Final report

Effect of liver defects on carcase characteristics, performance and health of feedlot cattle

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Abstract

This project was undertaken to determine the animal welfare, production and economic impacts of liver disease in feedlot cattle. A pilot study on approximately one thousand livers defined a grading and data collection system for liver pathology. Two main studies focused on 100-day Angus, 100-day mixed breed, and 300-day Wagyu cattle classes. Retrospective analysis of data from over four hundred thousand cattle slaughtered between 2014 and 2020 from one supply chain identified a decreasing trend in disease prevalence over time, and variable seasonal effects on abscessation, fluke and hydatid. In the retrospective cohort the most commonly recorded defects were abscess 4.4% of carcases, 3.4% fluke and 2.3% hydatid. Prospective data from over eleven thousand livers assessed on the slaughter floor identified severe liver abscessation as the most important disease impacting production parameters and carcase value. Conversely, mild liver abscessation was associated with increased performance in mixed breed cattle. Prevalence of the important defects—abscess, fluke and hydatid—varied by cattle class. By defining the production and health impact of common liver defects in feedlot cattle, the value and importance of control measures for those diseases can be inferred to guide management decisions for the beef feedlot supply chain.

Executive summary

Background

Liver disease has the potential to impact economic performance for all stakeholders in the feedlot beef supply chain due to reduced animal performance and negative effects on carcase yield and quality, and from condemnation or downgrading of livers. Major stakeholders include cattle producers, feedlot operators and processing plants.

The major aims of this project were to determine:

1. The effect of liver defects on growth performance, carcase characteristics, and health and thus welfare of feedlot cattle.
2. The economic impact of liver defects in the context of an Australian feedlot beef supply chain.

Objectives

The final objectives, all of which were achieved for this project were as follows:

1. To develop a grading scheme for liver lesions in feedlot beef cattle in Australia and a kill floor data collection methodology for liver defects to ensure coordination between the abattoir, feedlot and research team.
2. To determine the prevalence, temporal patterns, and severity of different forms of liver pathology in feedlot cattle in Southeast Qld.
3. To determine the effect of different liver defects on the performance and health of cattle in the feedlot, on carcase characteristics.
4. To investigate the economic value of reducing liver defects for the Australian feedlot beef supply chain.

Methodology

1. A pilot study conducted at abattoir A defined a grading scheme and data collection methodology to be applied to a high throughput prospective data collection.
2. A retrospective study using data from 2014-2020 from a single supply chain B assessed liver defects across three cattle classes (100-day Angus, 100-day mixed breed, and 300-day Wagyu) to determine associations between liver defect, year and season.
3. A prospective study conducted in 2020-2021 assessed liver defects across three cattle classes (100-day Angus, 100-day mixed breed, and 300-day Wagyu) from supply chain B determined the impact of liver defects on multiple production and carcase parameters.

Results/key findings

The most significant liver defects in both studies were abscess, fluke and hydatid. The retrospective study showed decreased prevalence in liver defects over the time period, with variable seasonal effects on the prevalence of the defects across cattle classes. The prospective study determined a threshold level of liver abscessation of >20% of the organ affected indicating severe disease. This severe abscessation was associated with poorer performance, including reducing one or more of average daily gain (ADG), hot standard carcase weight (HSCW), dressing percentage, P8 fat, rib fat and carcase value across the different carcase types. It is recommended that producers and processors use the severity threshold of > 20% liver abscessation to assess for economic impacts on their supply chain.

Notably hydatid was associated with poorer performance in Wagyu cattle, typically ~ 9.1kg lower HSCW, reduced dressing percentage, P8 and rib fat, and increased ossification.

Benefits to industry

This project provides current Australian data on the extent of and potential for economic and animal welfare impact from liver disease in feedlot cattle. Results from the study can be used to prioritise and inform management decisions and improve production and economic performance and animal welfare.

Future research and recommendations

- Further exploration of the microbiological causes of liver abscessation in feedlot cattle is warranted to explore the generalisability of our finding of the lack of *Fusobacterium and Trueperella spp* in the pilot study. This would further understanding of currently important causal organisms in feedlot cattle, and further investigate the pathogenesis of liver abscesses.
- Determination of the abscess causing microorganisms under different production conditions and with various interventions to reduce abscessation would be of value. This would allow greater understanding of the aetiopathogenesis of feedlot liver abscesses and intervention benefits.
- Future research is highly recommended on the epidemiological drivers, such as season, weather, geographic location of liver disease, particularly fluke and hydatid.
- Given that the grading scheme for liver defects developed and validated in this research was able to identify meaningful thresholds associated with carcase performance parameters, the deployment of a similar scheme to monitor for disease impacting production would be beneficial for stakeholders throughout the beef feedlot supply chain.
- The threshold of >20% liver abscessation should be deployed by processors and producers to assess for economic impacts on their supply chain, and to determine if interventions to reduce liver abscessation, and its associated conditions like rumenitis, will have economic benefit.
- Given the identification of a threshold for severe liver abscessation and its negative impact, research for strategies to prevent severe abscesses and its associated conditions is warranted to improve animal welfare and productivity.
- The negative associations between hydatid disease and Wagyu cattle performance parameters needs to examined in other production contexts, and a possible mechanism for the breed’s sensitivity to this parasite identified.
- Future R&D should extend the prospective collection methodology across different supply chains in other geographic areas to determine a more holistic impact of liver disease on the Australian beef feedlot supply chain, as only two supply chains were examined in this study, and both were located within Queensland. Notably, the prevalence of disease in the abattoir B supply chain was lower than previously reported in other studies, so the impact of liver disease in other Australian supply chains may be higher.
- Based on this body of work, an economic calculator could be developed allowing various supply chains and producers to input their price grids to assess the economic impact of liver disease and associated conditions, thus guiding management decisions.

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1. Background

1.1 Project summary

Liver disease has the potential to impact economic performance for all stakeholders in the feedlot beef supply chain due to reduced animal performance and negative effects on carcase yield and quality, and from condemnation or downgrading of livers. This project provides current Australian data on the extent of and potential for economic impact from liver disease in feedlot cattle. Results from the study can be used to prioritise and inform management decisions, and improve animal and economic performance and animal welfare. Major stakeholders include cattle producers, feedlot operators and processing plants.

The major aims of this project were to determine:

1. The effect of liver defects on growth performance, carcase characteristics, and health and thus welfare of feedlot cattle.
2. The economic impact of liver defects in the context of an Australian feedlot beef supply chain.

1.2 Project background and significance

Disease in feedlot cattle often results in lesions in offal and subsequent condemnation or downgrading of the affected tissue at slaughter. The lesions most frequently recognised in liver include abscessation, telangiectasis, fibrosis from plant toxins and aflatoxicosis, and parasitic infections including liver fluke (*Fasciola hepatica*) and hydatid cysts (*Echinococcus granulosus*) (Roberts, 1982; Baldock and Arthur, 1985; Brown and Lawrence, 2010). However, the most important liver diseases—due to frequency and either impacts on animal health or condemnations of affected livers—are abscess, liver fluke and hydatid disease.

Liver abscessation is relatively common in feedlot cattle, with a prevalence that typically ranges from 12 to 32% (Nagaraja and Chengappa, 1998). In a 1981 study on the prevalence of liver pathology in grain fed cattle at a Queensland (QLD) abattoir, liver abscessation was correlated with days on feed, with 5.6% of 80-day on feed, and 11.1% of 120-day on feed cattle having abscesses (Roberts, 1982). In the same study, 8.4% of cattle had telangiectasis, 3.3% *Echinococcus granulosus*, and 0.4% had *Fasciola hepatica* lesions (historically referred to as distoma) (Roberts, 1982). A 1998 review on liver abscesses in feedlot cattle in North America reported liver abscess incidence in grain fed cattle can range between 1-2% to as high as 90-95%, with an average of 12-32% in most feedlots (Nagaraja and Chengappa, 1998). Abscesses occur at a slightly higher incidence in steers compared to heifers, theorised to be due to higher feed intake (Nagaraja and Chengappa, 1998). A further study performed in 1985 examining the prevalence of *Fasciola hepatica* lesions in beef cattle from abattoirs in southeast QLD showed an overall prevalence of 1.1% but this ranged from 0 to 36% in different shires (Baldock and Arthur, 1985). A more recent series of Australian studies by Wilson et al. 2019[A,B] have reported a prevalence of hydatid disease in any organ, including liver, lungs, heart, spleen, and kidneys to be 8.8%, with the disease more prevalent in older cattle and females; these authors also noted a low sensitivity (24.9%) but high specificity (98%) of detection of hydatids in liver at routine meat inspection in abattoirs (Wilson et al. 2019[A]: Wilson et al. 2019[B]). Liver disease of various aetiologies are thus an important impact on the beef feedlot supply chain.

Liver disease has a significant economic impact on the feedlot and abattoir industries due to reduced animal performance, carcase yield and quality characteristics. In addition, there is loss of income from condemned or downgraded livers and from increased carcase trimming where the liver lesions have affected adjacent tissue (Nagaraja and Chengappa, 1998; Brown and Lawrence, 2010). A study conducted in the United States of America (USA) demonstrated cattle with hepatic abscesses had a reduction of average daily live weight gain (ADG) of up to 14% and a reduction in gain to feed ratio (G:F) of up to 13% (Brown and Lawrence, 2010).

Compared to carcases with normal livers, those with diseased livers typically show reduced hot carcase weight (HCW), longissimus muscle (LM) area, 12th rib subcutaneous fat thickness, estimated %KPH (Kidney, Pelvic, Heart fat), marbling score and yield grade (Brown and Lawrence, 2010). The estimated losses associated with liver pathology in grain-fed cattle from a Queensland abattoir in a 1982 study (Roberts, 1982) were $224.92 per 100 head, equivalent to approximately $812.86 in 2020 terms; (https://www.rba.gov.au/calculator/annualDecimal.html accessed 5/4/2021).

In feedlot cattle, rumenitis from acidosis or 'grain overload' causes liver abscesses, as the damaged rumen mucosa allows bacteria, frequently *Fusobacterium necrophorum,* to enter the portal blood supply and then seed to the liver (Rezac et al. 2014). The study performed by Rezac et al. 2014, again in the USA, demonstrated the greatest production losses in cattle with severe abscesses or cirrhosis, though the latter is very rare and only observed in 0.2% of their entire study population. Further, this study noted that cattle with rumenitis, regardless of grade mild to severe, had a much higher percentage of liver abscessation (32%) than cattle with normal rumens (19%) (Rezac et al. 2014). Lung pathology is a common comorbidity with liver abscesses, with the same study reporting a pulmonary lesion prevalence of 15% severe lung and 28% mild lung disease in animals with liver abscesses (Rezac et al. 2014). As severe pulmonary lesions and severe rumenitis can reduce ADG and HCW in their own right (Rezac et al. 2014), it is important that their potential influence is considered when assessing the impact of liver pathology on feedlot cattle performance. Despite the complexity of liver and comorbid diseases in feedlot cattle, it is important to understand the impact of liver disease on animal health and productivity in order to define strategies to mitigate its impact on the Australian feedlot industry.

Most research on the prevalence of liver disease and its impact on carcase characteristics and health has been conducted in overseas contexts, particularly in the USA. Such data may not be necessarily useful in the Australian context due to significant differences between Australian and overseas production environments, e.g., rations being fed, breed and age differences, consumer preferences for fat content of beef. Research conducted on the Australian beef feedlot supply chain is either scarce or out of date. Therefore, current data is needed to fully assess the economic impact of liver disease and optimally prioritise and inform management decisions to improve performance and animal welfare. This is particularly warranted given the expansion of the feedlot sector since the 1980s-90s when much of the Australian data was derived, and the significant changes that have subsequently occurred in associated markets and price structures for feedlot-produced beef.

This project will provide data on the prevalence, production and economic impact of liver disease in feedlot cattle in the modern Australian context.

2. Objectives

The final objectives of this project were as follows:

1) To develop a grading scheme for liver lesions in feedlot beef cattle in Australia and a kill floor data collection methodology for liver defects to ensure coordination between the abattoir, feedlot and research team.
2) To determine the prevalence, temporal patterns, and severity of different forms of liver pathology in feedlot cattle in Southeast Qld.
3) To determine the effect of different liver defects on the performance and health of cattle in the feedlot, on carcase characteristics.
4) To investigate the economic value of reducing liver defects for the Australian feedlot beef supply chain.

An original objective, to compare diagnoses between meat inspectors and researchers, was removed early in the project prior to the completion of the pilot study. Another original objective, to assess lung and rumen tissues for an understanding of the influence of co-morbidities on health and carcase parameters, was also removed due to logistical constraints imposed by chain speed and inability to match carcase data with rumen assessments, and number of personnel required.

Originally, studies to meet the objectives were planned to all be conducted at one abattoir so that pilot data from objective 1 would also be usable for analysis to meet the other objectives. However, due to unforeseeable circumstances, the abattoir partner withdrew from the study, so studies for objectives 2-4 utilised a different abattoir and some parts of objective 2 were achieved using the abattoir's retrospective data rather than freshly collected prospective data.

3. Methodology

The objectives of this research were investigated through three separate studies undertaken at two different abattoirs in SE Qld: a pilot study addressed objective 1, a retrospective study using previously collected feedlot data addressed objective 2, and a prospective study addressed objectives 2, 3 and 4.

3.1 Pilot study

3.1.1 Liver collection

The pilot study was conducted at abattoir A. The UQ research team spent 2.5 to 4 hours at the abattoir on 5 occasions during April-May, 2019. During these visits, researchers observed livers after meat inspector assessment as they passed on the conveyor belt, calculating the total number of livers observed from the sequential carcase numbers, and collecting those livers condemned by the meat inspectors. The condemned livers were transported immediately after the visit to the University of Queensland for detailed examination. In addition, 40 grossly normal livers as identified by meat inspectors at abattoir A, collected over several days, were frozen at the abattoir and also taken back to the University where they were thawed slowly at 2-4°C over 4 days, prior to detailed examination.

3.1.2 Evaluation of liver lesions

Different types of lesions in the collected livers were characterised by a detailed examination, including a gross physical examination, thorough dissection and measurement, and histological examination. Where indicated, microbiological, and parasitological testing were conducted using standard sample collection and laboratory techniques.

For abnormal livers, representative samples of the lesion(s) were taken. For histological assessment of normal livers, samples were collected from the left, right, caudate and quadrate lobes. As freezing can damage tissue, a representative sample from each normal liver was assessed by histopathology for diagnostic quality before all 4 samples from each liver were processed. As the test samples were deemed fit for assessment, the analysis of the normal livers was completed. The histology dataset for normal livers comprised thirty livers, with four lobes assessed separately, except for one, which had only caudate and quadrate lobes sampled due to a technical omission. The complete data set was 118 slides.

Histological parameters assessed included vacuolation [type (lipid, hydropic, glycogen) and distribution]; parenchymal leukocytes [type (lymphoplasmacytic, neutrophilic, eosinophilic) and distribution]; portal leukocytes [type (lymphoplasmacytic, neutrophilic, eosinophilic) and distribution]. necrosis [percentage of area and distribution]; cholestasis [presence/ absences and distribution]; bile duct proliferation [severity and distribution]; fibrosis [severity, distribution and location]; pigmentation [presence/absence, location, distribution and identification of pigment]; freezing artefact [location, distribution, and effect on interpretation].

For a survey on types of infecting bacteria, a culture was performed on 29 liver abscesses, sampling one abscess for each bracket of 25 carcase numbers to maximise pathogen variability sampled. The sample was collected from the largest, closed abscess on each liver using a sterile scalpel blade and a culture swab.

3.1.3 Stakeholder workshop

A stakeholder workshop, with representatives from Meat and Livestock Association, the processing plant and management of plant A, and research staff, was conducted to refine study protocols, to develop liver defect grading schemes and a training guide, and to discuss methods and logistics for accurate data capture on the abattoir floor. The workshop was conducted after analysis of the condemned livers and then the developed grading schemes were applied retrospectively to the collected normal and condemned livers.

3.2 Retrospective study

3.2.1 Study population

The retrospective study utilised data from cattle inducted at feedlot B and subsequently slaughtered at abattoir B between 01/01/2014 and 29/11/2020. Feedlot and processing data were merged using rfID. The resulting dataset was reshaped to one row per carcase and restricted to only include animals for which there was both feedlot and processing data from carcase types of interest (Angus, mixed breed and Wagyu).

3.2.2 Data management

Separate variables were created to identify if liver lesions (hydatid, fluke, abscess, adhesion, cancer, cirrhosis, emaciation, fatty liver, telangiectasis, or other defect) were detected at slaughter by the meat inspector.

Additional variables were created for a liver processing fault, liver contamination and condemnation of the liver due to other reasons (pneumonia, fever, pericarditis or peritonitis). A series of time variables were created based on the slaughter date: month, season (Summer: December- February; Autumn: March- May; Winter: June- August; Spring: September- November), year, month-year (e.g. January 2015) and a sequential season variable (from Autumn 2014 to Spring 2020).

The LotID and VendorID data from the feedlot data were used to assign cattle into groups that came from the same vendor and went into the same “lot”, and a new variable (GroupID) was created. A lot was a unique identifier assigned by the feedlot for cattle managed in the same way at the same time. In some cases all cattle kept in one home pen were assigned the same LotID but in other cases cattle from multiple LotIDs were kept in the same pen. A group-level dataset was then created by collapsing the animal-level data by group and creating new variables for the total number of animals in the group and the number with each of the liver defects of interest.

3.2.3 Data analysis

Pathologies recorded in the database could be reliably linked to a particular lot, carcase type and vendor, but could not be reliably linked to individual animals; therefore, individual animal data (e.g., breed, dentition) was not included in the analyses.

Data on breed, sex, dentition, number of days on feed, hot standard carcase weight and slaughter date were used to describe key features of each carcase type – after removing extreme and implausible values (<1 and >99 percentiles).

Time series plots showing the proportion of cattle slaughtered each month or season with each liver defect were produced separately for each of the main cattle types (Angus, mixed breed, Wagyu).

The extent of clustering of each defect by LotID and GroupID nested within LotID was assessed using null multi-level logistic regression models at the animal level with LotID and GroupID fitted as nested random effects. Separate models were fitted for each defect of interest for each carcase type.

Putative associations between each liver defect and each of year and season (e.g., spring for all years combined) were assessed using multi-level negative binomial or Poisson regression at a group level with LotID fitted as a random effect. Separate models were fitted for each defect of interest for each carcase type. Negative binominal models were chosen over Poisson models when a likelihood-ratio test of the dispersion parameter suggested that the data were over-dispersed.

3.3 Prospective study

3.3.1 Study population

This study was conducted at abattoir B from February 2020 to March 2021, targeting three classes of feedlot cattle associated with carcase types: 100-day Angus, 100-day mixed breed and 300-day Wagyu. Angus were backgrounded for about 2 weeks before entering the feedlot whereas mixed breed and Wagyu enter the feedlot immediately after arrival.

The collection period was meant to be evenly spread to maximise cattle sources and lots sampled and to represent all seasons within a full year. However, due to exclusion periods imposed by COVID-19 restrictions, data was collected in several intensive collection periods. These were between February and March 2020, and between October 2020 and March 2021.

The kill schedule for the abattoir and a live excel spreadsheet were used to plan appropriate collection days to ensure approximately equal representation of the three carcase types. However, given the collection restrictions, collection of the target sample size of 12,000 took priority over even sampling considerations. However, monitoring of the carcase type ratios during collection allowed a representative proportion of livers to be assessed.

