

- Technological advancement and innovation across surveillance and monitoring; data and analytics; genetics; and user-friendly smarter devices will take a lead in addressing future biosecurity challenges.
- Development of low cost sensors and automated systems will allow better real-time identification of pests and diseases and act as a game-changer in implementing quarantine protocols.
- Gene editing will significantly increase the opportunities to breed animals that are resistant to viral infections. It should be noted that genetic modification has been used to generate pigs resistant to porcine respiratory and reproductive syndrome virus and classical swine fever virus. Identification of genes in warthogs or bushpigs that are associated with ASF-resistance could be engineered into the pig genome of commercial pig breeds to generate animals in which replication and/or disease burden after ASF infection is reduced.[53]
- Long-term decision making will be aided by prevalence of big data which will allow enhanced pest and disease preparedness.
- Tools for characterising previously unknown diseases, or variants of existing diseases, will use our growing 'omics' knowledge to predict the biology, host range and potential pathogenicity of new pathogens before they emerge and spread.[54]
- High-throughput screening for disease will improve testing of humans, animals and plants in areas of concentration, such as airports and ports. Rapid, non-invasive detection of characteristic volatiles or electromagnetic radiation from infected individuals could improve the ability to detect new introductions, perhaps in concert with portable on-the-spot detectors once suspect shipments were identified.[55]
- Automation will continue to improve quality of life for farmers, while reshaping the sector's skills needs.

1.5 Rapid population growth, increasing protein demand and fierce new competition

There has been an increasing pressure to meet the growing global demand for high-value animal protein. The world's livestock sector is growing at an unprecedented rate and the driving force behind this enormous surge is a combination of population growth, rising incomes (increased middle class, especially in Asia) and urbanization. Annual meat production is projected to increase from 218 million tonnes in 1997-1999 to 376 million tonnes by 2030.[56] There is a strong positive relationship between the level of income and the consumption of animal protein, with the consumption of meat, milk and

53 Netherton, C.L. et al., 'The Genetics of Life and Death: Virus-Host Interactions Underpinning Resistance to African Swine Fever, a Viral Hemorrhagic Disease', *Front. Genet.*, vol.10, 2019, pp.402., doi: 10.3389/fgene.2019.00402

54 Waage, J.K. and Mumford, J.D., 'Agricultural biosecurity', *Philos Trans R Soc Lond B Biol Sci.*,vol. 363, no. 1492, 2008, pp. 863-76. doi:10.1098/rstb.2007.2188

55 Waage, J.K., Mumford, J.D., 'Agricultural biosecurity', 2008.

56 World Health Organization, '3.4 Availability and changes in consumption of animal products', *WHO* [website], https://www.who.int/nutrition/topics/3_foodconsumption/en/index4.html, (accessed 22 October 2019).

eggs increasing at the expense of staple foods.[57]

Moreover, a major transformation currently taking place in the global economy is a shift towards emerging-market economies. It is anticipated that, in the next decade, they will become powerful economic sectors in their own right, with Asia the centre of global economic activity.[58,59] China overtook the United States in 2014 as the largest economy in terms of purchasing power parity. If present trends continue, by 2050 the economic and political influence of the G7 (Group of 7 - Canada, France, Germany, Italy, Japan, the United States, and the United Kingdom) will steadily shift to the E7 (Brazil, China, India, Indonesia, Mexico, Russia, and Turkey).[60] The growing demand for livestock and aquaculture products is likely to have an undesirable impact on the environment. For example, there will be more large-scale, periurban industrial production, which brings with it a range of environmental, biosecurity and public health risks.[61] Importantly, for Australia it is absolutely critical to service the demand by maintaining its pest and disease free status.

As the developing nations modernise their farming practices and supply chains, the combination of increased productive capacity overseas and reduced government protection of local producers and industries in Australia has created enormous competitive pressures for many Australian farm businesses. Offsetting this has been the development of new export markets and the growth of old ones, driven increasingly by the growing affluence of consumers in the Asia-Pacific region. Asia and Oceania now take nearly 90% of our exports.[62] Recently negotiated Free Trade Agreements (FTA's) are likely to shift the market access agenda. However, while trade appears to be opening up, this is being countered with increased technical trade barriers. It is expected that the recently negotiated FTA's will assist Australia's price competitiveness, but it does not necessarily mean that market access is assured. Increasingly, technical trade barriers, based largely on biosecurity matters, are blocking market access and often these barriers are politically motivated.[63]

In fact, recent analysis of the Australian red meat and dairy industries indicates that they may be losing out on trade worth $1.25 billion and $1.57 billion respectively, as a result of technical barriers to trade.[64] There is however continuous movement on Non-Tariff Barriers (NTB's), as certification and regulatory challenges are constantly changing with context and being negotiated by governments. In addition to tariffs and quotas, market access is also impeded by these NTB's. These are a result of each country's complex (and often bureaucratic) import and export requirements. Sometimes NTB's relate to genuine biosecurity or food safety concerns, in other cases they are imposed for protectionist reasons.[65]

Biosecurity implications

- For Australia to maintain its competitive advantage in the global market for primary produce it is imperative to maintain 'pest and disease free' status.
- Global forces threaten to disrupt the established rules of international trade and thus increased imports pose additional biosecurity threats.
- With a range of potential spread of zoonotic disease and AMR globally as population and animal production intensifies, government prioritisation in where to allocate funds in prevention, eradication and control, needs to be evaluated.Trade liberalisation will also affect the price differential between domestic, imported and exported products, with important potential implications for government policy on biosecurity.

57 WHO, 3.5 Availability and changes in consumption of animal products, 2019.

58 Ward, K., *The World in 2050: From the Top 30 to the Top 100, Global Economics – January 2012*, London, HSBC Global Research, 2012, https://big.assets.huffingtonpost.com/world2050.pdf, (accessed 22 October 2019).

59 Bisson, P. et al., *What happens next? Five crucibles of innovation that will shape the coming decade*, McKinsey & Company, 2010.

60 PWC UK, 'Shift in global economic power', *PWC UK* [website], https://www.pwc.co.uk/issues/megatrends/shift-in-global-economic-power.html, (accessed 22 October 2019).

61 European Strategy and Policy Analysis System (ESPAS), *Global trends to 2030: Can the EU meet the challenges ahead?*, EU project, https://ec.europa.eu/epsc/sites/epsc/files/espas-report-2015.pdf, (accessed 22 October 2019).

62 Department of Foreign Affairs and Trade, 'World Trade Organization: Agricultural Trade', *DFAT* [website], https://dfat.gov.au/trade/organisations/wto/Pages/agricultural-trade.aspx, (accessed 22 October 2019).

63 McKinna et al., *Future Scan*, 2nd edn, Australia Meat Processor Corporation, 2015. https://www.ampc.com.au/uploads/pdf/strategic-plans/McKinna-Future-Scan-Final-Low-Res.pdf, (accessed 22 October 2019).

64 Hudson, V., *International Trade Report: Non-tariff barriers facing Australia's agri-food exports*, The Australian Food and Grocery Council, 2015. http://www.pc.gov.au/__data/assets/pdf_file/0004/195871/sub028-agriculture-attachment.pdf, (accessed 22 October 2019).

65 Levantis, G and Fell, J., 'Non-tariff measures affecting Australian agriculture', *Department of Agriculture, ABARES* [website], http://www.agriculture.gov.au/abares/research-topics/trade/non-tariff-measures, (accessed 22 October 2019).

2

EFFECTS OF CLIMATE CHANGE ON BIOSECURITY

The increase in the atmospheric concentration of greenhouse gases such as carbon dioxide and methane has resulted in an increase in the global-average surface and water temperatures over the past century.[66] These changes have had consequences for rainfall patterns, the intensity of droughts, incidents of bushfires and the viability of ecosystems. Taken together, these changes have had substantial effects on the transmission patterns of infectious diseases and pests and associated biosecurity risks.

The impacts of climate change are altering the environmental conditions for agricultural systems worldwide and there is a clear need to mitigate these negative impacts if we are to meet future global food demands. In particular, Australian livestock producers face significant challenges in maintaining their high level of productivity, quality and sustainability in the face of consequential risks to animal health and biosecurity moving into the future.

According to the Intergovernmental Panel on Climate Change (IPCC)[67] regional climates and ecosystems will be impacted into the future. Globally, there are predicted to be threats to food security due to climate change impacts that decrease crop yields for both human and animal consumption.

The global-warming induced shifts in climate zones in many world regions has led to increases in rainfall intensity, flooding, and drought frequency and severity.[68] Australian climatic zones are already shifting in a southerly direction.[69] Australian farmers can increasingly expect that higher temperatures will reduce crop yield and can expect rainfall to be reduced in the south (particularly over autumn and winter), but increased in the north-west.[70] The corresponding changes in geographical range of agricultural pests and diseases are resulting in new and compounded health and biosecurity risks.

2.1 Impact of climate change on ecosystem services for livestock production

Ecosystem services are the various benefits that humans gain from the natural ecosystem and include water availability and quality, soil health, air quality, biodiversity, and many other planetary 'life-support' services.[71] The continued prosperity of animal production businesses requires the safeguarding of our natural capital and the

66 Intergovernmental Panel on Climate Change (IPCC), *IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystem: Summary for Policy Makers, Approved Draft*, IPCC, 2019, https://www.ipcc.ch/site/assets/uploads/2019/08/4.-SPM_Approved_Microsite_FINAL.pdf, https://www.ipcc.ch/report/srccl/ (accessed 19 September 2019).

67 *IPCC Report and SPM*, IPCC, 2019, (accessed 19 September 2019).

68 *IPCC Report and SPM*, IPCC, 2019, (accessed 19 September 2019).

69 Stephens, D., Australian Export Grains Innovation Centre (AEGIC), cited in M. .Hambrett, 'The future of farming in the era of climate change', *ABC News* [website], 2 March 2019, https://mobile.abc.net.au/news/2019-03-02/the-future-of-farming-in-the-era-of-climate-change/10852926), (accessed 19 September 2019).

70 Howden, M., *Our Changing Climate Risk*, Opening Plenary Presentation to Farmers for Climate Conference October 2018, https://d3n8a8pro7vhmx.cloudfront.net/farmersforclimateaction/pages/1346/attachments/original/1555295536/Opening_plenary_Howden.pdf?1555295536, (accessed 19 September 2019).

71 United Nations Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (UN IPBES), *IPBES Global Assessment Report on Biodiversity and Ecosystem Services UN IPBES 2019 7th Report, UN Sustainable Goals*, [website], 6 May 2019, https://www.un.org/sustainabledevelopment/blog/2019/05/nature-decline-unprecedented-report/, (accessed 19 September 2019).

ecosystem services it provides, including from our grassland, forest and aquatic habitats. Ecosystem services, biodiversity, health, biosecurity and climate change are inextricably linked with the liveability and functionality of livestock and urban businesses and communities.

Sustainable animal production now relates to more than what happens just within the paddock, or even the farm business, but needs to embrace ecologically sustainable farming practices at landscape scales. Mitigating the impacts of climate change, and the associated increased risks of biosecurity incursions and adverse biodiversity changes, all need to be incorporated as part of a holostic approach to future farming practices.

2.2 Impact of climate change on animal biosecurity

Emerging infectious diseases and their vectors represent a large and increasing threat to Australian and global livestock industries into the future. Climatic changes are altering the habitat range of many livestock and human disease vectors (including ticks, midges and mosquitos)[72] as well as the carriers (reservoirs) for these diseases (feral pigs, deer, bats, waterbirds). This will result in the movement of disease into new areas and increase the risk of introduction and spread of livestock disease into expanded geographical regions. This also raises the possibility that diseases may 'jump' between species of vectors increasing the risk of disease spread, in particular the transfer of zoonotic diseases from animals to humans. Studies in Europe have shown that some pathogenic viruses can be transmitted by multiple vectors, thereby allowing spread to different climatic regions and enabling increased persistance.[73] Similar climate-driven re-distributions of disease vectors could occur in Australia following incursions through importation of agricultural products. Increases in biosecurity risk of incursion of exotic diseases, both known and unknown, is most likely to result from increased movement of people and trade. To 2025, Australia can expect a 28% increase in shipping, 72% more passengers, 75% more containers, and 100% more containerised cargo.[74]

The increase in average temperature and changes in rainfall patterns are very likely to shift the distribution of insect-borne diseases such as Cattle Tick Fever, Babesiosis and Anaplasmosis. These are

72 Bett, B. et al., ' Effects of climate change on the occurrence and distribution of livestock diseases', *Prev. Vet. Med.*, 2017, https://doi.org/10.1016/j.prevetmed.2016.11.019 CrossRefGoogle Scholar

73 Foxi, C. et al.,'Role of different Culicoides vectors (Diptera: Ceratopogonidae) in bluetongue virus transmission and overwintering in Sardinia (Italy)', *Parasit. Vectors*, vol. 9, no.1, p. 440. doi:10.1186/s13071-016-1733-9

74 L. O'Connor, June 2019, pers. comm.

examples of diseases that already cause severe losses in productivity, food security and socio-economic development, and an increase in their incidence or geographical coverage would intensify these losses. Even more critically, these changes increase the biosecurity risk of incursions of emergency disease that are transmitted by insect vectors and spread by reservoir hosts such as feral pigs, bats and waterbirds. Key diseases include (but are not limited to) Bluetongue, African Horse Sickness, ASF, Rift Valley Fever and Japanese Encephalitis.

Changes in freshwater temperatures and availability due to climate change can result in changes in mosquito populations that can carry and transmit diseases such as Rift Valley Fever, Japanese Encephalitis, West Nile, and Equine Encephalitis. Increased change to globalisation and landscape modification has resulted in widespread emergence and re-emergence of pathogens via changes in mosquito-friendly habitats and/or the introduction of more-adaptible mosquito species.[75] Furthermore, vector and viral adaptation to global climate change will place more animal and human populations at risk of these (in particular zoonotic) pathogens.

Bluetongue viruses are transmitted by biting Culicoides midges and cause disease in all ruminants, including cattle, goats, buffalo, camelids and deer, with sheep being the most severely affected.[76] Changing climatic conditions are altering the global distribution of BTV.[77] Australia has eight species of Culicoides midges with a current distribution range across northern and central Australia, however changes in temperature are likely to extend the range of this vector to sheep producing areas in southern regions. An incursion of Bluetongue virus is therefore more likely to spread due to a wider geographical range of vectors and potential wild hosts (feral goats, deer, camels).

Australian aquaculture industries have competitive advantages due to their ability to produce a large number of species over a range of climatic zones and due to their freedom from many of the diseases that affect aquaculture in other countries.

Ticks are important vectors of a wide range of pathogens that cause many diseases in livestock such as ASF, Cattle Tick Fever, anaplasmosis, babesiosis, and Q-Fever. These diseases can cause high mortality, especially in intensive production systems or result in losses due to lower fertility, reduced growth and productivity and increased susceptibility to other diseases. From a global perspective, a rise in temperature has the potential to expand the geographical range of about 50% of tick species, with 70% of these involving economically important tick species.[78] This is of particular concern to the pig industry and exacerbated with the increased range and number of feral pigs and their increasing urban proximity.

Ticks are a major parasite of cattle in northern Australia, with European breeds being most susceptible. Cattle ticks can also survive on other animals, e.g. sheep, goats and horses. There are several species of ticks, including the bush tick (Haemaphysalis longicornis), paralysis tick (Ixodes holocyclus) and cattle tick (Boophilus microplus). According to MLA, the annual on-farm cost of ticks (production losses plus control costs) to the Australian cattle industry is $146 million.[79]

Global aquaculture production has grown more than 6-fold over the past four decades and will soon account for half the world's fish production.[80] Australia has a reputation for producing safe, sustainable, high-quality and high-value

75 Bartlow, A. et al., 'Forecasting Zoonotic Infectious Disease Response to Climate Change: Mosquito Vectors and a Changing Environment', *Vet. Sci.* , vol.6, no.2, 2019. doi:10.3390/vetsci6020040.

76 Agriculture Victoria, 'Bluetongue Virus', *Agriculture Victoria* [website], 5 December 2017, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/animal-diseases/general-livestock-diseases/bluetongue-virus, (accessed 22 October 2019).

77 Samy, A. and Peterson, A., 'Climate Change Influences on the Global Potential Distribution of Bluetongue Virus', *PLoS One*, vol. 11, no. 3, 2016, e0150489. doi:10.1371/journal.pone.0150489

78 Wikel, S., 'Ticks and Tick-Borne Infections: Complex Ecology, Agents, and Host Interactions'. *Vet. Sci.*, vol. 5, no. 2, 2018, p.60. doi:10.3390/vetsci5020060

79 Meat and Livestock Australia, 'Animal health, welfare and biosecurity: Ticks', *MLA* [website], 2019, https://www.mla.com.au/research-and-development/animal-health-welfare-and-biosecurity/parasites/identification/ticks/, (accessed 22 October 2019).

80 DAWR, 'National Aquaculture Strategy and Water Resources', *Department of Agriculture* [website], 2019, https://www.agriculture.gov.au/fisheries/aquaculture/national-aquaculture-strategy, (accessed 22 October 2019).

aquaculture products. Australian aquaculture industries have competitive advantages due to their ability to produce a large number of species over a range of climatic zones and due to their freedom from many of the diseases that affect aquaculture in other countries. Maintaining this disease-free status is important for the aquaculture industry to ensure growth and profitability is not jeopardised

by exotic pathogens or the emergence of endemic pathogens. Recent disease outbreaks in the prawn, abalone and oyster industries serve to highlight the scale of losses that can be suffered in aquaculture and wild fisheries when disease strikes. Increases in ocean temperatures pose significant biosecurity risks to fishery and aquaculture industries. Incursions of exotic diseases and pest species (many of which harbour exotic pathogens) through illegal importation and release of ship ballast water, have increased their chance of survival and spread due to higher water temperature.

2.3 Biosecurity risks for livestock pasture, grain feed and natural grazing habitats

The changing temperatures in different regions of Australia will impact the temperature dependant development cycles of insects that are pests of animal feed crops, as well as vectors of animal and plant diseases. Modelling the temperature and other climatic requirements of existing, and not-yet present in Australia (exotic) weeds, pests and diseases can enable an improved assessment of biosecurity risk both to Australia, and to specific regions within Australia.[81,82]

As well as direct biosecurity risks for livestock, there will be changing biosecurity risks for the insect and pathogen pests of livestock fodder and grain, as well as changing growth patterns and therefore availability of the feed plants themselves. This in turn will impact the availability and quality of both local and bought (transported-in) grain and other plant feedstocks for livestock.

...there will be changing biosecurity risks for the insect and pathogen pests of livestock fodder and grain, as well as changing growth patterns...

81 Kriticos, D. et al., 'Regional climate-matching to estimate current and future sources of biosecurity threats', *Biological Invasions*, vol.14, no. 8, 2012, pp.1533-1544.

82 Aurambout, J., Finlay, K, and Beattie, G., 'A concept model to estimate the potential distribution of the Asiatic citrus psyllid', *Ecological Modelling*, vol. 220, no. 19, 2019, pp.2512-2524.

3

CURRENT AHA AND LIVESTOCK INDUSTRY STRATEGIES

Domestic livestock industries and AHA have developed a range of strategies over the past decade to articulate their respective roles in the support and development of their industries. In developing the current context and contemplating future scenarios for industry to consider, some reflection was undertaken of these strategies in order to identify complementarities, challenges and opportunities.

AHA works with government agencies, commercial companies, industry peak bodies, rural development corporations and research organisations (notably members listed in *Appendix B AHA Role and Responsibilities*) across the livestock production chain to maintain Australia's high standard of animal health.

Australia's competitive advantage in global livestock trade markets is its "supply chain integrity and product quality" and to this end, AHA's mission is to assist its members and partners to enhance, strengthen and protect animal health and the sustainability of Australia's livestock industries.[83]

The contribution of primary production to the national economy is very significant and warrants strenuous efforts to safeguard continued domestic and international market access.

AHA's strategic priorities[84] are to:

- effectively manage Australia's Emergency Animal Disease (EAD) response arrangements through partnerships with members
- enhance EAD preparedness and response capability of AHA and its members
- strengthen biosecurity, surveillance and animal welfare to enhance animal health and support market access and trade
- deliver member value, enhance organisational performance, and sustainable resourcing.

AHA works with industry and government partners by supporting and at times coordinating a wide range of activities including:

- terrestrial and aquatic animal health disease surveillance and management programs
- managing animal health emergencies (including response plans and coordination of biosecurity planning and EAD responses)
- livestock traceability, biosecurity and quality assurance programs
- coordinating animal health laboratories (Government, private, international)
- research and development strategies with organisations, CRCs, sector R&D corporations
- trade - international standards, exports, imports
- animal welfare - working together with industry and State governments to coordinate standards
- one Health, including antimicrobial resistance and surveillance for zoonotic diseases
- consumer food protection - food standards, hazards, import risks, foodborne disease
- regional animal health initiatives including pre-border surveillance and international animal health research.

83 Animal Health Australia, *AHA Strategic Plan 2015-20*, Australian Animal Health Council Ltd, AHA [website], 2019, https://www.animalhealthaustralia.com.au/our-publications/corporate-publications/strategic-plan/, (accessed 22 October 2019).

84 *AHA Strategic Plan 2015-20*, 2019.

AHA's Strategy states a number of key areas including:

Biosecurity: Australia has a long history of freedom from the major epidemic diseases of livestock. While our geographical isolation provides some level of protection, we need a strong biosecurity system that protects human, animal and plant health as well as our unique environment from the threat of pest and disease incursions. This reputation underpins our status as a safe, reliable trading nation and delivers a strong price advantage. This requires a modern biosecurity system that is responsive and targeted in a changing global trading environment.

EAD preparedness: AHA is responsible for managing our preparedness for specific disease incursions (see Appendix B AHA Role and Responsibilities). Recently, a number of diseases have received attention including FMD, ASF, AI and Hendra virus.

Trade: The export of live animals, reproductive material and animal products from Australia must meet the health requirements of importing countries while protecting the ongoing health and viability of Australia's livestock, wildlife, agriculture and other enterprises.

Welfare: While the Australian Government has responsibility for animal welfare relating to trade and international agreements, legislative responsibility for animal welfare rests primarily with State and Territory governments. AHA works together with industry and State governments to drive continuous improvement in animal welfare.

One Health: The One Health concept acknowledges that human and animal health are interdependent and are connected to the health of the environment. A One Health approach is critical for combating the growing global threat of AMR and emerging zoonotic diseases (approximately 70% of all emerging human infectious diseases originate from animals). AMR is driven by the spread of antibiotic-resistant organisms arising from antimicrobial misuse and overuse and poses a global risk to human and animal health.

The Animal Biosecurity RD&E strategy is based on broad industry support for the important role that RD&E plays in underpinning the productivity, growth, competitiveness and sustainability of Australia's livestock industries and their access to markets.

Individual peak industry and associate members of AHA, as well as other stakeholders, have Strategic Plans that focus on their particular industry priorities and goals. The timespans of their strategies vary considerably:

- Long term – RMAC 2030[85]; NFF 2030[86]; Aquaculture 2027[87];
- Short/Medium term – Wool 2022[88]; Egg 2021[89]; Biosecurity R&D 2022[90]
- Ending soon/need updating – MLA[91], APL[92], Dairy[93], AQUAPLAN.[94]
- There are several common and overarching goals amongst the majority of AHA members including:
- Maximising value for money;
- Increasing product demand – most scope is via trade;
- Increasing sustainability of production (especially health and biosecurity).

