Final report

Health, welfare and biosecurity of livestock exposed to Australian bushfires

Project code: B.AHE.2102

Prepared by: Brendan Cowled, Caitlin Pfeiffer and Karren Plain
Ausvet Pty Ltd, University of Sydney and University of Melbourne

Date published: 7 April 2022

PUBLISHED BY
Meat & Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

Bushfires are increasing in frequency globally, especially as a result of longer fire seasons, including in Australia. In the spring and summer of 2019, Australia experienced a severe bushfire event, now referred to as the Black Summer Bushfires. Little research has been conducted on the impacts of bushfires on livestock in any part of the world. This limits understanding and the ability to plan for bushfires or manage bushfire affected stock in an optimal way. This research sought to improve understanding of how red meat producers can better prepare for, respond to, and recover from bushfires. A case control study of burnt cattle and sheep farms was conducted in south eastern Australia. These farms were investigated for risk and protective factors. Samples from cattle from the farms were assessed in the laboratory for immune function, biosecurity markers and micro and macro minerals. Industry data describing meat and carcase quality were analysed. Expert workshops and online surveys were conducted. The results showed that producers can protect livestock with various steps such as developing farm fire plans and bushfire fighting. Investigations of immune system function from cattle on burnt farms showed that some animals may have reduced immune fitness.. Both carcase and meat quality decreased close to severe fires. Injuries to cattle included injuries to skin, hooves and respiratory systems. In recovery, risks to livestock welfare can be mitigated through effective recovery support for fire-affected farmers. Biosecurity and herd health management should be key considerations, as the lower immune fitness of the affected animals may mean they are more susceptible to disease. A key project outcome was a bushfire preparedness and recovery manual, which requires extension to the industry before the next severe fire season.

Executive summary

Background

Australia had its hottest and driest year on record in 2019 and endured a series of heatwaves over much of Australia in December 2019. Then in the spring and summer, Australia experienced a severe bushfire event. Approximately 60 000 livestock were killed or euthanised during the fires. Whilst this is a relatively small proportion of livestock in the affected areas, the real issues are (1) that the impact on some individual producers was very high due to large numbers of stock losses on particular farms, and (2) that sub-clinical impacts on other livestock may be widespread but were not well understood. In addition, bushfires are increasing in frequency globally, especially as a result of longer fire seasons in temperate or boreal regions.

Little systematic research has been conducted on the impacts of bushfires on livestock in any part of the world. This paucity of literature limits understanding and constrains the industry's ability to plan for bushfires or manage bushfire-affected stock in an optimal way. This is especially concerning given the increasing frequency and severity of such events. Consequently, red meat livestock producers require cannot prepare, respond or recover optimally without an evidence base of understanding about bushfire impacts on livestock. This research sought to improve understanding of how livestock producers can better prepare, respond and recover from bushfires.

Objectives

The objectives of the research were to:

1. Synthesize current understanding of bushfire impacts on livestock through a comprehensive literature review
2. Characterise how bushfires affect livestock in terms of:
    a. Pathology
    b. Immune fitness and association with reproduction and production
    c. Welfare
    d. Biosecurity
    e. Meat quality
3. Identify and describe mitigation and recovery strategies associated with positive producer outcomes
4. Presentation of the results as a livestock bushfire preparedness manual for producers

All objectives were addressed in the project, culminating in a bushfire preparedness and recovery manual.

Methodology

1. Case control study of bushfire affected farms
2. Laboratory research (immune function research, diagnostic testing (serology, parasites, bacterial culture), trace minerals analysis, hair cortisol analysis)
3. Analysis of carcase quality (National Sheep Health Monitoring Project), meat quality (Meat Standards Australia) and retrospective data
4. Meat quality, pathology and health assessment of cattle at slaughter
5. Expert workshops

6. Spatial analysis of bushfire affected farms
7. Interviews with government and private veterinarians who responded to bushfire injured livestock (qualitative epidemiological research)

Results/key findings

1. Basic understanding of the pathology of bushfire injured livestock, how to manage injured livestock and how to enhance government assessment and management of injured livestock
2. Factors were identified that protect livestock from bushfire injury (included farm fire plan, >2 fire fighting units, backburning and fire authority assistance)
3. There were indications that the animals that lived through the bushfires may have reduced immune fitness in relation to some aspects of their immune response and therefore be more susceptible to infection.
4. Carcase quality was affected by proximity to severe bushfires with ten times as much pneumonia in slaughtered sheep, although there was still a relatively low prevalence of pneumonia
5. Meat quality was reduced close to severe bushfires. This could likely be prevented through retaining stock for several weeks with appropriate supplementary feeding. However, industry must retain an ability to immediately slaughter livestock for welfare reasons, regardless of meat quality impacts.
6. In animals followed out to 15 months post-fires, there were no adverse effects to carcase quality or histology seen as a result of the bushfires. It was concluded that the animals examined presumptively overcame any deleterious effects caused by the acute inhalation of smoke.
7. Preparedness and recovery activities were associated with better outcomes, for example adequate insurance and carefully planning recovery activities. Supporting producers to make appropriate decisions in recovery is expected to be beneficial to both animal welfare and farm business.
8. Safe refuge areas on the farm during a fire include places away from woody vegetation and steep slopes, and low-lying areas such as creek beds. Where moving stock to safe paddocks is not possible, opening all internal gates within the farm is recommended.
9. Disease outbreaks associated with compromised biosecurity were identified at a low frequency (e.g. infection with pestivirus or abortions due to campylobacteriosis in cattle). Many farms experiencing compromised biosecurity post-fire (e.g. burnt fences, stock movements to agistment) did not observe direct biosecurity impacts for livestock. Laboratory results for pestivirus and vibriosis in cattle did not provide conclusive evidence of biosecurity breakdowns, though wandering stock were implicated in abortions seen on one farm. Weed invasion into pastures was common and problematic for farm productivity.
10. An evidence-based bushfire preparation and recovery manual has been produced. This will assist livestock producers in preparing for and responding to bushfires.

Benefits to industry

1. Mitigation of livestock injury and deaths due to bushfire
2. A resource to enhance preparation and recovery from bushfire for southern livestock producers

3. Enhanced understanding and mitigation of meat and carcases quality issues
4. An understanding that long term immune function impacts due to bushfire are evident, though cattle recover as time passes, hence attention to herd health management and biosecurity considerations should be a high priority during the recovery phase.

Future research and recommendations

The main recommendation is that appropriate extension of the Bushfire Preparation and Recovery Manual content must occur. Due to the *La nina* event during the time of this project, it may be one or more years before preparation for bushfires is considered a priority by producers in southern Australia. Therefore, alongside community extension strategies, stand-alone and self-guided materials that support the manual should be prepared for access ‘just in time’ before the next severe bushfire season.

Table of contents

1. Background

Australia had its hottest and driest year on record in 2019 and endured a series of heatwaves over much of Australia in December 2019 (Filkov et al., 2020). In the lead up to this, much of southeast Australia had suffered a protracted drought from 2017 with rainfall values in New South Wales (NSW) and southern Queensland near or below previous record low values (Filkov et al., 2020). The accumulated Forest Fire Danger Index in spring 2019 was significantly higher than in any other spring on record (Filkov et al., 2020). Then in the spring and summer, Australia experienced a severe bushfire event. During this bushfire event more than 19 million hectares of land burnt, more than 3 000 homes were destroyed and 33 people died (Filkov et al., 2020, Richards et al., 2020). It was estimated that the fires and exposure to particulate matter led to several hundred excess human deaths and thousands of hospitalisations (Borchers Arriagada et al., 2020). It has become known as the 'Black Summer Bushfires'.

It was estimated that more than 56 000 livestock were killed or euthanised in New South Wales, Victoria and South Australia, perhaps as many as 69 000 (Kotsios and Twomey, 2020, Condon, 2020). Livestock population data (Anon., 2016, Anon., 2019) indicate that there were 3.6 million cattle and 21 million sheep in bushfire affected regions of NSW and Victoria (BC, unpublished data). This indicated the overall proportion of livestock killed by bushfires was relatively low. The real issue is that the impact on some individual producers was very high due to stock losses.

Bushfires (wildfires) are increasing in frequency globally, especially as a result of longer fire seasons in temperate or boreal regions (Flannigan et al., 2009, Liu et al., 2010). Little research has been conducted on the impacts of bushfires on livestock in any part of the world. For example, a systematic literature review in this project revealed barely a dozen publications, mostly case studies in Australia (Gee, 1986, Dieckmann et al., 2020, Malmo, 2015, McAuliffe and Hucker, 1978, McAuliffe et al., 1980, Morita et al., 2006, Morton et al., 1987, Prat et al., 2017, Rethorst et al., 2018, Rogers et al., 2015, Smith et al., 2015, Traber et al., 2007, Willson, 1966, Wolff, 2009). More specific published research on immune fitness, meat and carcase quality, pathology, injuries, risk factors or mitigation strategies for burns due to bushfire are even more limited. This paucity of literature limits understanding and the ability to plan for bushfires or manage bushfire affected stock in an optimal way. This is especially concerning given the increasing frequency and severity of such events.