3.3.2 Liver examination

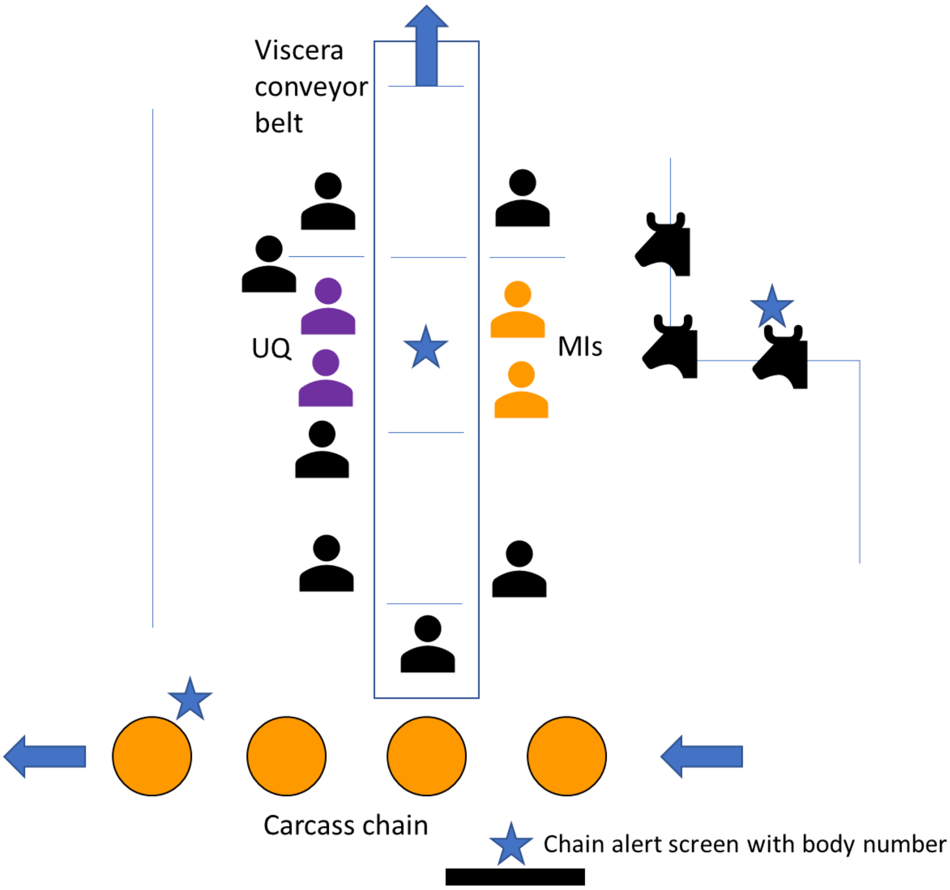
Livers were examined at slaughter by trained veterinary researchers and graded using the grading schemes developed in the pilot study. Veterinary researchers had post graduate training in pathology and used the training guide developed in the pilot study as a reference guide to the lesions.

Research staff stood opposite the meat inspectors on the viscera conveyor belt (Figure 1). Researchers visually inspected both surfaces of the liver and the bile ducts while it was inspected by the meat inspector, and then manually palpated and graded condemned livers passed to them by the meat inspectors. In addition to recording data as per the grading schemes, the following information was also recorded: the presence of grossly contaminated viscera and the proportion of viscera condemned, and the presence of severe extra hepatic pathology likely to affect weight gain and the nature of that pathology.

If researchers were unable to visualise the lesions for themselves—for reasons such as the inspector trimmed and discarded a lesion, or the liver was not able to be assessed due to meat inspector requirements—the liver was recorded as "not examined by UQ staff". On some occasions the liver was trimmed by the meat inspector. The percentage of the liver trimmed was recorded by the researchers. On some of these occasions the researchers were able to examine the trimmed piece, but on other occasions they were not. This was also recorded by the researchers. Livers that were trimmed were included in the analyses even when the trimmed part was not examined, despite incomplete examination. This may have resulted in possible underestimation of defect presence and/or severity estimates, however this methodology was considered less biased than excluding them, which would be expected to result in an underestimation of defect frequency overall.

Two researchers attended each abattoir visit: one to grade the livers and the other to record data on a tablet (Section 8.1) and track body counts and the carcase numbers of condemned livers (from overhead screens, or from the body or head). Researchers regularly alternated tasks to reduce fatigue. On rare occasions due to logistics only one researcher was present. After the day's collection, the completed forms were uploaded to Commcare data storage platform.

Figure 1: Diagram of how livers were graded by researchers on the viscera chain. The blue stars correspond to the body/head/body number of the viscera at the meat inspector station. The chain alert screen displays the body number corresponding to the viscera at the time that the viscera moves to the meat inspector station.



3.3.3 Data management

Processing data was received from the abattoir after each visit by researchers. Variables in the processing data export used in the analyses or as part of the data management process were body number, kill date, cattle type, rfID, carcase ID, live weight, bled weight, hot standard carcase weight, cold weight, dentition, p8 fat, rib fat, fat colour, meat colour, ossification, eye muscle area, marbling, kill time and carcase grading time. Carcases missing rfIDs were excluded from the dataset.

Feedlot data for the animals slaughtered were linked to processing data via rfID. Variables in the feedlot data export used in the analyses or to derive other values were body number, kill data, rfID, sex, breed, carcase type, exit date, first day on feed, lot ID, vendor ID, weight, session date and hospital reason. Each dataset included multiple rows per animal because each movement of an animal was recorded in a separate row. Each dataset was reshaped to one row per animal with variables created for weight on the first day on feed, number of days on feed and the presence or absence of each illness/injury—BRD, BRD suspect, bloat, buller, calving, cull, cast, ear infection, footrot, roarer, injury, neurological, non-eater, pink-eye, prolapsed pizzle, 3-day sickness.

Grading data was exported from CommCare's cloud data storage into an excel spreadsheet. Numbering issues were discussed and reviewed in conjunction with time-stamped processing data. Body numbers were edited when the team was confident about the nature of an error. Livers for which numbering issues could not be resolved were excluded from the analysis.

Feedlot, processing and grading data for each visit were merged using body number. Records missing one or more of the three sets of data were excluded. Merged data from all visits were then appended. Animals with duplicate rfIDs, an exit-kill interval of more than 2 days and those where the liver was not examined by the researchers were excluded from the final dataset.

After the final dataset was compiled, summary data on each lot represented in the dataset was obtained in the format of one row per animal status (dead, exited, still at the feedlot) per lot. Variables used in data management were first day on feed, exit date, animal status and animal count. The median number of days of feed for each lot was obtained and merged with main dataset.

3.3.3.1 Additional variables

Implausible values for weight on the first day on feed were changed to missing. Variables were created for weight gain between the first day on feed and slaughter and average daily gain during this period.

Dressing percentage was calculated from the hot standard carcase weight and live weight at slaughter.

Detailed feedlot-specific cattle type categories were consolidated into three categories of carcase type: Angus, mixed breed and Wagyu.

LotID and VendorID data from the feedlot data were used to assign cattle into groups that came from the same vendor and went into the same "lot", and a new variable (GroupID) was created. A lot was a unique identifier assigned by the feedlot for cattle managed in the same way at the same time. In most cases all cattle kept in one home pen were assigned the same LotID but in other cases cattle from multiple LotIDs were kept in the same pen.

Breed category variables were created from the more detailed feedlot-specific breed codes. The final breed variable for the mixed breed carcase type analyses had three categories. The Tropical/Tropical X breed category included any animals with feedlot-specific breed codes that referred to a tropical cattle breed (e.g. Droughtmaster, Brangus, Charbray), the European/European X category to any European cattle breed (e.g. Charolais, Simmental) but not a tropical breed and the British/British X category referring to animals recorded by the feedlot as British breed but not a tropical or European X (e.g.

Hereford, Angus). Wagyu cattle (n = 1) were excluded from the mixed breed analyses. The final breed variable for the Wagyu carcase type analyses had two categories, Waygu and Wagyu cross. Breed was not included in the Angus carcase type analyses as all cattle were pure-bred Angus.

A dichotomous non-liver associated illness/injury variable was created. Cattle that were hospitalised for one or more of BRD, BRD suspect, bloat, buller, calving, cull, cast, ear infection, footrot, roarer, injury, neurological, non-eater, pink-eye, prolapsed pizzle, 3-day sickness hospital reasons were considered to have had a non-liver associated illness/injury. Further, cattle that were not hospitalised or were hospitalised for bloat or as a non-eater were considered not to have had a non-liver associated illness/injury.

Dichotomous marbling variables were created for a marbling score of < 2/≥ 2 for Angus cattle, < 1/≥ 1 for mixed breed cattle and < 5/≥ 5 Wagyu cattle.

A dichotomous variable for late exit from the lot was created to describe whether or not each animal was late exiting the feedlot based on an exit date of > 10 days later than the median for Angus and mixed breed cattle and > 15 days later than the median for Wagyu cattle.

For Angus and mixed breed value/kg HSCW was estimated using a base price of $7.00/kg for mixed breed steers with 0 or 2 teeth, P8 fat from 7 – 28 mm, fat colour < 4 and HSCW between 300 – 400kg. Deductions were applied as follows: > 400 kg and ≤ 420 kg -$0.10/kg, > 420kg -$0.40/kg, < 300kg -$0.15/kg, 4-tooth -$0.05/kg, 6-tooth -$0.10/kg, 8-tooth -$0.50/kg, heifer -$0.05/kg, P8 fat < 7mm -$0.50, P8 fat > 28mm -$0.10, fat colour ≥ 4 -$0.50. A premium of $0.40/kg was applied to Angus cattle. For Wagyu cattle value/kg HSCW was estimated using a base price of $7.40 for marbling score 0 – 3. Premiums were applied as follows: marbling score 4 $1.00, score 5 $2.00, score 6 $3.50, score 7 $4.50, score 8 $5.50 and score 9 $6.50. Estimated carcase value was then calculated from the value/kg and HSCW.

3.3.4 Data analyses

All analyses were conducted separately for each carcase type—Angus, mixed breed and Wagyu—were conducted at the animal level.

Continuous variables were summarised by the mean and standard deviation. Categorical variables were summarised by absolute frequencies and percentages.

The prevalence of each type and subtype of liver defect identified was described by a point estimate and associated 95% confidence intervals (95% CI) adjusted for clustering by lot.

Crude associations between carcase types and defects were assessed using multilevel logistic regression models with each defect of interest fitted separately as the outcome of interest and carcase type fitted as an explanatory variable. Lot was fitted as a random effect. Other possible explanatory variables, such as dentition and breed (within mixed breed), were deliberately excluded.

The extent of clustering of each defect by Lot was assessed using null multi-level logistic regression models at the animal level with Lot fitted as a random effect. Separate models were fitted for each defect of interest for each carcase type.

The association between liver defects and the performance, health and carcase characteristics of interest was assessed using multilevel regression models appropriate to the data type of the outcome of interest (e.g., linear regression for continuous variables, logistic regression for binary variables). Each performance, health and carcase characteristic variable was separately considered as the outcome of interest. Liver defect (a categorical variable covering type and grade of defect) was fitted as the key explanatory variable of interest. Other variables expected to be associated with the outcome of interest (e.g., breed, gender, dentition, non-liver associated illness/injury) were fitted as covariates. Lot was fitted as a random effect. Analyses were conducted separately for each carcase type. Linear regression models were checked to assess whether the residuals were normally distributed. Where this was not the case, the outcome variable was log-transformed prior to the final analysis. To further explore some results, subset analyses were also conducted restricted to cattle from either lots or vendors from which at least one animal was affected with the given defect.

4. Results

4.1 Pilot study

4.1.1 Liver defect distribution

Table 1 details the dates and numbers of livers observed and collected from abattoir A. The number and frequency of each defect type across all livers and the percentage of condemned livers according to defect type is presented in Table 2.

Table 1: Numbers of livers observed and condemned at each visit to abattoir A.

Date	No. Livers observed	No. Livers condemned
01/04/2019	130[A]	23
08/04/2019	267	44
14/04/2019	223	33
24/04/2019	193 [A]	30
01/05/2019	193	32
TOTAL	1006	162

[A] Numbers are estimates, as absence of carcase numbers precluded accurate counts.

Table 2: The number and percentage of defects across all livers observed (n=1006) and across condemned livers (n=162) according to defect type. Some livers had multiple defect types.

Defect	Number	% all livers	% livers with defect
Abscess	85	8.4	52.5
Fibrosis	44	4.4	27.1
Fluke	42	4.2	25.9
Adhesion	34	3.4	21.0
Hydatid	18	1.8	11.1
Hepatitis	16	1.6	9.9
Telangiectasia	6	0.6	3.7
Cyst	4	0.4	2.5
Melanosis	1	0.1	0.6
Steatosis/ glycogen	1	0.1	0.6
Neoplasia	1	0.1	0.6
Cirrhosis	0	0	0

Lobar distributions of lesions in the condemned livers are presented in Table 3 and Table 4 .
A high percentage of livers had defects in the left and/or the right lobes with a relatively small percentage of livers having defects in the caudate or quadrate lobes. The largest percentage of livers had defects affecting one lobe.

Table 3: Number and percentage (n=162) of condemned livers with defects in particular lobes.

Lobe	No (%)
Right	123 (75.9)
Left	121 (74.7)
Quadrate	18 (11.1)
Caudate	37 (22.8)

Table 4: Number and percentage (n=162) of condemned livers with defects involving various numbers of lobes.

No. lobes	No (%)
0	1 (0.6)
1	66 (40.7)
2	59 (36.4)
3	29 (17.9)
4	7 (4.3)

4.1.2 Examination of livers considered grossly normal

Of the forty livers identified as grossly normal at abattoir A, ten were found to be abnormal by researchers on detailed examination and were excluded from the study.

The histological changes seen in grossly normal livers from abattoir A are detailed in Table 5 and illustrated in Figure 2.

Histological changes identified in grossly normal livers were generally either physiologic (glycogen accumulation) or considered non-adverse background changes unlikely to impact animal health (leukocytic infiltrates and mild fibroplasia and biliary hyperplasia). 15% of examined slides showed minimal multifocal necrosis, and 5% demonstrated neutrophilic infiltrates, both parameters consistent with acute minimal inflammation at the time of slaughter, which is likely to be both grossly undetectable and subclinical.

There was no lipid vacuolation identified. Only two slides contained hydropic vacuolation, indicative of non-specific mild cellular damage. All slides contained glycogen accumulation within hepatocytes, which is physiologic and expected to be present in healthy animals.

Parenchymal leukocytic infiltrates were identified in 96% of slides, with most (61%) being aggregates of 5-20 leukocytes, which is consistent with background infiltrates in healthy animals. The leukocytic infiltrates were typically multifocal (84% of slides), with 96% of slides containing lymphocytes and plasma cells; this mononuclear infiltrate was the predominant cell type in 83% of slides. Neutrophils were present in 59% of slides; however, neutrophils were only the predominant leukocyte in 6% of slides, consistent with only 6% of slides having mild acute neutrophilic parenchymal inflammation. Portal leukocytic infiltrates were identified in 89% of slides, with 62% containing aggregates of 5-20 leukocytes, again consistent with background levels in healthy animals. This infiltration affected up to 10% of portal tracts in 62% of slides and involved 10-30% of portal tracts in 24% of slides. The type of cell was primarily lymphoplasmacytic (84%). Portal inflammatory foci contained neutrophils about half the time (42%); however, neutrophils were only the predominant type of inflammation in 5% of slides, representing acute portal neutrophilic inflammation.

Necrosis was identified in 15% of slides. Of these 15% (18 slides), 16 slides had necrosis affecting 5% of hepatocytes or less. The most common distribution of necrosis was focal or multifocal random (14, or 12% of slides). Bile duct proliferation was observed in 47% of slides. Most of this hyperplasia was 3-4 ducts per triad (42% of slides), mostly involving up to 10% of portal triads (23% of slides) or 10-50% of triads (19% of slides). Mild to moderate fibrosis was observed in 66% of slides, all in portal areas, with no bridging fibrosis or cirrhosis observed. The observed mild to moderate portal fibrosis could be considered to not impact animal health and is consistent with grossly normal liver, as the change would be subtle. The fact that no bridging fibrosis or cirrhosis was observed is expected, as the latter two parameters are likely to have resulted in a gross abnormality. No cholestasis or pigment was identified in the 118 slides.

Freeze artefact was commonly observed, as consistent with the tissue preservation, but it was deemed to not interfere with histological evaluation of specimens. Freeze artefact (clear space indicative of ice crystals) was observed in 81% of slides. The ice crystals disrupted tissue architecture in 73% of slides and disrupted individual cell architecture in 55% of slides.

Table 5: Histological changes in grossly normal livers from abattoir A.

Parameter	Categories	Frequency	% of affected
Lipid vacuolation	0 - Nil	118	100.0
	1- 5% or less of hepatocytes	0	0.0
	2 - 5-20% of hepatocytes	0	0.0
	3 - >20% of hepatocytes	0	0.0
Lipid vacuolation distribution	0 - Nil	118	100.0
	1 - Focal or multifocal	0	0.0
	2 - Zonal	0	0.0
	3 - Massive	0	0.0
Hydropic vacuolation	0 - Nil	116	98.3
	1- 5% or less of hepatocytes	2	1.7
	2 - 5-20% of hepatocytes	0	0.0
	3 - >20% of hepatocytes	0	0.0
Hydropic vacuolation distribution	0 - Nil	116	98.3
	1 - Focal or multifocal	2	1.7
	2 - Zonal	0	0.0
	3 - Massive	0	0.0
Glycogen vacuolation	0 - Nil	0	0.0
	1 - Present	118	100.0
Parenchymal leukocytes	0 - Nil	5	4.2
	1 - Aggregates of 5 - 20 leukocytes	72	61.0
	2 - Aggregates of 20 - 50 leukocytes	33	28.0
	3 - Aggregates of 50+ leukocytes	8	6.8
Parenchymal leukocytes distribution	0 - Nil	5	4.2
	1 - Focal	14	11.9
	2 - Multifocal	99	83.9
	3 - Generalised	0	0.0
Parenchymal leukocytes lymphoplasmacytic	0 - Nil	5	4.2
	1 - Lymphocytes and plasma cells present	15	12.7
	2 - Lymphocytes and plasma cells predominate	98	83.1
Parenchymal leukocytes neutrophilic	0 - Nil	48	40.7
	1 - Neutrophils present	63	53.4
	2 - Neutrophils predominate	7	5.9
Parenchymal leukocytes eosinophilic	0 - Nil	116	98.3
	1 - Eosinophils present	2	1.7
	2 - Eosinophils predominate	0	0.0

Portal leukocytes	0 - Nil	13	11.0
	1 - Aggregates of 5 - 20 leukocytes	73	61.9
	2 - Aggregates of 20 - 50 leukocytes	20	16.9
	3 - Aggregates of 50+ leukocytes	12	10.2
Portal leukocytes distribution	0 - Nil	13	11.0
	1 - <10% of portal tracts	73	61.9
	2 - 10-30% of portal tracts	28	23.7
	3 - >30% of portal tracts	4	3.4
Portal leukocytes lymphoplasmacytic	0 - Nil	13	11.0
	1 - Lymphocytes and plasma cells present	6	5.1
	2 - Lymphocytes and plasma cells predominate	99	83.9
Portal leukocytes neutrophilic	0 - Nil	69	58.5
	1 - Neutrophils present	43	36.4
	2 - Neutrophils predominate	6	5.1
Portal leukocytes eosinophilic	0 - Nil	118	100.0
	1 - Eosinophils present	0	0.0
	2 - Eosinophils predominate	0	0.0
Necrosis	0 - Nil	100	84.7
	1- 5% or less of hepatocytes	16	13.6
	2 - 5-20% of hepatocytes	2	1.7
	3 - >20% of hepatocytes	0	0.0
Necrosis distribution	0 - Nil	100	84.7
	1- Single cell	2	1.7
	2 - Focal or multifocal random	14	11.9
	3 - Zonal	1	0.85[A]
	4 - Regional or massive	1	0.85[A]
Cholestasis	0 - Nil	118	100.0
	1 - Present	0	0.0
Cholestasis distribution	0 - Nil	118	100.0
	1 - <10% of canaliculi	0	0.0
	2 - 10-30% of canaliculi	0	0.0
	3 - >30% of canaliculi	0	0.0
Bile duct proliferation	0 - Nil	62	52.5
	1 - Mild 3 or 4 bile ducts per triad	50	42.4
	2 - Marked ≥ 5 bile ducts per triad	6	5.1
Bile duct proliferation distribution	0 - Nil	62	52.5
	1 - Single or <10% portal areas affected	31	26.3
	2 - 10-50% of portal areas affected	23	19.5
	3 - >50% of portal areas affected	2	1.7
Fibrosis	0 - Nil	39	33.1