There are also a number of overarching and common challenges, opportunities and threats

85 Red Meat Advisory Council, *The Meat Industry Strategic Plan 2020-30*, RMAC [website], https://rmac.com.au/our-sustainable-future/meat-industry-strategic-plan-2020/, (accessed 22 October 2019).

86 National Farmers' Federation, *NFF 2030 Roadmap*, NFF, 2018, https://www.nff.org.au/read/6187/nff-releases-2030-roadmap-guide-industry.html, (accessed 22 October 2019).

87 DAWR, 'National Aquaculture Strategy 2017-2027', *Department of Agriculture* [website], 2019, http://www.agriculture.gov.au/fisheries/aquaculture/national-aquaculture-strategy, (accessed 22 October 2019).

88 Australian Wool Innovation Ltd, *Australian Wool Innovation Strategic Plan 2019/20 to 2021/22*, https://www.wool.com/globalassets/start/about-awi/publications/awi-strategic-plan-2019-2022.pdf, (accessed 22 October 2019).

89 Australian Eggs Ltd, *Australian Eggs Strategic Plan 2017-2021*, Australian Eggs Ltd, 2017, https://www.australianeggs.org.au › dmsdocument › 740-strategic-plan-pdf, (accessed 22 October 2019).

90 Animal Health Australia, *National Animal Biosecurity Research, Development and Extension Strategy 2017-22*, https://www.npirdef.org/content/86/d6b19139/Animal-Biosecurity-RD-E-Strategy_digital.pdf, (accessed 22 October 2019).

91 Meat & Livestock Australia, *MLA Strategic Plan 2016-20*, MLA, 2016, https://www.mla.com.au/globalassets/mla-corporate/about-mla/documents/who-we-are--corporate-goverance/mla-strategic-plan_doc_2020_web.pdf, (accessed 22 October 2019).

92 Australian Pork Limited, *APL 2015–2020 Strategic Plan*, Australian Pork Ltd, 2015, https://australianpork.com.au/latest-news/strategic-plan-2015-2020/, (accessed 22 October 2019).

93 Dairy Australia, *Dairy Australia Strategic Plan 2016/17 to 2018/19*, Dairy Australia, 2016, https://www.dairyaustralia.com.au/publications/dairy-australia-3-year-strategic-plan?id=0D864E18B04E41279D3FA6A701547306, (accessed 22 October 2019).

94 Department of Agriculture, 'AQUAPLAN - Australia's National Strategic Plan for Aquatic Animal Health 2014-19', *Department of Agriculture* [website], http://www.agriculture.gov.au/animal/aquatic/aquaplan, (accessed 22 October 2019).

amongst AHA members that are linked to their Strategic Plans as described below:

Challenges

- Increasing the productivity and efficiency of meat, aquaculture, dairy and fibre production while maintaining an international reputation for high quality;
- Maintaining the health status of our animals is our number one priority;
- Strengthening emergency disease preparedness and response capability;
- Mitigating risks which could either reduce demand for products and/or impose impediments to productivity or introduce trade barriers;
- Leading sustainability - sustainable farming while lowering cost of production;
- Meeting new requirements for product traceability and provenance;
- Identifying biosecurity risks and developing mitigation strategies:
- Minimising risk and impact of emergency disease has the one of the biggest benefit:cost ratios (e.g.13:1 for beef) over the next 10 years;

- In particular, reviewing techniques and management strategies to mitigate the risk of disease transmission from non-farm animals.
- AMR – supporting initiatives which help to conserve the effectiveness of existing antibiotics for both veterinary and human applications (feral pests and wildlife);
- Minimising the impact of endemic disease - vaccines and other measures.

Opportunities

- Increasing global demand for quality Australian meat, aquaculture, dairy and fibre products;
- Building and growing new markets including key Asian markets;
- Improving health and biosecurity capability - adoption of information and technologies to improve productivity;
- Increasing engagement with, and training of private Veterinarians;
- Increasing focus on on-farm biosecurity;
- Adopting technologies that enhance effectiveness of surveillance and diagnostic services;
- Developing new alternative preventative measures and treatments for infectious diseases;
- Implementing genetic technologies.

Threats

- Preparedness for new types of EADs, particularly zoonotic diseases and the threat of bioterrorist activities;
- Trade barriers;
- AMR – eventuality of stricter antibiotic usage or possible bans;
- Competition from alternative (non-animal) protein and fibre products;
- Lack of recognition that some priorities may be long term threats but require short term or immediate investment to address (e.g. climate change, bioterrorism, politics;)
- Changing climate can alter the range, habitat and spread of pests and diseases.

Gaps

This meta-analysis has identified significant gaps and inconsistencies across individual industry strategies including:

- industries have taken different timeframes for their strategic planning – most have taken a short-term approach (usually 3 years)
- while animal health is a key factor that determines productivity and competitiveness, some industries have not clearly highlighted or prioritised biosecurity issues
- gaps in capability and external investment associated with national priorities are often not clearly articulated
- incomplete understanding or appreciation of the sociological factors associated with the adoption of risk mitigation measures by industry stakeholders and the general public
- limited application of the knowledge base and protocols for managing the invasion risks in complex behavioural and social systems posed by one sector for stakeholders in a different sector. For example, a biosecurity incursion affecting one species (pest, weed or disease incursion that effects feed crop or grain) impacting on another species (animal or aquaculture)
- insufficient mechanisms for cost-effectively demonstrating the absence of significant pests and diseases
- discussions are needed on considerations and pathways associated with the adoption of new technologies to reduce biosecurity risks.

COMMERCIAL OUTLOOK

4

4.1 Global protein markets

Currently the globally predominant form of protein for (direct) food consumption is animal derived. There are notable regional differences in the ratios of plant and animal protein. The World Economic Forum (WEF) recently suggested the key protein competitors are (Table 1):[95]

The WEF report identifies major (or mega) trends that impact the adoption of alternative proteins.[96] These trends include:

- greenhouse gas emissions
- land and water usage changes
- diet related mortality risk profiles
- nutrient intake profiles
- protein prices

These trends will impact the (direct) protein consumption patterns. However, 'an important conclusion from the report is that for the foreseeable future the meat and protein alternatives industries will coexist and that, as a result, there are great opportunities for synergies'.[97]

Alternative proteins that can act as substitutes for traditional animal-based foods are currently attracting considerable financial investment, research attention and interest...

The WEF report identifies a number of assumptions that will require testing and ongoing review through the coming decade and beyond in order for animal and alternative protein industries to adapt.

Alternative proteins that can act as substitutes for traditional animal-based foods are currently attracting considerable financial investment, research attention and interest from the media, as a pathway to meeting the nutritional needs and food

Table 1 Protein alternatives

Types of meat	Fruit and vegetables	Processed non-animal substitutes	Novel alternatives
Beef (cattle meat)	Nuts	Tofu/soybeans	Cultured meat
Pork	Peas	Wheat-gluten/seitan	Insects
Chicken	Beans	Mycoprotein/fungus	Alga spirulina
	Jackfruit		

Source: WEF, *'Meat: the Future' series: Alternative Proteins*, 2019, p.10.

95 World Economic Forum (WEF), *'Meat: the Future' series: Alternative Proteins*, Prepared by the Oxford Martin School, Oxford University for the World, Geneva, WEF, January 2019, p.10. http://www3.weforum.org/docs/WEF_White_Paper_Alternative_Proteins.pdf, (accessed 10 October 2019).

96 *WEF, 'Meat: the Future' series*: Alternative Proteins, pp.11-15.

97 *WEF, 'Meat: the Future' series*: Alternative Proteins, p. 5.

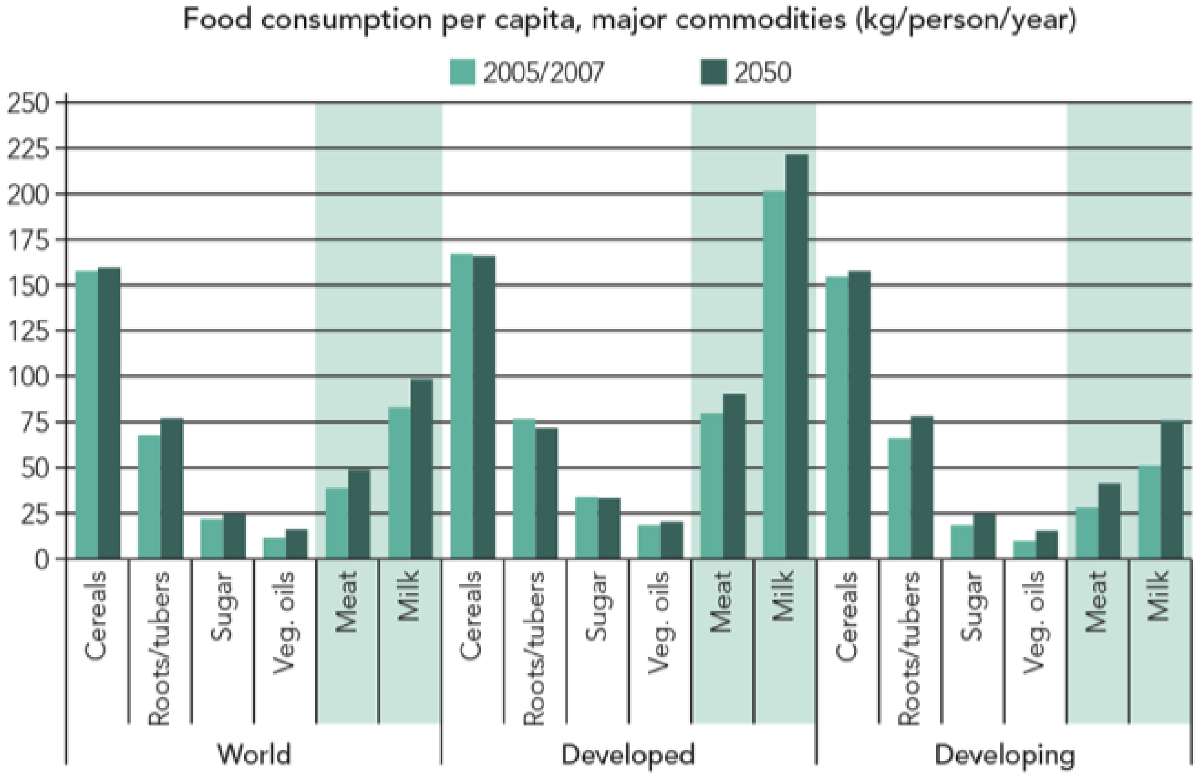

Figure 1. Food consumption per capita.

Source: FCRN, 4.2 Trends in food consumption – past and future', FCRN Foodsource, [website], n.d., https://foodsource.org.uk/book/export/html/41. (accessed 19 September 2019).

demands of a predicted mid-century population of 10 billion, in a healthy and sustainable manner (Figure 1).[98,99] The interest appears to be strongest from developed economies.

Globally, per capita consumption of animal products (meat and dairy) is projected to rise, while total meat consumption is expected to nearly double (Figure 1). To meet this demand, an additional 200 million tonnes of meat would need to be produced annually by 2050, compared with production in 2005/07. Meat, dairy, eggs and fish currently provide 40% of the world's protein supply and 18% of its calories.[100]

Much of the debate about meat production today centres on its environmental impact and in particular its greenhouse-gas emissions.[101] Impacts vary greatly between livestock types and production systems. Red meat (cow, sheep and goat) production is a particularly large source of greenhouse gases because of methane production in ruminant digestion. Approximately 15% of anthropogenic greenhouse-gas emissions come from livestock production, of which 40% are due to beef and dairy farming.[102,103,104]

In developed countries, aggregate meat consumption is not projected to rise much before 2050, if at all - since population growth is likely to be negligible and even negative in some countries, while per capita intakes also level off. In some countries, such as the United States, meat consumption has even started to decrease possibly due to increasing awareness of health concerns and to the weakened economy since the United States' recession in 2008. Other developed countries

98 H. Godfray et al., Food security: The challenge of feeding 9 billion people', *Science*, vol. 327, 2010, pp.812-818.

99 H. Godfray et al., 2010.

100 World Economic Forum (WEF), '*Meat: The Future' series: Options for the Livestock Sector in Developing and Emerging Economies to 2030 and Beyond*, Prepared by the Oxford Martin School, Oxford University for the World, Geneva, WEF, 2019, https://www.weforum.org/whitepapers/meat-the-future-series-options-for-thelivestock-sector-in-developing-and-emerging-economies-to-2030-and-beyond, (accessed 10 October 2019).

101 Buckwell, A. and Nadeu, E., *What is the 'safe operating space for EU livestock?*, Rural Investment Support for Europe (RISE) Foundation, Brussels, 2018. http://www.risefoundation.eu/images/files/2018/2018_RISE_LIVESTOCK_EXEC_SUMM.pdf, (accessed 10 October 2019).

102 Gerber, P. et al., *Tackling Climate Change Through Livestock: A global assessment of emissions and mitigation opportunities*, Rome, Food and Agriculture Organization (FAO), 2013. http://www.fao.org/3/a-i3437e.pdf, (accessed 10 October 2019).

103 Herrero, M. et al., 'Livestock and greenhouse gas emissions: The importance of getting the numbers right', *Animal Feed Science and Technology*, vol. 166, 2011, pp.779- 82.

104 Livestock, Environment and Development (LEAD) Initiative and the Food and Agriculture Organization of the United Nations (FAO), Livestock's Long Shadow: *Environmental issues and options*, Rome, FAO, 2006. http://www.fao.org/3/a0701e/a0701e00.htm, (accessed 10 October 2019).

showing decreased per capita meat consumption since 2008 include Canada and the UK. Demand in China and Brazil is also expected to eventually level off as saturation point is reached. The majority of the increase in expected meat production to 2050 is therefore projected to occur in developing countries, where significant income rises and population growth are, as mentioned, also expected. Population size in Sub-Saharan Africa is projected to nearly double, from 730 million in 2006 to 1.68 billion in 2050. This growth in population accounts for most of the overall growth in expected total animal product consumption – per capita intakes are not anticipated to rise substantially because poverty is likely to persist (per capita intakes of fish are actually thought to likely decline). Rapid growth in demand for meat is also expected in South Asia (although meat demand in India starts from a very low per capita baseline), and also in the Middle East/North Africa.[105]

A.T. Kearney have undertaken an analysis of likely disruptions of the meat industries by new technologies.[106] They categorised the market by conventional, novel vegan meat replacement (aka plant protein) and cultured meat (being cell-based,'slaughter-free' meat). Their report suggests that while global meat demand will increase by 3% p/a, consumption of conventional meat may drop by a third over the next 20 years with improving quality and reducing cost of alternative protein products gaining markt share (Figure 2).

To date, the most commercially successful novel protein products include those based on fungi-derived (mycoprotein)[107] and plant-derived[108,109] proteins. Insects have also received considerable attention as a protein source, in particular because they can be reared on low value feed that is unsuitable for livestock and which otherwise would be wasted, thus contributing to a more 'circular' agricultural economy.[110] Innovation in this area includes the discovery and investigation of new insect species of value for food production, and developments in how they may be produced economically at scale. High nutritional value, minimal space requirements, and low environmental impact combine to make insects an appealing option for animal feed. Another major advantage is that insects are already used for the natural part of many animal diets and are particularly attractive when considering the cost of standard feeds, currently accounting for 70% of livestock-production expenses. In addition to the nutritional value, insect-based feed could have a further advantage in improving the taste of final meat products. In the Philippines, for example, consumers prefer the taste of pasture-grown chickens fed with grasshoppers, resulting in higher price compared with chickens raised on commercial feed. Furthermore, replacing fish meal with dried mealworm increased egg production by 2.4%.[111] Insects are also growing in popularity for human consumption and are being developed as alternative forms of flour.[112]

Producing meat in the laboratory without the involvement of living animals is a huge technical feat made possible by the advancement of novel bio-technologies.[113] An additional issue that this approach addresses is the growing social concerns over animal welfare in livestock production systems.[114] Only in the past decade have technologies advanced enough to make this conceivable, with forms of meat that might be used in products which traditionally contain minced

An additional issue that this approach addresses is the growing social concerns over animal welfare in livestock production systems.

105 Food Climate Research Network (FCRN),'4.2 Trends in food consumption – past and future', *FCRN Foodsource,* [website], n.d., https://foodsource.org.uk/book/export/html/41, (accessed 19 September 2019).

106 Gerhardt, C. et al., 'How Will Cultured Meat and Meat Alternatives Disrupt the Agricultural and Food Industry', *AT Kearney* [website], https://www.atkearney.com/retail/article/?/a/how-will-cultured-meat-and-meat-alternatives-disrupt-the-agricultural-and-food-industry, (accessed 19 September 2019).

107 Quorn Foods, *Quorn*, [website], 2019, https://www.quorn.co.uk/, (accessed 19 September 2019).

108 Beyond Meat, *Beyond Meat* [website], https://www.beyondmeat.com/products/, (accessed 19 September 2019).

109 Impossible Foods Inc, *Impossible* [website], 2019, https://impossiblefoods.com/food/, (accessed 19 September 2019).

110 van Huis, A., 'Potential of insects as food and feed in assuring food security', *Annual Review of Entomology*, vol. 58, 2013, pp.563– 83.

111 Kim, T.K. et al., 'Edible Insects as a Protein Source: A Review of Public Perception, Processing Technology, and Research Trends', *Food Sci. Anim. Resour.*, 2019; vol. 39, no.4, 2019, pp.521–540. https://www.ncbi.nlm.nih.gov/pubmed/31508584

112 Bizarre Food, *Bizarre Food*, [website], 2019, https://www.bizarrefood.com/insect-bug-flour-powder, (accessed 19 September 2019).

113 Kadim, I et al., 'Cultured meat from muscle stem cells: A review of challenges and prospects', *J. Integ.r Ag.r*, vol.14, 2015, pp.222-33.

114 Dawkins, M.S., 'Animal welfare and efficient farming: is conflict inevitable?', *Animal Production Science*, vol. 57, 2017, pp.201-208.

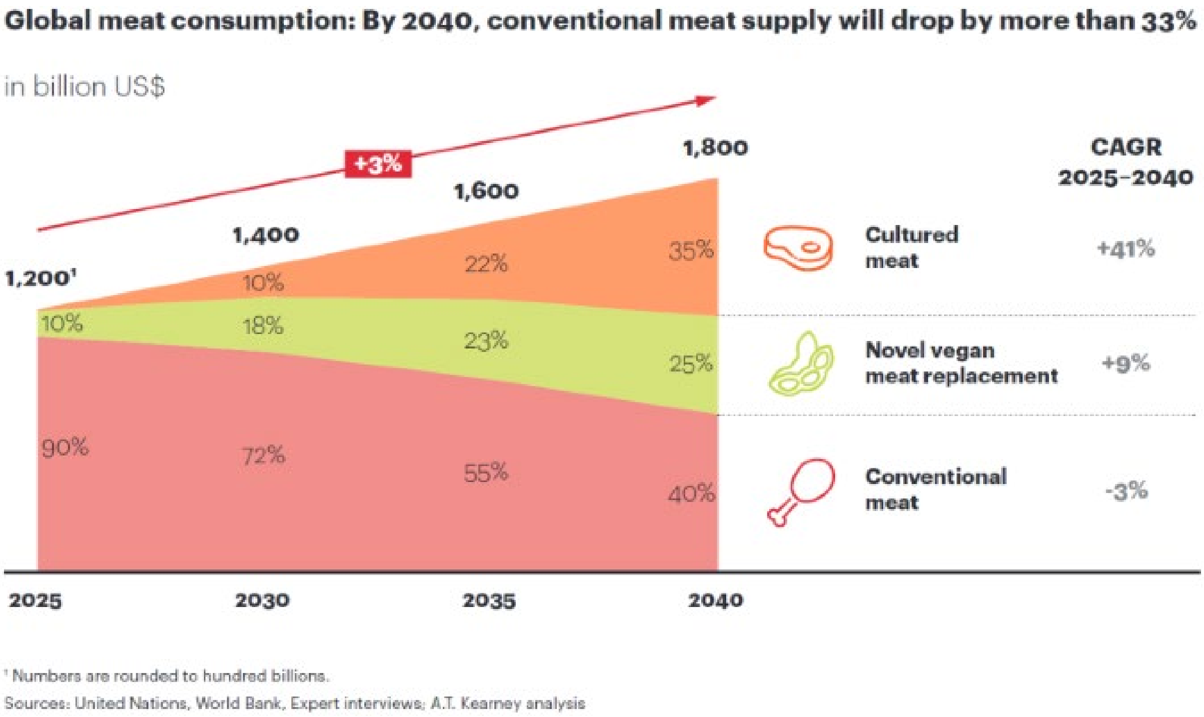

Figure 2. Global meat consumption.

Source: A.T. Kearney, 'How Will Cultured Meat and Meat Alternatives Disrupt the Agricultural and Food Industry', p.2.

meat (such as burgers) already quite advanced and projected to be available to the public in the next few years. Furthermore, through more research into stem-cell technology and muscle development, and its medical applications in fields such as wound healing, there is a real prospect of rapid advances within the consumable laboratory-based meat sector in the next decade.[115] Another target of innovation is not to produce products that replace meat completely but to partially substitute or 'extend' meat.[116] Any of the above protein substitutes could be used in this approach, though plant-derived mycoproteins and insect-derived proteins are especially suitable as they can be produced relatively cheaply today and can be incorporated with minimal additional processing.

Alternative dairy products are also entering the market to compete with traditional animal based products. Similar to meat industries, competition is arising from both plant-based and fermentation-driven sources. There are well established soy-based alternatives and increasing interest in other plant-based products such as almond, oat and coconut based products. The Guardian reported in January 2019 that "…a refrigerated aisle overflowing with choice: almond milk, hazelnut milk, peanut, tiger nut, walnut, cashew – and that's just the nuts. Coconut, hemp, spelt, quinoa, pea – you name it, somewhere a health-food startup is milking it."[117] Futher alternatives are being developed by Perfect Day[118] who are seeking to combine dairy milk proteins and fats manufactured in engineered microbial biofermentation systems to produce cow-free milk equivalents.

Taken from the research information service, CBS insights, Figure 3 shows the 50 startups that are playing a leading role in the alternative protein market.[119]

An important driver for change will be the comparative price of protein alternatives. Historically, the consumer value equation has had three dimensions – cost, choice and convenience. Protein consumption in high- and upper and middle-

115 Post, M., 'Cultured beef: Medical technology to produce food', *J. Sci. Food Agric.*, vol. 94, 2014, pp.1039-1041.

116 The Better Meat Co., *The Better Meat Co.* [website], 2019, https://www.bettermeat.co/, (accessed 19 September 2019).

117 Franklin-Wallis, O.,' White gold: the unstoppable rise of alternative milks', *The Guardian* [website], 29 January 2019, https://www.theguardian.com/news/2019/jan/29/white-gold-the-unstoppable-rise-of-alternative-milks-oat-soy-rice-coconut-plant, (accessed 5 December 2019).

118 Perfect Day Inc., *Perfect Day* [website], 2019, https://www.perfectdayfoods.com/mission/, (accessed 5 December 2019).

119 CB Information Services, *Research Portal* [website], https://www.cbinsights.com/research/alternative-proteins-market-map-expert-intelligence/, (accessed 19 September 2019).