It can be impossible or difficult to collect field data during bushfire emergencies. Under such circumstances it is difficult to collect data as veterinary and research resources are scarce or difficult to deploy. However, there are several efficient and plausible methods of conducting such data collection, all of which were used in this project. Retrospective case control studies are efficient to collect information about risk factors for rare events such as bushfire injured livestock. Examining existing abattoir collected data can be an efficient way to collect large amounts of information about carcase and meat quality of bushfire affected livestock. Qualitative research methods seek to uncover a diversity of views and meanings that people bring to an issue under investigation (May, 2018). Such approaches can provide the veterinary profession with insights into topics that are hard to reach with more widely used quantitative research methods (May, 2018), such as observational epidemiological studies. These and other techniques were all used to collect systematic data on bushfire impacts, risk and protective factors, livestock injury and immune fitness and preparedness activities in this research project. Thus there were two broad areas being addressed in this project: (1) collect data to provide an evidence base about the impacts of bushfires on livestock, and; (2) prepare a bushfire manual for livestock producers to use to prepare for and respond to bushfire.

This information will be useful to both livestock producers, animal health professionals and farm advisors.

2. Objectives

Table 1 The objectives detailed in contracts, achievement of objectives and summary of results for each objective.

Objective as outlined in research agreement	Achieved	Comments
1. Synthesis of current understanding of bushfire impacts on livestock through a comprehensive literature review	Yes. A literature review was prepared and is presented as Appendix 1. In addition, a second literature review, detailing meat quality issues is presented as Appendix 2.	Reveals a paucity of data and research on bushfire impacts on livestock. General meat quality science provides hypotheses about the possible impacts and mechanisms of bushfire damage to meat quality.
2. Characterise how bushfires affect livestock in terms of:	-	-
a. Pathology	Yes. Qualitative veterinary epidemiologic research using interviews of government veterinarians involved in the response occurred to investigate pathology observed. In addition, understanding of decision making about injured livestock and risk factors for livestock injury was also collected. This research was published in Frontiers in Veterinary Science. See Appendix 3. In addition, a group of fire-exposed cattle were followed through to slaughter and examined for gross and histopathological evidence of pathological changes associated with fire exposure. See Appendix 4,	Identified that timely and competent veterinary services were available to livestock producers with injured livestock. Injuries observed were largely of the external integument (especially hooves, but also teats, scrotum, pizzle etc.) and respiratory system, but widely variable depending on the fire. Some excess culling of bushfire injured livestock was evident, and this may be reduced by revisiting injured livestock progressively after fires to avoid risk based culling on the first visit. This would require additional veterinary resources and prioritising veterinary services into an emergency area. Treatment of livestock was possible in some circumstances using a range of treatments and

		approaches but was time consuming at a time when producers can be overwhelmed. Follow-up of cattle sent to slaughter 15 months after the fires indicated no evidence of histopathology as a result of the bushfires.
b. Immune fitness and association with reproduction and production	Yes. Laboratory testing of samples was undertaken. Submission (n-12 cattle/farm) were from bushfire-affected Case and Control farms and Non fire-affected (NFA) Control farms (located in regional areas of NSW that were unburnt during the bushfires). Assessment of immune fitness biomarkers, indicating the functional state of the immune system, stress biomarkers (hair cortisol) and trace minerals was performed. See Appendix 5.	Identified changes that were indicative of reduced immune fitness in Case farms compared to NFA controls. This was reflected in multiple biomarkers (i) interleukin-8 and C-X-C motif chemokine ligand (CXCL)10 levels in response to *in vitro* stimulation; (ii) gene expression biomarkers of immune fitness. Hair cortisol levels (an indicator of chronic stress) and serum levels of the trace minerals Zinc and Selenium (important for immune function) were not associated with the bushfire farm classification (Case, Control or NFA Control), but there was a presumptive association identified with body condition score. There was no indication of toxic exposure to metals such as lead, aluminium or nickel associated with the bushfires at >200 days post-fires.
c. Welfare	Yes. Data collected during on-farm interviews and supplemented by an online survey described the observations of producers about animal health issues in their livestock post-fire, as well as some comments on livestock behaviour, biosecurity and quantifications of the outcomes for burnt stock.	On the studied farms, livestock injured by bushfire either died or were euthanised in 80% of cases for cattle and 95% for sheep. For un-injured animals, animal welfare is affected immediately post-fire by challenges in supplying clean water, sufficient feed and secure fencing. Once these challenges are addressed, welfare effects of bushfire can include the occurrence of health problems due to changes in farm management during fire

	See Appendix 6.	recovery, as well as behavioural changes that were not fully characterised in the current study. More than half of the farms studied reported health problems, with common diagnoses including lameness, plant toxicities, eye disease and respiratory disease. Unexplained disease was also reported and is often difficult to investigate on farms undertaking fire recovery. Loss of yards in some cases prevents producers from undertaking routine husbandry tasks or treatment of injured or unwell animals. This emphasises the welfare benefit of investing in farm infrastructure as part of fire preparedness.
d. Biosecurity	Yes. An observational case control study of bushfire affected farms was conducted, with all farms being burnt. Case farms had bushfire injured livestock and control farms had un-injured livestock. Non-fire affected farms were also sampled as a further comparison. During the observational study, data on an infectious disease was collected. This included data collection via questionnaire surveys and biological specimen collection. Questions focused on risk factors for biosecurity breakdowns such as fence losses, agistment, restocking and other biosecurity risks that occurred after the fires. The biological specimens focused on internal parasites and serology for Bovine Viral Diarrhoea Virus (Round 1) and *Campylobacter fetus* testing through EMAI (Round 2), which enabled an investigation into reproductive failures within bushfire affected herds.	Faecal worm egg counts (FWEC) were un-informative. In almost all cases Nematode egg counts were very low with the rare pool from farms having >20 eggs/gram. Fluke sedimentation tests identified around 20% of farms as positive. These results likely reflect the several years of dry conditions before the fires. No statistical evaluation to differentiate between cases, controls or NFA farms was therefore possible. BVD serology was also uninformative. Dairy farms invariably had a high level of BVD seropositivity, reflecting the highly admixed nature of dairy herds. Beef farms usually had no BVD seropositivity. The exceptions were the beef herds that vaccinated or farms with poor biosecurity that traded livestock regularly. Nonetheless, the confounding factor of sector (dairy verse beef) and rareness of the outcome in beef cattle precluded statistical analysis and inference about biosecurity. *Campylobacter fetus* positive herds/animals by culture were only identified four times; this precluded statistical

	The objective was to enable comparisons about biosecurity outcomes (BVD prevalence) between case, control and unburnt farms and their biosecurity practices so that inferences could be made on whether biosecurity was impacted by bushfires. For example we hypothesised that infectious diseases were more common in farms that were badly burnt (cases) as agistment, restocking and escape of livestock due to burnt fences may be more common. In addition faecal egg counts and larval differentiation was conducted as a thank-you to producers who participated. See Appendix 5.	analysis about the impact of biosecurity on *C. fetus* prevalence. An investigation of the positive herds was made in relation to reproductive history. One of these involved a confirmed case of *C. fetus* subspecies *venerealis* in which the animal went on to abort twice. This case was suggestive of a biosecurity breakdown. In summary the biosecurity research was uninformative due to the rareness of the outcome and lack of knowledge regarding prior infection status. We would have required a sample of several hundred farms to address this question which is extremely difficult to achieve given the challenges of research on farms undertaking fire recovery activities. Some qualitative data about biosecurity were collected through interviews during the case control study and indicated that biosecurity breakdowns were uncommon but caused substantial losses when they did occur. In response to limited findings regarding biosecurity through the laboratory testing, a case study was of a Local Land Services veterinarian is included in the manual. This case study presents the veterinarian talking about the cases of biosecurity breakdown observed in his district including Theileria deaths in re-stocked cattle and bull movements leading to pregnancies in immature heifers. Anecdotally there was an increased prevalence of many weeds reported during on farm sampling after the fires, including fireweed.
e. Meat Quality	Yes.	**Meat Quality (MSA)**

	Three comprehensive studies occurred investigating both carcase and meat quality. These focused upon: • investigating associations between pneumonia and pleurisy in sheep using the National Sheep Health Monitoring Project – see Appendix 7. • investigating the association between meat quality in cattle and bushfire intensity using the Meat Standards Australia (MSA) data from several abattoirs and +400 000 cattle – see Appendix 8. This has been submitted to Preventive Veterinary Medicine and is currently in peer review. • examining the mechanism of meat quality declines by investigating associations between loin pH at grading, meat colour at grading and bushfire exposure in a separate analyses of MSA data and bushfire intensity – see Appendix 9. In addition, a further study of meat quality traits was undertaken with two producers whose farms burnt whose cattle were subsequently slaughtered. See Appendix 4.	There was a consistent and plausible biological gradient of decreasing MSA index scores in carcases originating from cattle in closer proximity to, and less time since, exposure to bushfire. This was particularly prominent in carcases from cattle that were located up to approximately 11 km from a medium-to-high intensity fire. These findings may have implications for the management of cattle after a bushfire. Beef cattle may be sent to meat processors for slaughter in the immediate aftermath of bushfires: for example, because the effects of fire on pasture can make feeding difficult. This approach may maximise financial returns (by sale before decline in body condition) and manage animal welfare impacts (including avoiding starvation). However, given that meat quality can have impacts on financial returns, bushfire-affected stock could be hypothesised to have a lower economic value if meat quality is affected. This could lead to competing interests between processors and farmers, for example with processors discounting the price they are prepared to offer. **Bushfire exposure associated with loin pH and meat colour** Distance from bushfire and duration of the nearest bushfire were both associated with non-compliance for both pH and meat colour at grading, likely contributing to the MSA index score effect above. Importantly, these effects were strongest for grass-fed cattle (compared to grain-fed) and for cattle receiving hormonal growth promotants (compared to no promotants). The combination of fire exposure and production factors in the study results suggests that strategic management