	1 - Mild up to 2 fold expansion of normal tissue thickness	56	47.5
	2 - Moderate 2-5 fold expansion of normal tissue thickness	22	18.6
	3 - Marked >5 fold expansion of normal tissue thickness	1	0.8
Fibrosis distribution	0 - Nil	117	99.2
	1 - Focal or post-necrotic scarring	0	0.0
	2 - Diffuse or generalised	1	0.8
Fibrosis Location	0 - Nil	40	33.9
	1 - Portal areas only	78	66.1
	2 - Bridging fibrosis	0	0.0
	3 - Cirrhosis	0	0.0
Pigmentation	0 - Nil	118	100.0
	1 - Present	0	0.0
Pigmentation location	0 - Nil	118	100.0
	1 - Sinusoidal	0	0.0
	2 - Zonal	0	0.0
	3 - Portal	0	0.0
Pigmentation distribution	0 - Nil	118	100.0
	1- 5% or less of tissue	0	0.0
	2 - 5-20% of tissue	0	0.0
	3 - >20% of tissue	0	0.0
Pigment identification	0 - Nil	118	100.0
	1- Haemosiderin	0	0.0
	2 - Ceroid	0	0.0
	3 - Lipofuscin	0	0.0
	4 - Melanin	0	0.0
Freeze artefact	0 - Nil/negligible	22	18.6
	1 - 5-10% of tissues	38	32.2
	2 - >10% of tissues	58	49.2
Freeze effect on tissue	0 - Nil	32	27.1
	1 - Disrupts tissue architecture	86	72.9
Freeze effect on cell	0 - Nil	53	44.9
	1 - Disrupts cell architecture	65	55.1

^{A} Two decimal places were included to allow total to equal 100%

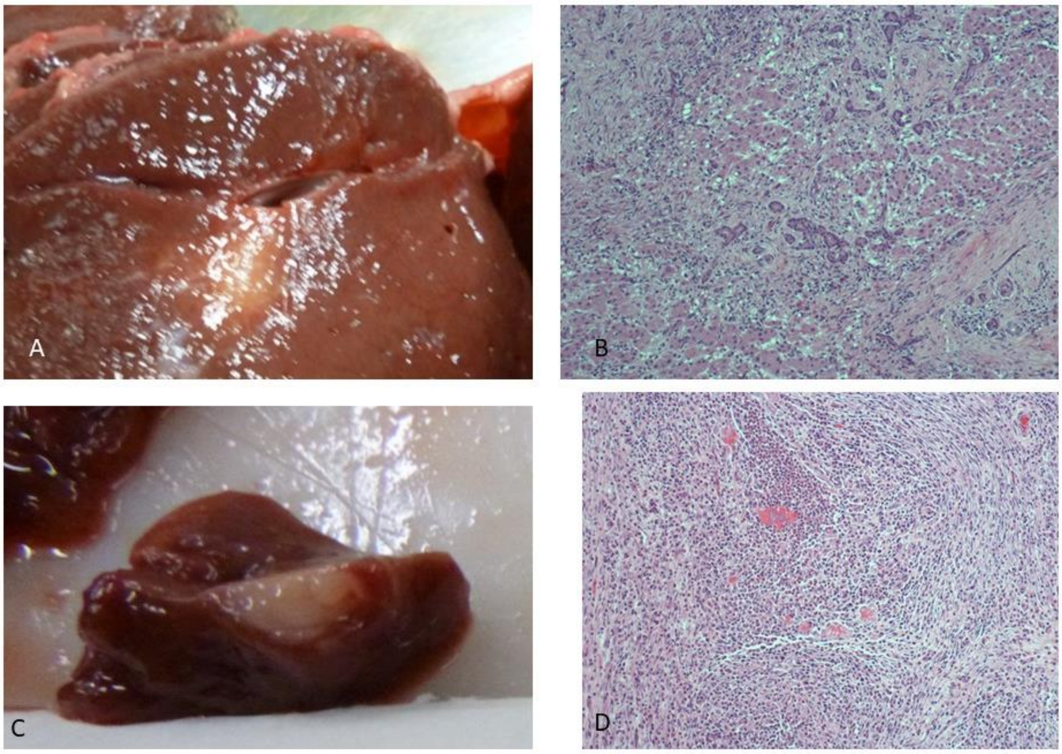
Figure 2: An example of a grossly normal liver from abattoir A (grass-fed group).

4.1.3 Liver defect gross pathology and histopathology

The following figures demonstrate gross lesion and histological appearance of the different defects observed (Figure 3, Figure 4, Figure 5, Figure 6, Figure 7).

A liver defect training guide was compiled for examiners of liver lesions; this guide provides an illustration of the most commonly observed liver lesions (Section 0).

Figure 3: Chronic inflammatory lesions. A. Chronic lesion with fibrosis consisted of a focal, firm, poorly demarcated area of pallor within the parenchyma. B. Histology from lesion A. Focus of



fibrous tissue containing a mononuclear inflammation +/- biliary ductile hyperplasia. C. Chronic active inflammatory lesion. Confluent, well demarcated area of pallor beneath the capsule. D. Histology from C. Focus of fibrous tissue containing a mononuclear inflammation sometimes centred on Splendore Hoeppli material.

Figure 4: Adhesion. A. Circular, firm, pale depression in capsule +/- fibrous tags. B. Histology of A. Fibrous tissue containing multifocal aggregates of inflammatory cells and hyperplastic biliary ductules at the capsular surface.

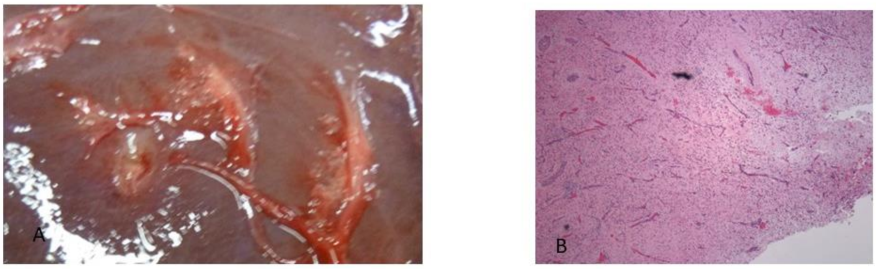


Figure 5: Hydatid. A. Spherical lesion with hard (mineralised), pale capsule, containing colourless fluid. B. Histology of A. Cystic lesion lined by an intermittent band of eosinophilic, hyaline material with purple granular mineral, surrounded by a layer of predominantly mononuclear inflammatory cells, fibrosis and mineralisation.

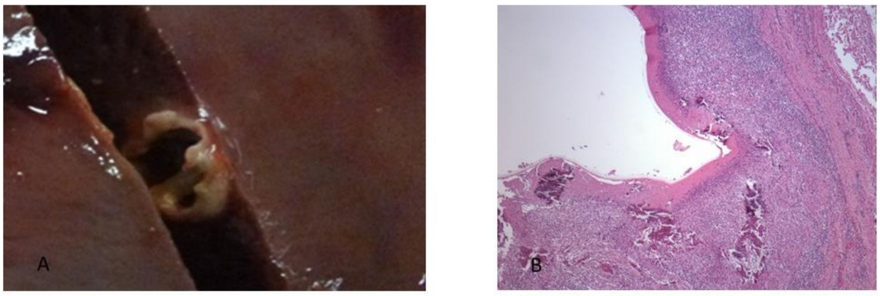


Figure 6: Fluke. A. Ventral aspect of the liver with thickened bile ducts ('pipe stem liver'). B. Histology of A. Adult fluke within bile duct. The epithelium is ulcerated and underlying parenchyma markedly inflamed and fibrotic.

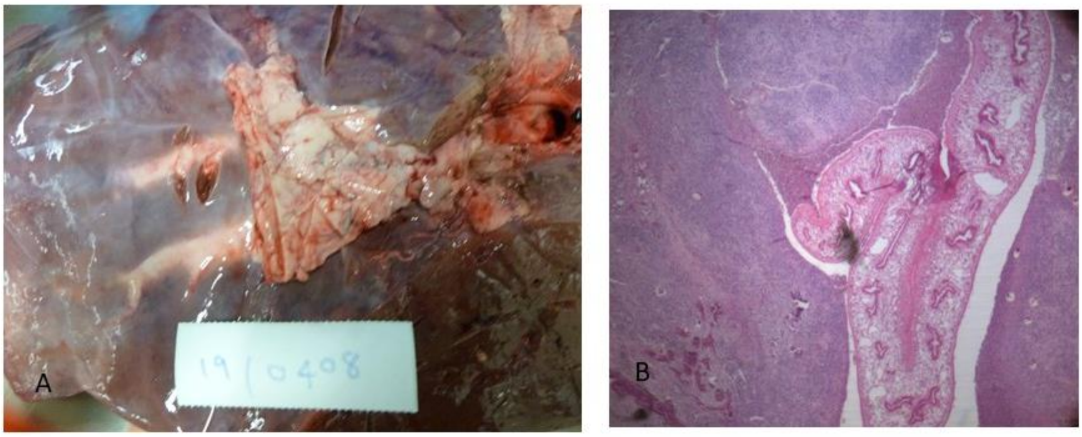
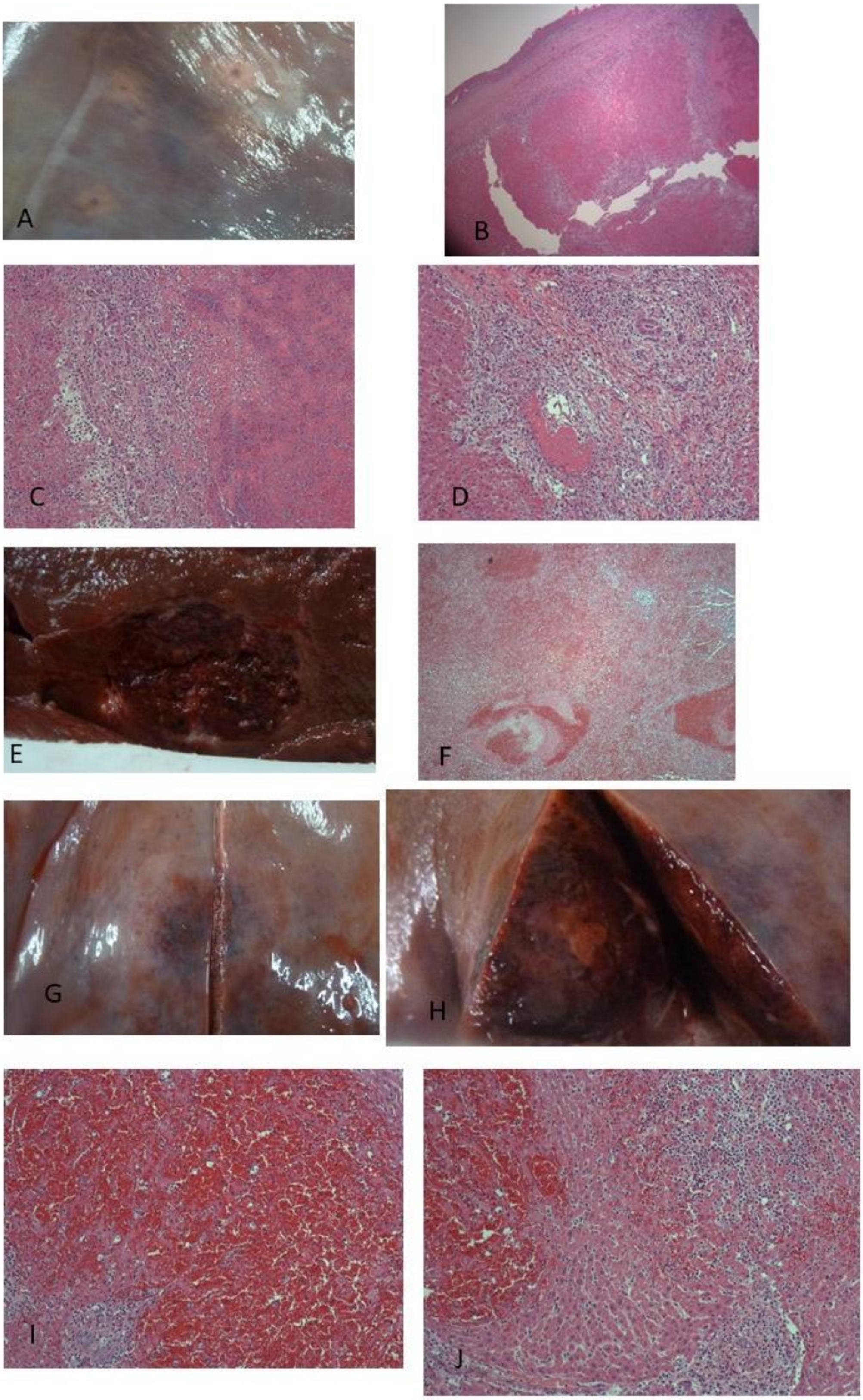


Figure 7: Hepatitis. A, E, G, H. Multifocal dark or pale, firm, reasonably well demarcated confluent lesions, some pale mottling. C, D, F, I, J. Within parenchyma, locally extensive areas of necrosis, haemorrhage, and hepatitis.



4.1.4 Construction of liver grading schemes

The stakeholder workshop concluded that the existing Elanco liver check scheme (Elanco, Greenfield, IN) was deemed unsuitable as a stand-alone grading system as it fails to capture enough detail about the lesions, does not have categories that encompass all observed disease, and lacks sensitivity at the severe end of the spectrum. In addition, the Elanco open abscess and adhered categories did not capture the number of lesions involved or the size of the lesions. A modified Elanco grading scheme was proposed as follows:

Score	Elanco Description	Modified description
A-	1-2 small abscesses or inactive scars	≤ 2 abscess ≤2cm in diameter or resolved abscess scars
A	1-2 large abscesses or multiple small abscesses	2-4 abscesses 2-4cm in diameter
A+	Multiple large abscesses	3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter
A+D	Liver adhered to gastrointestinal tract, or diaphragm or both	Score adhesion separately
A+O	Open liver abscess	Score open abscess separately.

The full CommCare data collection workflow is presented in Appendix 8.1. The scheme captures the assessment of the meat inspector of the liver (non-condemned, trimmed, condemned), percentage trimmed by meat inspector (less than 10%, 10-20%, more than 20%), whether the trimmed part was examined by UQ pathologists, the UQ pathologist assessment (no defect, defect, not examined), and a detailed assessment of the pathology present by the UQ pathologists. This was done as a ‘select all that apply’ checklist of possible liver pathologies (abscess, adhesions, hydatid, fluke, fibrosis, hepatitis, telangiectasia, cyst, steatosis, cirrhosis, neoplasia, melanosis). Of these, further grading for severity, chronicity, or morphologic category were applied as detailed in Appendix 8.1 to abscess, hydatid, fluke, fibrosis, and hepatitis, as specific to the morphologic defect. In free text, severe non-liver pathology was noted and described, if present, as well as the reason why the liver was not examined, if this occurred—e.g., paunch rupture contamination. There was also a free text field for additional notes, typically used to record technical issues with the data collection, such as carcase number inconsistencies. Paunch rupture details were captured at the request of management at abattoir B but are not reported in this analysis.

4.1.5 Retrospective grading of condemned livers

The proposed grading schemes were applied retrospectively to livers previously collected. The characteristics of condemned livers are detailed in Table 6, Table 7, Table 8,and Table 9.

In condemned livers, abscess was the most common defect observed (Table 2). Characterisation of liver abscess using the proposed grading schemes is presented in Table 6.

Table 6: Number and percentage (n=85) of condemned livers with abscess graded according to the different proposed and established grading schemes (see Appendix A)

Abscess grades	**No (%)**
Percentage	
<10%	52 (61.2)
10-20%	27 (31.8)
>20%	6 (7.1)
Size and number	

≤4 abscesses 2-4cm in diameter	30 (35.3)
1-2 abscesses >4cm in diameter and/or 4-8 smaller abscesses	33 (38.8)
≥3 abscesses >4cm in diameter and/or >8 smaller abscesses	22 (25.9)
Open	
None open	70 (82.4)
Open	11 (12.9)
Not graded	4 (4.7)
Adhered	
None adhered	71 (83.5)
Adhered	10 (11.8)
Not graded	4 (4.7)
Postcaval	
Not postcaval	0 (0)
Postcaval	0 (0)
Not graded	85 (100)
Chronicity	
Acute	0 (0)
Chronic	85 (100)
Mixed	0 (0)
Elanco	
A-	16 (18.8)
A	17 (20)
A+	25 (29.4)
A+O	11 (12.9)
A+A	10 (11.8)
Did not fit in grade	3 (3.5)
Not graded	3 (3.5)

In most livers with hydatid lesions, less than 10% of tissue was involved and were mostly cystic rather than mostly calcified (Table 7).

Table 7: Number and percentage (n=18) of condemned livers with hydatid graded according to the different proposed grading schemes (see Appendix A).

Hydatid grades	**No (%)**
Percentage	
<10%	17 (94.4)
10-20%	1 (5.6)
>20%	0 (0)
Chronicity	
Mostly cystic	11 (61.1)
Mostly calcified	7 (38.9)
Mixed	0 (0)

Most livers with fluke had bile duct thickening that was palpable/ visible in at least one lobe (Table 8).

Table 8: Number and percentage (n=42) of condemned livers with fluke graded according to the different proposed grading schemes (see Appendix A)

Fluke grade	**No (%)**
Severity	
Fluke on opening bile duct but bile duct thickening not obvious more peripherally.	6 (14.3)
Obvious bile duct thickening in at least one lobe	36 (85.7)

Most livers with hepatitis were less than 10% affected (grade 1; Table 9).

Table 9: Number and percentage (n=16) of condemned livers with hepatitis graded according to the different proposed grading schemes (see Appendix A).

Hepatitis grades	**No (%)**
Percentage	
<10%	15 (93.8)
10-20%	1 (6.3)
>20%	0 (0)

4.1.6 Liver abscess microbiological analysis

Sixteen species of bacteria were cultured from the livers with abscess (Table 10), with only a light growth in most cultures. At least one species of bacteria was cultured from 28/29 abscesses. The most common species cultured was nonhaemolytic *E. coli* followed by *Aeromonas veronii bio sobria* and haemolytic *E.coli.* Based on microbiological data previously published relating to bovine livers or offal (Stotland et al. 2001; Lehreena et al. 2010; Amachawadi and Nagaraja, 2016), all of the identified bacteria are representative of flora that can be found naturally in healthy and abscessed livers.

Table 10: Number and percentage (n=29) of condemned livers with abscess that cultured particular species of bacteria.

Bacteria	**No growth**	**Light growth**	**Moderate growth**	**Heavy growth**	**Positive (%)**
nonhaemolytic *E. coli*	6	20	3	0	23 (79.3)
Aeromonas veronii bio sobria	16	11	2	0	13 (44.8)
haemolytic *E.coli*	18	6	4	1	11 (37.9)
Staphylococcus species	25	3	1	0	4 (13.8)
Aeromonas caviae	26	2	1	0	3 (10.3)
Acinetobacter baumannii	27	2	0	0	2 (6.9)
Citrobacter species	27	1	1	0	2 (6.9)
Clostridium perfringens	27	2	0	0	2 (6.9)
Enterococcus faecalis	27	2	0	0	2 (6.9)
Pasteurella multocida	27	2	0	0	2 (6.9)
Bacillus cereus	28	0	1	0	1 (3.4)
Enterobacter cloacae	28	0	1	0	1 (3.4)
Escherichia hermannii	28	0	1	0	1 (3.4)
Klebsiella pneumonia	28	0	0	1	1 (3.4)
Mannheimia haemolytica	28	1	0	0	1 (3.4)
Streptococcus bovis	28	0	1	0	1 (3.4)

4.1.7 Data entry methodology

The stakeholder workshop identified the following requirements for recording liver grading data:

- must be completed in real time on the abattoir floor for efficiency
- should be standardised in format
- should avoid manual data entry to a database to minimise recording errors and maximise data accuracy.

The proposed grading system was set up as a form within a mobile data collection app, CommCare (www.dimagi.com/commcare), and run on a tablet for time-stamped data entry at the viscera chain, which met all of the above requirements for data entry. At the end of each day, data recorded through the app offline on the kill floor was uploaded to CommCare's cloud-based software, from where it could be exported to an excel spreadsheet.

4.2 Retrospective study

4.2.1 Descriptive results

A total of 403,733 carcases were included in the final animal-level dataset. Of these, 26.0% were Angus, 55.6% were mixed breed, and 18.4% were Wagyu. (Table 11).

Table 11: Number and percentage of each carcase type included in the final dataset.

Carcase type	Number (%)	No groups	No lots
Angus	104,870 (26.0)	3,575	577
Mixed breed	224,405 (55.6)	3,565	1,371
Wagyu	74,458 (18.4)	1,749	787
Total	403,733		

A total of 58,548 liver defects were recorded (Table 12). Overall, the most commonly recorded pathological defects were abscess (4.4% carcases), fluke (3.4%), hydatid (2.3%) and adhesion (1.7%), but the relative frequency of each of these defects differed between carcase types. In Angus carcases, fluke was most common (10.2%), then abscess (6.2%), adhesion (2.3%) and hydatid (1.6%). In mixed breed carcases, abscess was most common (3.8%), then hydatid (2.7%), adhesion (1.3%) and fluke (0.8%). In Wagyu carcases, abscess was most common (3.9%), then hydatid (2.1%), adhesion (2.1%) and fluke (2.1%).