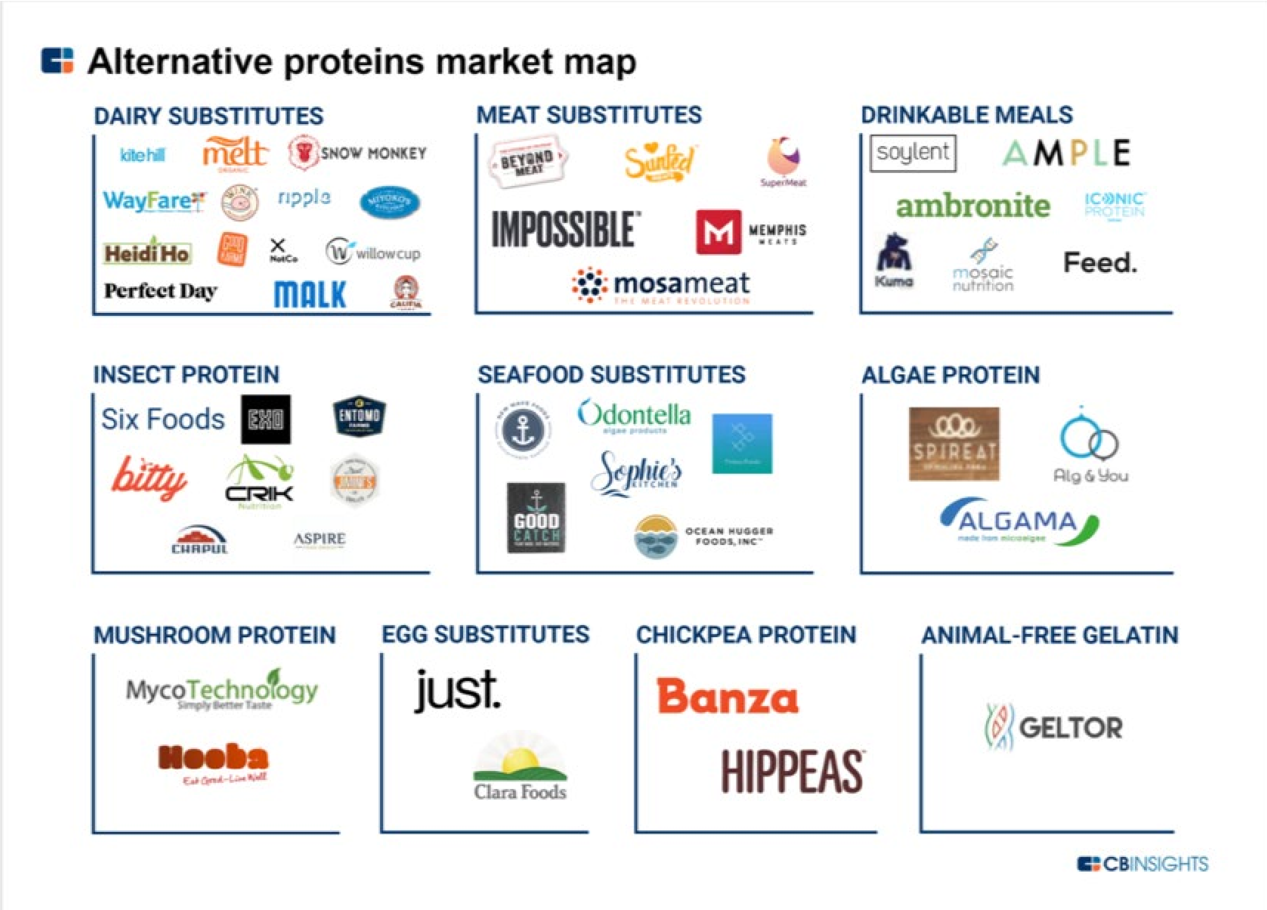

Figure 3. Alternative protein market activity.

Source: CB Information Services, Research Portal, [website], https://www.cbinsights.com/research/alternative-proteins-market-map-expert-intelligence/, (accessed 19 September 2019).

income countries shows that current available alternative proteins (including well-established alternatives such as tofu and mycoproteins) are not currently competitive with beef and pork (see Figure 4).[120]

Implications for the Livestock sector might include:

- alternative-protein products are already developing niche markets in developed economies. This may become more mainstream over the next decade
- continuous improvement in quality and choice of novel products at reduced costs may accelerate the change
- given the immediate clear trend of globally-increasing protein demand, Australian farmers are likely to earn a price premium for producing high-quality, sustainable meat that is underpinned by our disease-free status. Biosecurity and health risks are therefore key in maintaining future prosperity of the livestock sector
- some thought could be given to potential implications of a dramatic shift in consumer needs in the longer term with animal protein production becoming a niche market as alternative proteins become mainstream.

However, for the foreseeable future, the meat and alternative-protein industries will coexist and have the opportunity to complement one other.

...for the foreseeable future, the meat and alternative-protein industries will coexist and have the opportunity to complement one other.

120 World Economic Forum, '*Meat: The Future*'series: *A Roadmap for Delivering 21st-Century Protein*, WEF, 2019, http://www3.weforum.org/docs/WEF_White_Paper_Roadmap_Protein.pdf, (accessed 10 October 2019).

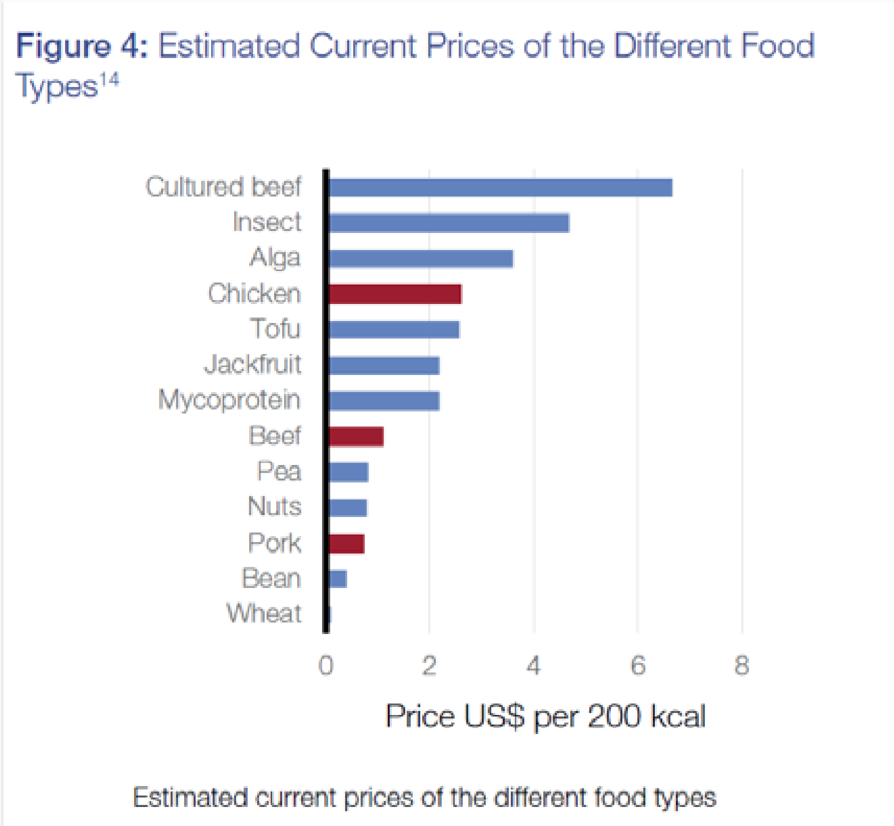

Figure 4. Estimated current prices of the different food types.

Source: http://www3.weforum.org/docs/WEF_White_Paper_Roadmap_Protein.pdf (accessed 10 October 2019).

4.2 Global fibre markets

Global fibre markets can be simplistically aggregated into major themes including:

- textiles for clothing & apparel
- fibres for engineering composites
- technical textiles.

Major trends impacting textile and fibre markets include:[121]

- increasing consumer power and choice
- new and evolving business models and supply chains
- advanced manufacturing technologies and trends in low cost production regions
- increased focus on sustainability (including Sustainability Development Goals – SDG's, Circular Economy and Bioeconomy.[122]

There is a broad range of raw material options used within the global fibres market, across both the natural and synthetic fibre segments.[123] As AHA stakeholders are focussed on natural fibres these alternatives are shown in Figure 5.

Competitive alternatives as applicable to textile and clothing markets are the focus of further discussion. Within this market segment, beyond natural fibres (from the above table), synthetic fibres and an emerging class of bio-based polymers (which currently arise from production through fermentation) producing replacements for currently petrochemical-based fibres via renewable feedstocks (such as maize and sugarcane).[124]

The building blocks arising in this field include:

- nylon fibres and (monomer) precursors[125]

121 Sheik, A', Growth Avenues for Indian Textile Industry, Gherzi, https://texprocil.org/circular/Growth_Avenues_for_Indian_Textile_Industry.pdf, (accessed 21 October 2019).

122 Textile Exchange, *Preferred Fiber and Materials Market Report 2018*, Textile Exchange, 2019, pp.78-87, https://www.ecotlc.fr/ressources/Documents_site/2018-Preferred-Fiber-Materials-Market-Report.pdf, (accessed 22 October 2019).

123 Pecas, et al., 'Natural Fibre Composites and Their Applications: A Review', *J. Compos. Sci.*, vol. 2, no. 4, 2018, p.66. doi:10.3390/jcs2040066

124 Lane, J.,'Leaps and bounds in sustainable plastics and nylons: U Wisconsin, Genomatica, Aquafil, Anellotech, Suntory, ADM, DuPont in the mix', *BiofuelsDigest* [website], 23 January 2018, https://www.biofuelsdigest.com/bdigest/2018/01/23/leaps-and-bounds-in-sustainable-plastics-and-nylons-u-wisconsin-genomatica-aquafil-anellotech-suntory-adm-dupont-in-the-mix/, (accessed 21 October 2019).

125 Textile Exchange, *Preferred Fiber and Materials Market Report*, 2018, p.72.

Natural Fibre	Cellulose/Lignocellulose	Bast	Flax, Hemp, Jute, Kenaf, Ramie
		Leaf	Abaca, Banana, Pineapple, Sisal
		Seed	Cotton, Kapok
		Fruit	Coir
		Wood	Hardwood, Softwood (e.g., Eucalyptus)
		Stalk	Wheat, Maize, Oat, Rice
		Grass/Reed	Bamboo, Corn
	Animal	Wool/Hair	Cashmere, Goat hair, Horse hair, Lamb wool
		Silk	Mulberry
	Mineral	-	Asbestos, Ceramic fibres, Metal fibres

Figure 5. Summary of natural fibres.

Source: Pecas, et al., 'Natural Fibre Composites and Their Applications: A Review', *J. Compos. Sci.*, vol. 2, no.4, 2018, p.66, doi:10.3390/jcs2040066

- polyester alternatives such as, bio-PET, bio-PLA and associated (monomer) precursors[126] and 2,5-furandicarboxylic acid (FDCA)[127]
- 1,3 propanediol (PDO, DuPont)[128]
- aromatic solvents and precursors (Allenotech).[129]

There is also a class of fermentation derived protein biopolymers which present as a novel class of fibres that may emerge as a new type of competitor to 'traditional' animal fibre markets.[130] These include bio-based pathways to novel protein biopolymers being placed in a range of consumer markets.[131]

There has been historical use of natural textiles and leather in automotive and sporting apparel markets. However, these markets are also under increasing pressure from competitive alternatives, including artificial bio-based, mushroom or by-product based 'leathers'.[132]

In reflecting on the market forces at play in the aforementioned global markets, animal health doesn't present as a critical driver in consumer behaviour at this time (in either fibre, in particular wool, or food markets). However there are trends pertaining to new products, traceability, circular economy and regulations that AHA and its stakeholders should continue to monitor. It is also noteworthy that each (production) industry appears to be addressing these issues independently, noting that for example there are biosecurity risks that affect both red meat and wool. From an animal health and biosecurity perspective, there are likely commonalities that could be systematically addressed to underpin consumer confidence, production efficiencies and regulatory/policy engagement. Furthermore, clothing manufacturers, fashion houses and retailers are increasingly seeking to brand or market with environmental and / or social credentials – 'eco-friendly.'

126 Textile Exchange, *Preferred Fiber and Materials Market Report*, 2018, p.68.

127 Kennedy, H.L., 'Five-year EU flagship project for FDCA and PEF launched', *Biofuels Digest* [website], 28 October 2017, https://www.biofuelsdigest.com/bdigest/2017/10/28/five-year-eu-flagship-project-for-fdca-and-pef-launched/, (accessed 22 October 2019).

128 Dupont, *Dupont Sorona* [website], 2019, http://sorona.com/our-story/, (accessed 22 October 2019).

129 Lane, J., 'Scaling up biobased BTX: The Digest's 2018 Multi-Slide Guide to Anellotech', *BiofuelsDigest* [website], 7 October 2018, https://www.biofuelsdigest.com/bdigest/2018/10/07/scaling-up-biobased-btx-the-digests-2018-multi-slide-guide-to-anellotech/, (accessed 22 October 2019).

130 Textile Exchange, *Preferred Fiber and Materials Market Report*, 2018, p.75.

131 Hahn, J., 'Spiber creates first commercially available jacket from emulated spider silk for The North Face', *Dezeen* [website], 24 October 2019, https://www.dezeen.com/2019/10/24/spiber-moon-parka-spider-silkthe-north-face-japan/, (accessed 5 December 2019).

132 Textile Exchange, *Preferred Fiber and Materials Market Report*, 2018, p.47.

New preferred fibers and materials are emerging.

Man-made cellulosics see a particularly vibrant innovation landscape e.g. Refibra™, Naia™, Orange Fiber.

Biosynthetics such as bio-based polyester, nylon and spidersilk are an important new emerging fiber category e.g. Fulgar's EVO®, Bolt Threads' Microsilk.

The number of leather alternatives is growing e.g. Modern Meadow's Zoa™, Apple Peel Skin, Vegea.

The use of standards is increasing, and the availability of traceability systems is growing.

The number of facilities certified to sustainability standards is increasing e.g. Global Organic Textile Standard, Global Recycled Standard, Responsible Down Standard, and the Responsible Wool Standard.

New supply chain connectivity and traceability systems (including blockchain) are starting to change the way and speed in which we communicate, and share knowledge and data.

Circular economy gains importance but market shares remain low.

Commitment to circularity and closing material loops has increased e.g. Global Fashion Agenda's 2020 Commitment Call.

The number of initiatives working on fiber-to-fiber recycling is increasing e.g. Re:newcell, HKRITA, Infinited Fiber.

There are recycled fiber options in all fiber categories e.g. recycled cotton, wool, down, MMCs, polyester and nylon but the share of fiber-to-fiber recycling is still very low (estimated at below 1% by the Ellen MacArthur Foundation).

Textile regulations are creating debate and impacting the industry.

The ban on importing certain plastic waste including PET bottles to China has caused increasing prices and will result in a lower rPET production volume.

The ban of mulesing in New Zealand has led to a shift in the debate on mulesing beyond the national borders.

The proposals for synthetic textile labeling regulations in California and Connecticut, US have received major media and industry attention.

Figure 6. Trends in global fibre markets.

Source: https://www.ecotlc.fr/ressources/Documents_site/2018-Preferred-Fiber-Materials-Market-Report.pdf, p.5 (accessed 22 October 2019).

SCENARIOS

5

Future vision for the livestock industry (aspirations)

The Australian agricultural sector has experienced sustained growth over the past decade based primarily on its ability to grow high quality and safe products. Annual farm gate returns exceed $60 billion, with farmers exporting $45 billion, representing 3% of our GDP.[133] Almost half of Australia's agricultural productivity comes from the livestock (meat and fibre) and aquaculture industries as shown in the Table 2.[134]

Table 2. Contribution of the animal industry to Australia's agricultural productivity.

Product	Contribution ($ billion)
Beef	11.4
Dairy	4.4
Pig	1.4
Poultry meat and egg	3.8
Aquaculture	3.1
Wool	3.0

Australia's competitive advantage in premium high-value global livestock markets is based on its long-standing reputation for high product safety and quality and a long history of freedom from the major epidemic diseases of livestock that are present in most other countries. The significant contribution that the livestock sector makes to the national economy has been underpinned by strenuous efforts to safeguard continued domestic supply and international market access by maintaining strong biosecurity controls that protect our agriculture industry, environment and community from pests and diseases.

However, Australian agriculture faces significant changes (both challenges and opportunities) driven by various factors, as outlined in the Megatrends section, such as climate change, technological disruption, limiting resources, and changing consumer and market needs. The immediate key question that arises from the challenges described is: "How are these trends best dealt with, mitigated or taken advantage of?"

A reasonable starting point is to ask: "What do we want the future livestock sector to look like in 2040?" Our study suggests that the obvious desired outcomes for livestock production businesses is that they want to be:

- sustainable (financially, environmentally, socially)
- resource / environment friendly
- efficient and profitable
- producing nutritious and healthy products
- responsive to consumer needs and expectations
- given access to open trade markets.

133 ABARES, 'Agricultural commodities: September quarter 2019', *Department of Agriculture – ABARES* [website], 2019, http://www.agriculture.gov.au/abares/research-topics/agricultural-commodities/sep-2019, (accessed 29 October 2019).

134 National Farmers' Federation, *NFF 2030 Roadmap*, NFF, 2018, https://www.nff.org.au/read/6187/nff-releases-2030-roadmap-guide-industry.html, (accessed 22 October 2019).

However, the question remains on what needs to be done to get there?

Key factors include:

- maintaining a disease-free status
- more cooperative industry approaches.

Given the variety of megatrends that impact on the livestock sector and the variability and unpredictability of future change, it is paramount that we explore ways to better our current decision-making processes or at least have informed discussion of the various issues, that will have significant impact on animal health and biosecurity.

The value of scenarios

Scenario planning is a structured process of thinking about and anticipating the unknown future, without being able to predict it. Scenarios inform present-day decision-making by exploring different possible future events in the context of one or more megatrends (*See Appendix A Megatrend Review* for detailed descriptions that are relevant to health and biosecurity). In contrast to forecasting, scenarios examine what is most uncertain and surprising such as conditions or events that are likely to be game-changers or shocks to the system. It provides a mechanism to generate insight and provoke discussion and action regarding future-focused risks as well as opportunities.

The value of scenarios analysis is to examine all of the possible futures identified – rather than focusing on the more desirable ones – with the understanding that any scenario may occur. For Australian livestock and aquaculture industries, which are highly impacted by evolving changes, scenarios can provide unique contextual intelligence to inform discussion around choices, risk reduction, improved strategic and operational planning, and pursuit of mutually desired outcomes. This is not an attempt to predict the future for animal health and biosecurity but rather to present relevant available information and data to facilitate informed discussion and decisions on possible future directions.

5.1 Scenario 1 – Major biosecurity breaches result in disease outbreaks decimating the livestock sector – simultaneous incursions of FMD, ASF, and avian influenza (the triple whammy)

Australia's reputation for safe, high-quality livestock products is based on its freedom from most of the serious diseases that are present in other countries. Our multi-million dollar premium trade position is underpinned by a strong biosecurity system.

An outbreak of an emergency animal disease would have dire consequences on the livestock export sector, especially if it resulted in broad establishment and/or protracted eradication. For example, it is estimated that an outbreak of FMD would have a $50 billion impact on the Australian economy over a 10-year period.[135] An outbreak of ASF would decimate our pork industry, costing billions and potentially bringing the industry to a halt, as currently seen in China.

Australia's reputation for safe, high-quality livestock products is based on its freedom from most of the serious diseases that are present in other countries.

Scenario 1 takes a unique approach to describe a possible case where Australia experiences incursions of three of the biggest threats to the livestock sector, FMD, ASF and AI. Simultaneous and/or staggered outbreaks of these diseases would potentially bring the entire industry to stand still and likely place our biosecurity system under enormous stress.

Biosecurity risks

FMD is a highly contagious viral disease that spreads rapidly between cloven-hoofed animals including cattle, sheep and pigs. The clinical signs

135 Beutre, B. et al., 'Consequences of a foot-and-mouth disease outbreak'', *Department of Agriculture – ABARES* [website], 2019, http://www.agriculture.gov.au/abares/research-topics/biosecurity/biosecurity-economics/consequences-foot-mouth-disease-outbreak, (accessed 22 October 2019).

are fever followed by the appearance of vesicles between the toes, on mammary glands and on the llips and tongue. Foot lesions leave animals lame and unable to walk to feed or water.[136] Tongue and mouth lesions are very painful and cause animals to drool and stop eating. The virus is very easily spread as is excreted from infected animals via breath, saliva, milk and faeces. FMD virus can also be spread on wool, hair, grass or straw; by the wind; or by mud or manure sticking to footwear, clothing, equipment or vehicle tyres.[137] Pigs are regarded as 'amplifying hosts' because they can excrete large quantities of the virus in their breath. Cattle are highly susceptible and can be infected by breathing in small quantities of the virus. Some animals can act as asymptomatic carriers and can shed virus for several years.

FMD is found in many parts of the world and while it is not highly lethal, it has a significant impact on trade in livestock and livestock products. Countries that are free of the disease, like Australia, ban or restrict imports from countries where FMD is endemic or where animals have been vaccinated (as these animals cannot be serologically distinguished from infected animals).

ASF is a highly contagious viral disease of pigs that has up to 100% mortality rates. The ASF virus originated from soft ticks that originally infected wild pigs (warthogs, bush pigs) causing asymptomatic infection. After spreading to susceptible domestic pigs, it caused outbreaks in Europe in the 1950s and was eventually eradicated via slaughter in the 1990s. Outbreaks throughout the Russian Federation in 2007 resulted in persistence and eventual uncontrolled spread to China and several SE Asian countries since 2018 with devastating consequences.[138]

ASF is spread by soft ticks and possibly other biting insects and flies, but transfer can also occur via infected bedding, feed, equipment, clothes, footwear, vehicles, and through infected feed swill. The virus is very stable and survives for long periods (months) under most environmental conditions, is resistant to a number of commercial disinfectants and is resistant to freezing and thawing.[139] There are no approved vaccines and no effective treatment for infected animals and the disease can only be controlled through slaughter.

AI is a respiratory viral disease of birds with various species of waterbirds acting as natural hosts of the virus where it causes asymptomatic infection. Low pathogenic AI (LPAI) can sometimes mutate to a highly pathogenic (HPAI) form which is highly lethal in poultry species.[140] A novel genotype of HPAI H5N1 arose in 1996 in southern China and through ongoing mutation, re-assortment, and natural selection, has diverged into distinct lineages and expanded into multiple reservoir hosts.[141] A 1997 outbreak of HPAI H5N1 in Hong Kong poultry resulted in infection of 18 people with 6 deaths and was the first indication of the danger it poses to humans. Since then, there have been 861 reported human cases of HPAI H5N1 infection with 455 deaths.[142] In addition, it has had dire consequences for poultry markets in China (millions of chickens culled) and has transformed the poultry industry practices. The ecology of HPAI has significantly changed from sporadic outbreaks in poultry markets to persistent circulation of numerous strains in domestic poultry and in wild waterfowl. HPAI viruses are continuing to evolve and adapt to new hosts and pose an incalculable risk to humans. Since 2013 there have been 1,568 confirmed human cases and 616 deaths worldwide from the HPAI H7N9.[143]

Over the last 32 years, Australia has had seven LPAI and HPAI outbreaks on chicken farms, four of which have occurred in the last 10 years, suggesting that the frequency of outbreaks is increasing. In the past seven HPAI outbreaks, involving 12 farms, all viruses

136 Department of Agriculture, 'Animal pests and diseases: Foot and mouth disease', *Department of Agriculture* [website], 2019, http://www.agriculture.gov.au/pests-diseases-weeds/animal/fmd, (accessed 22 October 2019).