		could mitigate the effects of nearby bushfire on meat quality. For example, providing high metabolisable energy feed (such as grain or pellets) for at least 7 days after fire exposure would restore the glycogen deficit that is likely driving pH and meat colour changes, and should improve meat quality at subsequent processing. Definitions for four risk categories of stock are provided that could be used as to develop a simple calculator or grid to support producer decision-making. **Carcase quality (NSHMP) – Pneumonia and Pleurisy** There was a consistent and plausible biological gradient of increasing numbers of sheep affected by pneumonia with shorter distance to, and shorter time since, exposure to mid to high intensity bushfire. The findings of this study may reflect a causal relationship between bushfire smoke and pneumonia in sheep. In contrast, there was no association identified between pleurisy and bushfire. **Carcase assessment:** Only 2 producers were interested in obtaining animal health and meat quality feedback and had suitable (fire and/or smoke affected) stock, with a total of 25 animals followed to abattoir and sampled for meat quality traits. No adverse effects on carcase quality were evident at 15 months post-fires.
3. Describe which paddock features are associated with the risk of the paddock burning	Yes. During farm visits the farm boundaries of each farm were mapped on paper with the assistance of the producers. Fire location and mitigation steps were identified (e.g. previous burns history, firebreaks, back burns etc.). These maps were digitised and georeferenced. In addition, various landscape features that may confound any inferences such as slope were identified.	Geographic features of the safest paddocks vary between farms. Therefore, there is no single recommendation to reduce livestock losses, but rather a number of considerations that can be used as appropriate on individual farms to reduce the likelihood of severe livestock injuries from fire. Key protective factors included being away from fencelines, low paddock fuel loads (pasture dry matter), increasing distance from wooded areas, and possible beneficial

	The data were analysed to identify possible paddock features associated with likelihood of serious injury to stock. Results of analysis are aligned with anecdotal advice about safe places on-farm for livestock and increase confidence in these recommendations. This is reported in Appendix 10.	effects of close proximity to watercourses. The statistical findings are aligned with anecdotal advice including from producers who provided map data as well as members of the consultative panel.
4. Identify and describe mitigation and recovery strategies associated with positive producer outcomes	Yes. This work was completed in two parts. **Case control study of risk factors for burnt livestock** The case control study primarily focused on identifying differences between farms that burnt and had injured or killed livestock and those farms that burnt and had no injured or killed livestock. Several important differences were observed between the two farms groups enabling recommendations about mitigation strategies. See Appendix 11 for a full report. This report was submitted to the Australian Veterinary Journal as a manuscript and is currently undergoing peer review. **Consultative panel** Successful preparedness and recovery strategies were explored during a series of workshops with various experts. Seven panellists (state government bushfire recovery coordinators, district veterinarians, emergency management researcher, farm consultants, farmer with experience as a Country Fire Authority fire-fighter) contributed. They were provided discussion papers with key questions addressed in writing before meeting in a series of workshops for further discussion.	**Case control study of risk factors for burnt livestock** Having a bushfire plan, backburning, more than two farm bushfire fighting units and receiving assistance from fire authorities all appeared to have a protective relationship with bushfire injuries. A risk factor for bushfire injury to livestock appeared to be if the farm was a combined beef and sheep grazing enterprise (compared with being either a beef or a dairy cattle enterprise alone). However, the knowledge that farmers can save livestock and other infrastructure should be cautiously applied. This is because the primary objective of farmers should be to protect the physical safety of themselves and other people on the property. There was a significant amount of variation in outcome that was not explained by the best fitting model *post hoc* model(pseudo r^2 value of 38%). There were also outliers in the data where farms in the data set had protective factors in place but livestock still died or were injured. Together this implies that there is some level of chance or other risk factors not modelled in our study that can be associated with livestock injury, and potentially human injury. Therefore, consistent with fire authorities advice, farmers who cannot be certain of their safety should evacuate to safer areas in the face of catastrophic fires.

	This work is summarised in Appendix 12.	**Consultative panel** The consultative panel was a rich source of detailed and specific advice for preparedness and recovery. The majority of recommendations and suggestions from the panellists aligned with existing knowledge from the research team and comments from producers participating in the various studies within the broader project. Most recommendations were incorporated into the producer manual.
5. Presentation of the results as a livestock bushfire preparedness manual for producers	Yes. A manual of bushfire preparedness has been prepared and is attached as Appendix 13. This is a professionally illustrated and edited manual. It has been reviewed by co-authors from NSW Local Land Services, Animal Health Australia, Mackinnon Project, Melbourne Veterinary School, Country Fire Authority and Agriculture Victoria. Importantly a fire scientist, Mr David Packham (OAM) formally reviewed a late-stage draft of the manual, resulting in refinement of manual recommendations in March 2022. This review is provided as Appendix 13, recognising that the refinements recommended have been implemented. Following the review Mr Packham was invited to be a co-author and was added to the contributors list.	The manual presents preparation, response and recovery strategies for bushfires. It is a combination of information from existing resources, experience of collaborators/co-authors and new data from this research study.

3. Methodology

3.1 Case control study – what are risk or protective factors for bushfire injured livestock?

The foundation for the project was sampling farms affected by bushfires. This was structured in a case control study design. Here case farms were those farms that were burnt by bushfire in late 2019 and early 2020, but that also had bushfire injured or killed livestock. Control farms were those farms that burnt in the same time period but that had no injured livestock. These farms were largely randomly selected across NSW and Victoria. This design allowed a comparison between cases and controls to enable identification of risk or protective factors that were associated with livestock injury.

Data collection occurred using a questionnaire delivered with Qualtrics. Analyses occurred using information theoretical approaches after Burnham and Anderson (2002). Here competing hypotheses about what was associated with being a case farm compared with a control farm were implemented as generalised linear models. Supported models were identified through bias corrected AIC values and inferences made about what was associated with case farms. These were explored as risk or protective factors and learnings introduced into the bushfire manual for extension to producers.

See Appendix 11 for more detailed methodology.

3.2 Immune Fitness – Does immune fitness change due to bushfire?

Cattle were sampled from the same farms included in the case control study, along with an additional 4 non-fire affected (NFA) farms from unburnt regions. A sample size of n=12 cattle/farm that were on-farm during the fires was planned (for some farms, <12 animals were sampled dependent on logistics, available infrastructure and stock retained). Sampling Round 1 was conducted between 27th August 2020 and 22nd December 2020 and Round 2 between 2nd March and 6th April 2021. The samples collected included: blood tubes, a faecal and a tail hair sample from each animal. The analyses performed by sample type are outlined in Table 1.

Table 1: Laboratory analyses by sample type.

Sample/vial	Assay Description	Biomarker(s)
LiHep blood	Whole blood stimulation	Immune fitness biomarkers
PAXgene blood	Gene expression	Immune fitness biomarkers
Tail hair	Hair cortisol measurement	Stress biomarker
Serum gel tube	Trace element analysis (Na, Mg, Al, Si, P, S, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Sr, Ag, Cd, Ba, Pb)	Health/toxic exposure
Serum gel tube	Pestivirus (BVDV) ELISA*	Biosecurity
Faeces	Internal parasites*	General health/biosecurity
Faeces	Johne's disease*	Biosecurity
Visual assessment	External parasites, BCS	General health/biosecurity

Vaginal swab	Bovine venereal campylobacteriosis (Vibriosis)[b]	Biosecurity

BCS: Body condition score. BVDV: bovine viral diarrhoea virus. ELISA: enzyme-linked immunosorbent assay. * Diagnostic testing offered to producers. These diagnostic tests were performed only when explicit consent was provided.

Faecal worm egg counts (FWEC) and larval cultures were performed on pools of 4 animal faeces, with larval differentiation culture and liver/stomach fluke egg sedimentation performed on pools of 12 (Dawbuts Animal Health). Serological testing for BVDV was conducted using the SVANOVIR®BVDV-Ab Antibody ELISA (Abacus). Vibriosis (*Campylobacter fetus*) testing was conducted by the Microbiology and Parasitology group at Elizabeth Macarthur Agricultural Institute, in collaboration with Dr Mark Westman.

Immune biomarkers included cytokine (protein) detection by specific enzyme-linked immunosorbent assays (ELISA) after an *in vitro* blood stimulation with immune stimulants, and gene expression analysis using reverse-transcription quantitative PCR of a panel of genes previously validated as correlates of immune fitness in MLA project P.PSH.0816. A method was developed for stabilisation of the RNA and cost-effective processing that is suitable for future projects.

Serum trace minerals were assessed using a validated protocol for cattle serum that involved a single acid digestion prior to inductively coupled plasma mass spectrometry (IC-PMS). The standard used included the elements sodium (Na), magnesium (Mg), aluminium (Al), silicone (Si), phosphorus (P), sulphur (S), potassium (K), calcium (Ca), thallium (Ti), vanadium (V), chromium (Cr), magnesium (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), selenium (Se), strontium (Sr), silver (Ag), cadmium (Cd), barium (Ba), lead (Pb).