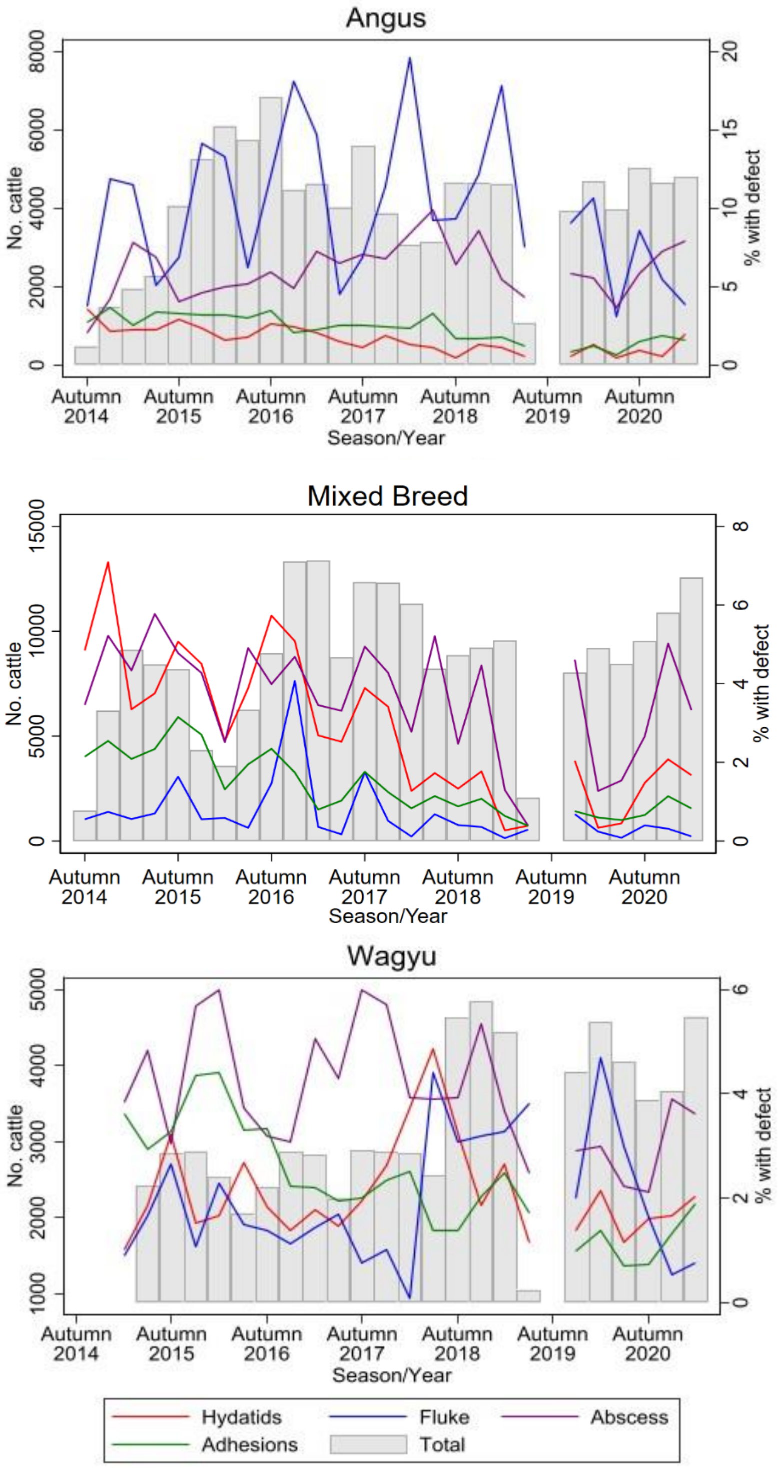
Table 12: Number and percentage of carcases in each carcase type with each liver defect.

Defect	Angus	Mixed breed	Wagyu	Total
Abscess	6,464 (6.2)	8,436 (3.8)	2,940 (3.9)	17,840 (4.4)
Fluke	10,664 (10.2)	1,701 (0.8)	1,563 (2.1)	13,928 (3.4)
Hydatid	1,643 (1.6)	6,156 (2.7)	1,598 (2.1)	9,397 (2.3)
Adhesion	2,409 (2.3)	3,015 (1.3)	1,566 (2.1)	6,990 (1.7)
Cirrhosis	1,87 (0.2)	153 (0.1)	53 (0.1)	393 (0.1)
Telangiectasis	23 (0.0)	143 (0.1)	24 (0.0)	190 (0.0)
Emaciated	2 (0.0)	0 (0.0)	0 (0.0)	2 (0.0)
Fatty	0 (0.0)	2 (0.0)	2 (0.0)	4 (0.0)
Cancer	1 (0.0)	5 (0.0)	0 (0.0)	6 (0.0)
Condemned	7 (0.0)	8 (0.0)	1 (0.0)	16 (0.0)
Other	108 (0.1)	298 (0.1)	95 (0.1)	501 (0.1)
Total	23,972	24,765	9,811	58,548

4.2.2 Time series

Time series plots of the relative frequency of the four most common liver defects (hydatid, fluke, abscess and adhesion) in each season from Autumn 2014 to Summer 2020 are shown for each carcase type in Figure 8, overlayed on the total number of cattle of that type slaughtered in that season.

Figure 8: Time series plot of the total number of cattle slaughtered in each season from Autumn 2014 to Summer 2020 and the relative frequency of the four most common liver defects—hydatid, fluke, abscess and adhesion—in Angus, mixed breed and Wagyu carcases.



4.2.3 Clustering analyses

The extent of clustering by lot and group nested with lot of each of the four most common liver defects—hydatid, fluke, abscess and adhesion—was estimated from the Lot and Group|Lot intra-class correlation coefficients (ICC) for each carcase type (Table 13). There was evidence of clustering by lot for all defects for all carcase types. Additional clustering by group was apparent for hydatid in Wagyu cattle and for fluke for all carcase types. Clustering was particularly high for fluke (Group|Lot ICC: 0.49 and 0.52 for mixed breed and Wagyu cattle, respectively).

Table 13: The extent of clustering, estimated by the intra-class correlation coefficient, of each of the four most common liver defects: hydatid, fluke, abscess and adhesion, by lot and group nested within lot for each carcase type.

Liver defect	Carcase type	Lot ICC	Group|Lot ICC
Hydatid	Angus	0.15 (0.12 - 0.18)	0.16 (0.13 - 0.19)
	Mixed breed	0.27 (0.25 - 0.30)	0.30 (0.28 - 0.33)
	Wagyu	0.16 (0.11 - 0.23)	0.24 (0.21 - 0.28)
Fluke	Angus	0.21 (0.18 - 0.24)	0.29 (0.26 - 0.31)
	Mixed breed	0.39 (0.34 - 0.43)	0.49 (0.46 - 0.53)
	Wagyu	0.43 (0.37 - 0.49)	0.52 (0.47 - 0.56)
Abscess	Angus	0.05 (0.04 - 0.06)	0.06 (0.05 - 0.07)
	Mixed breed	0.16 (0.14 - 0.18)	0.17 (0.15 - 0.19)
	Wagyu	0.09 (0.07 - 0.12)	0.13 (0.11 - 0.15)
Adhesion	Angus	0.08 (0.07 - 0.11)	0.09 (0.07 - 0.11)
	Mixed breed	0.11 (0.09 - 0.13)	0.13 (0.11 - 0.15)
	Wagyu	0.12 (0.09 - 0.14)	0.12 (0.09 - 0.14)

4.2.4 Regression analyses

Negative binomial or Poisson regression models, as appropriate, were fitted at the group level with lot fitted as random effect and year and season fitted as fixed effects for hydatid, fluke, abscess and adhesion for each of Angus, mixed breed and Wagyu carcase types. Negative binomial models were used for hydatid (all breeds), fluke (all breeds) and adhesion (mixed breeds and Wagyu); Poisson models were used for abscess (all breeds) and adhesion (Angus).

Regression model results are presented as count ratios (CR) (Table 14, Table 15, Table 16, Table 17) and predicted counts for a group of 100 cattle from a group with a random effect of zero (Figure 9, Figure 10, Figure 11, Figure 12).

In Angus cattle, the occurrence of hydatid varied by year (Table 14, Figure 9, $p<0.001$). Compared to 2014, hydatid was less common in 2017, and much less common in 2018, 2019 and 2020. There was little evidence of variation in hydatid by season (Table 14, Figure 9; $p = 0.388$). In mixed breed cattle, the occurrence of hydatid varied by year (Table 14, Figure 9 $p<0.001$). Compared to 2014, hydatid was less common in 2015 and 2016 and much less common in 2017, 2018, 2019 and 2020. The occurrence of hydatid varied by season. Compared to Summer, hydatid was more common in Autumn and Winter, and less common in Spring.

In Wagyu cattle, no conclusion could be reached regarding variation in the occurrence of hydatid by year as the effect estimates were imprecise. There was some evidence of variation in occurrence of hydatid by season (Table 14, Figure 9 $p=0.08$). Compared to Summer, hydatid was less common in Winter.

Table 14: Count ratios and 95% confidence intervals (95% CI) for the association between year and season on the relative number of cattle in a group with hydatid. Analyses were conducted separately for each of the three carcase types, Angus, mixed breed and Wagyu, and results are from models with both year and season fitted concurrently as fixed effects with vendor fitted as a random effect. Overall likelihood ratio tests are shown in bold and individual Wald test p values are non-bolded.

Variable	Level	Angus		Mixed breed		Wagyu	
		Count Ratio (95% CI)	p-value	Count Ratio (95% CI)	p-value	Count Ratio (95% CI)	p-value
Year			**<0.001**		**<0.001**		**0.126**
	2014	Ref		Ref		Ref	
	2015	0.99 (0.70 - 1.42)	0.971	0.78 (0.59 - 1.02)	0.064	1.61 (0.73 - 3.56)	0.242
	2016	1.02 (0.72 - 1.46)	0.899	0.78 (0.62 - 0.98)	0.032	1.56 (0.70 - 3.48)	0.272
	2017	0.64 (0.44 - 0.93)	0.021	0.49 (0.39 - 0.62)	<0.001	1.46 (0.66 - 3.26)	0.350
	2018	0.41 (0.28 - 0.60)	<0.001	0.18 (0.14 - 0.23)	<0.001	1.58 (0.72 - 3.48)	0.256
	2019	0.41 (0.27 - 0.62)	<0.001	0.17 (0.12 - 0.23)	<0.001	1.27 (0.56 - 2.88)	0.564
	2020	0.41 (0.28 - 0.60)	<0.001	0.28 (0.22 - 0.35)	<0.001	1.05 (0.47 - 2.33)	0.912
Season			**0.388**		**<0.001**		**0.080**
	Summer	Ref		Ref		Ref	
	Autumn	1.09 (0.85 - 1.39)	0.507	1.62 (1.34 - 1.95)	<0.001	0.94 (0.70 - 1.25)	0.670
	Winter	1.14 (0.89 - 1.45)	0.300	1.75 (1.46 - 2.10)	<0.001	0.72 (0.54 - 0.95)	0.020
	Spring	1.23 (0.97 - 1.56)	0.091	0.73 (0.60 - 0.88)	0.001	0.80 (0.60 - 1.07)	0.132

In Angus cattle, the occurrence of fluke varied by year (Table 15, Figure 10, p<0.001). Compared to 2014, fluke was less common in 2020. The occurrence of fluke also varied by season (Table 15, Figure 10, p < 0.001). Compared to Summer, fluke was more common in Autumn and much more common in Winter and Spring. In mixed breed cattle, the occurrence of fluke varied by year (Table 15, Figure 10, p<0.001). Compared to 2014, fluke was less common in 2017 and 2019 and much less common in 2018 and 2020. The occurrence of fluke varied by season (Table 15, Figure 10, p<0.001). Compared to Summer, fluke was much more common in Autumn and Winter and less common in Spring. In Wagyu cattle, the occurrence of fluke varied by year (Table 15, Figure 10, p<0.001). Compared to 2014, fluke was much more common in 2018. Estimates were imprecise for most other years but suggest marked variation between years. There was weak evidence of variation in occurrence of fluke by season (Table 15, Figure 10, p=0.15). Compared to Summer, fluke was less common in Winter (p=0.02).

Table 15: Count ratios and 95% confidence intervals (95% CI) for the association between year and season on the relative number of cattle in a group with fluke. Analyses were conducted separately for each of the three carcase types, Angus, mixed breed and Wagyu, and results are from models with both year and season fitted concurrently as fixed effects with vendor fitted as a random effect. Overall likelihood ratio tests are shown in bold and individual Wald test p values are non-bolded.

Variable	Level	Angus		Mixed breed		Wagyu	
		Count Ratio (95% CI)	p-value	Count Ratio (95% CI)	p-value	Count Ratio (95% CI)	p-value
Year			**<0.001**		**<0.001**		**<0.001**
	2014	Ref		Ref		Ref	
	2015	1.09 (0.78 - 1.54)	0.603	0.90 (0.54 - 1.52)	0.702	2.59 (0.64 - 10.55)	0.184
	2016	1.27 (0.90 - 1.78)	0.167	1.17 (0.75 - 1.83)	0.488	1.70 (0.41 - 6.97)	0.463

	2017	1.05 (0.74 - 1.50)	0.786	0.53 (0.33 - 0.84)	0.007	0.82 (0.20 - 3.44)	0.788
	2018	1.09 (0.77 - 1.53)	0.625	0.37 (0.22 - 0.61)	<0.001	4.41 (1.10 - 17.70)	0.036
	2019	0.77 (0.53 - 1.13)	0.186	0.55 (0.31 - 0.96)	0.034	3.69 (0.88 - 15.39)	0.073
	2020	0.51 (0.36 - 0.73)	<0.001	0.24 (0.15 - 0.40)	<0.001	1.42 (0.35 - 5.86)	0.625
Season			**<0.001**		**<0.001**		**0.147**
	Summer	Ref		Ref		Ref	
	Autumn	1.73 (1.37 - 2.19)	<0.001	3.13 (2.17 - 4.51)	<0.001	0.69 (0.43 - 1.10)	0.115
	Winter	2.43 (1.93 - 3.06)	<0.001	2.56 (1.79 - 3.66)	<0.001	0.59 (0.37 - 0.93)	0.022
	Spring	2.46 (1.96 - 3.09)	<0.001	0.64 (0.43 - 0.95)	0.026	0.70 (0.44 - 1.11)	0.131

In Angus cattle, the occurrence of abscess varied by year (Table 16, Figure 11, p<0.001). Compared to 2014, abscess was more common in 2017 and 2018. There was some evidence that the occurrence of abscess also varied by season (Table 16, Figure 11, p = 0.06). Compared to Summer, abscess was more common in Spring. In mixed breed cattle, the occurrence of abscess varied by year (Table 16, Figure 11, p<0.001). Compared to 2014, abscess was less common in 2016, 2017 and 2020 and much less common in 2018 and 2019. The occurrence of abscess varied by season (Table 16, Figure 11, p<0.001). Compared to Summer, abscess was more common in Winter and less common in Spring. In Wagyu cattle, the occurrence of abscess varied by year (Table 16, Figure 11, p<0.001). Abscess was most common in 2017 and least common in 2019 and 2020. The occurrence of abscess varied by season (Table 16, Figure 11, p<0.001). Compared to Summer, abscess was more common in Winter and Spring.

Table 16: Count ratios and 95% confidence intervals (95% CI) for the association between year and season on the relative number of cattle in a group with abscess. Analyses were conducted separately for each of the three carcase types, Angus, mixed breed and Wagyu, and results are from models with both year and season fitted concurrently as fixed effects with vendor fitted as a random effect. Overall likelihood ratio tests are shown in bold and individual Wald test p values are non-bolded.

Variable	Level	Angus		Mixed breed		Wagyu	
		Count Ratio (95% CI)	p-value	Count Ratio (95% CI)	p-value	Count Ratio (95% CI)	p-value
Year			**<0.001**		**<0.001**		**<0.001**
	2014	Ref		Ref		Ref	
	2015	0.89 (0.73 - 1.10)	0.292	0.83 (0.66 - 1.05)	0.116	1.18 (0.73 - 1.91)	0.495
	2016	1.07 (0.87 - 1.32)	0.493	0.81 (0.67 - 0.98)	0.033	0.96 (0.59 - 1.55)	0.857
	2017	1.36 (1.10 - 1.68)	0.005	0.72 (0.60 - 0.88)	0.001	1.29 (0.80 - 2.08)	0.306
	2018	1.27 (1.03 - 1.56)	0.025	0.46 (0.38 - 0.57)	<0.001	1.11 (0.69 - 1.79)	0.655
	2019	0.91 (0.73 - 1.15)	0.433	0.46 (0.36 - 0.58)	<0.001	0.69 (0.42 - 1.13)	0.136
	2020	1.17 (0.95 - 1.44)	0.137	0.59 (0.48 - 0.72)	<0.001	0.75 (0.46 - 1.21)	0.233
Season			**0.064**		**<0.001**		**<0.001**
	Summer	Ref		Ref		Ref	
	Autumn	1.01 (0.89 - 1.15)	0.835	1.03 (0.89 - 1.19)	0.714	0.97 (0.80 - 1.18)	0.772
	Winter	1.07 (0.95 - 1.22)	0.268	1.35 (1.17 - 1.56)	<0.001	1.32 (1.10 - 1.57)	0.003
	Spring	1.16 (1.02 - 1.31)	0.021	0.74 (0.64 - 0.86)	<0.001	1.22 (1.02 - 1.47)	0.033

In Angus cattle, the occurrence of adhesion varied by year (Table 17, Figure 12, p<0.001). Compared to 2014, adhesion was less common in 2018 and much less common in 2019 and 2020. There was no evidence that the occurrence of adhesion varied markedly between seasons. In mixed breed cattle, the occurrence of adhesion varied by year (Table 17, Figure 12, p<0.001). Compared to 2014, adhesion was less common in 2016 and much less common in 2017, 2018, 2019 and 2020. The occurrence of adhesion varied by season (Table 17, Figure 12, p<0.001). Compared to Summer, adhesion was more common in Autumn and Winter and less common in Spring. In Wagyu cattle, the occurrence of adhesion varied by year (Table 17, Figure 12, p<0.001). Compared to 2014, adhesion was more common in 2015 and much less common in 2019 and 2020. The occurrence of adhesion varied by season (Table 17, Figure 12, p<0.001). Compared to Summer, adhesion was more common in Winter and Spring.

Table 17: Count ratios and 95% confidence intervals (95% CI) for the association between year and season on the relative number of cattle in a group with abscess. Analyses were conducted separately for each of the three carcase types, Angus, mixed breed and Wagyu, and results are from models with both year and season fitted concurrently as fixed effects with vendor fitted as a random effect. Overall likelihood ratio tests are shown in bold and individual Wald test p values are non-bolded.