137 OIE World Organization for Animal Health,'Foot and Mouth Disease Portal', *OIE* [website], https://www.oie.int/animal-health-in-the-world/fmd-portal/prevention-and-control/, (accessed 22 October 2019).

138 VISAVET Research Centre, 'African Swine Fever (ASF)', *Sanidad Animal Info* [website], 2018, https://www.sanidadanimal.info/en/104-emerging-diseases/379-african-swine-fever/, (accessed 22 October 2019).

139 5M Enterprises, 'Disease Guide: Agrican swine fever (ASF)', *The Pig Site* [website], https://thepigsite.com/disease-guide/african-swine-fever-asf, (accessed 22 October 2019).

140 Poultry CRC, 'Types of disease: Avian Influenza', *Poultry Hub* [website], http://www.poultryhub.org/health/disease/types-of-disease/avian-influenza/, (accessed 22 October 2019).

141 Sonnberg, S., Webby, R.J. and Webster, R.G.,'Natural history of highly pathogenic avian influenza H5N1', *Virus Res.*, vol. 178, no. 1, 2013, pp.63-77.

142 World Health Organization, 'Cumulative number of confirmed human cases of avian influenza A(H5N1) reported to WHO', *WHO* [website], https://www.who.int/influenza/human_animal_interface/H5N1_cumulative_table_archives/en/, (accessed 22 October 2019).

143 CNN, 'Avian Flu Fast Facts', *CNN* [website], 10 June 2019, https://edition.cnn.com/2013/08/23/health/avian-flu-fast-facts/index.html, (accessed 22 October 2019).

were of subtype H7 and of Australian lineages but the mechanisms for spread between farms were not identified.[144] Both H5 and H7 LPAI viruses, which have the potential to mutate into HPAI, are endemic in wild birds of Australia.[145] It is believed that AI outbreaks in Australia occur via endemic LPAI exposure following contact with wild birds followed by mutation to HPAI on poultry farms.

Observations that influence this scenario

There are several megatrends that are involved in this scenario:

- **Climate Change and Environmental Sustainability:** increasing evolutionary dynamics and greater opportunity for emergence of new disease threats and altering the geographical range of vectors and feral animal hosts.
- **Global Interconnectedness and Trade Intensification:** amplifying the risk of increasing numbers and species diversity of invasive organisms reaching our shores.
- **Increased Consumer Expectations:** upping the ante for meeting market requirements for welfare-friendly and disease-free animal products.
- **Technology Accelerates:** providing solutions to respond to increased health and biosecurity challenges including data collection and analysis and genetic solutions.

There are several emerging trends or potential disruptive changes that will impact on this scenario:

- **Government policy and priorities**: adverse trends include progression of protectionist trade policy by governments leading to breakdowns in international free trade agreements (for example current US-China trade war); Governments failing to make substantive progress to decelerate climate change by prioritising trade over support of sustainable resource management. Alternatively, Governments may embrace international free trade with provisions for responsible practices; increase the use of environment and nutrition incentives; and support policies that enable food value chains to become more transparent.
- **Business practices**: industry adopts social concerns over environmental sustainability as core business; farmers use resources more efficiently and embrace environmental stewardship; businesses source locally and use fewer resources. This is countered by food producers continuing to struggle to maintain business in a weak economy and in the face of competing products.
- **Consumer power**: consumer and retailer concerns over animal welfare are driving growth of free-range poultry and pig production; consumer choices may shift more towards food convenience, over-consumption and unhealthy food choices; environmental problems are not immediately addressed, but rather seen as resolvable "further down the track", albeit new campaigns to influence consumer demand and understanding on nutritional and environmental issues.
- **Technology**: adoption of new technologies will transform the livestock industry and assist in the management of animal health and biosecurity; technology innovators will engage with farmers and consumers and influence acceptance.
- **Environmental issues**: reduced ecosystem services resulting from changing climatic conditions and land usage, resource limitations and associated changes in farming practices (intensification of production, feed sources) will impact on the scenario.

Observations that further point to these trends include:

- increased traffic: Annually, over 18,000 vessels, 1.8 million sea cargo consignments, 41 million air cargo consignments, 152 million international mail items and 21 million passengers arrive in Australia, and these numbers are growing every year[146]
- increased visitors and students from high-risk regions and associated increased undeclared animal products

144 Singh, M. et al.,'Assessing the probability of introduction and spread of avian influenza (AI) virus in commercial Australian poultry operations using an expert opinion elicitation', *PLoS ONE*, vol.14, no. 2, 2019, e0212895.

145 Haynes, L. et al., 'Australian surveillance for avian influenza viruses in wild birds between July 2005 and June 2007', *Australian VeterinaryJournal*,;vol. 87, no. 7, 2009, pp. 266-72. PMID:19573149.

146 Inspector-General of Biosecurity, *Pest and disease interceptions and incursions in Australia: a report by the Inspector General of Biosecurity*, Review report No. 2018–19/05, 2019, igb.gov.au/Pages/completed-audits-and-reviews.asp, (accessed on 29 October).

- increased border interceptions: Between 2012 and 2017 more than 272 tonnes of meat products and about two-thirds of this came from countries with endemic emergency animal diseases (FMD, ASF).3 In 2018 approx. 80,000 mail seizures were recorded - live animal and animal products made up more than 20%
- biosecurity resources are becoming stretched: Increasing resource constraints leading to gradual decline of biosecurity support that is not keeping pace with increasing risks.[147] The number of sniffer dogs (currently the most effective detection system for animal products) has been halved since 2012.[148] Furthermore, the uptake of new technologies such as 3D X-rays has been slow[149]
- increased regional spread of emergency diseases, such as ASF and HPAI, which are now endemic in China and several SE Asian trading partners
- consumer and supermarket demands have increased the proportion of poultry that are raised under free range conditions which increases the risk of transmission of AI from wild birds to chickens
- climate change is driving geographical re-distribution of animal-disease vectors and increased the range of feral animals such as pigs, deer and camels that are capable of transmitting diseases to livestock.

In summary, this scenario will be influenced by balancing externalities and choices that involve:

- whether international governments turn inwards to protect their populations or embrace international free trade with provisions for responsible practices
- whether consumers (in various markets) base their food choices on nutrition, health and convenience or cost and availability
- whether farm businesses prioritise profitability and efficiency over social and environmental responsibility.

Game-changing events – disruptions and megashocks

Freedom from many of the world's major biosecurity threats is a source of competitive advantage for Australia's livestock industries. Incursions of diseases such as FMD, ASF and HPAI would have dramatic economic as well as public health implications. An incursion of one of these threats would have significant impacts on Australia's livestock sector, in particular if it leads to an extended outbreak. However, imagine a scenario where there are simultaneous (or overlapping) incursions of FMD, ASF and HPAI.

FMD can cause serious production losses but its most significant impact is its effect on international trade in livestock and livestock products. Countries without the disease, which include many of Australia's major trading partners do not import from, or severely restrict imports from FMD-infected countries.[150] Australia is currently free from FMD and an outbreak would seriously threaten our livestock industries for an extended period.

ASF is an example of an external sudden shock to agricultural markets, and as a disease that has no vaccine or treatment, it is severely and uncontrollably affecting food production, food security and trade flows. The current ASF outbreak in China has been a 'transformational event' for the global pork sector. Prior to the ASF outbreak, the Chinese pig herd numbered more than 440 million which is nearly three times larger than all of Europe and almost six times larger than the U.S., the second largest pork-producing nation. Prior to 2018, China produced 50 MT pork per annum (half of the worlds' production) and pork represents 62% of China's meat consumption and 36% of world meat consumption.[151]

147 Craik, W., Palmer, D. and Sheldrake, R., *Priorities for Australia's biosecurity system, An independent review of the capacity of the national biosecurity system and its underpinning Intergovernmental Agreement*, 2017, http://www.agriculture.gov.au/SiteCollectionDocuments/biosecurity/partnerships/nbc/priorities-for-aus-bio-system.pdf, (accessed 29October 2019).

148 Coughlan, M., 'Sniffer dogs work overtime on biosecurity', *The Canberra Times* [website], 22 October 2019, https://www.canberratimes.com.au/story/6451922/sniffer-dogs-work-overtime-on-biosecurity/?cs=14231, (accessed 29 October 2019).

149 Gillezeau, N., 'Australian industries missing out on benefits of digital technologies', *Australian Financial Review* [website], 19 December 2018, https://www.afr.com/technology/australian-industries-missing-out-on-benefits-of-digital-technologies-20181219-h19ao9, (accessed 29 October 2019).

150 Beutre, B. et al., 'Consequences of a foot-and-mouth disease outbreak', *Department of Agriculture – ABARES* [website], 2019, http://www.agriculture.gov.au/abares/research-topics/biosecurity/biosecurity-economics/consequences-foot-mouth-disease-outbreak, (accessed 29 October 2019).

151 Nuveen LLC, 'The impact of African Swine Fever on the agricultural industry: a complex puzzle', *Nuveen* [website], 2019, https://www.nuveen.com/the-impact-of-african-swine-fever-on-the-agricultural-industry, (accessed 29 October 2019).

A recent ABARES report[152] showed that there has been an approximate 40% decline in the national pig herd in China and is likely to reach 50% by end of 2019. The rest of the world's combined pork production cannot fill the resultant 25 MT pork meat deficit in China. The loss of breeding herds will take several years to replace, even longer if the disease cannot be controlled. In the meantime, the cost of other meat sources (chicken, fish and beef) has risen sharply, resulting in a 10% increase in the food price index.

ASF currently poses a significant biosecurity threat to Australia given its recent rapid spread throughout our SE Asian neighbours. From Jan – May 2019, 16 MT of pork and pork-related commodities were intercepted at Australian international mail facilities and airports. There have been almost 20,000 interceptions of undeclared pork products and of those that were tested up to 50% proved positive for ASFV.[153] Australia has 2,500 pig farmers and 36,000 pork supply chain workers[154] so if ASF gets into Australia, it will be devastating to our pork industry, because there will be nothing that can be done apart from eliminating all the pigs within and around the outbreak region. According to Agriculture Minister Bridget McKenzie "African Swine Fever is potentially the biggest animal disease event the world has ever seen and it's marching south through Asia, towards Australia".[155]

Although Australia is currently free from HPAI, the impacts of an epidemic on Australia's commercial broiler and layer industries can be substantial.[156] New and emerging risks for the poultry industry in Australia need to be evaluated in the context of an increase in barn and free-range farms. The Australian Egg Limited's annual report shows that

ASF currently poses a significant biosecurity threat to Australia given its recent rapid spread throughout our SE Asian neighbours.

free-range eggs now account for 51% of all grocery egg sales by volume, up from 20% a decade ago.[155] Even though HPAI has not been isolated from wild birds in Australia, there have been a number of confirmed LPAI detections in wild birds in Australia. In most outbreaks of AI in Australia, direct and indirect contact between wild waterfowl and poultry has been identified as an important introduction pathway for the virus.[157] In at least two of the seven Australian outbreaks of HPAI, surface drinking water contaminated with waterfowl faeces was suspected to be the source of infection.[158]

Beyond the aforementioned scenarios there are also risks of pathogen mutation and malfeasance that could impact domestic animal production systems, such as:

- outbreak of a disease with FMD-like symptoms, but that cannot be definitively diagnosed because it is a previously unseen FMD variant
- mergence of an entirely new disease with no established diagnostics or treatment resulting in unpreparedness and industry chaos.
- the potential for an agri-bioterrorism event.

Implications

In a future scenario of multiple simultaneous outbreaks of different emergency diseases, the Australian biosecurity system would be unlikely to be able to cope. Australia has effective plans in place to deal with individual diseases (AUSVETPLAN)[159] and has undertaken desk-top exercises for emergency responses, but may not have the overall (human and financial) resources to undertake parallel multiple responses over an extended period of time.

152 Pitts, N. and Whitnall, T., 'Impact of African swine fever on global markets', ABARES Report 2019, *Department of Agriculture – ABARES* [website], 17 September 2019, http://www.agriculture.gov.au/abares/research-topics/agricultural-commodities/sep-2019/african-swine-fever, (accessed 29 October 2019).

153 Hynninen, E., 'African swine fever fears spike in Australia as woman deported for smuggling pork into Sydney airport', *ABC News* [website], 16 October 2019, https://www.abc.net.au/news/rural/2019-10-15/woman-deported-for-smuggling-uncooked-pork/11603336, (accessed 29 October 2019).

154 Australian Pork Limited 2015–2020 Strategic Plan, *Australian Pork* [website], https://australianpork.com.au/latest-news/strategic-plan-2015-2020/, (accessed 22 October 2019).

155 Sydney Morning Herald, 'Swine fever fears prompt emergency meeting at Parliament House', *Sydney Morning Herald* [website], 6 September 2019, https://www.smh.com.au/national/swine-fever-fears-prompt-emergency-meeting-at-parliament-house-20190906-p52opj.html, (accessed 29 October 2019).

156 Australian Egg Corporation Limited, *AECL Annual Report 2016, Australian Eggs* [website], 2019, https://www.australianeggs.org.au/who-we-are/annual-reports/, (accessed 29 October 2019).

157 Arzey, G., 'The role of wild waterfowl in the epidemiology of AI in Australia', *Australian Veterinary Journal*, vol. 83, no. 7, 2005, p.445. PMID:16035188.

158 Sims, L.D., Weaver, J. and Swayne, D.E., 'Epidemiology of avian influenza in agricultural and other man-made systems', in *Avian influenza*, (Swayne, DE (ed.)), 2nd ed, John Wiley and Sons, 2008, pp.59-85. doi:10.1002/9781118924341

159 Animal Health Australia, 'AUSVETPLAN', *AHA* [website], https://www.animalhealthaustralia.com.au/our-publications/ausvetplan-manuals-and-documents/ (accessed 29 October 2019).

An outbreak of FMD would have a massive impact on the meat and wool industry as it would result in an immediate halt to exports of animal-related products that could last 6-12 months in the first instance. Depending on the extent of disease establishment it is estimated to cost the industry $50 billion over a 10-year period due to loss of market access and cost of eradication.[160]

The Australian pig industry is largely focused on the domestic market, with exports accounting for only 10% of production due to it being uncompetitive on world markets. Australian pork production is already insufficient to meet domestic consumption as 50% of our pork is imported, so a significant ASF outbreak would lead to higher imports and higher pork prices. Overall the pork industry will be severely affected and there is a risk of pork farmers going out of business.

AI outbreaks will reduce farm profits as a result of lost production of poultry meat and eggs (due to high mortality and morbidity), decontamination costs and costs to return the farm to normal operations.[161] Control measures require the immediate destocking of the entire flock, including healthy birds, and decontamination before restocking. Australia does not export significant amounts of eggs or poultry meat, so trade market access losses are negligible. The highest concern is over public health issues due to possible transmission of HPAI to humans. These concerns are also likely to result in a fall in domestic demand for chicken meat and egg products.

Opportunities

There are direct and indirect impacts of ASF incursions on Australian meat exports:

- **The pork industry**: if Australia is able to maintain freedom from ASF, there may be opportunities for the pig industry to benefit from increased exports to affected countries. The ongoing ASF situation in China and it's spread throughout the Asia region is likely to continue for several years and probably get worse. This would significantly add to the already increasing demand for imported meat throughout China and Asia and continue to drive up the price of pork (and other meat). This trend may increase opportunities for the export of more Australian pork to countries that are diverting their product to China. Prices for Australian pigs have already increased by around 40% this year.[162]
- **The beef industry**: exports of beef to China grew by 68% year–on–year, mostly as lower-priced frozen beef. Exports to China are forecast to grow due to shortages of meat , in particular pork, and China is expected to become Australia's second-largest beef export market.[163]
- **The sheep Industry**: Australian sheep meat exports to China are expected to continue to increase. This growth is due to long-term Chinese sheep meat supply and demand trends rather than ASF, because fish, low-priced beef cuts and poultry meat are currently more price competitive than Australian sheep meat.[164] However, given that the impact of ASF is very likely to grow over a considerable period of time, the level of sheep meat exports may grow in the future.

Additional opportunities are in the area of adoption of new technologies (see scenario 2) that will improve the type, quality and geographical spread of real-time data collection, enhanced data analysis and improved communication and management of emergency disease responses. Furthermore, there are opportunities to adopt new genome editing technologies to improve the resilience of Australian livestock breeds (pigs, cattle, sheep, chicken and fish) to a range of emergency disease threats.

...there are opportunities to adopt new genome editing technologies to improve the resilience of Australian livestock breeds...

160 Beutre, B. et al., 'Consequences of a foot-and-mouth disease outbreak', 2019).

161 Hafi, A. et al., *The value of Australia's biosecurity system at the farm gate: an analysis of avoided trade and on-farm impacts*, ABARES Research Report 15.2, Department of Agriculture, 2015. https://www.agriculture.gov.au/abares/research-topics/biosecurity/biosecurity-economics/farm-gate-value-biosecurity, (accessed 29 October 2019).

162 Daly, J., 'African swine fever drives up price of Christmas pork, with other meats set to follow', *ABC News*, 8 November 2019, https://www.abc.net.au/news/rural/2019-11-08/african-swine-fever-is-pushing-christmas-ham-prices-up/11684320, (accessed 18 November 2019).

163 Beutre, B. et al., 'Consequences of a foot-and-mouth disease outbreak', 2019.

164 Beutre, B. et al., 'Consequences of a foot-and-mouth disease outbreak', 2019.

5.2 Scenario 2 – Embracing the agricultural 4.0 revolution – adoption of new technolgies

We have now entered into the fourth revolution in agriculture that involves embracing and adopting new electronic, information management and biomaterial technologies including the Internet of Things (IoT), precision technologies including sensors, robotics and mobile apps.[165] This scenario describes recent advances in biomaterials and engineering research together with big data computing and digital technologies that are being integrated for enhanced data collection and analysis. These systems can provide a step-change for animal biosecurity by being designed to monitor animal health and amongst other things, automatically collect diagnostic data, provide real-time data analysis, enable rapid dissemination of intelligence, and inform timely decision making around biosecurity response actions. This is one of the ways that Australia can create and implement agtech and foodtech solutions that enable farmers and food producers to manage key challenges.[166]

165 Zambon, I. et al., 'Revolution 4.0: Industry vs. Agriculture in a Future Development for SMEs.', *Processes 2019*, vol. 7, no. 36, 2018, doi: 10.3390/pr7010036

166 Australian Trade and Investment Commission, 'Why Australia for Agriculture 4.0', *ATIC* [website], 2019, https://www.austrade.gov.au/agriculture40/why-australia, (accessed 29 October 2019).

Background – emerging technologies

Surveillance

Surveillance (pre-border, at the border and post-border) is a critical activity that helps protect Australia from incursions of new pests and diseases. These activities involve collection and interrogation of data, distribution of information, formulation of responses, and implementation of actions. During an emergency disease outbreak, these steps need to occur as quickly as possible, ideally in real-time. These steps are currently supported by underlying "classical technologies" of detection, data analysis and information communication, and responsiveness is often limited in effectiveness by the inherent limitations of these technologies. They are resource intensive and are therefore challenged in the breadth of protective coverage that they can achieve, especially in times of declining resource availability and competing demands.

However, these areas are now undergoing rapid technology evolution in their portability, precision and speed. The adoption and integration of a number of technological advances, especially in the areas of biosensors, DNA-based detection analysis and robotics-enhanced logistics has the potential to completely transform disease surveillance. Greatly enhanced surveillance effectiveness would result in fewer incursions, more rapid and flexible responses to limit the impact of incursions and reduced risk of disease establishment. The benefits combine to enable more specific, thorough and widespread detection and prevention strategies to be implemented.

Biosensors

Novel biosensing technologies have the potential to address the problem of a lack of reliable, cost-effective diagnostic tests for early detection of diseases in livestock animals. These new diagnostic tools will enable rapid disease investigation and diagnosis and allow timely (point-of-care) decision-making for disease outbreaks.[167] Such responsiveness can be critical for effective control of disease outbreaks, especially in the case of rapidly-spreading viral diseases, such as ASF, AI and FMD.

In recent years, there have been developments of miniaturised assays that can be used on-farm for diagnosis of AI virus (AIV). A biosensor based on impedance spectroscopy has been developed to detect H7N1 AIV by immobilised antibodies on gold electrodes.[168] Another is based on quartz-crystal based aptasensors (biosensors where the recognition element is a small oligonucleotide or peptide) for viral DNA detection that has been adapted for the rapid, sensitive and specific diagnosis of AIV.[169]

Likewise, several types of portable biosensors have been developed for the diagnosis of FMD virus (FMDV). Lateral flow immunochromatography has been adapted for the detection of antibodies against FMDV proteins, allowing discrimination of different FMDV serotypes.[170] Portable real-time PCR assays have been developed that allow the on-site detection and identification of FMDV in minutes and displayed as a Yes/No readout using a hand-held device.[171] Complementary infrared thermography for the assessment of body surface temperature can allow isolation of potentially sick animals at an early stage and prevent the spread of disease.[172] Adaption of biosensors to a wearable form has been a big advance in the ability to measure the overall health status (including pathogen detection) of individual animals and linking their data to online systems allows real-time monitoring.[173] Sensors could be fixed, mobile or a combination and act as de facto sentinels.

In addition, advances in portable (organic) chemical detection (e.g. eNose) may also enable the rapid sampling of the environment for the detection of key signature volatile organic compounds that are diagnostic for pests and diseases.[174]

Robotics and artificial intelligence

Developments in drone technology and artificial intelligence could enable in situ detection or provide for sample collection from the environment, including areas that are too remote or too extensive to be regularly manually sampled.[175] Advances in equipment robotics could also enable remote mechanised retrieval and DNA sequencing of samples, with the data being automatically uploaded via wireless networks to be accessible to online expert analysts. This could enable a network of collection points to be arrayed as a grid, analogous to remote sensing of meteorological stations, and for user-friendly visualisation of data in the same style as a weather chart where isobars are actually contours of equal frequency of the organism (disease agent, vector or feral animal host) being surveyed for. Furthermore, collections could be obtained from critical places of animal/human/vector movement at border crossing points, industry hot spot and abattoirs.

Unmanned aerial and submarine robotic vehicles have been developed for high spatial and temporal

167 Suresh Neethirajan, S. et al., 'Recent Advancement In Biosensors Technology For Animal And Livestock Health Management', *Biosens Bioelectronics*, vol. 98, 2017, pp.398-407.

168 Wang, R. et al., 'Interdigitated Array Microelectrode-Based Impedance Immunosensor For Detection of Avian Influenza Virus H5n1', *Talanta, vol. 79*, no.2, 2009, pp.159-164.

169 Wang, R. and Li, Y., 'Hydrogel Based Qcm Aptasensor For Detection of Avian Influenza Virus', *Biosensors and Bioelectronics, vol.* 42, 2013, pp.148-155.

170 Yang, M. et al., 'Development of A Quick and Simple Detection Methodology For Foot-And-Mouth Disease Virus Serotypes O, A And Asia 1 Using A Generic Rapid Assay Device', *Virology Journal*, vol. 10, 2013, pp.125.

171 Bhatta, D. et al, 'Rapid Detection of Foot-And-Mouth Disease Virus with Optical Microchip Sensors'. *Procedia Chemistry*, vol. 6, 2012, pp.2-10.