Cattle tail hair samples were stored protected from light, cut into standardised lengths and cortisol measurements were performed on 100 mg of hair by Stratech Scientific (https://www.stratechscientific.com.au/services/hair-analysis/) (Sydney, Australia).

See Appendix 5 for more details on methods.

3.3 Qualitative epidemiology – what pathology was observed and what decision making occurred by attending veterinarians?

A qualitative study was implemented to gather data to understand the perspectives and decision-making of professional veterinarians when assessing and responding to bushfire-affected livestock. The methodology reporting was structured to comply with the Consolidated Criteria for Reporting Qualitative Research (COREQ) (Tong et al., 2007). In short, a semi-structured interview guide was developed. Dr Cowled conducted all interviews and these focused on all the government veterinarians from the bushfire affected regions of SE Australia. Some interviews occurred face to face, but some occurred via teleconferencing (Zoom) due to Covid-19 restrictions on contact. Interviews were recorded, then transcribed via artificial intelligence (Amazon Web Services). The interviews where then analysed descriptively to understand risk factors for bushfire injury and pathology. Thematic analyses occurred to understand decision making around injured livestock using NVivo software. . Human ethics support and approval was provided by the University of Melbourne’s Human Research Ethics Committee (ethics ID 2057893.1). Key members of the research team underwent trauma informed care training.

See Appendix 3 for more detail on the methods.

3.4 Consultative panels – how can producers prepare for and recover from bushfire?

A consultative panel was convened of seven experts from backgrounds including bushfire recovery, district veterinary officers, emergency management research, private farm consultants and producers with rural fire authority experience. A discussion paper was circulated for structured written feedback prior to workshop meetings. Subsequently, two meetings were held, the first focussed on recovery and the second focussed on preparedness and extension of advice to producers. Meetings were audio recorded and transcribed. A thematic analytical approach was used to summarise findings from written feedback and meeting transcripts, to yield information that has been directly incorporated into the producer manual.

See Appendix 12 for more detail on methodology.

3.5 Analysis of big data – cross sectional surveys of existing data – is carcase or meat quality affected by bushfires?

3.5.1 Carcase quality (NSHMP) – Pneumonia and Pleurisy

The basic study design is summarised below but more detail is available in Appendix 6.

- Aim of the study: Examine the association between bushfire exposure and pneumonia and pleurisy in slaughtered sheep.
- Study Design: Cross sectional study using historical data
- Target population and study area: sheep from PICs in statistical local areas from the central and eastern parts of New South Wales (NSW). There are approximately 20,000,000 sheep in this area, and these are the areas that had nearby fire during the 2019/2020 bushfire season.
- Sampling strategy: all slaughtered sheep that were monitored in the NSHMP between August 2018 and July 2020, and that had a property of origin within 50 km of a bushfire that occurred between 2 and 180 days prior to slaughter, were included in the data set. Due to restrictions on transporting injured livestock, it is believed that few of the sampled sheep were burned; instead, most had been exposed to bushfire smoke and associated conditions (for example, extreme heat and drought).
- Data structure:
    - Outcome: count of pneumonia or pleurisy in lines of sheep sent for slaughter (with offset of the total number of sheep inspected on the line)
    - Exposure variables: Bushfire variables including time since fire exposure, distance to fire, and fire intensity.
    - Covariates: age categories of sheep, indicators of drought and feed availability, and feedlot versus grazed sheep.
    - Clustering occurred at the Property Identification Code (PIC) level (representing the property of origin of the sheep): the unit of interest was a line of sheep (individual sheep were aggregated into a consignment line for an abattoir), and a property may send multiple lines to slaughter across the study period.
    - Clustering also occurred at the abattoir level.
- Data analysis:

  - Two models, one for each outcome (pleurisy and pneumonia).
  - Generalized additive models with negative binomial distributions and random effects
  - The coefficients from the models are difficult to interpret due to interaction and non-linear relationships
  - Estimated marginal means derived from the models were used to interpret findings by providing an estimate of the mean number of affected sheep per 1,000 under different levels of time and distance of fire exposure.
- Inferences and management implications: It was inferred that any excess pneumonia or pleurisy observations were due to bushfire exposure, with smoke inhalation a likely mechanism, possibly compounded by stressors associated with bushfire (for example, extreme weather conditions and transport stress). Implications for abattoir slaughtering of sheep were considered.

See Appendix 7 for more detail.

3.5.2 Meat Quality (MSA)

The basic study design is summarised below but more detail is available in Appendix 7.

- Aim of the study: Examine the association between bushfire exposure and MSA index scores in cattle.
- Study Design: Cross sectional study using historical data
- Target population and study area: cattle carcases originating from PICs in statistical local areas from the central and eastern parts of New South Wales (NSW), the Australian Capital Territory (ACT) and Victoria. There were approximately 5.3 million cattle in this area, and these are the areas of these states that had the majority of fires during the 2019/2020 bushfire season.
- Sampling strategy: all slaughtered cattle that were graded under the Meat Standards Australia (MSA) program between November 2018 and July 2020, and that had a property of origin within 50 km of a bushfire that occurred between 2 and 180 days prior to slaughter, were included in the data set. Due to restrictions on transporting injured livestock, it is believed that few of the sampled cattle were burned; instead, most had been exposed to bushfire smoke and associated conditions (for example, extreme heat and drought).
- Data structure:
  - Outcome: MSA Index score
  - Exposure variables: Bushfire variables including time since fire exposure, distance to fire, and fire intensity.
  - Covariates: age proxy (ossification score), sex, grain vs grass finishing, hump height (indirect measure of Bos indicus genetics), and indicators of drought and feed availability.
  - Clustering occurred at the consignment level: the unit of interest was an individual cow, and a property may send multiple consignments of cows to slaughter across the study period.
  - Clustering also occurred at the abattoir level.
- Data analysis:

  - Generalized linear mixed model with random effects.
  - The coefficients from the models are difficult to interpret due to interaction.
  - Estimated marginal means derived from the models were used to interpret findings. Estimated marginal means provide estimates of the mean MSA index score at different times and distances to fire exposure.
- Inferences and management implications: It was inferred that any substantial change in MSA index score observations were due to bushfire exposure, possibly compounded by stressors associated with bushfire (for example, extreme weather conditions and transport stress). Implications for abattoir slaughtering of cattle were considered.

See Appendix 8 for more detail on methods.

3.5.3 Bushfire exposure associated with loin pH and meat colour

The basic study design is summarised below but more detail is available in Appendix 8.

- Aim of the study: Examine the association between bushfire exposure and MSA recorded loin pH and meat colour in cattle.
- Study Design: Cross sectional study using historical data
- Target population and study area: cattle carcases originating from PICs in statistical local areas from the central and eastern parts of New South Wales (NSW), the Australian Capital Territory (ACT) and Victoria. There were approximately 5.3 million cattle in this area, and these are the areas of these states that had the majority of fires during the 2019/2020 bushfire season.
- Sampling strategy: all slaughtered cattle that were graded under the Meat Standards Australia (MSA) program between November 2018 and July 2020, and that had a property of origin within 50 km of a bushfire that occurred between 2 and 180 days prior to slaughter, were included in the data set. Due to restrictions on transporting injured livestock, it is believed that few of the sampled cattle were burned; instead, most had been exposed to bushfire smoke and associated conditions (for example, extreme heat and drought).
- Data structure:
  - Outcomes: loin pH and meat colour scored at grading
  - Exposure variables: Bushfire variables including time since fire exposure, distance to fire, and fire intensity.
  - Covariates: age proxy (ossification score), sex, grain vs grass finishing, hump height (indirect measure of Bos indicus genetics), and indicators of drought and feed availability.
  - Clustering occurred at the consignment level: the unit of interest was an individual cow, and a property may send multiple consignments of cows to slaughter across the study period.
  - Clustering also occurred at the abattoir level.
- Data analysis:
  - Four generalized linear mixed models with random effects (modelling loin pH as continuous, loin pH as compliant/non-compliant, meat colour as continuous, and meat colour as compliant/non-compliant).

- Inferences and management implications: It was inferred that any substantial change in loin pH and meat colour grading were due to bushfire exposure, possibly compounded by stressors associated with bushfire (for example, extreme weather conditions and transport stress). Implications for abattoir slaughtering of cattle were considered.

See Appendix 9 for more detail on methods.

3.5.4 Prospective meat quality and pathology assessment

To understand the effect of bushfire (fire and/or smoke) on carcase quality traits (eye muscle area, pH, meat colour and fat colour) and animal health through both ailments detected at processing, a prospective study was undertaken. Of the producers involved in the study, only a small proportion indicated that they were willing to be involved and this led to very few animals being able to be followed through from farm to slaughter at the abattoir (n=25).

Systematic sampling of lungs, trachea, mediastinal lymph node, heart, liver and kidney was performed, with sections assessed histologically by a specialist veterinary pathologist. Muscle samples from the *longissimus dorsi* muscle were taken and carcase and meat traits were assessed.

See Appendix 4 for more details on the methods.