Variable	Level	Angus		Mixed breed		Wagyu	
		Count Ratio (95% CI)	p-value	Count Ratio (95% CI)	p-value	Count Ratio (95% CI)	p-value
Year			**<0.001**		**<0.001**		**<0.001**
	2014	Ref		Ref		Ref	
	2015	1.10 (0.85 - 1.43)	0.454	0.98 (0.81 - 1.18)	0.817	1.55 (0.97 - 2.48)	0.067
	2016	0.88 (0.68 - 1.15)	0.352	0.62 (0.53 - 0.74)	<0.001	1.04 (0.65 - 1.68)	0.865
	2017	0.83 (0.63 - 1.09)	0.191	0.50 (0.42 - 0.59)	<0.001	0.86 (0.53 - 1.38)	0.522
	2018	0.62 (0.47 - 0.81)	0.001	0.35 (0.29 - 0.43)	<0.001	0.75 (0.47 - 1.20)	0.234
	2019	0.32 (0.23 - 0.45)	<0.001	0.29 (0.23 - 0.37)	<0.001	0.39 (0.23 - 0.64)	<0.001
	2020	0.50 (0.38 - 0.65)	<0.001	0.33 (0.27 - 0.40)	<0.001	0.47 (0.29 - 0.77)	0.002
Season			**0.697**		**<0.001**		**<0.001**
	Summer	Ref		Ref		Ref	
	Autumn	1.03 (0.87 - 1.21)	0.759	1.32 (1.14 - 1.52)	<0.001	1.02 (0.84 - 1.25)	0.822
	Winter	0.95 (0.80 - 1.12)	0.541	1.20 (1.04 - 1.37)	0.011	1.27 (1.04 - 1.54)	0.017
	Spring	0.95 (0.80 - 1.12)	0.512	0.77 (0.66 - 0.89)	<0.001	1.44 (1.19 - 1.74)	<0.001

Figure 9: Predicted number of cattle of Angus, mixed breed, and Wagyu in a group of 100 with hydatid by year and by season

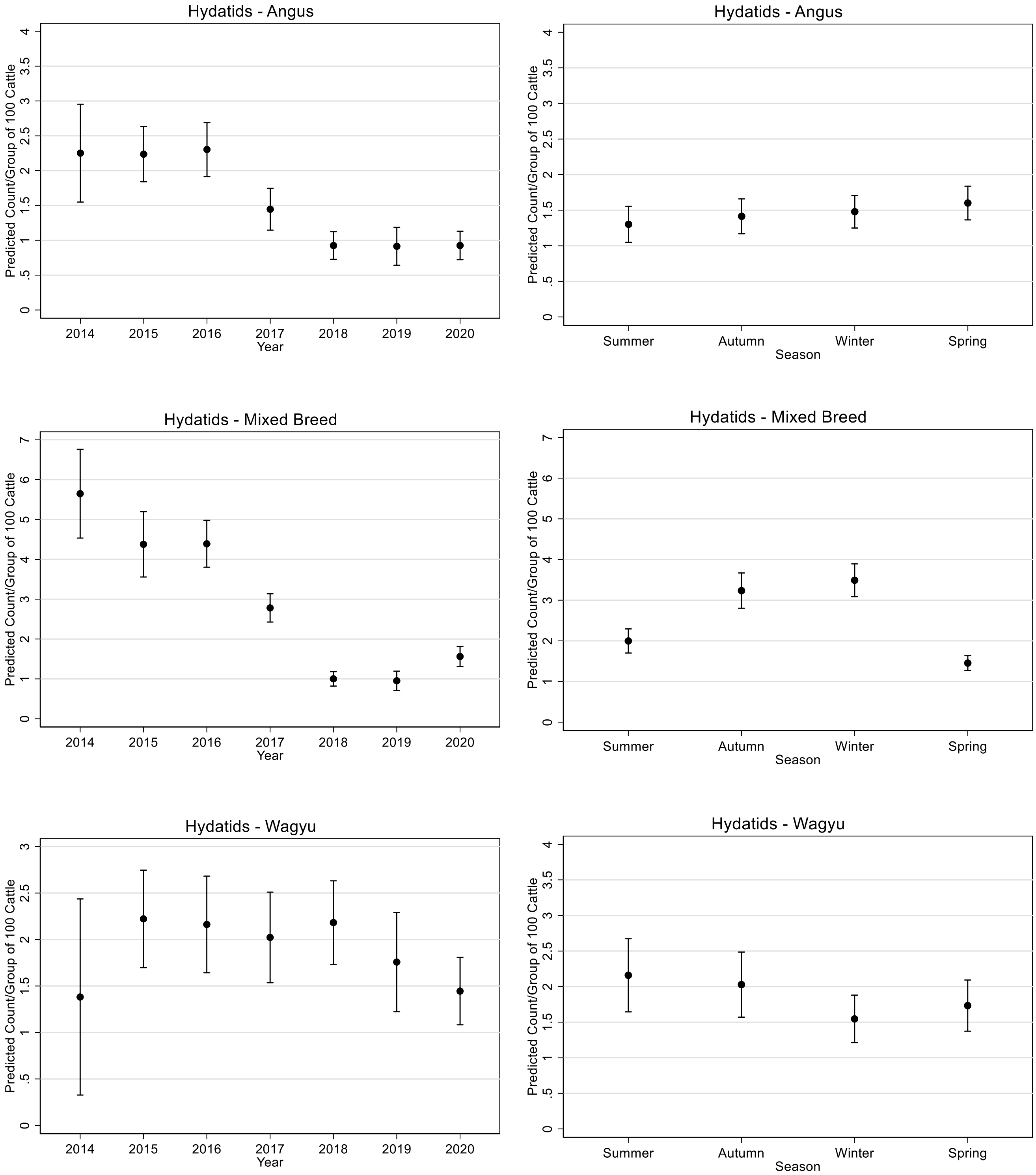


Figure 10: Predicted number of cattle of Angus, mixed breed, and Wagyu in a group of 100 with fluke by year and by season.

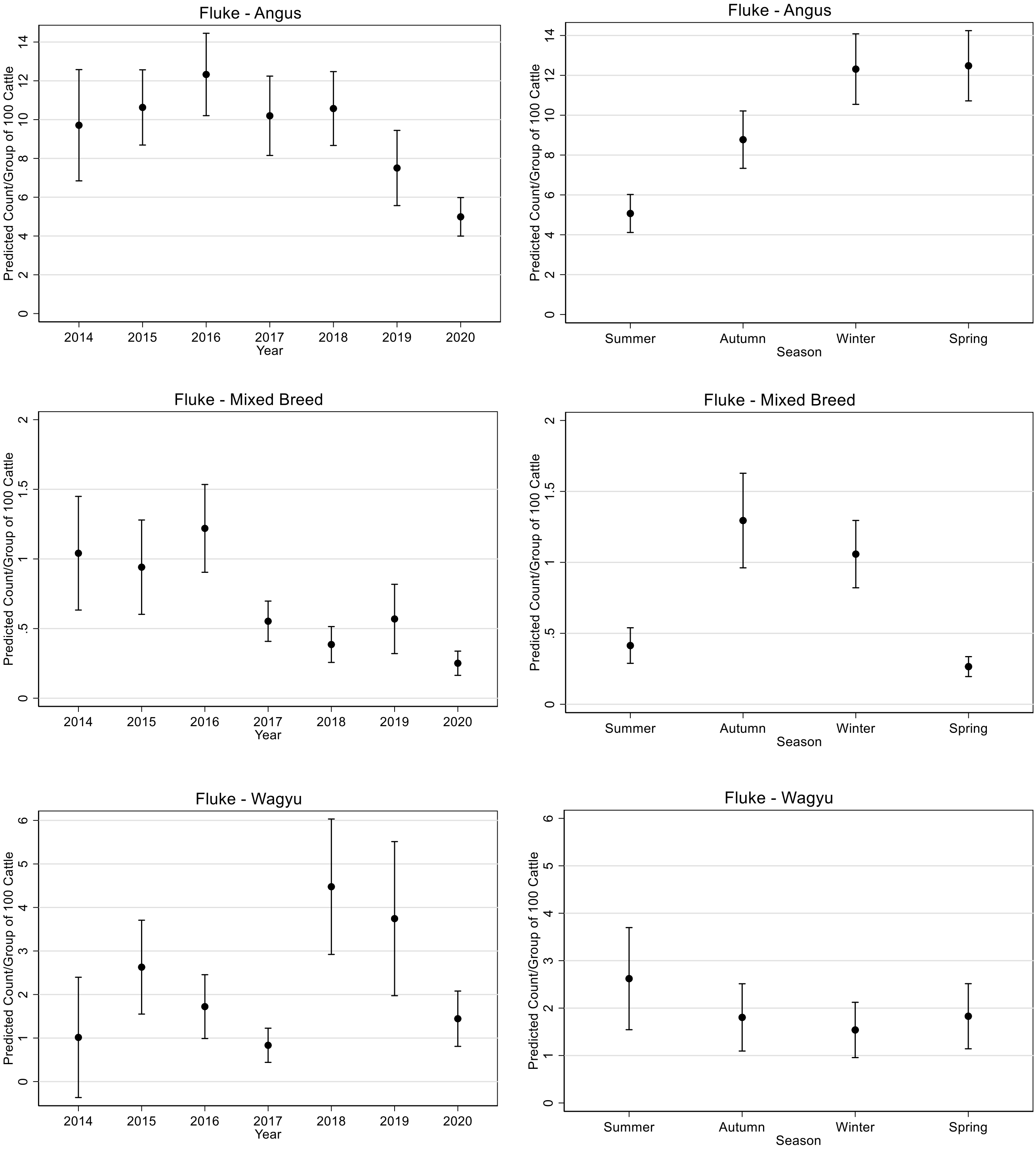
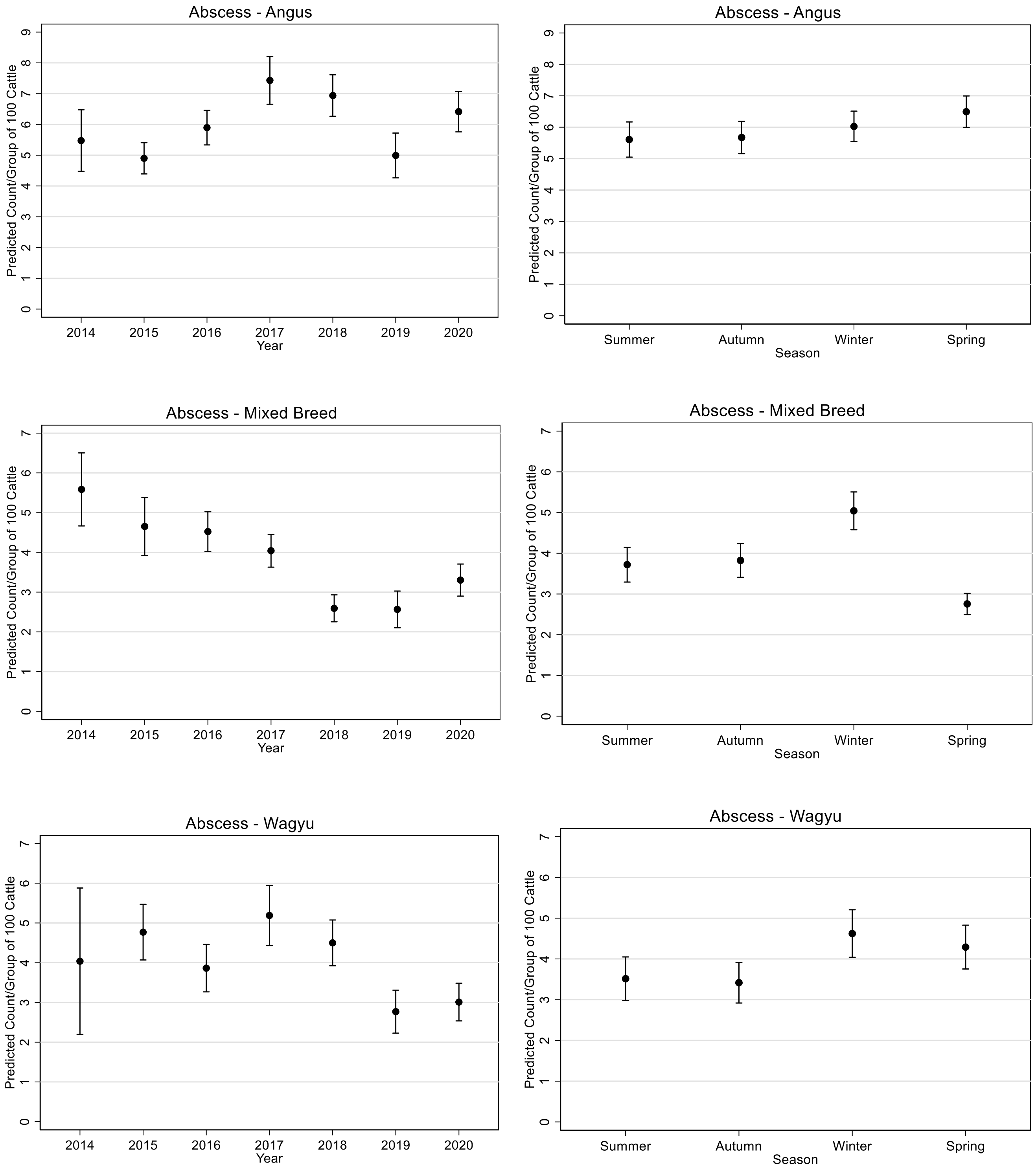


Figure 11: Predicted number of cattle of Angus, mixed breed, and Wagyu in a group of 100 with abscess by year and by season.



Abscess - Angus

Abscess - Angus

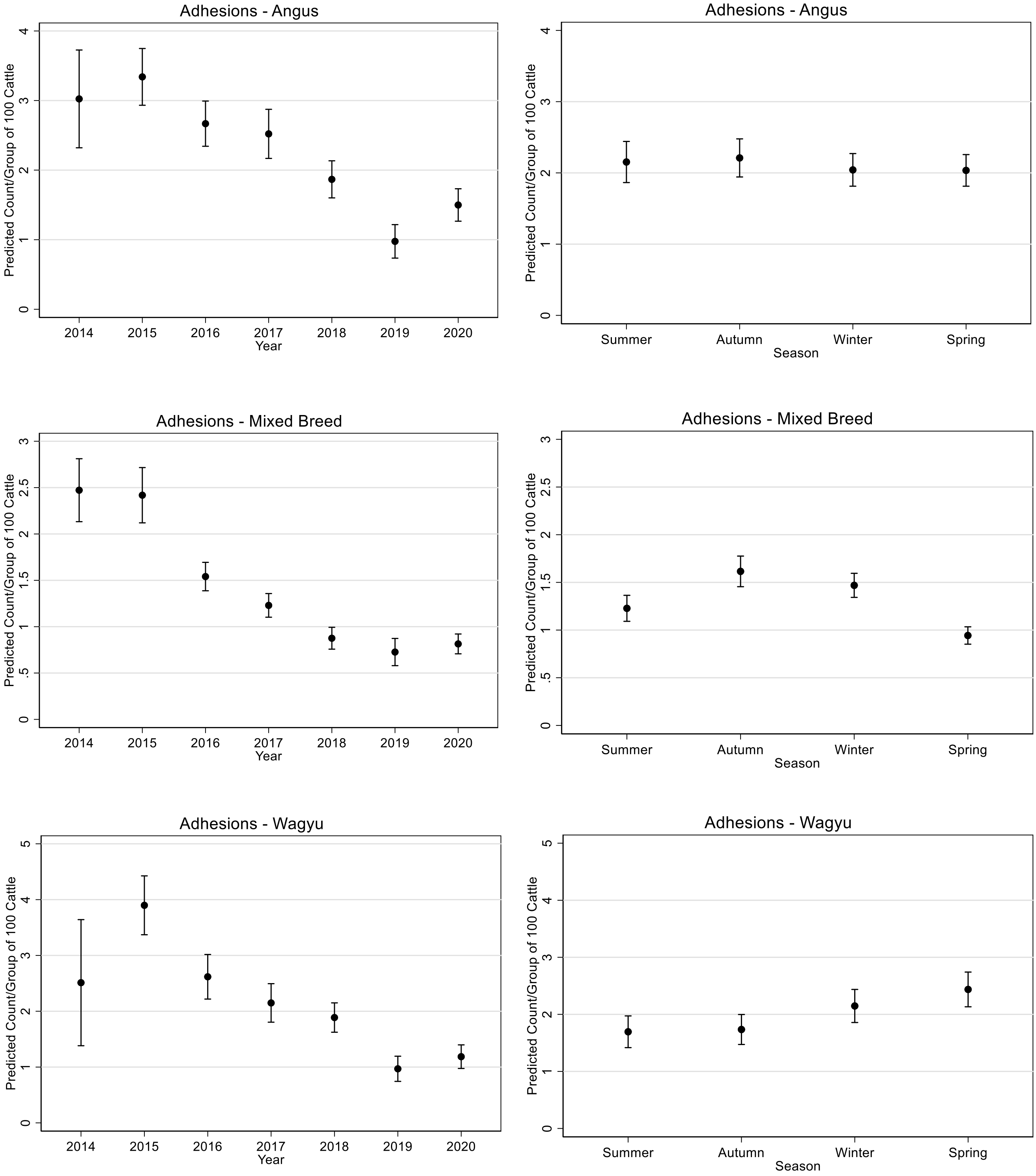
Abscess - Mixed Breed

Abscess - Mixed Breed

Abscess - Wagyu

Abscess - Wagyu

Figure 12: Predicted number of cattle of Angus, mixed breed, and Wagyu in a group of 100 with adhesion by year and by season.



4.3 Prospective study

4.3.1 Liver collections

A total of 12,470 livers were examined during the intensive collection periods. The collection dates and numbers of livers graded for each target breed are detailed in Section 8.3.1.

Of the 12,470 livers observed at the abattoir, 11,613 were eligible for inclusion in the analyses. Of these, 2,366 (20.4%) were Angus, 6,199 (53.4%) were mixed breed and 3,048 (26.3%) were Wagyu carcase types.

Occasionally, abattoir staff made errors in carcase and head numbering such that data integrity could not be guaranteed for short periods during the collection. The recorded livers from these periods were not included in statistical analyses (n=776). Other exclusions were missing rfID (n=13), missing feedlot data (n=7), duplicate rfID (n=2), livers not assessed (n=32), long exit-kill interval (n=17) and non-target cattle (n=10).

The entire liver was examined by researchers in most cases, but 285 (2.5%) livers were trimmed by meat inspectors and of these, the trimmed part was not examined in 122 cases (1.4%).

4.3.2 Descriptive results

4.3.2.1 Study population characteristics

The 2,366 Angus cattle were from 33 lots comprising 6,076 cattle initially inducted at the feedlot of which 54 (0.9%) died while on feed. The 6,199 mixed breed cattle were from 73 lots comprising 16,045 cattle initially inducted at the feedlot of which 64 (0.4%) died while on feed. The 3,048 Wagyu cattle were from 44 lots comprising 8,594 cattle initially inducted at the feedlot of which 75 (0.9%) died while on feed. The median and interquartile range of the median number of days on feed for each lot were 104.5 (104 – 108.5), 108 (104 – 109.5) and 323 (302.5 – 354.5) days for Angus, mixed breed and Wagyu lots, respectively. Additional data on vendors, lots and groups are shown in (Table 18).

Characteristics of the study population are detailed in Table 19, Table 20, and Table 21.

Angus cattle were mostly 0-tooth (67.9%) and steers (95.0%). Mixed breed cattle were mostly 0-tooth or 2-tooth (29.0 and 45.9%, respectively), tropical/X breed (83.2%) and steers (96.4%). Wagyu cattle were mostly 4-tooth (52.3%), pure-bred Wagyu (83.4%) and with similar numbers of steers and heifers.

Mean (s.d.) ADG for Angus was 1.51kg (0.31), for mixed breeds was 1.86kg (0.41), and for Wagyu was 1.01kg (0.19) (Table 21).

Mean (s.d.) HSCW for Angus was 347.1 (29.2) kg, for mixed breeds was 346.5 (33.7) kg and for Wagyu was 407.3 (47.1) kg (Table 21).

Mean (s.d.) DOF for Angus was 105 (4.5) days, for mixed breeds was 106 (4.2) days and for Wagyu was 332 (30.3) days (Table 21).

Mean (s.d.) dressing percentage for Angus was 55.7 (1.4) %, for mixed breeds was 57.1 (1.8) % and for Wagyu was 57.1 (1.6) % (Table 21).

Mean (s.d.) P8 fat for Angus was 14.8 (3.8) mm, for mixed breeds was 12.9 (4.3) mm and for Wagyu was 21.4 (8.1) mm (Table 21).

Mean (s.d.) rib fat for Angus was 12.7 (3.0) mm, for mixed breeds was 10.1 (2.6) mm in cattle and for Wagyu was 19.4 (4.0) mm (Table 21).

Mean (s.d.) EMA for Angus was 79.3 (6.6) cm^2, for mixed breeds was 78.2 (6.2) cm^2 and for Wagyu was 92.2 (7.7) cm^2 (Table 21).

Most Angus cattle had a marbling score of 2, most mixed breed cattle had a marbling score of 1, whereas most Wagyu cattle had a marbling score between 4 and 7.

Mean (s.d.) ossification score for Angus was 141 (15), for mixed breeds was 162 (18) and for Wagyu was 163 (16) (Table 21).

Mean (s.d.) pH level for Angus was 5.5 (0.1), for mixed breeds was 5.6 (0.1) and for Wagyu was 5.5 (0.1) (Table 21).

Mean (s.d.) carcase value for Angus was $2,561 (220), for mixed breeds was $2,409 (231) and for Wagyu was $4,228 (937) (Table 21).

Table 18: Distribution of study population across vendors, lots and groups by carcase type.