172 Zaiqin. Z., Hang, Z. and Tonghai, L., 'Study on Body Temperature Detection of Pig Based on Infrared Technology: A Review',. *Artificial Intelligence in Agriculture*, vol.1, 2019, pp.14-26.

173 Neethirajan, S., 'Recent Advances In Wearable Sensors For Animal Health Management', *Sensing Bio-Sensing Research*, vol. 12, 2017, pp.15-29.

174 Farraia, M.V. et. al, 'The Electronic Nose Technology in Clinical Diagnosis: A Systematic Review', *Porto Biomed. J.*, Vol.4, no. 4, 2019.

175 'Why Use Drones For Environmental Monitoring?', senseFly Parrot Group, 2019, https://www.sensefly.com/Industry/Drones-Environmental-Monitoring/, (accessed 5 October 2019).

surveillance of terrestrial[176] and aquatic[177] environments.

Digital technologies

The Internet of Things (IoT) is a network of objects that are connected wirelessly using sensors, and can transmit information to each other, or a wider digital network, without human intervention. IoT is linked to other applications including remote sensing for disease surveillance, big data analysis and sharing, robotic and artificial intelligence for diagnostics, risk-mapping for emergency disease management (preparedness, response, eradication and proof of disease absence).

Synthetic biology

Synthetic biology technologies are based on knowledge and understanding of living organisms at a molecular level to (re)design existing biological systems. The products that can be developed and bio-processed at scale and for a range of food and fibre products (e.g. synthetic meat and clothing), biochemicals, biofuels, and high value pharmaceuticals. We are only at the dawn of the age of synthetic biology and there is great and somewhat unpredictable potential for completely unique bio-based solutions to current problems to be envisaged and developed.

DNA sequencing

Classical diagnostic testing for pathogens is based on identifying the presence of specific pre-determined, known agents, but cannot inform on the presence of other (unanticipated or unknown) organisms. In contrast, mass sequencing of DNA has the ability to detect the presence of any and all organisms present in a sample, without isolation of a particular organism[178]. Rapid and ongoing advances in DNA sequencing, metabolomics and bioinformatic analysis is bringing amazing refinements to this capability for mass screening of DNA from non-selective samples collected either from the wild (eDNA, environmental DNA)[179] or from controlled situations. Collections composed of

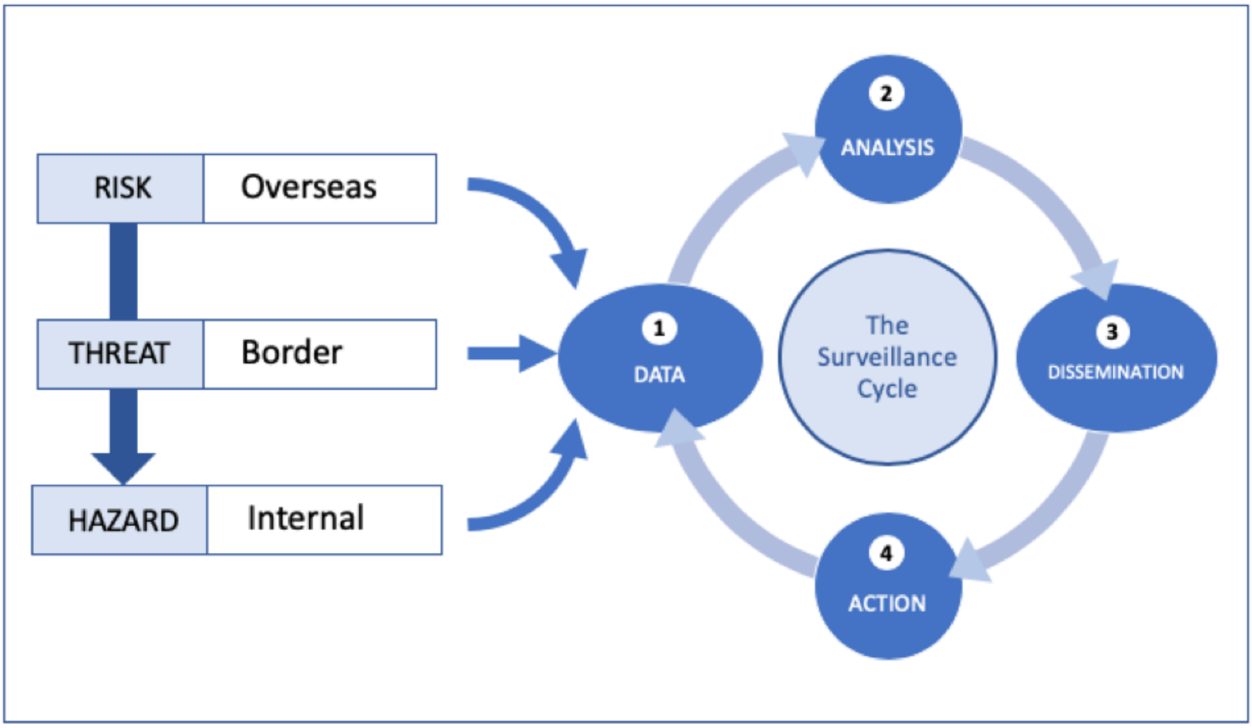

Figure 7. The role of emerging technologies in the biosecurity system.

176 Tahir, A. et al., 'Swarms of Unmanned Aerial Vehicles – A Survey', *Journal of Industrial Information Integration*, https://Www.Sciencedirect.Com/Science/Article/Pii/S2452414x18300086#!, (accessed 5 October 2019).

177 Verfuss, U.K. et al., 'A Review of Unmanned Vehicles for The Detection and Monitoring Of Marine Fauna', *Marine Pollution Bulletin*, vol. 140, 2019, pp.17-29.

178 Deiner, K. et al., ' Environmental DNA Metabarcoding: Transforming How We Survey Animal and Plant Communities', *Molecular Ecology, vol.* 26, 2017, pp.5872-5895.

179 Seymour, M., 'Rapid Progression and Future of Environmental DNA Research', *Communications Biology*, vol. 2, 2019, pp.80-83.

Table 3. Possible examples arising from Figure 7.

	Threat level	1. Data collection	2. Analysis	3. Dissemination	4. Actions
Overseas	Potential Risk	eDNA screening in neighbouring countries, trade routes, embarkation points for inbound flights & ships. Monitoring of regional outbreaks, and emergent threats from further afield.	Screening datasets for presence of organisms that may pose potential threat. Identification of potential new virulent species based on observed divergence in DNA sequence.	Alerts provided to relevant industry, and regulators to engage proactively with relevant jurisdictions.	Implement/ intensify trade route and border screening for approaching threats.
Border	Imminent Threat	eNose screening of passengers and animal cargo.	Point of Use analysis for immediate action at location and time of detection.	Immediate alerts to responsible personnel.	Quarantining of threat until subsequent risk & harm minimisation can be undertaken.
Internal	Actual Hazard	Environmental surveillance. Testing of production animals, insect vectors, feral animals, etc.	Screening of datasets for shifting patterns of biological activity.	Alerts to relevant authorities and community.	To be determined case-by-case basis. eg. development of risk maps.

numerous diverse organisms obtained by sampling, for example, soil and water[180], or gut microflora[181], can now be mass sequenced to provide a databank of all DNA contained in the targeted population. This databank can be screened either physically by diagnostic PCR or bioinformatically in silico to detect the presence/absence and relative abundance of any component organism.

Gene editing

Gene editing technologies allow small and precise heritable changes to be made to the genome of animals for health and/or economic benefits. It is able to precisely replicate changes that already occur in natural mutations that already exist in animal breeds. Gene editing is distinct from GMO approaches as it does not incorporate foreign DNA or genes into the genome. Gene editing has already created improvements such as polled cattle, in-egg sex identification for poultry, and generation of virus-resistant pigs.[182]

180 Vierheilig, J. et al., (2015). 'Potential Applications of Next Generation DNA Sequencing Of 16s rRNA Gene Amplicons in Microbial Water Quality Monitoring', Water Sci. Technol., vol. 72, no. 11, pp.1962-1972.

181 Fricker, A.M., Podlesy, D. and Fricke, F.W., 'What is New and Relevant for Sequencing-Based Microbiome Research? A Mini-Review', *Journal Of Advanced Research*, vol. 19, 2019, pp.105-112.

182 Tait-Burkard, C. et al.,'Livestock 2.0 – Genome editing for fitter, healthier, and more productive farmed animals', *Genome Biology*, vol. 19, no. 204, 2018. doi:10.1186/s13059-018-1583-1

Regulatory approval of gene editing has recently been reviewed in Australia by the Office of the Gene Technology Regulator (OGTR). The OGTR has determined that genetic edits made that introduce change to a single or small number of nucleotides in a gene are no different from changes that can occur in nature, and therefore do not pose an additional risk to the environment or human health. Updated regulations that are now in effect, allow the use of certain genome-editing techniques in plants and animals without the need for government approval.[183]

The intersection of these emerging technologies with current industry practices can be represented as a range of sensor systems abroad, at border and within Australia that drive data collection and a subsequent surveillance cycle as represented in Figure 7.

Observations that influence this scenario (Including links to megatrends)

Several of the identified megatrends are involved in this scenario:

- Climate change and environmental sustainability

183 'Australian gene-editing rules adopt 'middle ground'', *Nature*, 2019, https://www.nature.com/articles/d41586-019-01282-8, (accessed 23 October 2019).

– increasing evolutionary dynamics and greater opportunity for emergence of new threats.

- Global interconnectedness and trade intensification – amplifying the risk of increasing numbers and species diversity of invasive organisms reaching our shores.
- Increased consumer expectations – upping the ante for meeting market requirements for disease-free, safe and ethically produced animal products.
- Technology accelerates – providing solutions to respond to increased health and biosecurity challenges.

There are a number of emerging trends or potentially disruptive changes that have potential to shape this scenario:

- Increased international traffic requires more efficient and effective testing of people and goods (containers, bulk goods, mail) for disease and pest incursions (pre-, at- and post-border).
- Changes in the geographical range of vectors and feral hosts due to climate and environmental changes is stretching surveillance capability and capacity.
- Changes in Government resourcing and shifts to user-pay systems exacerbates the need to achieve improvements in resource use efficiency – technology can provide solutions.
- A higher level of consumer interest in provenance and its role in both food safety and value-added (differentiated) products.
- Citizen-science and the rapid dissemination of information (including misinformation and disinformation) by individuals, groups and communities.
- Continual multiple threats to Australia's disease-free status.
- Legislation in data protection and ownership, Privacy, Freedom of Information and Right-to-Know.

Game-changing events – disruptions and megashocks

Information is moving between a range of parties and stakeholders at ever increasing volumes and speeds. This information presents the potential for significant disruption to animal industries ranging from unintended public access leading to misunderstanding through to deliberate acts of malfeasance, disrupting industry practices and trade. Information that is "notionally controlled" needs to be considered for the risk of false-positives or false-negatives and their production and trade consequences.

As detection limits continue to reach part per trillion (ppt) and quadrillion (ppq) levels, previously undetected or undetectable pathogens and diseases may begin to present themselves, presenting new challenges around the "disease free" status of Australian production systems. These same advances in detection limits may also influence future Maximum Residue Limits, for chemical and biotic components, for internationally traded agricultural products, presenting both opportunities and challenges for Australian producers.

Implications

New business practices and consumer expectations of more transparent traceability of food throughout the production chain (paddock to plate) can be achieved through adoption of new sensing and digital technologies. This will happen of its own accord to meet provenance requirements and will provide the capability for parallel implementation in relation to animal disease status and biosecurity threats.

Greatly enhanced surveillance effectiveness through adoption of new technology systems would result in fewer incursions, more rapid and flexible responses to limit the impact of incursions and reduced risk of disease establishment. It will also enable flexible targeting of monitoring activities driven by more dynamic availability of data on specific nature, intensity and distribution of biosecurity threats. This will enable containment responses to be targeted to particular regions of identified incursion and their associated animal movement and trade networks. This can generate more effective use of resources in implementing containment measures and result in less severe economic impacts to industry and trade compared to use of broad-brush whole-of-industry, country-wide response actions.

New DNA sequencing capabilities will enable the improved identification of micro-organisms (e.g. pathogenic viruses and bacteria and antibiotic-resistant microbes) in samples from individual animals and humans, or from environmental sampling conducted either systematically (such as across a survey grid network), or at specific points of interest/control, and is performed without the need for culture or isolation of the organism.

Furthermore, with the increased sensitivity of DNA analysis there is now an ability to detect the DNA signatures left behind by organisms through shedding, excreting or decaying into the environment[184]. This opens up the prospect of environmental surveying for presence of pests or feral animals (potential disease host) as well as pathogens, and even down to the identification of events of colocation of pests or pathogens with potential animal hosts.

In addition, advances in portable (organic) chemical detection (e.g. eNose) may also enable the rapid sampling of containers, organisms and environment for the detection of key volatile organic compounds that might alert biosecurity systems to the increased likelihood of threats.[185] This could complement and eventually replace the use of sniffer dogs.

DNA and chemotaxonomic approaches can also provide an encyclopaedic dataset that could be interrogated at retrospective time points to estimate progression rates, predict border arrival times, and enable back-traceability to point of origin. This can be applied for forensic analysis of incursions of agents known at the time of sampling or for retro-analysis of new agents that emerge subsequently as potential or actual biosecurity threats.

All of the technologies described in this scenario and their variety of uses can be linked through the IoT where remote sensing for disease surveillance, robotics/artificial intelligence for diagnostics and big data analysis and sharing can combine to develop real-time risk-mapping for emergency disease management (preparedness, response, eradication and proof of disease absence).

184 Seymour, M.,'Rapid progression and future of environmental DNA research', *Communications Biology*, vol. 2, 2019, pp.80-3.

185 Farraia, M.V. et al.,'The electronic nose technology in clinical diagnosis: A systematic review', *Porto Biomed. J.*, vol. 4, no. 4, 2019, p.e42.

Opportunities

The adoption of new technologies will provide several opportunities for livestock industries, particularly in the management of animal (and public) health and biosecurity.

- Technological advancement and innovation across surveillance and monitoring; data and analytics; genetics; and user-friendly smarter devices will take a lead in better addressing future biosecurity challenges faced by the livestock sector.
- Development of low-cost sensors and automated systems will allow better real-time identification of pests and diseases and act as a game-changer in implementing quarantine protocols.
- Long-term decision making will be aided by prevalence of big data analysis and allow enhanced risk mapping and improved pest and disease preparedness.
- Tools for characterising new (previously unknown) diseases, or variants of existing diseases (including antibiotic-resistant microbes), will allow our growing 'omics' knowledge to predict the biology, host range and pathogenicity of new pathogens before they emerge and spread.[186]
- New methods can be implemented for real-time high-throughput screening for disease in humans, animals and plants in areas of concentration, such as airports and ports.
- Rapid, non-invasive detection of characteristic volatiles or electromagnetic radiation from infected individuals could greatly extend capacity for intercepting new introductions, perhaps in concert with portable on-the-spot detectors once suspect shipments were identified.
- Gene editing provides opportunities to rapidly create animals that are resistant to viral infections. It should be noted that genetic modification has been used to generate pigs resistant to porcine respiratory and reproductive syndrome virus and classical swine fever virus and therefore could be a viable route to increase resistance to ASF.

186 Waage, J.K. and Mumford, J.D., 'Agricultural biosecurity', *Philos. Trans. R. Soc. Lond. B. Biol. Sci.*, vol. 63, no.1492, 2008, pp.863-76. doi: 10.1098/rstb.2007.2188. PMID: 17761470; PMCID: PMC2610114.

5.3 Scenario 3 – Consumers influence industry practices and government policy

This scenario considers several consumer and retail factors that will influence and shape future livestock production systems and how the sector may be affected by them. These include consumer (and supermarket) demands and expectations over food choices; increased scrutiny over production practices for animal- and aquaculture-based protein in the face of declining natural resources and increased expectations of social responsibility; competition from alternative (plant and non-traditional) protein products; and Government policies on trade and sustainability. Furthermore, the long-term success and sustainability of the livestock sector is dependent on maintaining its high-health status supported by a strong and responsive biosecurity system that must be appropriately resourced and continually improved. Considered in this is the growing threat of antimicrobial resistance (AMR) to both animal and public health and the urgent need to mitigate its emerging global impact.

Public issues

Antimicrobial resistance

The overuse and misuse of antibiotics in animal and public health over the past decades has led to the emergence of a large variety of antibiotic, and more worryingly multi-drug resistant microbes.[187] AMR is rising to dangerously high levels in all parts of the world, leading to escalating medical costs, prolonged hospital stays, and increased mortality. The classes of antbiotics that have been widely used in agriculture over the past decades include the tetracyclines, aminoglycosides, beta-lactams, lincosamides, macrolides, pleuromutilins, and sulphonamides.[188] These antibiotics have the same mode of actions or belong to the same general class as those used for humans; a situation that has led to the more judicious use of these drugs in animal farming, and a better appreciation of the degree of interaction between animals and humans.[189] The lack of stringent and effective supervision and regulatory control over antibiotic production, use, and disposal have led to the current worldwide AMR crisis.

In an attempt to contain the AMR crisis, the World Health Organization instituted a Global Action Plan in 2015 which demands that each country develop a national action plan in line with the global plan.[190] Australian livestock industries have a good track record on antibiotic use (JETACAR review[191]) and have adopted an antimicrobial stewardship strategy, which has limited the type and amounts of antibiotics that can be used in animal production, however, similar changes are slow to be adopted (or not occurring at all) in developing countries.[192]

The One Health concept recognises the interdependent links between human, animal and environmental health. AMR is driven by antimicrobial misuse and overuse in humans and in animal production systems and the subsequent spread of resistant organisms between humans and animals and the wider environment and is therefore best addressed by a One Health approach.[193]

Avian Influenza

LPAI viruses are naturally present in wild birds, particularly water birds such as ducks. These viruses do not cause clinical disease in these natural hosts, but can be transmitted to free-range chickens that come into direct contact with wild birds, or drink contaminated water. Because chickens are not "natural" hosts for AI, infection of poultry with LPAI viruses can lead to mutations and the emergence of HPAI over time within the flock. HPAI is an extremely infectious and fatal poultry disease, causing up to

187 Williams-Nguyen, J. et al., 'Antibiotics and Antibiotic Resistance in Agroecosystems: State of the Science', *J. Environ. Qual.*, vol. 45, 2016, pp.394-406.

188 De Briyne, N. et al., 'Antibiotics used most commonly to treat animals in Europe', *Vet. Rec.*, vol. 175, 014, p. 325.

189 Gelband, H. et al., *The State of the World's Antibiotics*, Centre for Disease Dynamics, Economics and Policy, 2015, Washington DC., https://cddep.org/wp-content/uploads/2017/06/swa_edits_9.16.pdf (accessed 23 October 2019).

190 World Health Organization, *Global Action Plan on Antimicrobial Resistance*, WHO, 2015, Geneva, https://www.who.int/antimicrobial-resistance/publications/global-action-plan/en/ (accessed 23 October 2019).

191 JETACAR, *The use of antibiotics in`food-producing animlas: Antibiotic- resistant bacteria in animals and humans*, Joint Expert Advisory Committee on Antibiotic Resistance, Commonwealth Department of Health and Aged Care, Department of Agriculture, Fisheries and Forestry, 1999, https://www1.health.gov.au/internet/main/publishing.nsf/Content/health-pubs-jetacar-cnt.htm/$FILE/jetacar.pdf, (accessed 23 October 2019).

192 Manyi-Loh, C. et al., 'Antibiotic Use in Agriculture and Its Consequential Resistance in Environmental Sources: Potential Public Health Implications', *Molecules*, vol. 23, 2018, p.795.

193 Department of Health and Department of Agriculture, 'Antimicrobial resistance' , *Australian Government* [website], https://www.amr.gov.au/, (accessed 23 October 2019).

100% flock mortality within only a few days.[194] Since the mid-1990s there have been regular outbreaks of HPAI in commercial poultry flocks world-wide and has caused significant disease and death in humans, as described in scenario 1.[195]

Influenza viruses are capable of infecting (jumping across) different species. Like free-range chickens, free-range (and feral) pigs could be infected with AI viruses from wild birds. These viruses can mutate and/or recombine with other influenza viruses within the pig and create public health issues – as was the case for the world-wide swine flu pandemic in 2009-10. This resulted in 37,537 confirmed Australian cases of Human Swine Influenza resulting in 191 human deaths[196] with 18,500 confirmed deaths worldwide, but this number is likely to be a huge underestimate.[197]

Observations that influence this scenario (Including links to megatrends)

There are several megatrends that are involved in this scenario:

- Climate Change and Environmental Sustainability – increasing expectations of sustainable and environmentally concious production.
- Global Interconnectedness and Trade Intensification – changing trade volume and policies.
- Increased Consumer Expectations – meeting market requirements for welfare-friendly products, increased tracability, public health (AMR, AI).
- Technology Accelerates – providing solutions to respond to increased health status and emergence of alternative meat production.

194 Koch, G. and Elbers, A.R.W., 'Outdoor ranging of poultry: a major risk factor for the introduction and development of High-Pathogenicity', *Avian Influenza, NJAS*, vol. 54, 2006, p.2.

195 OIE World Organization for Animal Health, *OIE Situation Report for Highly Pathogenic Avian Influenza 2018*, OIE, https://www.oie.int/fileadmin/Home/eng/Animal_Health_in_the_World/docs/pdf/OIE_AI_situation_report/OIE_SituationReport_AI_August2018.pdf (accessed 23 October 2019).

196 Department of Health, 'Australian influenza report 2009-12-18 December 2009 (#32/09)', *Department of Health* [website], December 2009, https://www1.health.gov.au/internet/main/publishing.nsf/Content/cda-ozflu-no32-09.htm, (accessed 23 October 2019).

197 *Dawood, F.S. et.al* 'Estimated global mortality associated with the first 12 months of 2009 pandemic influenza A H1N1 virus circulation: a modelling study', *The Lancet. Infectious Diseases*, vol. 12, no. 9, 2012, pp.687-95.

As touched upon in scenario 1, whilst there could be a broad range of government policy areas that affect consumer markets, notable areas for consideration are:

Trade and biosecurity policies

Adverse trends include pursuit of protectionist trade policy by governments that could lead to breakdowns in world trade dynamics and equilibria. Australia has pursued tariff free / non-protectionist trade policies for many years and has a number of bilateral trade agreements to support local agricultural exports. However, some international partners have been recently engaged in trade disputes (not involving Australia), disrupting global trends that may impact domestic supply/demand for animal products. Alternatively, Governments may in the future embrace free international trade with provisions for valuing and rewarding responsible social and environmental practices. Furthermore, governments failing to make substantive progress to address climate change may change risk profiles of biosecurity and trade. There is also some risk that consumers and sovereign trading partners may create "non-tariff trade barriers" around Corporate Social Responsibility (CSR) or Environment, Social & Governance (ESG) criteria for goods & services.

Australia has traditionally taken a strong policy position on biosecurity, underpinned by strong border-protection.

Australia has traditionally taken a strong policy position on biosecurity, underpinned by strong border-protection. Changes in policy, or enforcement of policy will impact accessibility of imported animal protein products. Notably, as domestic demand for animal products increases, in the absence of increased local production to meet demand, imports will naturally rise. Examples of risks associated with imported animal products include prawns (and the resulting biosecurity breach with White Spot Virus[198]) and consistent interception of pork products associated with tourists, students

198 Fisheries Research and Development Corporation, 'White spot disease update', FRDC [website], 2017, https://www.frdc.com.au/media-publications/fish/FISH-Vol-25-1/White-spot-disease-update, (accessed 10 October 2019).

and temporary workers and recent detections of FMV and ASF viruses in intercepted meat samples.