3.6 Spatial Analyses – Where should refuge paddocks be established on a farm?

In conjunction with collection of cattle samples and interviews for the case control and immune fitness, biosecurity and welfare studies, detailed map data including farm boundaries, the area that was burnt on their worst day of bushfire, the locations of their livestock at the time of the fire, locations where any carcasses were found post-fire, and related data about the location of preparedness and response activities were collected from participating farmers. These data were digitised and georeferenced and compiled together with publicly available environmental datasets for key risk factors including slope and aspect, tree cover and watercourses. The data were then analysed using spatial modelling techniques to identify possible protective factors. Unexpected limitations were encountered with the modelling approaches intended. Consequently, the sophistication of analyses was reduced, to still provide meaningful and practical insights from the unique dataset generated in this study.

See Appendix 10 for more detail in methodology.

3.7 Bushfire preparedness, response and recovery manual

The manual was written by Drs Pfeiffer, Cowled and Webb Ware. Important contributions were made by several other collaborators including text, discussions and review. The collaborators and their organisations are listed in the manual.

The manual was divided into several practical phases:

1. Introduction
2. Year-round presentation and recovery planning
3. Fire season preparation
4. Fire approaching

5. Immediate aftermath of fire
6. Short-term recovery
7. Long-term recovery

In addition, two appendices are attached to the manual: a guide to calculating the expected cost of feeding when all pasture is burnt in fire, and a Farm Fire Plan. The farm fire plan is a plan from New South Wales Rural Fire Service and is reproduced in full with permission. In addition, there are several additional features to the Farm Fire Plan which have been written by the project team and appended to the RFS plan to extend it to provide more information to producers.

4. Results

4.1 Case control study – what are risk or protective factors for bushfire injured livestock?

There were 46 farms in the case control study with 21 farms (46%) with bushfire injured or killed livestock meeting the criteria for a case farm. Of these farm categories with bushfire injured or killed livestock, 17 had burnt beef cattle, 6 had burnt sheep and one dairy had burnt. The proportion of livestock killed or injured per farm varied from 0 to 100%, with a median proportion killed of 20% (Q1-Q3: 8-43).

Farms were broadly comparable between cases and controls in terms of size and livestock numbers (DSE), although case farms had higher costs associated with bushfire damage. Costs were up to $AUD 2 000 000 per farm due to all costs from the bushfires, not just livestock impacts.

There were several interesting relationships identified between cases and controls and uncontrolled independent variables. For example, there appeared to be associations (possibly confounded) between several variables and being a case, including farm enterprise type, removal of woody vegetation, refuge paddocks, fire planning, the number of fire fighting units and backburning as fire approached.

The two most supported models were the preparation for fire and the type of production enterprise. In addition, there was also substantial support for the wind direction having a significant impact on stock injury and also back burning protecting livestock.

Conditional model averaging revealed several variables that appear to be associated with the bushfire injury (using relaxed P values <0.11), either as protective or risk factors. For example, having a bushfire plan, backburning, more than two farm bushfire fighting units and receiving assistance from fire authorities all appeared to have a protective relationship with bushfire injuries. A risk factor for bushfire injury to livestock appeared to be if you were a combined beef and sheep grazing enterprise (compared with being either a beef or a dairy cattle enterprise alone).

See Appendix 11 for more detail.

4.2 Immune Fitness – Does immune fitness change due to bushfire?

Submissions were received from 45 farms in regional areas of NSW and Victoria (Figure 1), with a total of 524 sampled in Round 1.

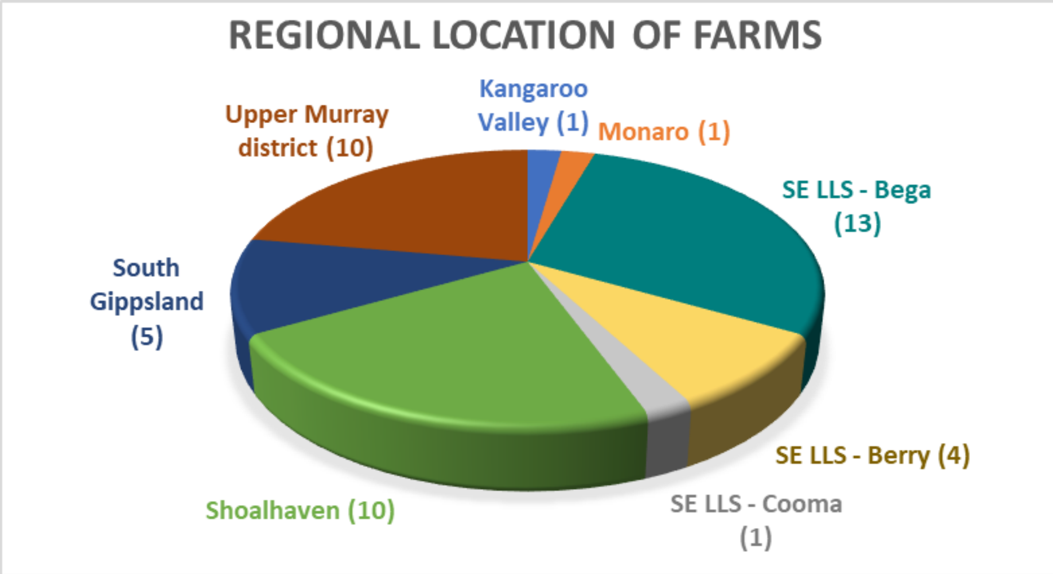

Figure 1: Regional location of farms included in Round 1 of sampling for the Bushfire project (n=45). South Gippsland and Upper Murray district comprised farms located in Victoria or just across the NSW border. All other farms were located in NSW. SE LLS: South East Local Land Service.

The number of farms and animals in each of the respective groups (Case, Control and non-fire affected (NFA) Control) for each round of sampling are shown in Table 2.

Table 2: Samples received in Sampling Round 1 and 2 by Bushfire farm type classification.

Bushfire Farm Type[a]	Round 1		Round 2	
	Number of farms	Number of cattle	Number of farms	Number of cattle
Bushfire Case	20	232	9	96
Bushfire Control	20	237	10	113
NFA Control	4	45	3	36
Excluded	1*	10	-	-
TOTAL	45	524	22	245

a. Bushfire Case farms were farms that were affected by the bushfires and experienced injured or killed livestock; Bushfire Control farms were farms that were affected by the bushfires but did not have any stock that were killed or significantly injured; Non-fire affected (NFA) Control farms were farms that were not affected by the bushfires, included as biological controls. * One farm (n=10 cattle) was excluded from subsequent testing and analysis due to the poor quality of the biological samples received.

Intestinal parasite burden was low across the majority of farms, with a range of genera identified (Figure 2). Fluke eggs were detected in 10 submissions (22% of farms).

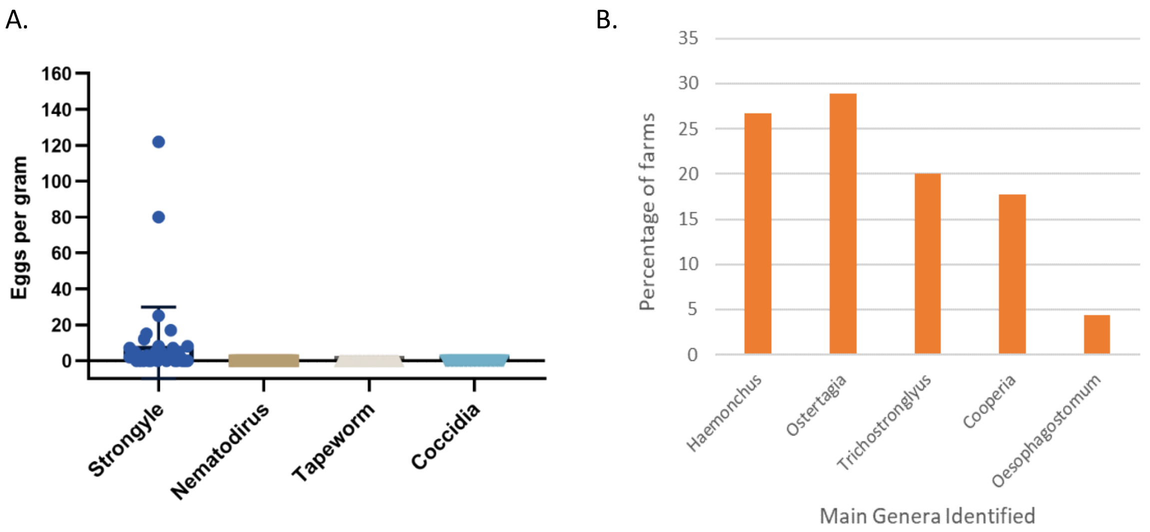

Figure 2: Intestinal parasite identified in Round 1 of sampling. A. Range of results (eggs per gram) by species, B. Main larval genera identified.

A broad range of results were obtained for serological testing for BVDV, from 100% negative to 100% positive results for the cattle of a particular property, as shown in Figure 3.