	Angus	Mixed breed	Wagyu
Vendors			
Number of vendors	65	93	50
Median (IQR) from vendor in study	20 (4 - 48)	39 (5 - 76)	26 (11.5 - 52.5)
Lots			
Number of lots	32	64	44
Median (IQR) in lot	241.5 (205.75 - 243)	260 (198 - 260)	231 (146 - 240)
Median (IQR) in lot in study	34 (1 - 127)	48 (4 - 158)	21 (2 - 121)
Median (IQR) median DOF for lots	104.5 (104 – 108.5)	108 (104 – 109.5)	323 (302.5 – 354.5)
Groups			
Number of groups in study	129	187	93
Median (IQR) in group in study	8 (2 - 26)	17 (3 - 48)	15 (2 - 48)

Table 19: Characteristics of study population (breed category, dentition, sex) summarised by number and percentage within carcase type.

Characteristic/category	Angus	Mixed breed	Wagyu
Breed			
Angus	2366 (100.0)	0	0
British/X	0	728 (11.7)	0
European/X	0	312 (5.0)	0
Tropical/X	0	5158 (83.2)	0
Wagyu	0	0	2542 (83.4)
Wagyu X	0	0	506 (16.6)
Excluded ^{A}	0	1 (0.0)	0
Dentition			
0	1607 (67.9)	1799 (29.0)	17 (0.6)
2	413 (17.5)	2848 (45.9)	665 (21.8)
4	338 (14.3)	1203 (19.4)	1593 (52.3)
6	8 (0.3)	325 (5.2)	640 (21.0)
8	0	24 (0.4)	133 (4.4)
Sex			
Heifer	119 (5.0)	222 (3.6)	1587 (52.1)
Steer	2247 (95.0)	5977 (96.4)	1461 (47.9)
Non-liver associated illness/injury			
No	2028 (85.7)	5563 (89.7)	2781 (91.2)

Yes	338 (14.3)	636 (10.3)	267 (8.8)
Exit timing^A			
Not late	2358 (99.7)	6185 (99.8)	3020 (99.1)
Late	8 (0.3)	14 (0.2)	28 (0.9)

^{A} Late exit was defined as > 10 days after median exit date for the lot for Angus and mixed breed cattle and > 15 days after median exit date for the lot for Wagyu cattle.

Table 20: Characteristics of study population – categorical carcase characteristic variables – by number and percentage within carcase type.

Characteristic/category	Angus	Mixed breed	Wagyu
Fat colour			
0	512 (21.6)	2262 (36.5)	1273 (41.8)
1	1462 (61.8)	2936 (47.4)	1519 (49.8)
2	370 (15.6)	878 (14.2)	233 (7.6)
3	22 (0.9)	122 (2.0)	22 (0.7)
4	0	0	0
5	0	1 (0.0)	0
Missing	0	0	1 (0.0)
Meat colour			
1B	1 (0.0)	0	0
1C	223 (9.4)	124 (2.0)	253 (8.3)
2	1352 (57.1)	2484 (40.1)	1473 (48.3)
3	790 (33.4)	3552 (57.3)	1321 (43.3)
4	0	0	0
5	0	17 (0.3)	0
6	0	22 (0.4)	0
Missing	0	0	1 (0.0)
Marbling			
0	3 (0.1)	1286 (20.7)	0
1	329 (13.9)	3900 (62.9)	5 (0.2)
2	1251 (52.9)	911 (14.7)	44 (1.4)
3	589 (24.9)	94 (1.5)	262 (8.6)
4	167 (7.1)	7 (0.1)	379 (12.4)
5	22 (0.9)	1 (0.0)	797 (26.1)
6	5 (0.2)	0	632 (20.7)
7	0	0	446 (14.6)
8	0	0	311 (10.2)
9	0	0	171 (5.6)
Missing	0	0	1 (0.0)

Table 21: Characteristics of study population – continuous variables – summarised by mean and standard deviation (s.d.) within carcase type.

	Angus		Mixed breed		Wagyu	
	No.	Mean (s.d.)	No.	Mean (s.d.)	No.	Mean (s.d.)
Weight at entry (kg)	2,362	463.6 (46.1)	6,198	408.7 (40.4)	3,048	377.0 (38.8)
Weight at slaughter (kg)	2,366	623.4 (50.3)	6,199	606.7 (57.4)	3,048	713.3 (78.1)

Days on feed	2,366	105 (4.5)	6,198	106 (4.2)	3,048	332 (30.3)
Average daily gain (kg)	2,362	1.51 (0.31)	6,198	1.86 (0.41)	3,048	1.01 (0.19)
Hot standard carcase weight (kg)	2,366	347.1 (29.2)	6,199	346.5 (33.7)	3,047	407.3 (47.1)
Dressing percentage	2,366	55.7 (1.4)	6,199	57.1 (1.8)	3,047	57.1 (1.6)
P8 fat (mm)	2,366	14.8 (3.8)	6,199	12.9 (4.3)	3,047	21.4 (8.1)
Rib fat (mm)	2,366	12.7 (3.0)	6,199	10.1 (2.6)	3,047	19.4 (4.0)
Eye muscle area (cm^2)	2,366	79.3 (6.6)	6,199	78.2 (6.2)	3,047	92.2 (7.7)
Ossification	2,366	141 (15)	6,199	162 (18)	3,047	163 (16)
pH level	2,366	5.5 (0.1)	6,199	5.6 (0.1)	3,047	5.5 (0.1)
Carcase value ($)	2,366	2,561 (220)	6,199	2,409 (231)	3,047	4,228 (937)

4.3.2.2 Liver defects

The frequencies of liver defects by carcase type and estimated prevalences with 95% CIs of each liver defect within each carcase type are shown in Table 22.

Table 22: Frequency of liver defects by carcase type – number, prevalence and 95% confidence intervals (CI) adjusted for clustering by lot.

	Angus		Mixed breed		Wagyu	
Defect	No.	Prevalence (95% CI)	No.	Prevalence (95% CI)	No.	Prevalence (95% CI)
Abscess	298	12.6 (11.2 - 14.2)	410	6.6 (5.5 - 7.9)	194	6.4 (4.4 - 9.0)
Fluke	119	5.0 (2.4 - 10.4)	22	0.4 (0.2 - 0.6)	29	1.0 (0.5 - 1.8)
Hydatid	22	0.9 (0.6 - 1.5)	209	3.4 (2.7 - 4.2)	120	3.9 (2.4 - 6.4)
Adhesion	91	3.8 (3.0 - 4.8)	124	2.0 (1.7 - 2.4)	79	2.6 (1.9 - 3.5)
Fibrosis	505	21.3 (17.6 - 25.7)	1744	28.1 (25.2 - 31.2)	629	20.6 (17.2 - 24.6)
Telangiectasis	11	0.5 (0.2 - 0.9)	21	0.3 (0.2 - 0.7)	10	0.3 (0.2 - 0.6)
Hepatitis	1	0.0 (0.0 - 0.3) [B]	0	0.0 (0.0 - 0.1) [B]	0	0.0 (0.0 - 0.0) [B]
Cyst	1	0.0 (0.0 - 0.3) [B]	2	0.0 (0.0 - 0.1 [B]	3	0.1 (0.0 - 0.3)
Steatosis	24	1.0 (0.4 - 2.7)	45	0.7 (0.4 - 1.3)	43	1.4 (0.8 - 2.5)
Cirrhosis	1	0.0 (0.0 - 0.3) [B]	1	0.0 (0.0 - 0.1) [B]	1	0.0 (0.0 - 0.2) [B]
Neoplasia	0	0.0 (0.0 - 0.2) [B]	1	0.0 (0.0 - 0.1) [B]	2	0.1 (0.0 - 0.3)
Melanosis	134	5.7 (4.1 - 7.8)	411	7.0 (5.5 - 8.9) [A]	151	5.0 (3.5 - 7.1)

[A] Melanosis status recorded for 5895 of 6199 livers

[B] 97.5% one-sided confidence interval not adjusted for clustering

Abscess was identified by researchers in 12.6% Angus, 6.6% mixed breed and 6.4% Wagyu cattle. Across all carcase types, most abscess was not adhered, affected <10% of the liver, were in the "1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter" category, not open, not postcaval and chronic (Table 23).

The frequency of combinations of abscess categories (adhered, percentage tissue affected, open, postcaval and chronicity) among animals with abscess by carcase type is shown in (Table 24). Across all three carcase types, nearly half of cattle with abscess had abscess that was not adhered, affected <10% tissue, was not open or postcaval and was either chronic or mixed. Abscesses that were more severe across multiple categories were very uncommon.

Table 23: Frequency of abscess categories among animals with abscess by carcase type – number, prevalence and 95% confidence intervals (CI) adjusted for clustering by lot.

	Angus		Mixed breed		Wagyu	
Abscess details	No.	Prevalence (95% CI)	No.	Prevalence (95% CI)	No.	Prevalence (95% CI)
Adhered						
No	184	75.8 (70.1 - 80.8)	205	75.1 (70.0 - 79.6)	130	68.0 (58.3 - 76.4)
Yes	67	24.2 (19.2 - 29.9)	78	24.9 (20.4 - 30.0)	52	32.0 (23.6 - 41.7)
% liver affected						
<10%	183	61.4 (55.4 - 67.1)	272	66.3 (61.3 - 71.1)	126	64.9 (58.9 - 70.6)
10-20%	76	25.5 (21.3 - 30.2)	104	25.4 (21.6 - 29.5)	52	26.8 (21.1 - 33.4)
>20%	39	13.1 (8.9 - 18.8)	34	8.3 (5.9 - 11.6)	16	8.2 (5.9 - 11.5)
Size/number [A]						
A	116	38.9 (33.8 - 44.4)	176	42.9 (36.9 - 49.2)	79	40.7 (32.9 - 49.1)
B	144	48.3 (43.7 - 53.0)	195	47.6 (41.6 - 53.5)	101	52.1 (43.2 - 60.8)
C	38	12.8 (9.6 - 16.8)	39	9.5 (6.9 - 12.9)	14	7.2 (4.5 - 11.4)
Open						
No	275	92.3 (86.4 - 95.8)	398	97.1 (92.1 - 98.9)	182	93.8 (90.5 - 96.0)
Yes	23	7.7 (4.2 - 13.6)	12	2.9 (1.1 - 7.9)	12	6.2 (4.0 - 9.5)
Postcaval						
No	222	74.5 (68.6 - 79.6)	331	80.7 (75.8 - 84.8)	150	77.3 (69.2 - 83.8)
Yes	76	25.5 (20.4 - 31.4)	79	19.3 (15.2 - 24.2)	44	22.7 (16.2 - 30.8)
Chronicity [B]						
Acute	10	3.4 (2.1 - 5.2)	10	2.5 (1.3 - 4.7)	6	3.1 (1.6 - 5.8)
Chronic	182	61.1 (53.1 - 68.5)	260	65.2 (57.9 - 71.8)	133	68.6 (59.8 - 76.2)
Mixed	106	35.6 (28.4 - 43.4)	129	32.3 (26.2 - 39.1)	55	28.4 (20.4 - 37.9)
Total	298		410		194	

[A] A: 4 or fewer abscesses 2-4cm in diameter, B: 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter, C: 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter

[B] Chronicity assessed for 399 of 410 livers from Mixed Breed.

Table 24: Frequency of combinations of abscess categories (adhered, percentage tissue affected, open, postcaval and chronicity) among animals with abscess by carcase type. Red shading used to highlight more severe categories.

Abscess categories					Frequency (% cattle with abscess)		
Adhered	% Tissue	Open	Postcaval	Chronicity	Angus	Mixed breed	Wagyu
No	<10%	No	No	Acute	5 (1.7)	5 (1.2)	2 (1.0)
No	<10%	No	No	Chronic	110 (36.9)	164 (40.0)	74 (38.1)
No	<10%	No	No	Mixed	27 (9.1)	36 (8.8)	21 (10.8)
No	<10%	No	No	Not recorded	0 (0.0)	2 (0.5)	0 (0.0)
No	<10%	No	Yes	Acute	0 (0.0)	0 (0.0)	1 (0.5)
No	<10%	No	Yes	Chronic	7 (2.3)	8 (2.0)	6 (3.1)
No	<10%	No	Yes	Mixed	4 (1.3)	9 (2.2)	2 (1.0)
No	<10%	No	Yes	Not recorded	0 (0.0)	3 (0.7)	0 (0.0)
No	<10%	Yes	No	Acute	0 (0.0)	1 (0.2)	0 (0.0)
No	<10%	Yes	No	Chronic	4 (1.3)	1 (0.2)	2 (1.0)
No	<10%	Yes	Yes	Chronic	1 (0.3)	1 (0.2)	0 (0.0)

No	<10%	Yes	Yes	Mixed	0 (0.0)	0 (0.0)	1 (0.5)
No	10-20%	No	No	Acute	0 (0.0)	2 (0.5)	0 (0.0)
No	10-20%	No	No	Chronic	13 (4.4)	20 (4.9)	12 (6.2)
No	10-20%	No	No	Mixed	18 (6.0)	27 (6.6)	2 (1.0)
No	10-20%	No	No	Not recorded	0 (0.0)	1 (0.2)	0 (0.0)
No	10-20%	No	Yes	Acute	1 (0.3)	0 (0.0)	0 (0.0)
No	10-20%	No	Yes	Chronic	5 (1.7)	2 (0.5)	2 (1.0)
No	10-20%	No	Yes	Mixed	12 (4.0)	12 (2.9)	4 (2.1)
No	10-20%	Yes	No	Acute	2 (0.7)	0 (0.0)	0 (0.0)
No	10-20%	Yes	No	Chronic	0 (0.0)	1 (0.2)	0 (0.0)
No	10-20%	Yes	Yes	Chronic	1 (0.3)	0 (0.0)	0 (0.0)
No	>20%	No	No	Chronic	5 (1.7)	3 (0.7)	1 (0.5)
No	>20%	No	No	Mixed	5 (1.7)	3 (0.7)	0 (0.0)
No	>20%	No	Yes	Chronic	1 (0.3)	3 (0.7)	1 (0.5)
No	>20%	No	Yes	Mixed	3 (1.0)	3 (0.7)	0 (0.0)
No	>20%	Yes	No	Mixed	0 (0.0)	1 (0.2)	1 (0.5)
No	>20%	Yes	Yes	Mixed	2 (0.7)	0 (0.0)	0 (0.0)
Yes	<10%	No	No	Acute	0 (0.0)	1 (0.2)	0 (0.0)
Yes	<10%	No	No	Chronic	8 (2.7)	20 (4.9)	11 (5.7)
Yes	<10%	No	No	Mixed	8 (2.7)	8 (2.0)	3 (1.5)
Yes	<10%	No	No	Not recorded	0 (0.0)	3 (0.7)	0 (0.0)
Yes	<10%	No	Yes	Acute	1 (0.3)	0 (0.0)	0 (0.0)
Yes	<10%	No	Yes	Chronic	2 (0.7)	4 (1.0)	2 (1.0)
Yes	<10%	No	Yes	Mixed	1 (0.3)	3 (0.7)	0 (0.0)
Yes	<10%	No	Yes	Not recorded	0 (0.0)	1 (0.2)	0 (0.0)
Yes	<10%	Yes	No	Chronic	1 (0.3)	2 (0.5)	0 (0.0)
Yes	<10%	Yes	No	Mixed	0 (0.0)	0 (0.0)	1 (0.5)
Yes	<10%	Yes	Yes	Chronic	3 (1.0)	0 (0.0)	0 (0.0)
Yes	<10%	Yes	Yes	Mixed	1 (0.3)	0 (0.0)	0 (0.0)
Yes	10-20%	No	No	Acute	0 (0.0)	0 (0.0)	1 (0.5)
Yes	10-20%	No	No	Chronic	8 (2.7)	10 (2.4)	10 (5.2)
Yes	10-20%	No	No	Mixed	2 (0.7)	9 (2.2)	3 (1.5)
Yes	10-20%	No	No	Not recorded	0 (0.0)	1 (0.2)	0 (0.0)
Yes	10-20%	No	Yes	Acute	1 (0.3)	0 (0.0)	0 (0.0)
Yes	10-20%	No	Yes	Chronic	5 (1.7)	10 (2.4)	5 (2.6)
Yes	10-20%	No	Yes	Mixed	3 (1.0)	5 (1.2)	6 (3.1)
Yes	10-20%	Yes	No	Acute	0 (0.0)	0 (0.0)	1 (0.5)
Yes	10-20%	Yes	No	Chronic	1 (0.3)	1 (0.2)	2 (1.0)
Yes	10-20%	Yes	No	Mixed	1 (0.3)	2 (0.5)	1 (0.5)
Yes	10-20%	Yes	Yes	Acute	0 (0.0)	0 (0.0)	1 (0.5)
Yes	10-20%	Yes	Yes	Chronic	2 (0.7)	0 (0.0)	0 (0.0)
Yes	10-20%	Yes	Yes	Mixed	1 (0.3)	1 (0.2)	2 (1.0)
Yes	>20%	No	No	Acute	0 (0.0)	1 (0.2)	0 (0.0)
Yes	>20%	No	No	Chronic	1 (0.3)	3 (0.7)	1 (0.5)
Yes	>20%	No	No	Mixed	2 (0.7)	2 (0.5)	1 (0.5)
Yes	>20%	No	Yes	Chronic	4 (1.3)	7 (1.7)	4 (2.1)

Yes	>20%	No	Yes	Mixed	13 (4.4)	7 (1.7)	7 (3.6)
Yes	>20%	Yes	No	Mixed	1 (0.3)	1 (0.2)	0 (0.0)
Yes	>20%	Yes	Yes	Mixed	2 (0.7)	0 (0.0)	0 (0.0)

Fluke was identified by researchers in 5.0% Angus, 0.4% mixed breed and 1.0% Wagyu cattle. Among Angus and mixed breed cattle, obvious bile duct thickening was more common than no obvious thickening but the two categories were of similar frequency among Wagyu cattle (Table 25).

Hydatid was identified by researchers in 0.9% Angus, 3.4% mixed breed and 3.9% Wagyu cattle. Across all carcase types, most hydatid affected <10% liver. Among mixed breed and Wagyu cattle, the most common stage of chronicity was mostly cystic, whereas all categories were of similar frequency among Angus cattle (Table 25).

Adhesion was identified by researchers in 3.8% Angus, 2.0% mixed breed and 2.6% Wagyu cattle.

Fibrosis was identified by researchers in 21.3% Angus, 28.1% mixed breed and 20.6% Wagyu cattle. Across all carcase types, stellate fibrosis was much more common than either capsular or parenchymal fibrosis. Of those with parenchymal fibrosis, most had <10% liver affected (Table 25).

Melanosis was identified by researchers in 5.7% Angus, 7.0% mixed breed and 5.0% Wagyu cattle..

Telangiectasis, steatosis, cirrhosis, neoplasia, hepatitis and cyst were occasionally identified by researchers.

Table 25: Frequency of categories of other defects by carcase type – number, prevalence and 95% confidence intervals (CI) adjusted for clustering by lot.

	Angus		Mixed breed		Wagyu	
	No.	Prevalence (95% CI)	No.	Prevalence (95% CI)	No.	Prevalence (95% CI)
Fluke	*119*		*22*		*29*	
Bile ducts						
No obvious thickening	40	33.6 (18.8 - 52.5)	8	36.4 (13.9 - 67.0)	15	51.7 (25.1 - 77.4)
Obvious thickening	79	66.4 (47.5 - 81.2)	14	63.6 (33.0 - 86.1)	14	48.3 (22.6 - 74.9)
Hydatid	*22*		*208*		*120*	
% liver affected						
<10%	20	90.9 (70.6 - 97.7)	200	95.7 (91.8 - 97.8)	113	94.2 (85.6 - 97.8)
10-20%	2	9.1 (2.3 - 29.4)	8	3.8 (1.9 - 7.8)	7	5.8 (2.2 - 14.4)
>20%	0	0.0 (0.0 - 0.2) [A]	1	0.5 (0.1 - 3.3)	0	0.0 (0.0 - 0.0) [A]
Chronicity						
Mostly cystic	6	27.3 (11.8 - 51.3)	95	45.5 (36.8 - 54.3)	65	54.2 (40.6 - 67.2)
Mostly calcified	5	22.7 (8.1 - 49.6)	23	11.0 (7.6 - 15.6)	14	11.7 (6.0 - 21.3)
Mixed	6	27.3 (13.1 - 48.3)	47	22.5 (15.7 - 31.2)	18	15.0 (7.5 - 27.7)
Unknown	5	22.7 (6.6 - 55.1)	44	21.1 (13.5 - 31.4)	23	19.2 (11.2 - 30.7)
Fibrosis	*505*		*1740*		*629*	
Type						
Stellate	395	78.2 (72.7 - 82.9)	1523	87.5 (84.5 - 90.0)	499	79.3 (73.4 - 84.2)
Capsular	51	10.1 (6.6 - 15.1)	120	6.9 (5.5 - 8.6)	61	9.7 (7.2 - 12.9)
Parenchymal	59	11.7 (9.4 - 14.4)	97	5.6 (4.1 - 7.6)	69	11.0 (7.3 - 16.1)
Parenchymal fibrosis	*59*		*96*		*69*	
% liver affected						

<10%	48	81.4 (68.9 - 89.6)	86	89.6 (81.5 - 94.4)	61	88.4 (79.0 - 93.9)
10-20%	10	16.9 (9.6 - 28.1)	6	6.3 (2.6 - 14.3)	8	11.6 (6.1 - 21.0)
>20%	1	1.7 (0.2 - 12.0)	4	4.2 (1.7 - 9.6)	0	0.0 (0.0 - 0.1) [A]

[A] 97.5% one-sided confidence interval not adjusted for clustering

The frequencies of each combination of liver defect within each carcase type are shown in Table 26. Multiple liver defects were uncommon, but the most commonly identified combination was fibrosis and melanosis.