Consumer demands and expectations

In 2015, the Food and Agriculture Organization of the United Nations (FAO) undertook an analysis of the major preferences of consumers in food consumption, as well as expected changes over time. It identified five important consumer trends and purchase drivers: food safety and health benefits; corporate social responsibility; production systems and innovations; sustainability; and food origin.[199]

The increasing global demand for animal-source protein in developing countries is driven by population growth and increasing incomes. A more affluent global population spends more on animal-source foods. In China, for example, each percentage point increase in income results in a proportional increase in expenditure on meat and milk.[200] As outlined in Section 4 "Commercial outlook", per capita consumption of animal products (meat and dairy) is projected to rise, with total meat and fish consumption expected to nearly double. To meet this demand, an additional 200 million tonnes of meat would need to be produced annually by 2050, compared with production in 2005/07. Meat, dairy, eggs and fish currently provide 40% of the world's protein supply and 18% of its calories.[201]

The largest increase in animal protein demand is estimated to be for poultry and pork (however, this is under threat from ASF – see Scenario 1). The projected increase in poultry meat demand is highlighted by a 725% increase by 2030 (from 2000 levels) in SE Asia, mostly in India.[202] This demand is driving the shift to large-scale intensive farming, requiring the routine use of antibiotics to maintain animal health and productivity. Antibiotic

The increasing global demand for animal-source protein in developing countries is driven by population growth and increasing incomes.

consumption is projected to double in major countries that are major producers and consumers of meat and fish (Brazil, Russia, India and China).[203] Surveillance and monitoring of antibiotic use and antibiotic resistance is one facet of the strategies in combating AMR. However, developing countries encounter challenges regarding surveillance systems because of lack of capacity, resources and integration.[204] Importation of agricultural products from these regions therefore poses significant risks in the introduction and spread of AMR, similar to the risks associated with emergency animal disease incursions.

According to Tang et.al.[205], the problems of antibiotic misuse and antibiotic resistance are particularly serious in China where total antibiotic usage in 2013 was 162,000 tons, with an equal share of usage in humans and animals. This amount accounted for half of the antibiotic usage worldwide with the per-capita use of antibiotics 5 times higher than in Europe and the USA. Without urgent action, we may be heading for a post-antibiotic era in which common infections and minor injuries can once again kill.

Consumers increasingly care about what they eat, how their food is produced and the impact that food production has on the animal, environment and society. Healthy eating will be one of the dominant consumer trends in food consumption in the coming decades. An increasingly ageing population and rising level of affluence means that the trend of healthy eating choices will continue to gain importance into the future. This trend is likely to be reinforced by consumers of the future having a better level of education and better knowledge about

199 Alena Lappo, A., et al., *Consumers' concerns and external drivers in food markets*, FAO Fisheries and Aquaculture Circular No. 1102, Rome, 2015. http://www.fao.org/3/a-i4939e.pdf, (accessed 10 October 2019).

200 World Bank, *Managing the livestock revolution: Policy and technology impacts to address a fast-growing sector*, Agriculture and Rural Development Department, Report No. 32725-GLB, 2005, Washington DC, http://siteresources.worldbank.org/INTARD/Resources/Livestock_final_wmapsandcov.pdf, (accessed 10 October 2019).

201 World Economic Forum, *Meat: The Future Series, Options for the Livestock Sector in Developing and Emerging Economies to 2030 and Beyond*, 2019, https://www.weforum.org/whitepapers/meat-the-future-series-options-for-thelivestock-sector-in-developing-and-emerging-economies-to-2030-and-beyond, (accessed 10 October 2019).

202 Robinson, T.P. and Pozzi, F., *Mapping supply and demand for animal-source foods to 2030*, Animal Production and Health Working Paper. No. 2, Rome, FAO, 2011, http://www.fao.org/docrep/014/i2425e/i2425e00.pdf

203 Van Boeckel, T.P. et al.,'Global trends in antimicrobial use in food animals', *Proc. Natl. Acad. Sci. USA*, vol. 112, 2015, pp649-5654.

204 Queenan, K., Häsler, B. and Rushton, J., 'A One Health approach to antimicrobial resistance surveillance: Is there a business case for it?', Int. *J. Antimicrob. Agents*, vol. 48, 2016, pp.422-427.

205 Tang, Q.; et al., 'Control of antibiotic resistance in China must not be delayed: The current state of resistance and policy suggestions for the government, medical facilities, and patients', *Biosci. Trends*, vol. 10, 016, pp.1-6.

health and healthy eating. An opposing trend may be shifts in consumer preference towards prioritization of cost and convenience over health and nutrition. Furthermore, consumers will increasingly require more transparency from producers about food products, and will demand more attention to production sustainability, ethical food sourcing, and food miles. They are willing to pay more for "socially responsible" products and support companies that produce them.

Retailers are driving free-range production

Supermarkets and food retailers are increasingly making marketing and food-sourcing decisions based on their perceptions of trending consumer demands and preferences. In seeking market differentiation and competitive advantage, they promote (and often contractually stipulate) production practices based on animal welfare, GMO status and vegetarian and vegan choices. There has been a clear consumer- and supermarket-driven increase in free-range production systems for poultry which now represents half of Australia's chicken eggs produced[206] and around 20% of chicken meat.[207] This trend is based on the public's perception that this is a more animal-welfare friendly system than intensive conditions, however, in reality it poses increased health and biosecurity risks to the chickens as well as humans because of AI. Furthermore, there is a growing trend towards free-range pig production[208] which increases the risk of transmission of diseases that are carried by feral pigs, deer, bats and wild birds, particularly following incursions of ASF, FMD and AI, through direct contact.

In summary, this scenario will be influenced by balancing externalities and choices that involve:

- Consumers are responding to climate change and the environmental impacts of food and fibre production and businesses are responding to emerging markets for alternative products and are now looking to strengthen their CSR and associated brand value.
- Emerging businesses are delivering new products such as bio-based fibres and plant-based alternatives to meat protein.
- Advances in technologies are addressing these converging areas, allowing new food and fibre products to be introduced to marke (as detailed in scenario 2).

Game-changing events – disruptions and megashocks

A dramatic and sudden shift in global trade dynamics could affect supply/demand dynamics of a number of food and/or fibre products. The shift could be triggered by a biosecurity event (e.g. FMD or ASF outbreaks) or trade dispute (such as supply disruptions in soybeans for animal feed). The impacts flowing from such disruptions could include:

- acute shortages of animal products resulting in domestic product price rises (which may offer opportunities for unaffected products and producers)
- tightening of animal feed supplies, constraining domestic production due to lack of import availability of key animal feed commodities (raising producer costs but not necessarily or so obviously consumer product prices.)

An exotic vector-borne disease arising in peri-urban or free-range production system would dramatically shift focus on production system changes driven by changing consumer preferences. The impacts could include:

- significant animal losses, quarantining and tightening of food and/or fibre supply
- loss of consumer confidence in CSR/ESG qualified or motivated production as prices rise and reports of impacts on animals are communicated through (formal and informal) media channels - this may lead to consumer avoidance of certain products
- damage to national animal production reputation and potential halt of export trading impacts the national economy.

Genuine implementation of the "risk creators" biosecurity funding model should reallocate costs to these relatively riskier (emerging) animal

206 Australian Eggs, *Annual Report 2019*, https://www.australianeggs.org.au/who-we-are/annual-reports/#item-1058, (accessed 10 October 2019).

207 Australian Chicken Meat Federation, 'Chicken Meat Production', *ACMF* [website], 2018, https://www.chicken.org.au/chicken-meat-production/, (accessed 10 October 2019).

208 Australian Pork, 'Our farming systems', *AussiePigFarmers* [website], 2019, https://aussiepigfarmers.com.au/pigs/our-farming-systems/free-range-system/, (accessed 10 October 2019).

production practices. The impacts of committed implementation could include:

- consumer (and analogously voter) dissatisfaction with increased costs of emerging food and fibre
- business actively engaging with government to delay or prevent increased compliance costs, for example the current container-levy situation
- increased access to new technologies to support "risk creators" that could have spill over benefits to other industry sectors.

Shifts in consumer demand for emerging sources of protein and fibre do not materialise (for whatever combination of reasons). This could lead to:

- consumers seeking a return to "traditional" animal products, whilst carrying higher ESG expectations will demand current or higher biosecurity and animal health standards
- business and Government Departments, perhaps having reduced both capacity and capability, will need to rebuild skilled biosecurity practitioners and veterinarians to maintain protocols and standards
- government, having disinvested in biosecurity due to perceptions or assumptions of decreased demand needing to review resource allocations to biosecurity efforts.

Implications

The shifting consumer dynamics that underpin this scenario should be considered manageable on the premise that animal industries engage with consumers in order to demonstrate their CSR credentials and proactively adopt technology that enable robust, sustainable production systems.

However, there are some early signals that the challenges being faced by consumers are being responded to with a more defensive mentality. This could move animal industries from a manageable opportunity to a difficult challenge, through reticence to adopt changes in production or having made changes in response to consumer demand to not undertake the necessary biosecurity system adjustments to manage risks.

The biosecurity risks are best exemplified through emerging peri-urban and free-range production of poultry and pork. In moving production from enclosed, highly-controlled and secure environments, exposure risk to wildlife and soil borne disease increases, presenting new modes for infectious and potential transmission of zoonotic diseases and exacerbating AMR issues. A specific example of a changing risk profile would be AI harboured in wild bird populations and the creation of new interfaces with production animals. Similar examples could arise with increased production intensity in cattle and aquaculture to meet forecast protein demand and increased resource constraints.

Government, as a custodian and significant investor in biosecurity, is also likely to respond to consumer and business sentiment. However, these may present contradictory influences on government decision making – with increasing costs to be borne by businesses under a "risk creators" model and expectations from consumers that appropriate biosecurity resources will be maintained to minimise risks to animal and human health.

With rising demand for non-animal protein and fibre, a risk also emerges of a diminishing base for livestock industries which could lead to a diminishing of (matching) industry funding to support biosecurity efforts which may in turn lead to sub-critical capacity and a loss of capability over the medium term. This could increase the likelihood of biosecurity incursions.

Opportunities

The shifts in consumer demand for protein and fibre and the associated changes in animal production systems will bring opportunities for the animal biosecurity (and health) community. These might include:

- clear articulation of changing risk profiles arising from production system shifts and opportunities to increase capacity and capabilities
- development of digital and biological technology interfaces to demonstrate and support animal industry practices and sustainable production claims
- opportunities for producers and the supply chain to (re)position animal products through demonstrated best-practice production

- opportunities to work in concert with, or divest in businesses for, alternative systems of protein and fibre production
- application of new technologies to meet the consumer demands for increased traceability of food production.

5.4 Scenario 4 – Changes in ecosystem services impact livestock production and biosecuirty risks

The continued prosperity of agricultural production industries relies on an inextricably-linked collection of natural resources, collectively referred to as ecosystem services, which includes a high quality and abundance of water, healthy soil, high air quality and biodiversity.[209] Changes to ecosystem services as a consequence of climate change, will negatively impact production systems and locations and increase the biosecurity risk of pests, weeds and diseases. The livestock and aquaculture sectors will consequently face a number of significant challenges resulting from a combination of complex interactions including: rapid and sudden restrictions to livestock feed availability and market access; degrading ecosystem services; disruptions to environmental sustainability; and livestock grazing and grain feed biosecurity related insecurity.

This scenario describes a situation where climate-driven changes to ecosystem services in combination with several biosecurity breaches over a brief period could find; the Karnal bunt fungus infecting wheat, rye and triticale feed sources; Red Imported Fire Ants (RIFA) blocking the use of pastural land across the country; the virus Xylella fastidiosa and the fungus Myrtle rust destroying significant numbers of native plant species in grazing ecosystems, including vegetation needed for waterway stabilisation and agroforestry; and aquatic biosecurity incursions destroying aquaculture ecosystems and blocking water supplies.

209 United Nations, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (UN IPBES), *IPBES Global Assessment Report on Biodiversity and Ecosystem Services UN IPBES 2019 7th Report, UN Sustainable Goals*, [website],6 May 2019, https://www.un.org/sustainabledevelopment/blog/2019/05/nature-decline-unprecedented-report/, (accessed 19 September 2019).

Climate change impacts

Ecosystem Services

There has been a drastic reduction in the availability and benefits derived from the ecosystem services that humans use in livestock production, regional value-adding processing of primary commodities and for living. Under climate change[210,211,212] Australia is already experiencing severe impacts[213] with climates moving southwards.[214] Without increased ecologically-sustainable awareness and practices built into livestock production and cropping for animal feed, we could see devastating reductions in the availability of ecosystem services. Worldwide around 23% of land area has seen a reduction in productivity due to land degradation.[215] Livestock production relies upon animal feed being available from plants or plant grains, which in turn rely upon ecosystem services.

Invasive pests, weeds and diseases of the native ecosystems, waterways, grazing plants and grains that livestock production relies on could cause ecosystem collapse in regions, as well as decimate agroforestry, grazing trees and grass species. They could also reduce the viability of native forest tree species being economically utilised as part of the farming system in the future for carbon farming or carbon neutral credits in livestock systems. Vegetation system breakdown due to one degrading impact, such as land clearing, or a plant pathogen incursion, combined with heat and water stress will lead to complex ecological problems. This is particularly serious in regions with degraded natural vegetation, waterways and stressed feed grain crops

210 Intergovernmental Panel on Climate Change (IPCC), *IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystem:, Summary for Policy Makers - Approved Draft*, IPCC, 2019, https://www.ipcc.ch/site/assets/uploads/2019/08/4.-SPM_Approved_Microsite_FINAL.pdf, (accessed 19 September 2019).

211 Farmers for Climate Action (FCA), 'Climate Change and Agriculture', *FCA* [website], 2019, https://www.farmersforclimateaction.org.au/climate_change_and_agriculture, (accessed 19 September 2019).

212 Howden, M., 'Our Changing Climate Risk', Opening Plenary Presentation to *Farmers for Climate Conference* October 2018, https://d3n8a8pro7vhmx.cloudfront.net/farmersforclimateaction/pages/1346/attachments/original/1555295536/Opening_plenary_Howden.pdf?1555295536, (accessed 19 September 2019).

213 Hughes, L. et al., *Feeding a hungry nation: Climate change, food and farming, Climate Council of Australia*, 2015, https://www.climatecouncil.org.au/uploads/7579c324216d1e76e8a50095aac45d66.pdf, (accessed 19 September 2019).

214 Stephens, D., Astralian Export Grains Innovation Centre (AEGIC), cited in Hambrett, M.,'The future of farming in the era of climate change', *ABC News*, [website], 2 March 2019, https://www.abc.net.au/news/2019-03-02/the-future-of-farming-in-the-era-of-climate-change/10852926, (accessed 5 November 2019).

215 *UN IPBES, 7th Report*, 2019.

which are even more susceptible to further invasion by new or existing pests, weeds and diseases.

Invasive species

Invasive species are now the number one threat to biodiversity.[216] The number and variety of invasive species introductions around the world have increased rapidly over the last few decades, and have not yet reached saturation in ecosystems.[217] Incursions of these species are therefore the greatest threat to the native grazing systems that rangeland grazing livestock rely upon, while climate change will alter temperature and rainfall and likely cause shifts in native species ranges and ecosystem composition. Invasive species also represent a significant threat to growing the feed crops that grainfed livestock rely on[218], as well as to stored grains – both for livestock and human consumption.

Invasive species already in Australia, including insect vectors of plant and animal diseases[219] will alter their geographical range due to changes in regional climates. Incursions and establishment of invasive exotic weeds, pests and diseases will have the potential to interact to create compounding devastating impacts on livestock industries.

Examples of key invasives include:

Red Imported Fire Ants (RIFAs) were first found in southeast Queensland in 2001. Almost $380 million has been spent up to 2016 in an attempt to eradicate them. In 2017, Australian governments came together to fund a $411.4 million eradication program over the subsequent 10 years.[220,221] This investment in eradication was made in Australia with the knowledge that RIFAs cost the United States economy $7 billion annually and have been responsible for over 100 deaths.[222]

Xylella fastidiosa is an exotic plant virus that poses extreme economic and environmental risks to Australia as it can be transmitted to 350 host plant species including Australian natives.[223] Xylella can be transported by a wide range of sucking insects that feed from plant water transport vessels (xylem), and can be vectors of spread for this diease[224]. In the EU, the potential cost of loss of production has been calculated as € 4.2 to 6.9 billion per year, compared to the total EU member states expenditure on surveillance activities of € 3.7 to 4.7 million per year from 2016 to 2019.[225]

Karnal bunt is an exotic fungus originating in India, but now present in several countries including the USA. Karnal bunt infects part of the wheat head in the field, and grains in storage, resulting in broken hollow grain, powdery masses of dark spores, and a strong fishy odour that remains present in products made from the grain. Of great detrimental impact to the saleability of the grain, only 3% of grain needs to be infected before consumers can taste and smell the fishy odour.[226,227] Areas affected by Karnal bunt are quarantined within countries that have this fungus. The economic impacts of suspected infestation with this fungus are severe, even when negative: In 2004, Pakistan claimed that Karnal bunt was present in Australian wheat shipments which affected $500 million of wheat on the water at the time. Offloading product from ships carrying Australian wheat was potentially affected in all ports of the world.[228] Karnal bunt would not

216 *UN IPBES, 7th Report*, 019.

217 Seebens, H. et al.,'Global trade will accelerate plant invasions in emerging economies under climate change', *Global Change Biology*, vol. 21, no.11, 2017, doi:10.1111/gcb.13021

218 Fischer, R. and Connor, D., 'Issues for cropping and agricultural science in the next 20 years', *Field Crops Research*, vol. 222, 2018, pp.121-142. https://doi.org/10.1016/j.fcr.2018.03.008.

219 Aurambout, K.Finlay, K. and Beattie, G., 'A concept model to estimate the potential distribution of the Asiatic citrus psyllid (Diaphorina citri Kuwayama) in Australia under climate change: A means for assessing biosecurity risk, *Ecological Modelling*, vol. 220, no.19, 2009, pp.2512-2524, https://doi.org/10.1016/j.ecolmodel.2009.05.010

220 Department of Agriculture and Fisheries QLD, 'Fire Ants: 10-year eradication plan', *Department of Agriculture and Fisheries QLD* [website], 2019, https://www.daf.qld.gov.au/business-priorities/biosecurity/invasive-plants-animals/ants/fire-ants/eradication/10-year-plan, (accessed 29 October 2019).

221 Invasive Species Council, *Fact Sheet: Red Fire Ants*, Invasive Species Council, 2017,https://invasives.org.au/wp-content/uploads/2015/01/Fact-Sheet-Red-Fire-Ants.pdf, (accessed 10 October 2019).

222 Whittington, T., One In All In On Biosecurity', *WA Farmers*, 16 September 2019, https://wafarmers.org.au/one-in-all-in-on-biosecurity/, (accessed 29 October 2019).

223 Rathé, A.A. et al., 'Feeding and Development of the Glassy-Winged Sharpshooter, *Homalodisca vitripennis*, on Australian Native Plant Species and Implications for Australian Biosecurity', PLoS One, vol. 9, no. 3, 2014, e90410. https://doi.org/10.1371/journal.pone.0090410

224 Australian Government, 'Plant Diseases and Weeds: Xylella (*Xylella fastidiosa*)', *Department of Agricuture* [website], November 2019, http://www.agriculture.gov.au/pests-diseases-weeds/plant/xylella, (accessed 29 October 2019).

225 Sanchez and Mosbach-Schulz, *Estimating the economic, social and environmental impacts of EU priority pests: a joint EFSA and JRC project with a focus on Xylella fastidiosa*, 2nd European Conference on *Xylella fastidiosa*, 29-30 October 2019. https://www.efsa.europa.eu/sites/default/files/event/191029-xylella/S6.P4%20SANCHEZ%20MOSBACH.pdf

226 Department of Agriculture, 'Plants, Diseases and Weeds: Karnal bunt', *Department of Agriculture* [website], http://www.agriculture.gov.au/pests-diseases-weeds/plant/karnal-bunt#how-to-identify-karnal-bunt, (accessed 2 November 2019).

227 Plant Health Australia, *Fact Sheet: Karnal bunt*, https://www.planthealthaustralia.com.au/wp-content/uploads/2013/01/Karnal-bunt-FS.pdf, (accessed 2 November 2019).

228 Grain Producers Australia, 'Biosecurity in the Grains Industry', *GPA* [website], https://www.grainproducers.com.au/component/k2/item/48, (accessed 2 November 2019).

only decimate wheat, rye and triticale grain volume and international exports from Australia to over 45 international markets[229], but would also likely cause trade and animal movement restrictions as the fungus is able to survive in the guts of animals.[230]

Myrtle rust (*Austropuccinia psidii*) is a fungal disease of over 350 native Australian plant species, causing heavy defoliation of branches, reduced fertility, dieback, stunted growth, and plant death.[231] It is not known how it arrived in Australia but it was first detected in NSW in 2010 and is now established across the entire country. Myrtle rust is extremely difficult to control and impossible to eradicate from natural settings because its spores can be spread easily via contaminated clothing and equipment, infected plant material, insect/animal movement and by wind dispersal. Given that eradication is not possible, a Myrtle Rust Transition to Management Program, managed by PHA, is in place to mitigate its impacts on natural, urban, and primary production environments.[232]

The exotic **Khapra beetle** is a major global pest of storage grain, can reduce grain volume by 75%[233],and if it breaches biosecurity efforts and establishes in Australia, will greatly impact livestock feed availability,[234] and potentially contaminate livestock.

Aquaculture

Fish and aquaculture products are important sources of animal protein in the human diet, accounting for about 17% of global protein consumption.[235] In order to meet the future protein demands of a growing global population, aquaculture production must grow to provide over 60% of food fish by 2030 to account for a decline of wild-fish capture.[236]

Food safety for aquaculture products can be affected by a number of parameters that are gradually altering due to climate change, such as the salinity, pH and temperature of water. Given the strong relationship between temperature and bacterial growth rates, the increasing temperatures of oceans and inland water due to global warming are likely to promote higher growth of pathogenic bacteria.[237] The increasing trend in aquaculture intensification is aimed at better controlling production and creating economically sustainable systems, however, this increases the risk of major disease outbreaks that are difficult to predict and control. The most common infectious pathogenic agents in aquatic ecosystems are parasites, bacteria, fungi and viruses. This would drive the increased use of antibiotics, further exacerbating AMR issues.

Furthermore, there is an increasing frequency, intensity and duration of algal blooms due to increasing water temperatures. This can lead to the production of potent toxins that not only reduce aquaculture production but also pose public food safety issues due to the presence of toxins in molluscs, crustaceans and fish.[238]

Observations that influence this scenario (Including links to megatrends)

There are several megatrends that are involved in this scenario:

- Climate Change and Environmental Sustainability – increasing evolutionary dynamics and greater opportunity for emergence of new disease threats and altering the geographical range of vectors and feral animal hosts.
- Global Interconnectedness and Trade Intensification – Increased visitors and trade volume increase the risk of invasive organism incursions.

229 Plant Health Australia, *Fact Sheet: Karnal bunt*, https://www.planthealthaustralia.com.au/pests/karnal-bunt/, (accessed 2 November 2019).