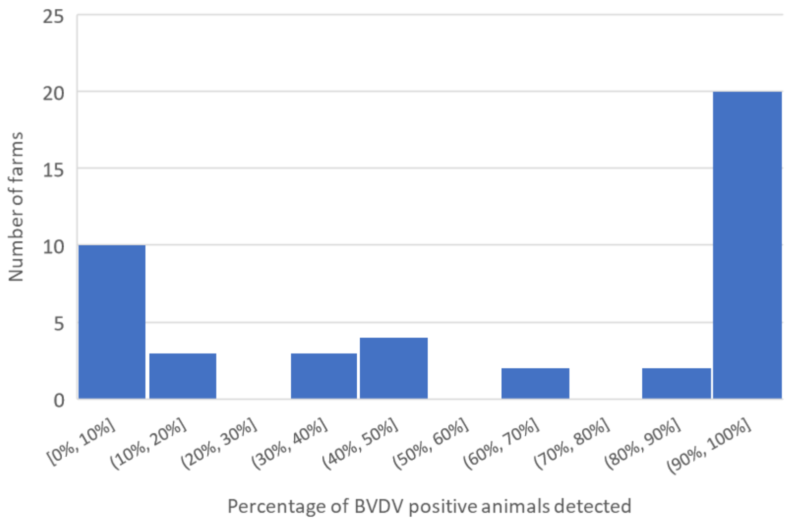

Figure 3: Histogram of the percentage of BVDV serum ELISA positive animals detected on the farms sampled. Results shown for all farms tested (n=44), including bushfire-affected and NFA control farms.

Fourteen producers in Round 2 opted to undertake testing for Vibriosis (*Campylobater fetus*). Four farms had cows test positive by culture; three were *C. fetus* subspecies *fetus* and one cow was culture positive for *C. fetus* subspecies *venerealis.* The latter animal went on to abort twice in 2021. The owners of this animal practiced natural mating on their farm and the two in-contact bulls tested negative. Fences were down due to the fires and there was the possibility of a wandering (and infected) bull visiting the farm and servicing the cow in question. Vaccination as part of the normal herd management was also impacted by the fires.

Two protein biomarkers showed results indicative of reduced immune fitness. Interleukin-8 levels were elevated in response to *in vitro* stimulation in Cases compared to NFA control farms (estimated effect 22% in a multivariable model that controlled for farm clustering). Similarly, CXCL10 was elevated in response to certain stimulants (estimated effect 27-36%). This heightened pro-inflammatory signature had been previously shown to be associated with reduced immune fitness. A similar result in relation to reduced immune fitness was found for one of the genes assessed (estimated effect 24%), with other genes trending the same way.

A number of proteins and genes showed an effect associated with time since the bushfires. These results should be taken with caution as there are potential confounders related to the change in season, feed availability and regional location.

Hair cortisol levels appeared to be higher in the NFA farms (Figure 3), however when analysed in the multivariable model controlling for farm clustering this was not significant. An interesting finding was the association of higher cortisol levels in animals with reduced body condition score. Zinc and Selenium levels also showed a potential association with body condition score in the multivariable model.

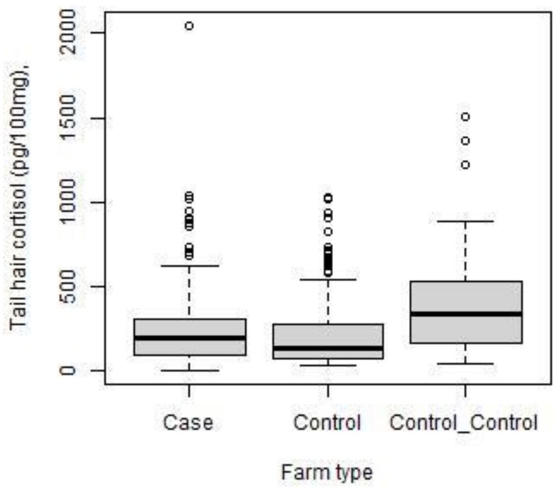

Figure 4: Box and whiskers plot of tail hair cortisol data by farm type. Control_Control refers to non-fire affected farms.

None of the trace elements that were statistically analysed showed a significant effect associated with the bushfires. This included toxic metals Lead and Aluminium, with no evidence for ongoing toxic levels due to possible exposure at the time of the fires.

See Appendix 5 for more details on results.

4.3 Qualitative epidemiology – what pathology was observed and what decision making occurred by attending veterinarians?

Livestock injured by the fires showed pathology predominantly associated with the common integument (feet, hooves and skin) and signs of acute respiratory damage. It could take several days for the full extent of burns to become apparent, leaving prognostic doubt. Treatment strategies included immediate euthanasia, salvage slaughter, retention for later culling, treatment and recovery on farm, hospitalization and intensive treatment, or no intervention. Risk factors reported for livestock injury included lack of warnings about an impending fire, the type and amount of vegetation around livestock and the weather conditions on the day the fire reached livestock. Moving stock to an area with little vegetation before fire arrived was seen as protective. Decision making regarding injured livestock appeared influenced by three main themes: (1) observations on the severity of pathology, clinical signs and level of prognostic doubt, (2) pre-existing beliefs about animal welfare (responsibility to minimize unnecessary suffering) and (3) assumptions about the future. The management of livestock was largely appropriate due to the rapid provision of veterinary expertise. However, it is likely that some injured livestock were euthanized due to conservative veterinary advice driven by a lack of opportunity to re-assess stock, with impacts on farmers. In future, resourcing regular revisits of injured livestock to manage risks of gradual progression of burn pathology may facilitate more accurate prognostic assessment, provided injured animals can receive appropriate pain relief. In addition, a more comprehensive burns classification system linked to prognosis that can be rapidly applied in the field may assist assessments.

See Appendix 3 for more detail on the results.

4.4 Consultative panel – how can producers prepare for and recover from bushfire?

Content from the individual written responses to the discussion paper and the two panel sessions covered a very broad range of topics and recommendations. Key themes for preparedness included the importance of having a plan, getting insurances right, and investing in setting up refuge paddocks that are also useful for multiple hazards (including flood and for biosecurity purposes_. Key themes for recovery included having a clear process, making a farm recovery plan, using containment areas or sacrifice paddocks to efficiently feed stock and prevent pasture damage where paddocks are burnt, and prioritising recovery to take advantage of opportunities and avoid opportunity costs (e.g. spending time on the farm business not just doing the practical recovery work). Recommendations around extension of the producer manual and project findings to farming communities included using local, trusted farmers with lived experience of bushfire response and recovery would be extremely useful to communicate key messages from the manual and increase uptake in the community. Extension through existing producer groups to provide a social learning environment for implementing manual recommendations for planning and preparedness was also strongly encouraged. Panellists also encouraged allocation of resources to maintain the currency of the manual in the future (i.e. a product life-cycle).

See Appendix 12 for more detail on results.

4.5 Analysis of big data – cross sectional surveys of existing data – is carcase or meat quality affected by bushfires?

4.5.1 Carcase quality (NSHMP) – Pneumonia and Pleurisy

The estimated mean number of pneumonia observations per 1,000 sheep at slaughter peaked amongst lines of sheep that were in close proximity to mid-to-high intensity fires shortly before slaughter; and there was a broad trend for a decrease in the estimates with time and space since exposure to mid-to-high intensity fires. These findings were limited by a lack of precision associated with sample size; nonetheless, the consistency in the trends across time and space was striking, with a clear biological gradient. The trend was similar, but considerably less marked, after exposure to low intensity fires.

Despite the association between fire and pneumonia, the biological impact of the effect in the immediate aftermath of close exposure to mid-to-high intensity fires was judged to be of relatively low importance to producers. That is, the estimated mean of 3.78 observations of pneumonia per 1,000 bushfire exposed sheep (95% CI 0.48, 30.02), compared to an estimated population mean of 0.387 observations per 1,000 sheep is not financially important enough to with-hold sheep from slaughter.

There was no clear spatiotemporal relationship between exposure to fire and estimated mean number of observations of pleurisy at slaughter, considering exposure to either mid-to-high or low intensity fires. However, this analysis cannot rule out a biological association, given a number of potential selection biases in the data used for this analysis.

See Appendix 7 for more detail on results.

4.5.2 Meat Quality (MSA)

Data from 400,760 cattle carcases were available for analysis, from 10,234 consignments across 2,736 PICs. The estimated mean MSA index was at its lowest for carcases in the immediate aftermath and in close proximity to medium-to-high intensity fires (57.12; 95% CI 56.91, 57.34). Amongst these carcases, there was a well-defined trend for increasing mean MSA index scores with increasing distance from fire (**Error! Reference source not found.**, **Error! Reference source not found.**). For carcases from cattle within approximately 11km of fire, there were consistent though generally small increases in estimated mean MSA index scores with increasing time since fire.

Amongst carcases from cattle where the closest fire exposure prior to slaughter was of a low intensity, there was small but consistent biological trend for relatively increased estimates for MSA index scores with increasing distance and time from fire.

See Appendix 8 for more detail on results.

4.5.3 Mechanism of MSA decline

Data from 451299 cattle carcases were available for analysis. Decreasing time since the nearest fire and decreasing distance from closest fire were associated with increasing loin pH, incidence of high pH carcases, meat colour darkness and incidence of dark colour defects ($P < 0.05$ for all). In all four models there were also significant interactions for distance of from the closest fire with feed type (grain vs grass) and for days of fire within a 50km radius of the property with HGP treatment (yes vs no). The incidence of high pH and dark colour defects were exacerbated in grass-fed cattle (relative to grain-fed) and this difference reduced with increasing distance of the property from the closest fire. Cattle treated with hormonal growth promotants (HGPs) also had increased high pH and dark colour defects relative to no HGP treatment, that were increasingly apparent as days of fire within 50km increased. Effects on pH but not meat colour decreased as time since fire increased.