Table 26: Frequency and percentage of combinations of the most common liver defects (abscess, fluke, hydatid, adhesion, fibrosis and melanosis) by carcase type.

Abscess	Fluke	Hydatid	Adhesion	Fibrosis	Melanosis	Angus	Mixed breed	Wagyu
No	No	No	No	No	No	1320 (55.8)	3271 (55.5)	1946 (63.8)
No	No	No	No	Yes	No	426 (18.0)	1516 (25.7)	556 (18.2)
Yes	No	No	No	No	No	249 (10.5)	331 (5.6)	162 (5.3)
No	No	No	No	No	Yes	89 (3.8)	249 (4.2)	107 (3.5)
No	No	Yes	No	No	No	19 (0.8)	164 (2.8)	104 (3.4)
No	No	No	No	Yes	Yes	27 (1.1)	132 (2.2)	34 (1.1)
No	No	No	Yes	No	No	53 (2.2)	81 (1.4)	48 (1.6)
No	Yes	No	No	No	No	96 (4.1)	19 (0.3)	26 (0.9)
Yes	No	No	No	Yes	No	21 (0.9)	32 (0.5)	11 (0.4)
Yes	No	No	Yes	No	No	15 (0.6)	15 (0.3)	16 (0.5)
No	No	No	Yes	Yes	No	11 (0.5)	22 (0.4)	12 (0.4)
No	No	Yes	No	Yes	No	1 (0.0)	27 (0.5)	12 (0.4)
Yes	No	No	No	No	Yes	8 (0.3)	15 (0.3)	4 (0.1)
No	Yes	No	No	Yes	No	12 (0.5)	1 (0.0)	3 (0.1)
No	No	Yes	No	No	Yes	0 (0.0)	10 (0.2)	3 (0.1)
No	No	No	Yes	No	Yes	4 (0.2)	0 (0.0)	2 (0.1)
Yes	No	Yes	No	No	No	0 (0.0)	3 (0.1)	1 (0.0)
No	No	Yes	No	Yes	Yes	2 (0.1)	2 (0.0)	0 (0.0)
No	Yes	No	Yes	Yes	No	4 (0.2)	0 (0.0)	0 (0.0)
Yes	No	No	No	Yes	Yes	1 (0.0)	2 (0.0)	0 (0.0)
Yes	Yes	No	No	No	No	2 (0.1)	1 (0.0)	0 (0.0)
No	No	No	Yes	Yes	Yes	0 (0.0)	1 (0.0)	1 (0.0)
No	Yes	No	No	No	Yes	2 (0.1)	0 (0.0)	0 (0.0)
No	Yes	No	Yes	No	No	2 (0.1)	0 (0.0)	0 (0.0)
Yes	No	No	Yes	No	Yes	1 (0.0)	0 (0.0)	0 (0.0)
Yes	Yes	No	Yes	No	No	1 (0.0)	0 (0.0)	0 (0.0)
No	No	Yes	Yes	Yes	No	0 (0.0)	1 (0.0)	0 (0.0)

4.3.2.3 Hospitalisations

The frequencies of hospitalisations by carcase type, both overall and by defect type are shown in Table 27. The most commonly reported ailment for all carcase types was bovine respiratory disease.

Table 27: Frequency and percentage of hospitalisations by carcase type and defect type. BRD: bovine respiratory disease.

	Overall	Abscess	Hydatid	Fluke	Fibrosis	Adhesion	Melanosis

Angus							
BRD	252 (10.7)	22 (7.4)	3 (13.6)	23 (19.3)	39 (7.7)	16 (17.6)	12 (9.0)
BRD suspect	27 (1.1)	4 (1.3)	1 (4.5)	3 (2.5)	5 (1.0)	2 (2.2)	2 (1.5)
Bloat	5 (0.2)	1 (0.3)	0 (0.0)	0 (0.0)	2 (0.4)	0 (0.0)	0 (0.0)
Buller	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Calving	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Cull	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Cast	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Down	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Ear	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Footrot	12 (0.5)	2 (0.7)	1 (4.5)	0 (0.0)	1 (0.2)	0 (0.0)	1 (0.7)
Honker	34 (1.4)	2 (0.7)	3 (13.6)	1 (0.8)	6 (1.2)	1 (1.1)	0 (0.0)
Injury	26 (1.1)	4 (1.3)	0 (0.0)	0 (0.0)	2 (0.4)	0 (0.0)	2 (1.5)
Non-eater	3 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Pink eye	23 (1.0)	1 (0.3)	0 (0.0)	2 (1.7)	4 (0.8)	0 (0.0)	1 (0.7)
Neurological	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Pizzle	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Three-day sickness	1 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.2)	0 (0.0)	0 (0.0)
Total	2366	298	22	119	505	91	134
Mixed breed							
BRD	258 (4.2)	21 (5.1)	8 (3.8)	8 (36.4)	58 (3.3)	3 (2.4)	7 (1.7)
BRD suspect	70 (1.1)	8 (2.0)	2 (1.0)	0 (0.0)	19 (1.1)	2 (1.6)	4 (1.0)
Bloat	12 (0.2)	1 (0.2)	0 (0.0)	0 (0.0)	4 (0.2)	0 (0.0)	1 (0.2)
Buller	192 (3.1)	13 (3.2)	6 (2.9)	1 (4.5)	56 (3.2)	4 (3.2)	9 (2.2)
Calving	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Cull	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.8)	0 (0.0)
Cast	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Down	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Ear	1 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Footrot	33 (0.5)	1 (0.2)	4 (1.9)	0 (0.0)	9 (0.5)	0 (0.0)	2 (0.5)
Honker	50 (0.8)	7 (1.7)	0 (0.0)	0 (0.0)	15 (0.9)	2 (1.6)	4 (1.0)
Injury	44 (0.7)	1 (0.2)	2 (1.0)	0 (0.0)	12 (0.7)	1 (0.8)	2 (0.5)
Non-eater	46 (0.7)	2 (0.5)	1 (0.5)	0 (0.0)	11 (0.6)	2 (1.6)	3 (0.7)
Pink eye	3 (0.0)	0 (0.0)	1 (0.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Neurological	3 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.1)	0 (0.0)	0 (0.0)
Pizzle	50 (0.8)	9 (2.2)	0 (0.0)	0 (0.0)	18 (1.0)	1 (0.8)	3 (0.7)
Three-day sickness	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Total	6199	410	209	22	1744	124	411
Wagyu							
BRD	192 (6.3)	15 (7.7)	10 (8.3)	2 (6.9)	32 (5.1)	4 (5.1)	10 (6.6)
BRD suspect	50 (1.6)	3 (1.5)	0 (0.0)	0 (0.0)	11 (1.7)	1 (1.3)	1 (0.7)
Bloat	7 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.3)	0 (0.0)	0 (0.0)
Buller	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Calving	1 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Cull	1 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Cast	1 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)

Down	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Ear	1 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Footrot	1 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Honker	9 (0.3)	0 (0.0)	0 (0.0)	0 (0.0)	3 (0.5)	0 (0.0)	0 (0.0)
Injury	11 (0.4)	1 (0.5)	0 (0.0)	0 (0.0)	2 (0.3)	0 (0.0)	0 (0.0)
Non-eater	14 (0.5)	1 (0.5)	0 (0.0)	1 (3.4)	5 (0.8)	0 (0.0)	0 (0.0)
Pink eye	4 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.7)
Neurological	1 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Pizzle	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Three-day sickness	5 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.3)	0 (0.0)	0 (0.0)
Total	3048	194	120	29	629	79	151

4.3.3 Outcome variable correlations

Correlations between carcase value ($), average daily gain (ADG), hot standard carcase weight (HSCW), days on feed (DOF), dressing percentage (%), P8fat, rib fat, eye muscle area (EMA), marbling and ossification for each carcase type are shown in Table 28. The only large (>0.4) and significant correlations were between each of carcase value, ADG and HSCW. This was consistent across carcase types.

Table 28: Correlations between carcase value ($), average daily gain (ADG), hot standard carcase weight (HSCW), days on feed (DOF), dressing percentage (%), P8fat, rib fat, eye muscle area (EMA), marbling and ossification by carcase type. Correlations with p<0.05 are starred and those >0.4 are bolded.

	Carcase $	ADG	HSCW	DOF	Dressing %	P8fat	Ribfat	EMA	Marbl-ling	Ossific-ation
Angus										
Carcase $	1									
ADG	**0.417***	1								
HSCW	**0.997***	**0.418***	1							
DOF	0.033	-0.034	0.037	1						
Dressing %	0.279*	-0.044*	0.280*	0.027	1					
P8fat	0.123*	0.042*	0.127*	0.014	-0.016	1				
Ribfat	0.135*	0.014	0.135*	-0.012	0.063*	0.227*	1			
EMA	0.139*	0.069*	0.142*	-0.004	0.122*	0.031	0.396*	1		
Marbling	0.194*	0.038	0.194*	-0.021	0.060*	0.104*	0.101*	0.143*	1	
Ossific'n	0.042*	0.003	0.054*	0.0001	-0.010	0.126*	0.269*	0.402*	0.054*	1
Mixed breed										
Carcase $	1									
ADG	**0.645***	1								
HSCW	**0.990***	**0.647***	1							
DOF	0.034*	-0.025	0.032*	1						
Dressing %	0.246*	-0.142*	0.246*	0.001	1					
P8fat	0.140*	0.157*	0.141*	-0.031*	-0.198*	1				

Ribfat	0.266*	0.213*	0.269*	0.042*	-0.081*	0.317*	1			
EMA	0.365*	0.228*	0.366*	-0.025	0.275*	-0.011	0.134*	1		
Marbling	0.139*	0.094*	0.148*	0.020	-0.074*	0.130*	0.280*	0.086*	1	
Ossific'n	0.127*	0.051*	0.130*	0.075*	0.074*	0.065*	0.107	0.099*	0.032*	1
Wagyu										
Carcase $	1									
ADG	**0.488***	1								
HSCW	**0.616***	**0.803***	1							
DOF	0.347*	0.033	0.258*	1						
Dressing %	0.131*	0.075*	0.345*	-0.117*	1					
P8fat	0.188*	0.150*	0.155*	0.289*	-0.193*	1				
Ribfat	0.222*	0.171*	0.195*	0.211*	-0.036*	0.336*	1			
EMA	0.353*	0.169*	0.204*	0.018	0.124*	0.069*	0.344*	1		
Marbling	0.844*	0.095*	0.121*	0.277*	-0.070*	0.141*	0.159*	0.313*	1	
Ossific'n	0.124*	-0.042*	-0.012	0.166*	-0.135*	0.273*	0.128*	0.021	0.175*	1

4.3.1 Modelling results – crude comparison of defects by carcase type

Crude comparisons of the relative frequency of defects between carcase types are shown in (Table 29). Relative to Wagyu cattle, abscess was more common in Angus cattle, hydatid was less common in Angus cattle, fluke was more common in Angus cattle and less common in mixed breed cattle, fibrosis was more common in mixed breed cattle and adhesion more common in Angus cattle. There was some evidence that melanosis was more common in mixed breed compared to Wagyu cattle.

Table 29: Crude comparison of the relative frequency of defects between carcase types.

Defect	Odds ratio (95% CI)	p value
Abscess		**<0.001**
Angus	2.6 (1.7 - 3.9)	<0.001
Mixed breed	1.1 (0.8 - 1.6)	0.614
Wagyu	Ref	
Hydatid		**0.007**
Angus	0.4 (0.2 - 0.8)	0.009
Mixed breed	1.1 (0.6 - 1.9)	0.765
Wagyu	Ref	
Fluke		**<0.001**
Angus	5.4 (2.2 - 13.1)	<0.001
Mixed breed	0.4 (0.2 - 0.9)	0.031
Wagyu	Ref	
Fibrosis		**<0.001**
Angus	1.0 (0.7 - 1.4)	0.821
Mixed breed	1.7 (1.2 - 2.2)	0.001
Wagyu	Ref	
Adhesion		**<0.001**
Angus	1.5 (1.0 - 2.2)	0.029
Mixed breed	0.8 (0.6 - 1.1)	0.114

Wagyu	Ref	
Melanosis		**0.249**
Angus	1.3 (0.7 - 2.5)	0.354
Mixed breed	1.5 (0.9 - 2.6)	0.095
Wagyu	Ref	

4.3.1 Modelling analysis results – clustering

The extent of clustering by lot of each of abscess, hydatid, fluke, fibrosis, adhesion and melanosis was estimated from the Lot intra-class correlation coefficients (ICC) for each carcase type (Table 30). There was evidence of clustering by lot for all defects for all carcase types. Clustering was particularly high in Wagyu cattle for hydatid and fluke (Lot ICC: 0.36 and 0.46, respectively).

Table 30: The extent of clustering, estimated by the intra-class correlation coefficient, of each of the four most common liver defects: abscess, hydatid, fluke, fibrosis, adhesion and melanosis by lot for each carcase type.

Liver defect	Carcase type	Lot ICC
Abscess	Angus	0.01 (0.00 - 0.18)
	Mixed breed	0.10 (0.05 - 0.19)
	Wagyu	0.18 (0.09 - 0.33)
Hydatid	Angus	0.23 (0.05 - 0.66)
	Mixed breed	0.11 (0.05 - 0.21)
	Wagyu	0.36 (0.20 - 0.56)
Fluke	Angus	0.25 (0.13 - 0.44)
	Mixed breed	0.20 (0.05 - 0.54)
	Wagyu	0.46 (0.20 - 0.74)
Fibrosis	Angus	0.09 (0.04 - 0.20)
	Mixed breed	0.09 (0.06 - 0.15)
	Wagyu	0.06 (0.03 - 0.13)
Adhesions	Angus	0.02 (0.00 - 0.22)
	Mixed breed	0.00 (0.00 - 0.00)
	Wagyu	0.06 (0.02 - 0.20)
Melanosis	Angus	0.09 (0.03 - 0.26)
	Mixed breed	0.20 (0.12 - 0.32)
	Wagyu	0.26 (0.12 - 0.46)

4.3.2 Modelling analysis results – Average daily gain (ADG)

Sex, dentition and non-liver associated illness/injury were included as covariates in all models fitted to assess putative associations between presence/absence of abscess and abscess categories and ADG. Breed was also included in the mixed breed and Wagyu analyses.

ADG was higher in steers compared to heifers, those without a non-liver associated illness/injury (except Wagyu) compared to those with and younger cattle. Among mixed breed cattle ADG was higher in British/X and European/X compared to Tropical/X cattle but among Wagyu cattle there was no evidence of an important difference in ADG between pure-bred and Wagyu X cattle.

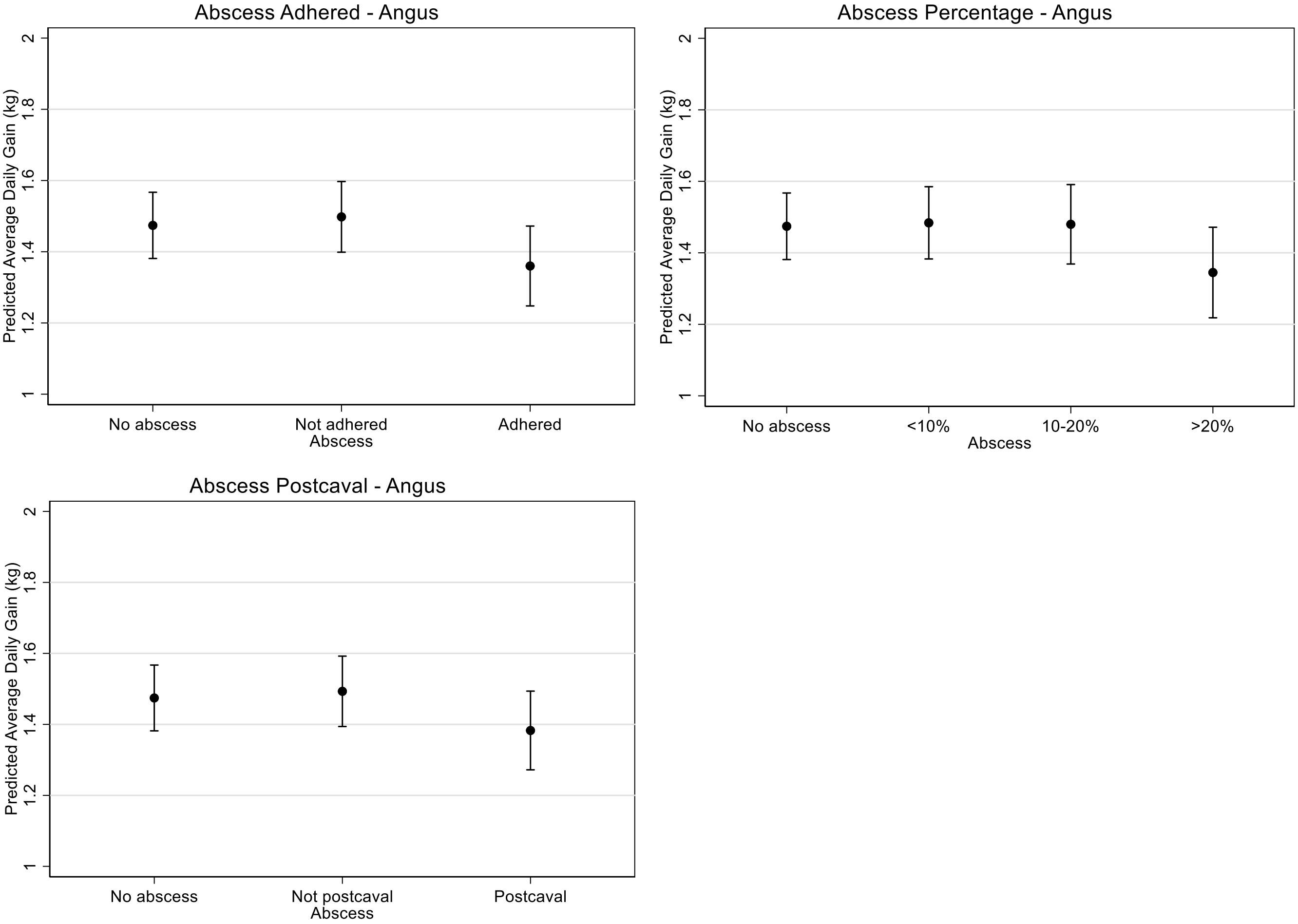
4.3.2.1 Abscess

4.3.2.1.1 Angus

Summary statistics for Angus cattle for ADG by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and ADG are shown in Table 31.

There was no evidence of a large difference in ADG in Angus cattle based on presence/absence of abscess. However, ADG was lower in cattle with adhered abscess (-0.11 kg/day [95%CI: -0.18 - -0.05]), cattle with abscess affecting >20% liver (-0.13 kg/day [95%CI: -0.22 - -0.04]), and cattle with postcaval abscess (-0.09 kg/day [95%CI: -0.15 - -0.03]) compared to those with no abscess (Figure 13). There was some evidence that ADG was lower in cattle with 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter (-0.10 kg/day [95%CI: -0.19 - -0.01]).

Figure 13: Predicted average daily gain of Angus cattle by adhered abscess status, by percentage of liver affected by abscess status and by postcaval abscess status.



4.3.2.1.2 Mixed breed

Summary statistics for mixed breed cattle for ADG by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and ADG are shown in Table 31.