230 'Plants, Diseases and Weeds: Karnal bunt', *Department of Agriculture*, http://www.agriculture.gov.au/pests-diseases-weeds/plant/karnal-bunt, (accessed 2 November 2019).

231 'Diseases, fungi and parasites: Myrtle rust (*Austropuccinia psidii*)', *Department of the Environment and Energy* [website], https://www.environment.gov.au/biodiversity/invasive-species/diseases-fungi-and-parasites/myrtle-rust (accessed 2 November 2019).

232 Plant Health Australia, 'Myrtle rust', *PHA* [website], https://www.planthealthaustralia.com.au/national-programs/myrtle-rust/, (accessed 2 November 2019).

233 Plant Health Australia, *Fact Sheet: Khapra beetle*, 2013, https://www.planthealthaustralia.com.au/wp-content/uploads/2013/01/Khapra-beetle-FS.pdf, (accessed 2 November 2019).

234 Australian Government, 'Khapra beetle (*Trogoderma granarium*)', *Department of Agriculture* [website], 4 November 2019, http://www.agriculture.gov.au/pests-diseases-weeds/plant/khapra-beetle#how-to-identify-khapra-beetle-trogoderma-granarium, (accessed 2 November 2019).

235 Food and Agriculture Organization of the United Nations, *The State of World Fisheries and Aquaculture: Contributing to food security and nutrition for all*, FAO, 2016, Rome. http://www.fao.org/3/a-i5555e.pdf

236 World Bank, Fish to 2030: *Prospects for Fisheries and Aquaculture*, Agriculture and environmental services discussion paper no. 3, World Bank, 2013, Washington DC. http://documents.worldbank.org/curated/en/458631468152376668/Fish-to-2030-prospects-for-fisheries-and-aquaculture

237 White, P.A. et al., 'The effect of temperature and algal biomass on bacterial production and specific growth rate in freshwater and marine habitats', *Microbial Ecology*, vol. 21, no. 1, 1991, pp.9-118.

238 Bravo, J. et al., 'Ciguatera, an emerging human poisoning in Europe', *J Aquac Mar Biol*, vol. 3, no. 1, 2015: 00053. doi: 10.15406/jamb.2015.03.00053.

- Increased Consumer Expectations – upping the ante for meeting market requirements for welfare-friendly and disease-free animal products.
- Technology Accelerates – providing solutions to respond to increased health and biosecurity challenges including surveillance, data collection and analysis and genetic solutions.

Climate-change impacts on the environment

Increased heating of global land and water due to climate change[239] and the overuse of our natural systems is negatively impacting ecosystem services. In combination with shifts in climate-driven changes in geographical ranges of invasive species, disease vectors and feral animal populations, this is posing increased risk to the health and biosecurity of livestock and aquaculture that will require strategies and activities to constrain current and emerging biosecurity risks.

Government policy

This scenario of ecosystem degradation will play out in a more extreme way if governments fail to make substantive progress to decelerate climate change or allow market forces to override sustainable resource management. Governments will also need to balance the embracing of international trade with including provisions for responsible practices towards the environment. Towards this end, governments will likely need to increase the use of environment and nutrition incentives to influence both the supply and demand for meat products. Creation of, and engagement in, international systems for valuing ecosystem services and biosecurity surveillance will be needed as these may become factored into the economy in food trade.

Business practices and priorities

This scenario will worsen dramatically if public and private sectors fail to prioritise immediate concerns over environmental sustainability. However, if they become increasingly environmentally aware, and businesses source locally and use fewer resources, and farmers use resources more efficiently, then the impact of the scenario will lessen. Industry, in response to environmental and community groups, actively increase the extent of biosecurity awareness and associated behavioural change across public and private sectors.

Consumer demands

A belief that society can grow now and fix environmental problems later will lead to worsening environmental problems as this is not the case, and the environment needs to be treated with a societal attitude of sustainability. This may become a generational issue, with younger generations only giving a social license to operate to producers who show evidence of environmental care and stewardship strategies. Domestic and export trade demand for livestock products and prices paid to farmers might include economic production and market valuations for ecosystem services and natural capital.

Adoption of new technologies

In an increasingly digitally connected world, new technologies need to be prioritised towards data collection, and maintenance of biosecurity and biodiversity issues. Without such a long-term strategy of information gathering it will be difficult to measure the impacts of livestock production and other impacts on the environment from farm to regional to national scales.

Increased trade and travel

By 2025, Australia can expect a 28% increase in shipping, 72% more passengers, 75% more containers, and 100% more containerised cargo.[240] This will increase the risk of introductions of new invasive species.[241]

Game-changing event/ megashocks

In a scenario where climate change has resulted in a severe depletion of the ecosystem services needed for agricultural production in combination with several concurrent biosecurity breaches of a fungus, a virus, ants and aquatic bacteria over a short period of time, the Australian livestock sector would find itself in a very hostile environment. In a possible scenario we envisage RIFA, Xylella fastidiosa, and aquatic disease establishing in aquaculture systems, and with Karnal bunt entering and contaminating

239 *IPCC Special Report*, 2019.

240 L. O'Connor June 2019, personal communication.

241 Seebens et al. 2017

grain supplies across Australia, in combination with ecosystems likely being under stress from climate change. Our livestock-product trade sector would be severely impacted, if not decimated, under such a scenario.

If these exotic species were to become endemic, many of our livestock export markets would collapse, feed supplies would be compromised and result in imports increasing in order to support the reduction in domestic supply. As a consequence, many livestock businesses would likely not remain viable. Under such a scenario, in the absence of a contingency plan, Australia's biosecurity system is likely to be stretched beyond breaking point and could possibly collapse.

Implications

This scenario highlights that ecosystem services provided by plants, waterways, air, animals, insects and other natural capital are under climate-change-induced stress from multiple fronts and are increasingly susceptible to decline and further assault by invasive pathogens, weedy plants, algae, pest insects and feral animals. For example, overclearing of land destroys tree and grass cover, reduces biodiversity, increases soil erosion, creates dust storms and heats up regional microclimates, further exacerbating climate impacts.

Furthermore, biosecurity breaches for native grazing plants used by the livestock industry present risks of severe impacts to international trade and to feed supply. For example, pests, weeds or diseases causing large losses to grazing plant growth restrict both feed availability and livestock movement due to contamination. The livestock industry should consider this in terms of it's impacts on native and irrigated grazing plant species, on it's potential for restricting animal movement from infected areas, as well as it's broader devasting impacts on the ecosystems, economy, regional and urban community amenity values, and livelihoods.

Australia has emergency response plans for biosecurity incursions of high risk (cost:benefit to industry) pest and diseases of production animals (AUSVETPLAN)[242], production plants (PLANTPLAN)[243], and for any incursion not covered under the previous two plans (NEBRA)[244]. The environmental biosecurity concerns, including the impacts on ecosystem services and future impacts from climate change are not well developed or coordinated by government and farm businesses. Much work needs to be done to improve preparedness for transformative changes to the ecosystem services that the livestock industry needs in order to underpin growth in meat and fibre production and future opportunities in growing international markets. Importantly, preparedness needs to include the distressing human and social impacts of these invasions, and the resulting community interactions where preparations are lacking or where significant stress now exists.[245]

There are several potential impacts arising from the establishment of these exotic pests, weeds and diseases including:

- RIFA infestation of large areas of Australia would cause enormous economic and social impacts. They swarm over prey when their nests are disturbed, can kill calves and native mammals, birds and reptiles, and cause pastoral land to become unprofitable to use. This could block the use of significant areas of pasture land, disrupt urban grass areas including back gardens, harm human health and devastate native small mammal, reptile and bird populations[246]
- Xylella which has the potential to severely impact, if not decimate, thirteen of Australia's thirty-three most economically-important industries in the $9 billion dollar horticulture sector[247] and could cause widespread vegetation loss for cattle grazing. In combination with the already growing spread of Myrtle rust, an incursion of Xyella (or

242 Animal Health Australia, 'AUSVETPLAN', *AHA* [website], https://www.animalhealthaustralia.com.au/our-publications/ausvetplan-manuals-and-documents/ (accessed 29 October 2019).

243 Plant Health Australia, 'PlantPlan', *PHA* [website], https://www.planthealthaustralia.com.au/biosecurity/incursion-management/plantplan/, (accessed 2 November 2019).

244 Australian Government, 'National Environmental Biosecurity Response Agreement (NEBRA) review', *Department of Agriculture* [website], 4 November 2019, http://www.agriculture.gov.au/biosecurity/emergency/nebra, (accessed 2 November 2019).

245 ABARES, 'ABARES Social Sciences', *Department of Agriculture – ABARES* [website], 4 November 2019, http://www.agriculture.gov.au/abares/research-topics/social-sciences, (accessed 2 November 2019).

246 Department of Agriculture, 'Tramp ants', *Department of Agriculture* [website], http://www.agriculture.gov.au/pests-diseases-weeds/plant/tramp-ants, (accessed 2 November 2019).

247 Whittle, P.,'Towards preparedness of Australian Industries – activities, coordination, challenges', International Symposium on Xylella fastidiosa, May 2017, Brisbane, Australia. *Department of Agriculture and Water Resources* [website], https://www.agriculture.gov.au/pests-diseases-weeds/plant/xylella/international-symposium-xylella-fastidiosa, (accessed 2 November 2019).

other plant pathogens) could cause devastating losses of: vegetation and native mammal, insect and reptile species; increased erosion and sediment loads in waters ways; and soil dispersion by wind, reducing air quality with dust storms and causing loss of soil layers

- a biosecurity breach of Karnal bunt, would result in the widespread infestation of wheat seeds, soil, agricultural products, and machinery infrastructure with the fungal spores. Livestock would be contaminated and become vectors as Karnal bunt spores can pass through the guts of animals without being damaged, and be spread in animal manure. Australia would therefore implement severely reduced movement of livestock, grain feed, and machinary infrastructure. The wheat industry would be severely threatened due to the loss of crop quality[248], so the remaining crop would most likely be committed to human food consumption, creating scarcity for livestock feed grain
- increased aquaculture intensification impacts directly on the health and biosecurity status of aquaculture species due to disease prevalence, virulence transmission and host susceptibility. Some of these issues will drive the need for antibiotic interventions, which will intensify AMR issues. These factors are driving the need for new food safety risk assessments and safeguarding aquaculture health which will inform biosecurity risk management, including policymaking and decision-making[249]
- smothering of native aquatic ecosystems by invasive aquatic algae such as Didymo[250] may result in the devastation of watercourse ecosystems, particularly in slow flowing streams or lakes and under cooler low phosphorus conditions. Invasive algae and weeds can also cause blockage of water extraction infrastructure.

Opportunities

There are several opportunities that could be explored in order to avoid or mitigate this scenario:

- Valuing and creating a market for natural capital and ecosystem services driven by the avoidance of future bisoecurity costs. Taking a (neo-classical) economic approach, farmers may receive clearer economic benefits for looking after natural ecosystems.
- Increasing Australia's initiatives towards international cooperation and systems for valuing ecosystem services and biosecurity surveillance is achieved and factored into the economy in food trade.
- A livestock feeding strategy that straddles plant and animal industries to ensure sustainable low cost feed is developed and available for local animal industry needs and takes into account cross-sectoral biosecurity risks.
- Capability and capacity investments to meet the need for increased production and environmental biosecurity diagnostic and taxonomy espertise in Australia to undertake relevant targeted animal, plant, insect, pathogen studies at undergraduate, and graduate specialist PhD levels.
- Collaboration between plant and animal production industries and environmental biosecurity and biodiversity organisations to develop a biosecurity and ecosystem management strategy that increases public awareness of the critical linkages between biosecurity and the sustainable production of the food we eat.

The four scenarios outlined above were presented at an AHA workshop (26/11/2019) where participants discussed issuses posed by the scenarios around future challenges and opportunities faced by the livestock sector. They were asked to respond to key questions of what AHA should continue doing, or do differently, and how it could assist members to respond to the scenarios.

248 Department of Agriculture, 'Plants, Diseases and Weeds: Karnal bunt', *Department of Agriculture* [website], http://www.agriculture.gov.au/pests-diseases-weeds/plant/karnal-bunt#how-to-identify-karnal-bunt, (accessed 2 November 2019).

249 Melba, G. et al., *Climate change-driven hazards on food safety and aquatic animal health*, (2018) FAO Fisheries and Aquaculture Technical Paper 627, 2018, pp.517-34.

250 NIWA, 'Didymo in New Zealand: ten years on', *NIWA* [website], 16 September 2014, https://niwa.co.nz/freshwater-and-estuaries/freshwater-and-estuaries-update/freshwater-update-62-september-2014/didymo-in-new-zealand-ten-years-on, (accessed 2 November 2019).

6

CONCLUDING REMARKS

AHA finds itself at the nexus of a number of industry and external forces that will shape Australian animal health and biosecurity over the next two decades.

Australian agriculture has undergone considerable change over the last few decades. Due to sustained productivity growth, agricultural output has more than doubled during this period. Nevertheless, with the even faster growth of the services sector, agriculture's relative share of the economy has declined. At the same time, there have been marked changes in the makeup of the sector, driven by a variety of domestic and international forces. Some key factors driving change in the sector include globalisation, trade liberalisation, changing consumer tastes, technological advances and innovation, and environmental constraints. The unrelenting decline in farmers' terms of trade (that is, the ratio of prices received for farm products compared to prices paid for farm inputs) has also been an important pressure for change.

AHA finds itself at the nexus of a number of industry and external forces that will shape Australian animal health and biosecurity over the next two decades. The megatrends and current commercial outlook set the scene for the challenges and opportunities local industries face. The scenarios are intended as a catalyst for industry, and invite discussion and development of new strategies to deal with potentially rapidly changing circumstances that affect the immediate and ongoing threats of incursion from exotic diseases and pests that threaten both domestic production and global industry competitive advantage. There are challenges arising from increased complexity; but also new opportunities coming from rapid technological developments.

In broad terms, the scenarios can be summarised as highlighting:

- The livestock production sector's high dependency on safe and secure supply of feed.
- The impact of pests, weeds, diseases of animals, plants and environment as well as feral animals require higher and ongoing consideration for livestock production.
- Climate change disruption of ecosystem services will have an increasing and to a considerable degree unpredictable impact.
- Consumer demands and public health will shape production practices and associated biosecurity activities to retain our current disease-free status.
- Contingency is needed for the possibility of multiple, possibly catastrophic, concurrent invasions leading to biosecurity "shock" or breakdown.
- New technologies offer a pathway to address these challenges and create opportunities, but must be developed strategically and collaboratively.

The immediate key question that arises is: "How are these trends best dealt with, mitigated or taken advantage of?" and answering this demands a more holistic, far-sighted and collaborative approach to future AHA strategy and activities.

APPENDIX A MEGATREND REVIEW

Published data on global megatrends

In recent years a range of forward-looking analyses have been undertaken to describe the major forces shaping the future, to categorise these into sets of "megatrends", and in some cases to integrate them to project potential alternative future scenarios. The global megatrends considered most likely to have a profound impact on Australia's food and agriculture sector were identified by CSIRO and RIRDC in the 2015 report "Rural Industry Futures - Megatrends impacting Australian agriculture over the coming twenty years" as shown in Figure 8.

The report noted that the megatrends identified covered both domestic and global drivers of change because Australian agriculture is an export oriented industry which presently sells approximately two thirds of its produce offshore. Whilst domestic market requirements will necessarily remain an important priority for Australian farm production, there are faster-growing and more-rapidly approaching opportunities in emerging markets, especially in Asia, where food and fibre demand has doubled or trebled in recent years and are set for continued growth with increasing population and a rising middle class demographic.

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Several themes were identified in the report which represent key opportunities and/or challenges for Australian rural industries:[251]

- Continued productivity gains (including labour productivity) are required in agriculture to deal with competitive terms of trade and a labour force that is declining through ageing.
- Australian agriculture is predominantly export-oriented which means the sector benefits from, and is heavily reliant on, the market demand and consumer preferences of these global markets.
- Variability in agricultural profitability has significantly increased due to climate variability, volatile exchange rates and fluctuations in market demand.
- The trend of production consolidation to fewer, larger farms continues in response to the need for improved efficiency and competitiveness. The family farm remains the most common ownership structure and it increasingly faces pressure to grow and to maintain efficiency.
- Growth and diversification of exports is required in response to structural change in emerging economies – for example, an increased middle-income class, especially in Asia, driving stronger demand for a more diverse range of products whilst global commodity production becomes increasingly competitive.
- Access to quality production resources (arable

251 Hajkowicz, S. and Eady, S., *Rural Industry Futures: Megatrends impacting Australian agriculture over the coming twenty years*, Publication No. 15/065 Project No. PRJ-009712, CSIRO and RIRDC, 2015.

Figure 8. Megatrends impacting Australian rural industries.

Source: Hajkowicz, S. and Eady, S. *Rural Industry Futures:Megatrends impacting Australian agriculture over the coming twenty years.* Australia: CSIRO and RIRDC, 2015.

land, reliable water, cost efficient nutrition, elite adapted breeds, leading-edge pesticides and veterinary medicines and strong biosecurity) and proximity to markets remain major factors in planning for increased production capacity.

In 2014 CSIRO published a report that focussed on biosecurity megatrends.[252] This report identified five biosecurity megatrends (An Appetite for Change; The Urban Mindset; On the Move; A Diversity Dilemma; and The Efficiency Era) that all point towards a shift in the types of biosecurity risks we are likely to face in the future and the way that these risks will need to be managed. The report importantly showed how that megatrends relating to agricultural expansion and intensification, urbanisation and changing consumer expectations, global trade and travel, biodiversity pressures, and declining resources could lead to a future where existing processes and practices relating to biosecurity are not sufficient,

252 Simpson, M. and Srinivasan, V., *Australia's Biosecurity Future: Preparing for future biological challenges*, Canberra, CSIRO, 2014. https://www.csiro.au/en/Research/BF/Areas/Our-impact-strategy/Biosecurity-Future-Report

and continuous improvement needs to be made. Importantly, it emphasised that the megatrends should not be considered in isolation as they are all interrelated and the interactions of the different megatrends have the potential to lead to biosecurity mega-shocks and the associated potential for industry disruption.

Besides the above mentioned reports, EY in their 2015 study identified six broader megatrends that will shape the decades to come. These are digital future; entrepreneurship rising; global marketplace; urban world; resourceful planet; and health reimagined as shown in Figure 9.

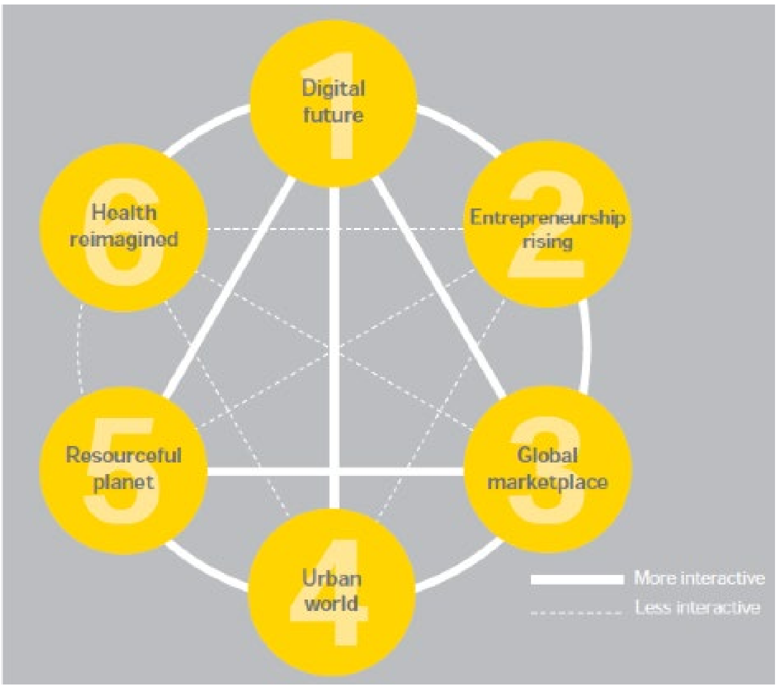

Figure 9. Global megatrend as identified by EY.

Source: *Megatrends 2015: Making sense of a world in motion*, EY, 2015.

The potential impacts of the megatrends within the food and agribusiness sector were highlighted further in a recent report by Cole et al.[253] (Figure 10) and are also highly consistent with both of the CSIRO/RIRDC and EY reports mentioned previously.

In 2018, the National Farmer's Federation unveiled their roadmap for 2030 (Figure 11).

Because of Australia's vast geography and

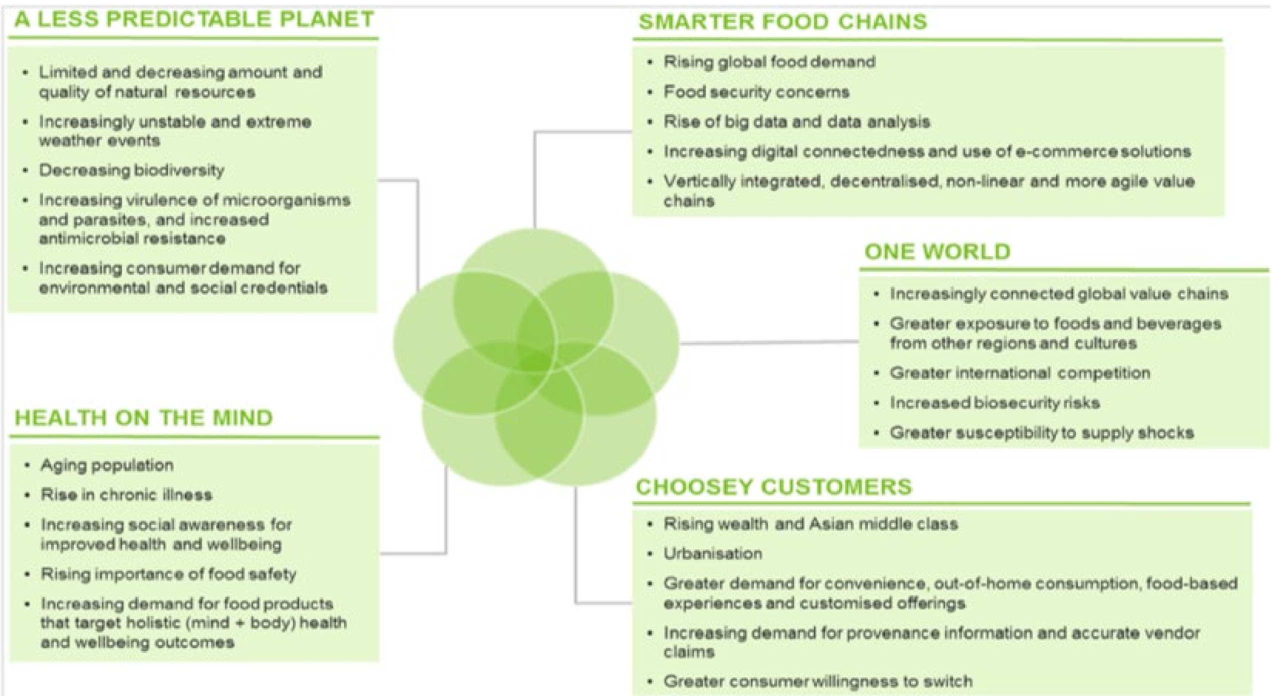

Figure 10. Key drivers and potential impacts arising from global megatrends.