These results are biologically plausible and indicate that there are modifiable on-farm management decisions that may help mitigate effects of bushfire exposure on subsequent meat quality. It is recommended that to reduce possible meat quality impacts, fire affected stock could be supplied with high ME feed for at least 7 days after fire exposure to restore animal glycogen stores. Fire affected stock may be categorised and ranked in order of their susceptibility to fire impacts on meat quality and predicted odds of high pH or dark colour defects. Four “risk” categories are defined in order of increasing susceptibility to high pH; (1) Grain-fed no HGP treatment (equivalent to 35% of cattle in this study), (2) Grass-fed no HGP treatment (6.5% of the study group) (3) Grain-fed with HGP treatment (23% of the study group), and (4) Grass-fed with HGP treatment (36% of the study group). There is opportunity for further investigation of re-feeding/withholding strategies in alignment with the livestock category needs.

See Appendix 9 for more detail on results.

4.5.4 Meat quality and histopathology

The results indicated that after 15 months post fires, there were no adverse effects to carcase quality or histology as a result of the bushfires. Therefore, it was concluded that the animals examined in this study presumptively overcame any deleterious effects caused by the acute inhalation of smoke. However, it is important to note that carcase inspection and sampling was performed 15 months after bushfires and did not reflect acute side-effects of the bushfires.

To further understand the immediate post fire impacts on livestock a retrospective study utilising data from Wingham abattoir in the mid North coast of NSW obtained to investigating animals processing prior, during and after the bushfires. Retrospective carcase chiller assessment, meat standards Australia grading data, and animal health data obtained from the *Health for Wealth* project were collated and statistically analysed to determine any correlations. The analysis of this data is ongoing.

See Appendix 4 for more detail on results.

4.6 Spatial Analyses – Where should refuge paddocks be established on a farm?

Data were available from 45 farms, all of which reported their property boundaries and area burnt. 17 out of 19 who had stock losses due to fire reported the point locations where carcasses were found. 24 farms provided paddock-level data including locations of stock on the farm at the time of fire.

There was substantial variation between farms with regards to risk factors for paddocks burning and stock losses. Important factors that were frequently identified on individual farms included the protective effects of being away from fencelines (in practical terms, the effect that animals fleeing fire get caught against fencelines and perish); away from forested areas of the farm; areas where there is low 'greenness' (NDVI), indicating the importance of fuel load and using bared-out paddocks for refuge where possible; and an inconsistent but important protective effect for some farms of proximity to watercourses and low-lying areas such as creeks and gullies. Due to statistical anomalies, initial analytical approaches were not successful, and a small amount of analysis is ongoing to attempt to extract further insights and more conclusive results from the unique dataset generated in this study.

See Appendix 10 for more detail in results.

4.7 Bushfire preparedness and recovery manual

The bushfire manual is attached as Appendix 13.

See Appendix 14 for a report from an independent reviewer of the manual, prepared in response to a late-stage draft from March 2022. This review is complementary and also enabled some improvements to the manual. Note: the reviewer was afterwards added to the manual as a contributor due to the contribution of the review feedback for the final revision of the manual. Thus even though the reviewer is a contributor to the manual, their review was conducted prior to any involvement as an author and thus was independent.

5. Conclusion

Prior to this project, there was a major gap in research into the impacts and mitigation of bushfires on livestock. For example, a systematic literature review revealed barely a dozen research publications, a concerning gap given that bushfires are predicted to increase in severity and occurrence in the future. Fortunately, this research programme has filled several gaps with research into mitigation strategies for producers, meat and carcase quality, immune fitness, decision-making about injured livestock and how producers can recover better after bushfires. Whilst gaps remain, this research provides an evidence base for producers to better plan for future bushfires.

It is important to realise that producers do have an ability to contribute to mitigating bushfire impacts for their livestock. For example, the development and use of a farm fire plan, refuge paddocks for livestock, actively fighting fire (e.g. using farm fire units and backburning) and assistance from fire authorities can all help protect livestock from damage. These protective actions have been captured in the evidence-based bushfire preparedness and recovery manual which serves as a resource for producers, especially in southern Australia where it will be most suitable due to similar ecologies and production practices. It is recommended that MLA now extends the manual to southern producers. The required extension activities will be a significant further body of work.

However, it should be stressed that bushfires can still be very dangerous even if producers follow the advice in this manual. In our research, even if a farmer undertook the majority of the recommended strategies, on some farms damage was still extensive, and livestock and even people were injured or died during the fires (revealed as outliers in our models, and models that only explained part of the variability in whether livestock burnt). In these cases, there were other things that were impacting outcomes for farms and livestock, independently of the mitigation strategies identified in the studies presented. In other words, producers cannot always protect themselves even if they do most things right. We suspect that the severity of weather conditions when a fire reaches a farm present important chance events that have a big impact on farm damage and outcomes post-fire. It is therefore critical that producers continue to listen to fire authority warnings about catastrophic and severe bushfire days. On those days the best way to ensure the safety of people on the farm may be to leave the farm early.

5.1 Key findings

- Bushfire injuries to livestock can be mitigated, for example by:
    - Developing a farm fire plan
    - Using two or more fire units on a farm
    - Backburning when threatened by fire (if legal)
    - Presence of government fire services to assist in responding to fire
    - Refuge paddocks that satisfy certain criteria, namely bared out or minimal dry vegetation, away from steep slopes and forested areas on-farm
- Livestock can still be impacted even with mitigation strategies in some cases – likely due to chance events associated with when and how extreme conditions are when fire arrives at a farm. This also has implications for farmers that tend to stay on a farm – sometimes the only safe option is to leave early (if, for example, conditions are catastrophic).
- Carcase and meat quality can be affected by severe bushfires that are close and recent

  - Pneumonia in sheep was 10 times as likely if near a severe bushfire – however, the biological and economic impact was likely modest, with the rate of pneumonia still quite low even if it was raised 10 times more than normal.
  - Meat quality in cattle was significantly reduced after a severe and close bushfire (<11 km). This was associated with increased non-compliance for meat pH and meat colour. Non-compliance was more common in cattle on grass and that were administered growth promotants. To mitigate this, special care of cattle through supplementary feeding (e.g. meet energy requirements with grain) and withholding cattle from slaughter for at least multiple weeks after a fire may mitigate effects on meat quality. However, the ability to slaughter cattle immediately after fire is still a useful and important welfare tool and should be supported by the meat industry when it is required for welfare or management reasons.
- Cattle immune fitness was impacted negatively by bushfires. This was reflected in results from a number of validated biomarkers. What this may mean in terms of recovery is difficult to predict, however given that the results suggest animals that survived the fires may be more susceptible to infection and have a slower recovery, an increased awareness of biosecurity considerations on-farm and active animal health management are advised in the months and years following a fire event to prevent losses.
- Bushfire injured livestock principally showed injuries to their external integument (skin, hooves, udders etc.) and respiratory systems. These were competently and appropriately assessed by various government veterinary services throughout the Black Summer Bushfires. It is possible that some excess culling occurred to manage welfare risks as it took several days for pathology to become fully evident, and usually a single visit from a veterinarian occurred in the first day or two after fire. To deal with this, a number of revisits and additional veterinary resources may be required.
- Farm recovery from bushfires is enhanced by having adequate insurance, by developing a suitable recovery plan, accepting assistance, and talking through decisions with trusted people, whether professional advisors or community members. Producers who are able to manage their farm recovery without burning out are likely better able to meet the welfare needs of their livestock and return to stable cashflow and farm productivity.

5.2 Benefits to industry

- Preparedness

Producers wishing to enhance preparedness and recovery from fire should read the bushfire manual, prepare a farm fire plan and focus on continually improve their farm’s resilience to fire. This will reduce bushfire impacts on livestock.

- Recovery

The manual provides a level of detail not previously available to fire-affected producers. Advisors and people supporting fire-affected producers can also use the recovery recommendations from the manual to assist producer recovery post-fire, to get their farm businesses back on track and support the wellbeing of both producers and their livestock.

- Response to injured livestock

Producers with livestock injured by fire should immediately euthanase severely injured livestock on veterinary advice. However, they could request several re-visits from veterinarians for moderately injured livestock if they can administer treatment to injured livestock. Given many livestock are un or under insured this may reduce over-culling injured livestock and mitigate financial losses to producers.

- Carcase and meat quality

Whilst pneumonia was more common in bushfire affected sheep it should have only modest financial impact as its prevalence was still low overall. There is no need for withholding bushfire exposed sheep from slaughter for carcase quality issues associated with pneumonia or pleurisy.

In contrast, where possible, withholding cattle for some time after fire and meeting nutritional needs (e.g. grain feeding) may improve meat quality which will improve financial returns to producers and processors. This is especially true of grass fed cattle or cattle that have received growth promotants.

- Cattle immune fitness and biosecurity

Following a fire, cattle immune function may be reduced and farm biosecurity impacted. Greater awareness of these potential issues and early detection of ill-thrift or sick animals utilising immune fitness markers may be beneficial. Keeping up-to-date with vaccination if possible will assist in supporting the health animals and of the farm.

6. Future research and recommendations

- **Extension**

The key challenge for MLA is to now extend these results to southern livestock producers.

The frequency of severe bushfire is approximately every 30 years but it is well recognised that within 5 to 7 years after fire, the importance of preparation and motivation to act declines substantially. At the time of preparation of this first edition of the manual, there will likely be a large number of producers seeking information on bushfire preparedness in time for the next severe bushfire season which may come at an indefinite time in the future. That is, some producers may not perceive this topic to be urgent during a *La nina* event and it may be several years before bushfires are an urgent topic again for many producers.