Source: Food and Agriculture (Adapted from Hajkowicz and Eady, 2015 in Cole et al 2018; *CSIRO Futures*, 2017.

253 Cole, M. et al.,'The science of food security', *NPJ Science of Food*, vol. 2, no. 14, 2018, doi.10.1038/s41538-018-0021-9.

2030 Megatrends

Driver	Outlook	Assessment
Unprecedented demand	Burgeoning global populations and incomes – particularly on our Asian doorstep – will fuel demand for food and fibre in years to come. Improved market access will position Australia to service that demand, amplifying our geographic advantage.	Strength
Heightened expectations	Environmental, health, and welfare considerations will increasingly sway purchasing decisions. Meeting these expectations presents opportunities to build on our competitive advantage. It also increases reputational risks if expectations are not met.	Opportunity / Weakness
Disruptive technology	Digital and genetic technologies promise to unlock new waves of productivity growth across the sector. Automation will continue to improve quality of life for farmers, while reshaping the sector's skills needs.	Opportunity
Responding to climate change	Climate change will play a major role in Australian agriculture's next decade, exacerbating climate risk while creating diverse new income opportunities. Australia's policy response can position us as a global leader in low-emissions agriculture. Done poorly, our policy response could saddle farm businesses with additional costs.	Opportunity / Threat
Consolidating communities	Without intervention, growth in Australia's major cities and regional centres will continue to outstrip that of our smaller towns. This will compound existing pressure on labour and services for farm businesses and families.	Weakness
Fierce new competition	Competition will intensify as developing nations modernise their farming practices and supply chains. Competition will also arrive from non-traditional sources, as alternative proteins stake out a larger portion of the market. Meanwhile, global forces threaten to disrupt the established rules of international trade.	Threat

Figure 11. SWOT analysis of impact of megatrend's on Australian agriculture.

Source: *Road map 2030, Australian Agriculture's Plan for a $100 Billion Industry*, National Farmers' Federation, 2018.

associated wide range of climatic conditions, impacts of global megatrends will vary between localities, depending on the unique characteristics of each region. Global megatrends are not short-term issues and are anticipated to have relevance for decades to come,[254] shaping the role of government policy, environmental, social and economic outcomes. The opportunity exists to establish Australia's role in a world that will need to feed an estimated population in excess of 9 billion by 2050 with diminishing natural resources, whilst ensuring the health of people and the planet as shown in Figure 12 below.

Australian agriculture, especially the animal food products sector (meat, dairy etc.), is in a strong position to benefit from this increased demand due to a strong global reputation for producing consistently safe, sustainable and healthy foods, supported by a highly regulated and transparent food chain and a pristine natural environment (see Table 4).

These characteristics position Australia well in light of increasing biosecurity and food safety concerns overseas – particularly in many Asian regions. Australia's strong biosecurity framework, absence of key animal diseases and comparatively low prevalence of food-borne illnesses signals consistent safety and is reassuring for consumers. Completely surrounded by water and with high biosecurity protocols, Australia has an absence of many of the most undesirable pests, diseases and weeds, allowing products to be sold at a premium price in overseas markets. Studies have found the profits of beef, dairy and sheep enterprises would be 8 to 12% lower, pig enterprises 15% lower, and cropping enterprises 7% lower without an effective biosecurity system.

But with these challenges related to megatrends and evolving concern regarding food security comes a number of opportunities as shown in Figure 13. Possible opportunities arising from megatrends for Australian agricultural sector. Figure 7, discussed in a CSIRO Futures: Food and Agribusiness report.[255]

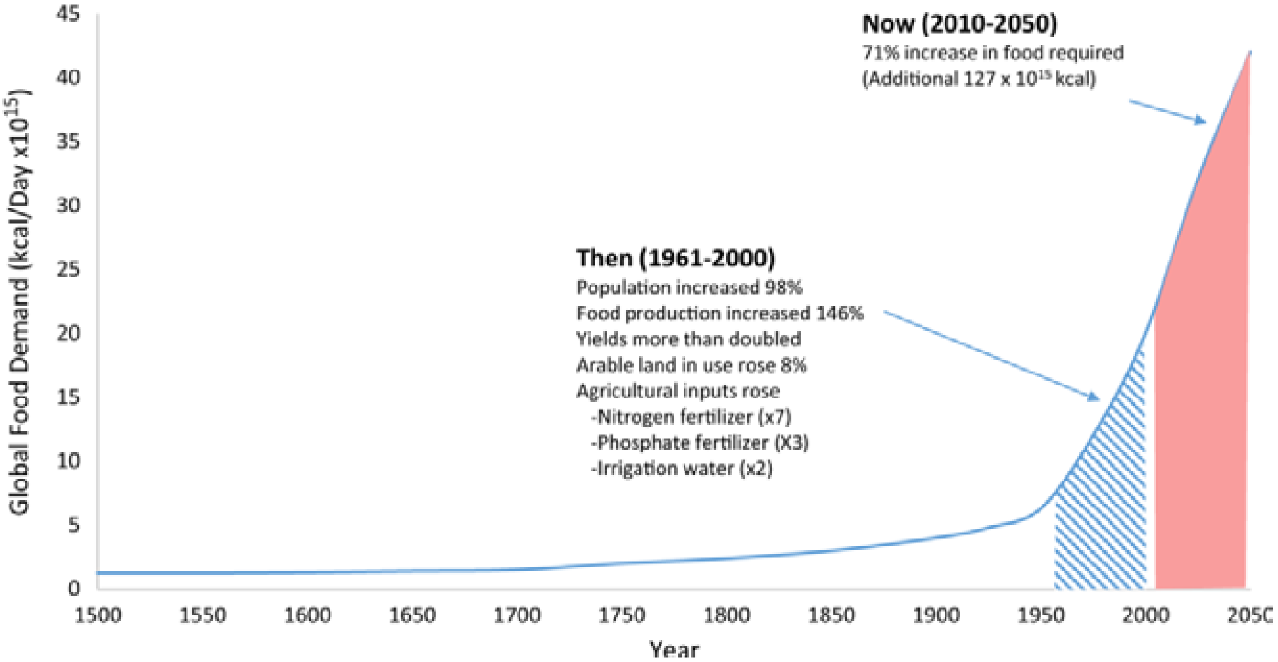

Figure 12. Framing the food security challenge.

Source: Adapted from Keating et al., 'Food wedges: framing the global food demand and supply towards 2050', *Glob. Food Sec.*, vol. 3, pp.125-132, 2014; Keating, B. A. & Carberry, P. S., 'Sustainable production, food security and supply chain implications', *Asp. Appl. Biol.*, vol. 102, 2010, pp.7–20.

254 KPMG International Cooperative, Future State 2030: The global megatrends shaping governments, KPMG, 2014, p.6. https://assets.kpmg/content/dam/kpmg/pdf/2014/02/future-state-2030-v3.pdf

255 CSIRO Futures, *Food and Agribusiness: A Roadmap for unlocking value-adding growth opportunities for Australia*, Australia, CSIRO, 2017. https://www.csiro.au/en/Do-business/Futures/Reports/Food-and-Agribusiness-Roadmap

Table 4. Comparative reputation of Australian products.

	AUSTRALIA (%)	MALAYSIA (%)	USA (%)	CHINA (%)	FRANCE (%)	BRAZIL (%)	CANADA (%)
Good value	32	21	30	31	20	24	24
High quality	37	14	41	12	42	18	34
Safe	39	17	34	13	31	19	36
Sustainable	31	15	19	13	20	21	25
Healthy	30	13	21	12	22	18	26

Source: https://ri.reputationinstitute.com/resources/registered/pdf-resources/most-reputable-countries-2013.aspx

Figure 13. Possible opportunities arising from megatrends for Australian agricultural sector

Source: CSIRO Futures, *Food and Agribusiness: A Roadmap for unlocking value-adding growth opportunities for Australia*, Australia, CSIRO, 2017.

Review of Agrifutures report on emerging technology and industry trends[256]

The Agrifutures report[257] mentions that the adoption of emerging technologies in Australian agriculture is expanding at a rate greater than the consumer's capacity to understand the opportunities. It identifies that Agtech will:

- support Australian agricultural goals to boost productivity and yield
- address consumer requirements to know where and how their food is grown, processed, packaged, and transported
- help primary producers maintain their "social licence" to farm, remain competitive in the global marketplace, and thrive in a world of rapidly changing consumer preferences.

The report then further classifies these technologies into having a) positive and b) negative attributes based on customer behaviour as shown below:

Consumer purchasing drivers (positive attributes)

- Quality/taste
- Health benefits
- Convenience
- Price
- Transparency/provenance of production

256 GHD and Agthentic, *Emerging agricultural technologies: Consumer perceptions around emerging agtech*, Publication No. 18/048 Project No. PRJ-011141, Agrifutures Australia, 2018. https://www.agrifutures.com.au/wp-content/uploads/2019/01/18-048.pdf.

257 GHD and Agthentic, Emerging agricultural technologies, 2018.

- Local origin
- Corporate social and environmental responsibility.

Areas of increasing consumer concern (negative attributes)

- Lack of sustainability
- Adversity of environmental impacts, especially with respect to climate change
- Social impacts
- Poor animal welfare
- Lack of Corporate Social Responsibility
- "Industrial" agriculture or "factory" farming (vs. smaller scale farming that is perceived to be more "natural").

The report further indicates that many technologies still require further research and development, and clear regulatory pathways before commercialisation and adoption in agriculture will be possible. They are therefore characterised by significant uncertainty and have not yet had a chance to demonstrate benefits that align with consumer expectations and desires. Millennial and GenZ consumers are more likely than previous generations to accept new technologies, especially when they have demonstrable benefits – they will be the majority of future consumers.

Unsurprisingly the report states that agricultural enterprises face many challenges such as high labour costs; challenging climatic conditions; and growing and changing global demands for food and fibre. However there is an increasing anticipation that the adoption of emerging technologies will help maintain competitive market advantages by: reducing production costs, increasing production yields; improving product safety and quality; and reducing environmental impacts.

Key technologies relevant to livestock production identified in the report are:

The Internet of Things (IoT): This can be best defined as a network of objects that are connected wirelessly using sensors, and can transmit information to each other, or a wider network, without human intervention. IoT is linked to other applications including remote sensing for disease surveillance, big data analysis and sharing, robotics/AI for diagnostics, risk-mapping for emergency disease management (preparedness, response, eradication and proof of disease absence).

Gene editing (as distinct from GMO): Newly emerging gene editing technologies allow small and precise inheritable changes to the genome of animals and plants. It can replicate changes that occur in the natural processes of genetic variation in living organisms and take advantage of mutations that already occur in nature. Gene editing has already created improvements such as polled cattle, in-egg sex identification for poultry, and generatrion of virus-resistant pigs.[258] However, gene editing has a risk of being negatively perceived by consumers, largely because it may be seen to be associated with GMOs. Gene editing is distinct from GMO approaches as it does not incorporate foreign DNA into the genome. As development and commercialisation of gene editing progresses, it is critical that the lessons from GMO cases be learned to ensure adoption of this technology for the benefit of Australian agriculture. Regulatory approval of gene editing has recently been reviewed in Australia by the Office of the Gene Technology Regulator (OGTR). The OGTR has dertermined that genetic edits made without templates are no different from changes that occur in nature, and therefore do not pose an additional risk to the environment or human health. Updated regulations that are now in effect, allow the use of certain genome-editing techniques in plants and animals without the need for government approval.[259]

Synthetic biology: This technology harnesses knowledge and understanding of living organisms at a molecular level to (re)design existing biological systems. The products that can be developed range from food and fibre (e.g., synthetic meat and clothing) to biochemicals and biofuels, to high value pharmaceuticals.[260]

258 Tait-Burkard, C. et al., 2018.

259 Mallapaty, S., Australian gene-editing rules adopt 'middle ground'", *Nature*, 23 April 2019, 2019, https://www.nature.com/articles/d41586-019-01282-8, (accessed on 23 October 2019).

260 Rural Industries Research and Development Corporation (RIRDC), *Synthetic Biology*, RIRDC publication no.16/035, 2016, https://www.agrifutures.com.au/wp-content/uploads/publications/16-035.pdf.

APPENDIX B AHA ROLE AND RESPONSIBILITIES

AHA members and stakeholders

Animal Health Australia (AHA) is a not-for-profit public company that facilitates innovative partnerships between governments, major livestock industries and other stakeholders.

AHA works with its Members[261] and stakeholders to strengthen animal health in Australia and maximise confidence in the safety and quality of Australia's livestock products in domestic and international markets.

AHA's collaborative programs improve animal and human health, food safety and quality, market access, animal welfare, livestock productivity and national biosecurity.

AHA has 34 members spread across four categories:

- Australian Government, state and territory governments
- livestock industry organisations
- service providers
- associate members.

Consultative processes

The key factor behind the success of AHA's programs is the ability of Members to work together to achieve a common outcome.

AHA's consultative processes seek to engage Members throughout the year to ensure that all Members have the opportunity to contribute to each stage of a project.

Members have a high level of involvement in the management of all activities and have formal input to the development of company annual and strategic plans through the Members' Forum.

The Member's Forum meets at least twice a year to consult with the Board and management on national animal health system issues and the company's role. This group plays a major role in prioritising company activities and enables Members to address issues of importance to their jurisdiction or industry.

The Livestock Industry Forum, comprised of AHA livestock industry Members, meets to discuss animal health issues, independent of the presence or influence of other Members, AHA or third parties.

Meetings of the Member's Forum and Livestock Industry Forum generally coincide with general meetings, which allows discussion of key issues directly with the Board and management and provision of feedback.

Funding

Members fund AHA's activities through annual subscriptions calculated on a formula using the gross value of production (GVP) of the industry or jurisdiction using a 3-year rolling average.

EAD response agreement

The Emergency Animal Disease Response Agreement[262] ('the Agreement' or EADRA) is a unique contractual arrangement signed in 2002 that brings together the Australian, state and territory governments and livestock industry groups to

261 Animal Health Australia, 'Members', *AHA* [website], 21 October 2019, https://www.animalhealthaustralia.com.au/who-we-are/information-for-members/members/, (accessed 31 October 2019).

262 Animal Health Australia, 'EAD Response Agreement', *AHA* [website], 2 March 2018, https://www.animalhealthaustralia.com.au/what-we-do/emergency-animal-disease/ead-response-agreement/, (accessed 31 October 2019).

Our members

Australian, State and Territory Governments

Livestock Industries

Service Providers

Associate Members

collectively and significantly increase Australia's capacity to prepare for—and respond to—emergency animal disease (EAD) incursions.

The EADRA covers 66 categorised animal diseases and 23 Signatories to the Deed (governments and industry bodies).

The main benefit of the Agreement is that it allows for the ability to respond quickly and effectively to an EAD incident while minimising uncertainty over management and funding arrangements.

EADRA approaches

All signatories have agreed to work collectively to reduce the risk of emergency animal disease (EAD) incursions and share the approved costs of EAD responses. The EADRA also provides an innovative framework (outlined below) to combine multiple dynamic approaches to combating EADs.

Participation and cooperation

All parties commit to the participation in an EAD response through informed and empowered representatives who cooperate to determine and direct the response. This unique approach facilitates effective participation across state and territory boundaries and gives each participating industry a 'real voice'.

Risk management

While the Agreement ensures that funds to combat an EAD are made available and the costs shared among the beneficiaries of the response, it also commits parties to take all reasonable steps to minimise the risk of an EAD occurrence in the first place (eg through the development and implementation of biosecurity plans.

Detection and response

All parties commit to maintaining the capability to ensure early detection of—and an effective response to - an EAD.

Cost sharing

All parties commit to contribute to funding the eligible costs of responding to an EAD by which they are affected. The costs to be shared are identified under the Agreement. Some of the rules around cost sharing can be summarised as follows:

- Cost sharing is aimed at equitable contributions from all parties, commensurate with their respective resource base and status as a beneficiary of the response.
- The total amount of response costs that government and industry parties share in the event of an EAD is capped, depending on the size of the affected industry.
- EADs are categorised according to the impact they can have on livestock industry production (eg international trade losses, domestic market disruptions, production losses), human health and the environment. An EAD's category determines how much of the response costs are borne by affected industries in aggregate and how much by governments.
- A party that is not a beneficiary of the response is not required to share the costs, but neither does it have a say in determining the response.
- Compensation payable to an owner under state or territory legislation, which may vary from jurisdiction to jurisdiction, may be included in cost-sharing under the Agreement.

Training

Training is an essential part in ensuring the efficacy of a response. The EADRA provides for the training of relevant personnel.

Maintenance of the EADRA

Since 2002, the EADRA has been used in a number of real and simulated responses. When using the EADRA, various parties may identify areas where the Deed could be improved.

To maintain the EADRA, AHA:

- holds regular workshops to address identified issues and amend the Deed as necessary
- prepares supporting EADRA business rules and guidance documents.

REPORT AUTHORS

Cameron Begley,
Managing Director, Spiegare Pty Ltd

Cameron Begley completed his undergraduate degree in Chemical Engineering then took technical sales and marketing roles in the chemical industry, initially with Dow Chemical and then Akzo Nobel Chemicals with a range of regional roles and responsibilities.

On completing an Executive MBA he then moved into technology transfer and commercialisation with CSIRO, initially linked to Chemical Engineering Sciences and then to a Commercial General Management role at the then Division of Entomology. There he was involved in business development and commercial activities linked to biosecurity, agriculture and industrial biotechnology, facilitating a range of R&D and commercialisation transactions working across CSIRO, external researcher, commercial and government partnerships in seeking to catalyse Australia's bioeconomy industries.

In 2014, Cameron established Spiegare Pty Ltd, which is a consultancy focused on technology transfer and commercialisation advisory for companies, R&D investors and publicly funded research institutions.

Dr Allan Green,
Managing Director, AGRENEW Pty Ltd

Dr Allan Green devoted his lifetime research career at CSIRO to understanding the genetic control of oil and fatty acid biosynthesis in plants, and using this knowledge to develop new and improved oil crop products for Australian and global agriculture. He has been a pioneer in using increasingly sophisticated genetic technologies for the modification of fatty acid composition in oilseed crops to provide improved nutritional value, enhanced functionality, and novel industrial end uses.

The CSIRO Plant Oil Engineering Group that he founded in the 1990s and provided the strategic leadership for, has risen to the forefront of global research to improve plant oil production. The Group has generated significant opportunities for innovation in the Australian and global oilseeds industries, through the creation, development and commercialisation of DHA Canola and Super High Oleic Safflower, that will be Australia's first two "home-grown" GM crops. Their recent development of game-changing technology for synthesising and accumulating high levels of oils in plant leaves has the potential to create new oil- producing energy crops capable of sustainably delivering advanced biofuels cost-competitively with petroleum-based fuels.

In 2003 Allan established the Food Futures National Research Flagship, and subsequently established and led CSIRO's Metabolic Engineering of New Plant Products Program that delivered breakthrough research into Food Futures. Food Futures has delivered a number of new high-value grain crops for the Australian industry including DHA-canola, ultra-low gluten barley, and high-amylose wheat. Allan recently retired from CSIRO and has established a new company AGRENEW Pty Ltd to assist the grains and oilseeds industry to capitalise on the latest genetic technologies for creating new high-value products.

Dr John Lowenthal,
Senior Associate, Spiegare Pty Ltd

John Lowenthal obtained his PhD in immunology from The Walter and Eliza Hall Institute at the University of Melbourne and completed Post-doctoral positions at the Ludwig Institute for Cancer Research in Lausanne, Switzerland and at the Howard Hughes Medical Institute at Duke University, USA.

John joined CSIRO in 1990 where he held various senior positions until 2016. As the former Research Director for Infectious Diseases located at CSIRO AAHL, his responsibilities included managing an extensive portfolio of projects aimed at developing medical therapeutics and vaccines for a range of infectious diseases of animals and humans. His research areas included studying pandemic viral diseases under high biocontainment; developing novel therapeutics, vaccines and medical countermeasures for viruses such as highly pathogenic avian influenza, Ebola and Hendra viruses; establishing new animal models for emerging zoonotic diseases; developing alternatives to antibiotics to combat anti-microbial resistance (AMR); and developing genetically modified disease-resistant animals.

Throughout his 30-year research career, he has been involved in large-scale international project management and working collaboratively with commercial and university partners across the biosecurity and medical technologies sector. He has published over 150 journal articles (many in prestigious journals including Nature, Science, PNAS) and is an inventor on 10 internationally-granted patents. John is currently an adjunct Professor at Deakin University's School of Medicine and provides advice to medical biotechnology companies, research organisations and the health and biosecurity industries.

Dr Rachel Melland,
Senior Associate, Spiegare Pty Ltd

Rachel brings her purpose and commitment to researching, research management and delivering research strategies, investment landscape analysis and technology transfer to her clients. Rachel works towards improving Australia's natural ecosystems, and agricultural, horticultural and urban food and fibre production systems. Rachel brings deep experience with building constructive collaborations from very complex relationships across key stakeholders, including researchers, practitioners, policy makers, industry members, and all levels of government.

Rachel has 25 years of experience, delivery and leadership in biosecurity and invasive species management, including organising Australasian Weeds Conferences – now key global weed management events. Rachel has extensive experience bringing people together towards common goals, ensuring FTO, ROI and path to market requirements, and is passionate about research impact planning. Rachel has been a Research Program Manager at the Grains Research and Development Corporation and has consulted to many RDC's and research/industry entities. She has worked in both the for-profit and not-for-profit sectors.

Rachel is currently a Senior Associate for Spiegare Pty Ltd, runs her own consultancy, is Immediate Past President of the Council of Australasian Weed Societies, and an executive member of the Weed Management Society of South Australia. She is a member of the 'National Biosecurity Statement Working Group', and the 'Environmental Biosecurity Advisory Group', both Federal Department of Agriculture and Water Resources. Rachel is a member of the Australasian Research Management Society (ARMS).

Rachel's voluntary role as a member of the Juvenile Diabetes Research Foundation (JDRF) ACT State Leadership Group focuses on Federal Government relations, fundraising, and working towards further vital medical research to improve the quality of life, and find a cure, for people suffering from the non-preventable autoimmune disease, type 1 diabetes.

Dr Faisal Younus,
Associate,
Spiegare Pty Ltd

A scientist and researcher with over 7 years of experience, Faisal holds a First Class Honours degree in Biotechnology from Deakin University, Australia and a PhD degree in neuro-biochemistry from the Australian National University.

He has been involved in technology and commercialisation projects globally. Faisal has also undertaken multiple projects supporting the development of policy and regulatory change to enable various industries to access new technologies and markets. His multidisciplinary research is shown by publications in international high impact scientific and educational professional journals such as PNAS and Nature with over hundreds of citations. His scientific works have been also heavily publicised by local and international media. Winner of numerous academic and industry awards and scholarships,

Faisal was heavily involved in the inaugural CSIRO Acceleration Program, pitching 'Scientific equipment and facility access platform'. He was also the winner of the inaugural CSIRO 2020 strategy competition with his ideas being incorporated into the CSIRO 2020 Strategy Policy. Faisal has a tremendous track record of creating organisational value by developing and executing innovative projects at both strategic and tactical levels with national and international collaborators such as Grain Research Development Corporation (GRDC), Mitsubishi Chemical Corporation (MCC), Queensland University of Technology (QUT), Sugar Research Australia (SRA), Agilent Technologies (USA) and Institut National de la Recherche Agronomique (INRA, France) and multiple ministries of the Government of Bangladesh.