Therefore, rather than holding dedicated field days or workshops to extend the manual's advice,we recommend that , extension of this material is integrated with other events where producers will already be in attendance. In addition, presentations of the material should be led by producers who have experienced bushfire in recent decades and have lived through the recovery period, rather than experts who lack this kind of practical perspective.

In addition, we recommend a multimedia approach to extend the learnings from the Bushfire Preparation and Recovery manual. For example, sustainable online training resources that can sit online for an indefinite period until producers feel they need them could be of value, as could carefully curated video and podcast resources. Demand for these kinds of media resources may happen suddenly as a drought develops and the risk of a severe bushfire season looms without producers seeing it coming. Whilst the manual itself is a resource, it will only suit a certain proportion of literate producers and farm advisors where the manual will provide an excellent reference. For others in the community who need this advice, a series of multimedia resources that could be distributed, for example in bite sized chunks reflecting the chapter structure of the manual may be a successful means of extending the results. We recommend engaging in a follow-up project with suitable experts to design an extension strategy. A strategy for periodic revision and updating of the manual content to retain its value and in response to producer feedback is also recommended.

- **Future research**

There are still some gaps in understanding the impacts and mitigation of bushfires on livestock and producers. These gaps include:

  - Identification of further risk and protective factors for livestock and infrastructure damage – a case control (observational study) can only address some areas. Other approaches such as qualitative epidemiological research may be a more efficient and informative approach in the future, rather than further observational studies that are difficult to implement in and after an emergency.
  - Occupational health and safety of producers and bushfires. Farmers may tend to stay regardless of what fire authorities say about leaving early. Given that assumption, how do fire authorities work with producers to protect them from injury whilst they protect their livelihoods. That is, what alternative mitigation strategies may appropriate given that advice that simply instructs a producer to leave may not be practical or followed by a large proportion of producers.
  - More detailed spatial analyses of burned land on farms. Whilst extensive spatial analyses have occurred in the current project and are ongoing, more detailed spatial analyses utilising fire scientists and spatial analysts may lead to greater understanding of where is safe on a farm for a refuge paddock. Alternatively, a more

qualitative approach may be the most effective way to establish the evidence base required for understanding of the spatial drivers of bushfire damage and livestock losses on-farm. In addition, the present study has been largely limited to spatial analysis of cattle farms, and if an effective analytical approach can be established, further investigation of similar data from sheep farms would be helpful as there is likely variation between species in important spatial risk factors.

- While welfare was addressed thoroughly in the present project from an animal health and basic needs perspective, detailed investigations of changes to livestock behaviour potentially associated with the effects of trauma were not undertaken. Some producers did report behavioural changes in their animals post-fire and further investigation would be warranted.
- Mixed results were obtained from producer reports of reproductive outcomes in burnt stock. Rather than a project involving many farms, case study investigations of reproductive outcomes for fire-affected stock on farms with good record keeping practices would be useful to further elucidate the possible impact of bushfire on reproductive performance of sheep and cattle.
- Further research is required regarding the potential to mitigate the risks associated with reduced immune fitness through interventions, such as dietary supplementation and pro-biotics.
- Assessment of immune function and vaccine efficacy following adverse events such as bushfires, flooding and other environmental stressors is warranted.

7. References

ANON. 2016. 1270.0.55.003 - Australian Statistical Geography Standard (ASGS): Volume 3 - Non ABS Structures, July 2016 In: STATISTICS, A. B. O. (ed.). Canberra.

ANON. 2019. 7121.0 - Agricultural Commodities, Australia, 2017-18. In: STATISTICS, A. B. O. (ed.). Canberra

BORCHERS ARRIAGADA, N., PALMER, A. J., BOWMAN, D. M., MORGAN, G. G., JALALUDIN, B. B. & JOHNSTON, F. H. 2020. Unprecedented smoke-related health burden associated with the 2019–20 bushfires in eastern Australia. Medical Journal of Australia, 213, 282-283.

BURNHAM, K. P. & ANDERSON, D. R. 2002. Model selection and multimodel inference: A practical information-theoretic approach., New York, Springer-Verlag.

CONDON, J. 2020. Bushfire livestock loss estimates downgraded. Beef Central BeefCentral.com.

DIECKMANN, H. G., COSTA, L. R. R., MARTÍNEZ-LÓPEZ, B. & MADIGAN, J. E. 2020. Disaster Medicine: Implementation of an animal health database in response to the 2018 California Camp Fire. Journal of the American Veterinary Medical Association, 256, 1005-1010.

FILKOV, A. I., NGO, T., MATTHEWS, S., TELFER, S. & PENMAN, T. D. 2020. Impact of Australia's catastrophic 2019/20 bushfire season on communities and environment. Retrospective analysis and current trends. Journal of Safety Science and Resilience, 1, 44-56.

FLANNIGAN, M. D., KRAWCHUK, M. A., DE GROOT, W. J., WOTTON, B. M. & GOWMAN, L. M. 2009. Implications of changing climate for global wildland fire. International Journal of Wildlife Fire, 18, 438-507.

GEE, C. Involvement of veterinary inspectors in bushfire situations. Veterinary Inspectors of NSW 1986 Conference Proceedings. 69th Annual conference, 1986 1986. 259-271.

KOTSIOS, N. & TWOMEY, S. 2020. National livestock toll from raging bushfires mounts. The Weekly Times.

LIU, Y., STANTURF, J. & GOODRICK, S. 2010. Trends in global wildfire potential in a changing climate. Forest Ecology and Management, 259, 685-697.

MALMO, J. Assessment of cattle burnt in bushfires. Australian Cattle Veterinarians and Australian Sheep Veterinarians (ACV/ASV) Annual Conference, 2015 2015. Hobart, 4.

MAY, C. 2018. Discovering new areas of veterinary science through qualitative research interviews: introductory concepts for veterinarians. Australian Veterinary Journal, 96, 278-284.

MCAULIFFE, P. R. & HUCKER, D. A. 1978. Recovery of sheep from bushfire damage. Victorian Veterinary Proceedings, 36, 40–1.

MCAULIFFE, P. R., HUCKER, D. A. & MARSHALL, A. N. 1980. Establishing a Prognosis for Fire Damaged Sheep. Australian Veterinary Journal, 56, 123-132.

MORITA, N., TRABER, M. G., ENKHBAATAR, P., WESTPHAL, M., MURAKAMI, K., LEONARD, S. W., COX, R. A., HAWKINS, H. K., HERNDON, D., TRABER, L. D. & TRABER, D. L. 2006. AEROSOLIZED ALPHA-TOCOPHEROL AMELIORATES ACUTE LUNG INJURY FOLLOWING COMBINED BURN AND SMOKE INHALATION INJURY IN SHEEP. Shock, 25, 277–282.

MORTON, J. M., FITZPATRICK, D. H., MORRIS, D. C. & WHITE, M. B. 1987. Teat burns in dairy cattle – the prognosis and effect of treatment. Australian Veterinary Journal, 64, 69-72.

PRAT, N. J., HERZIG, M. C., KREYER, S., MONTGOMERY, R. K., PARIDA, B. K., LINDEN, K., SCARAVILLI, V., BELENKIY, S. M., CANCIO, L. C., BATCHINSKY, A. I. & CAP, A. P. 2017. Platelet and coagulation function before and after burn and smoke inhalation injury in sheep. Journal of Trauma and Acute Care Surgery, 83, S59.

RETHORST, D. N., SPARE, R. K. & KELLENBERGER, J. L. 2018. Wildfire Response in Range Cattle. Veterinary Clinics of North America: Food Animal Practice, 34, 281-288.

RICHARDS, L., BREW, N. & SMITH, L. 2020. 2019–20 Australian bushfires—frequently asked questions: a quick guide. In: LIBRARY, P. (ed.). Canberra Department of Parliamentary services, Parliament of Australia.

ROGERS, D. J., SCHOLZ, T. & GILLEN, A. 2015. Dealing with livestock affected by the 2014 bushfires in South Australia: decision-making and recovery. Australian Journal of Emergency Management, 30, 5.

SMITH, B., TAYLOR, M. & THOMPSON, K. 2015. Risk perception, preparedness and response of livestock producers to bushfires: A South Australian case study. Australian Journal of Emergency Management, The, 30, 38.

TONG, A., SAINSBURY, P. & CRAIG, J. 2007. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. International Journal for Quality in Health Care, 19, 349-357.

TRABER, M. G., SHIMODA, K., MURAKAMI, K., LEONARD, S. W., ENKHBAATAR, P., TRABER, L. D. & TRABER, D. L. 2007. Burn and smoke inhalation injury in sheep depletes vitamin E: Kinetic studies using deuterated tocopherols. Free Radical Biology and Medicine, 42, 1421-1429.

WILLSON, R. L. 1966. Assessment of Bush Fire Damage to Stock. Australian Veterinary Journal, 42, 101-103.

WOLFF, P. L. Small ruminants in disasters - hurricanes to wildfires. North American Veterinary Conference, 2009 2009 Orlando, Florida. Gainesville: The North American Veterinary Medical Association 369-371.

8. Appendices

See appendices 1-14 attached to this report.