ADG was higher in cattle with abscess (0.06 kg/day [95%CI: 0.02 – 0.10]), cattle with unadhered abscess (0.06 kg/day [95%CI: 0.02 – 0.10]), cattle with abscess affecting <10% liver (0.06 kg/day [95%CI: 0.03 – 0.12]), cattle with 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter (0.10 kg/day [95%CI: 0.04 – 0.15]), cattle with closed abscess (0.06 kg/day [95%CI: 0.02 – 0.10]), cattle with non-postcaval abscess (0.08 kg/day [95%CI: 0.04 – 0.12]) and cattle with chronic abscess (0.07 kg/day [95%CI: 0.03 – 0.12]) compared to no abscess. There was some evidence that ADG was higher in cattle with 4 or fewer abscesses 2-4cm in diameter (0.05 kg/day [95%CI: -0.01 – 0.10]) compared to those with no abscess.

4.3.2.1.3 Wagyu

Summary statistics for Wagyu cattle for ADG by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and ADG are shown in Table 31.

There was no evidence of a large difference in ADG in Wagyu cattle based on presence/absence of abscess or abscess categories.

4.3.2.2 Hydatid

4.3.2.2.1 Angus

Summary statistics for Angus cattle for ADG by presence/absence of hydatid and by hydatid category are shown in Table 32. As only 22/2,366 (0.9%) Angus cattle had hydatid, no analyses assessing putative associations between hydatid and ADG were conducted.

4.3.2.2.2 Mixed breed

Summary statistics for mixed breed cattle for ADG by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and average daily gain are shown in Table 32.

4.3.2.2.3 Wagyu

Summary statistics for Angus cattle for ADG by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and average daily gain are shown in Table 32.

4.3.2.3 Fluke

4.3.2.3.1 Angus

Summary statistics for Angus cattle for ADG by presence/absence of fluke and by fluke category and associations between presence/absence of fluke and by fluke category and average daily gain are shown in Table 32.

4.3.2.3.2 Mixed breed

Summary statistics for mixed breed cattle for ADG by presence/absence of fluke and by fluke category are shown in Table 32. As only 22/6,199 (0.4%) mixed breed cattle had fluke, no analyses assessing putative associations between fluke and ADG were conducted.

4.3.2.3.3 Wagyu

Summary statistics for Wagyu cattle for ADG by presence/absence of fluke and by fluke category are shown in Table 32. As only 29/3,048 (1.0%) Wagyu cattle had fluke, no analyses assessing putative associations between fluke and ADG were conducted.

4.3.2.4 Fibrosis

4.3.2.4.1 Angus

Summary statistics for Angus cattle for ADG by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and ADG are shown in Table 33.

There was some evidence of higher ADG among cattle with fibrosis compared to those without (0.03 kg/day [95%CI: 0.00 – 0.05]).

4.3.2.4.2 Mixed breed

Summary statistics for mixed breed cattle for ADG by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and ADG are shown in Table 33.

ADG was higher among cattle with fibrosis compared to those without (0.03 kg/day [95%CI: 0.01 – 0.05]) and there was some evidence that it was higher among those with stellate fibrosis compared to those without fibrosis (0.03 kg/day [95%CI: 0.00 – 0.05]).

4.3.2.4.3 Wagyu

Summary statistics for Wagyu cattle for ADG by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and ADG are shown in Table 33.

ADG was higher among cattle with fibrosis (0.02 kg/day [95%CI: 0.00 – 0.03]) and those with stellate fibrosis (0.02 kg/day [95%CI: 0.01 – 0.04]) compared to those without.

4.3.2.1 Adhesion

4.3.2.1.1 Angus

Summary statistics for Angus cattle for ADG by presence/absence of adhesion and associations between presence/absence of adhesion and ADG are shown in Table 33.

There was no evidence of a large difference in ADG in Angus cattle based on presence/absence of adhesion.

4.3.2.1.2 Mixed breed

Summary statistics for mixed breed cattle for ADG by presence/absence of adhesion and associations between presence/absence of adhesion and ADG are shown in Table 33.

There was no evidence of a large difference in ADG in mixed breed cattle based on presence/absence of adhesion.

4.3.2.1.3 Wagyu

Summary statistics for Wagyu cattle for ADG by presence/absence of adhesion and associations between presence/absence of adhesion and ADG are shown in Table 33.

There was no evidence of a large difference in ADG in Wagyu cattle based on presence/absence of adhesion.

4.3.2.2 Melanosis

4.3.2.2.1 Angus

Summary statistics for Angus cattle for ADG by presence/absence of melanosis and associations between presence/absence of melanosis and ADG are shown in Table 33.

There was no evidence of a large difference in ADG in Angus cattle based on presence/absence of melanosis.

4.3.2.2.2 Mixed breed

Summary statistics for mixed breed cattle for ADG by presence/absence of melanosis and associations between presence/absence of melanosis and ADG are shown in Table 33.

ADG was higher among cattle with melanosis compared to those without (0.07 kg/day [95%CI: 0.04 – 0.11]).

4.3.2.2.3 Wagyu

Summary statistics for Wagyu cattle for ADG by presence/absence of melanosis and associations between presence/absence of melanosis and ADG are shown in Table 33.

ADG was higher among cattle with melanosis compared to those without (0.03 kg/day [95%CI: 0.01 – 0.06]).

Table 31: Descriptive statistics for average daily gain by abscess and associated categories for each carcase type. Associations between abscess and abscess categories and average daily gain by carcase type.

Abscess	Angus[B]			Mixed breed[C]				Wagyu[D]	
	Observed mean (s.d.)	Coefficient	p-value	Observed Mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Presence			**0.576**			***0.001***			**0.835**
No abscess	1.51 (0.31)	Ref		1.86 (0.41)	Ref		1.01 (0.19)	Ref	
Abscess	1.53 (0.34)	-0.01 (-0.04 - 0.02)	0.576	*1.93 (0.44)*	*0.06 (0.02 - 0.10)*	*0.001*	1.04 (0.19)	0.00 (-0.02 - 0.02)	0.835
Adhered			***0.001***			***0.006***			**0.770**
No abscess	1.51 (0.31)	Ref		1.86 (0.41)	Ref		1.01 (0.19)	Ref	
No	1.57 (0.35)	0.02 (-0.01 - 0.06)	0.219	*1.93 (0.45)*	*0.06 (0.02 - 0.10)*	*0.004*	1.04 (0.18)	0.01 (-0.02 - 0.03)	0.579
Yes	*1.41 (0.29)*	*-0.11 (-0.18 - -0.05)*	*0.001*	1.91 (0.41)	0.06 (-0.02 - 0.13)	0.124	1.02 (0.20)	-0.01 (-0.05 - 0.03)	0.660
% affected			***0.034***			***0.009***			**0.156**
No abscess	1.51 (0.31)	Ref		1.86 (0.41)	Ref		1.01 (0.19)	Ref	
<10%	1.54 (0.37)	0.01 (-0.03 - 0.05)	0.653	*1.95 (0.43)*	*0.07 (0.03 - 0.12)*	*0.001*	1.05 (0.19)	0.02 (-0.01 - 0.04)	0.217
10-20%	1.56 (0.28)	0.01 (-0.06 - 0.07)	0.864	1.88 (0.46)	0.04 (-0.04 - 0.11)	0.329	1.01 (0.16)	-0.01 (-0.05 - 0.03)	0.579
>20%	*1.41 (0.30)*	*-0.13 (-0.22 - -0.04)*	*0.004*	1.87 (0.51)	0.02 (-0.10 - 0.15)	0.710	0.98 (0.26)	-0.07 (-0.14 - 0.01)	0.072
Size/number[A]			**0.172**			***0.001***			**0.300**
No abscess	1.51 (0.31)	Ref		1.86 (0.41)	Ref		1.01 (0.19)	Ref	
A	1.57 (0.38)	0.01 (-0.04 - 0.07)	0.612	1.94 (0.43)	0.05 (-0.01 - 0.10)	0.088	1.03 (0.18)	0.01 (-0.03 - 0.04)	0.669
B	1.52 (0.31)	0.00 (-0.05 - 0.04)	0.838	*1.95 (0.43)*	*0.10 (0.04 - 0.15)*	*<0.001*	1.05 (0.18)	0.01 (-0.02 - 0.04)	0.570
C	*1.45 (0.34)*	*-0.10 (-0.19 - -0.01)*	*0.031*	1.74 (0.55)	-0.07 (-0.18 - 0.05)	0.249	0.93 (0.27)	-0.07 (-0.15 - 0.01)	0.077
Open			**0.308**			***0.006***			**0.300**
No abscess	1.51 (0.31)	Ref		1.86 (0.41)	Ref		1.01 (0.19)	Ref	
No	1.54 (0.34)	0.00 (-0.04 - 0.03)	0.881	*1.93 (0.45)*	*0.06 (0.02 - 0.10)*	*0.002*	1.04 (0.19)	0.00 (-0.02 - 0.02)	0.944
Yes	1.37 (0.24)	-0.09 (-0.20 - 0.03)	0.126	1.75 (0.27)	0.07 (-0.14 - 0.27)	0.536	1.05 (0.19)	0.03 (-0.06 - 0.11)	0.559
Postcaval			***0.010***			***0.001***			**0.181**
No abscess	1.51 (0.31)	Ref			Ref		1.01 (0.19)	Ref	
No	1.56 (0.35)	0.02 (-0.02 - 0.06)	0.340	*1.95 (0.44)*	*0.08 (0.04 - 0.12)*	*<0.001*	1.04 (0.18)	0.01 (-0.01 - 0.04)	0.302
Yes	*1.45 (0.29)*	*-0.09 (-0.15 - -0.03)*	*0.005*	1.84 (0.46)	-0.01 (-0.09 - 0.07)	0.881	1.02 (0.21)	-0.03 (-0.08 - 0.01)	0.136
Chronicity			**0.319**			***0.007***			**0.507**
No abscess	1.51 (0.31)	Ref		1.86 (0.41)	Ref		1.01 (0.19)	Ref	

Acute	1.39 (0.35)	-0.10 (-0.27 - 0.07)	0.267	1.95 (0.37)	0.17 (-0.06 - 0.39)	0.146	1.10 (0.15)	0.04 (-0.08 - 0.16)	0.534
Chronic	1.57 (0.34)	0.01 (-0.03 - 0.05)	0.624	*1.98 (0.44)*	*0.07 (0.03 - 0.12)*	*0.002*	1.02 (0.19)	-0.01 (-0.04 - 0.02)	0.526
Mixed	1.48 (0.33)	-0.04 (-0.09 - 0.02)	0.160	1.84 (0.45)	0.03 (-0.03 - 0.09)	0.365	1.06 (0.19)	0.03 (-0.02 - 0.07)	0.225

[A] A: 4 or fewer abscesses 2-4cm in diameter, B: 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter, C: 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter.

[B] Angus - 2,363 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates

[C] Mixed breed - 6,197 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates

[D] Wagyu - 3,048 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates

Table 32: Descriptive statistics for average daily gain by hydatid, fluke and associated categories for each carcase type. Associations between hydatid and associated categories and average daily gain for Angus and associations between fluke and fluke bile duct status and average daily gain for mixed breed and Wagyu.

Defect	Angus [B]			Mixed breed [C]				Wagyu [D]	
	observed mean (s.d.)	Coefficient	p-value	observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Hydatid									
Presence						**0.519**			**0.126**
No	1.52 (0.31)	n/a		1.86 (0.41)	Ref		1.02 (0.19)	Ref	
Yes	1.48 (0.45)	n/a		1.85 (0.44)	-0.02 (-0.07 - 0.03)	0.519	0.93 (0.19)	-0.02 (-0.05 - 0.01)	0.125
% liver						**0.936**			**0.296**
No hydatid	1.52 (0.31)	n/a		1.86 (0.41)	Ref		1.02 (0.19)	Ref	
<10%	1.48 (0.47)	n/a		1.85 (0.45)	-0.02 (-0.07 - 0.03)	0.519	0.93 (0.19)	-0.02 (-0.05 - 0.01)	0.119
10-20%	1.52 (0.10)	n/a		1.93 (0.35)	-0.01 (-0.26 - 0.24)	0.949	1.04 (0.18)	-0.01 (-0.12 - 0.11)	0.918
>20%	n/a	n/a		1.96 (n/a)	-0.02 (-0.73 - 0.69)	0.965	n/a	n/a	
Chronicity						**0.183**			**0.139**
No hydatid	1.52 (0.31)	n/a		1.86 (0.41)	Ref		1.02 (0.19)	Ref	
Mostly cystic	1.55 (0.23)	n/a		1.85 (0.44)	-0.01 (-0.08 - 0.07)	0.831	0.92 (0.19)	0.00 (-0.04 - 0.04)	0.947
Mostly calcified	1.35 (0.41)	n/a		1.78 (0.58)	-0.02 (-0.16 - 0.13)	0.838	0.94 (0.16)	-0.02 (-0.10 - 0.06)	0.666
Mixed	1.44 (0.65)	n/a		1.96 (0.41)	0.06 (-0.04 - 0.17)	0.241	0.97 (0.22)	-0.04 (-0.11 - 0.03)	0.260

Unknown	1.58 (0.48)	n/a		1.77 (0.39)	-0.12 (-0.23 - -0.01)	0.030	0.93 (0.19)	-0.07 (-0.14 - -0.01)	0.018
Fluke									
Presence			**0.810**						
No	1.52 (0.31)	Ref		1.86 (0.41)	n/a		1.01 (0.19)	n/a	
Yes	1.47 (0.29)	0.01 (-0.05 - 0.06)	0.810	1.98 (0.45)	n/a		1.03 (0.17)	n/a	
Bile ducts			**0.971**						
No fluke	1.52 (0.31)	Ref		1.86 (0.41)	n/a		1.01 (0.19)	n/a	
No obvious thickening	1.45 (0.29)	0.01 (-0.09 - 0.10)	0.900	1.94 (0.31)	n/a		0.99 (0.18)	n/a	
Obvious thickening	1.49 (0.30)	0.01 (-0.06 - 0.07)	0.827	2.01 (0.52)	n/a		1.07 (0.16)	n/a	

[B] Angus - 2,363 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates

[C] Mixed breed - 6,197 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates

[D] Wagyu - 3,048 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates

Table 33: Descriptive statistics for average daily gain by fibrosis, fibrosis type, adhesion and melanosis for each carcase type. Associations between fibrosis, fibrosis type, adhesion and melanosis and average daily gain for each carcase type.

Defect	Angus [B]			Mixed breed [C]			Wagyu [D]		
	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Fibrosis									
Presence			**0.075**			***0.013***			***0.012***
No	1.51 (0.32)	Ref		1.85 (0.41)	Ref		1.01 (0.19)	Ref	
Yes	1.53 (0.30)	0.03 (0.00 - 0.05)	0.075	*1.88 (0.41)*	*0.03 (0.01 - 0.05)*	*0.013*	*1.03 (0.18)*	*0.02 (0.00 - 0.03)*	*0.012*
Type			**0.228**			**0.093**			***0.050***
No fibrosis	1.51 (0.32)	Ref		1.85 (0.41)	Ref		1.01 (0.19)	Ref	
Stellate	1.53 (0.30)	0.02 (-0.01 - 0.05)	0.160	*1.89 (0.41)*	*0.03 (0.00 - 0.05)*	*0.020*	*1.03 (0.18)*	*0.02 (0.01 - 0.04)*	*0.008*
Capsular	1.52 (0.29)	0.01 (-0.07 - 0.08)	0.857	1.83 (0.44)	0.00 (-0.06 - 0.07)	0.911	1.01 (0.19)	-0.01 (-0.04 - 0.03)	0.787
Parenchymal	1.55 (0.28)	0.06 (-0.01 - 0.13)	0.099	1.88 (0.35)	0.04 (-0.03 - 0.12)	0.244	1.05 (0.19)	0.02 (-0.02 - 0.05)	0.352
Adhesion									

Presence			**0.278**			**0.151**			**0.435**
No	1.52 (0.31)	Ref		1.86 (0.41)	Ref		1.01 (0.19)	Ref	
Yes	1.44 (0.26)	-0.03 (-0.09 - 0.03)	0.278	1.88 (0.43)	0.05 (-0.02 - 0.11)	0.151	1.02 (0.19)	0.01 (-0.02 - 0.05)	0.435
Melanosis									
Presence			**0.417**			***<0.001***			***0.008***
No	1.51 (0.31)	Ref		1.86 (0.41)	Ref		1.01 (0.19)	Ref	
Yes	1.59 (0.30)	0.02 (-0.03 - 0.07)	0.417	*1.98 (0.38)*	*0.07 (0.04 - 0.11)*	*<0.001*	*1.07 (0.19)*	*0.03 (0.01 - 0.06)*	*0.008*

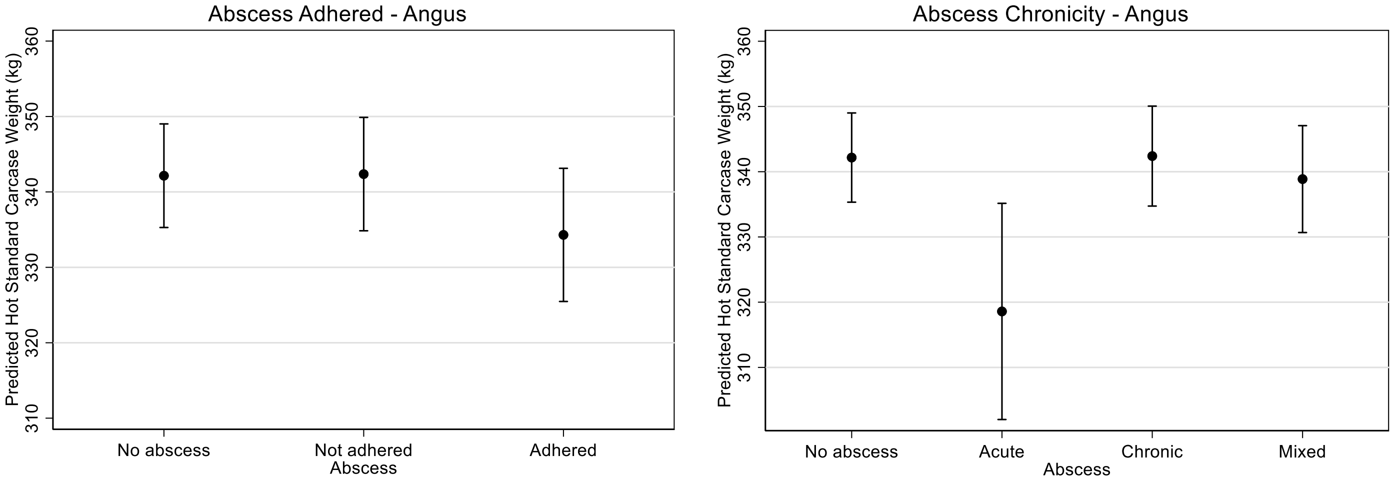
[B] Angus - 2,363 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates

[C] Mixed breed - 6,197 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates

[D] Wagyu - 3,048 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates

4.3.3 Modelling analysis results – Hot standard carcase weight (HSCW)

Figure 14: Predicted hot standard carcase weight of Angus cattle by adhered abscess status, and by abscess chronicity status.



Sex, dentition and non-liver associated illness/injury were included as covariates in all models fitted to assess putative associations between presence/absence of abscess and abscess categories and HSCW. Breed was also included in the mixed breed and Wagyu analyses. Weight at entry and DOF were not included in the analyses, as this would effectively repeat the ADG analyses. Estimates that have not been adjusted for these two variables should be directly comparable to those from other studies where these data were unavailable.

HSCW was higher in steers compared to heifers, those without a non-liver associated illness/injury (except Wagyu) compared to those with, 2 and 4-tooth Angus cattle compared to 0 and 6-tooth, 2-tooth mixed breed cattle compared to 0, 4 or 6-tooth, and 4-tooth Wagyu compared to 0, 2, 6 or 8-tooth. Among mixed breed cattle, HSCW was higher in European/X cattle compared to British/X and Tropical/X cattle and British/X compared to Tropical/X but among Wagyu cattle was no evidence of an important difference in HSCW between pure-bred and Wagyu X cattle.

4.3.3.1 Abscess

4.3.3.1.1 Angus

Summary statistics for Angus cattle for HSCW by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and HSCW are shown in Table 34.

There was no apparent difference in HSCW in Angus cattle based on presence/absence of abscess. However, HSCW was lower in cattle with adhered abscess (-7.9 kg [95%CI: -13.6 - -2.1]) and cattle with acute abscess (-23.6 kg [95%CI: -38.8 - -8.4]) compared to those with no abscess (Figure 14). There was some evidence that HSCW was lower in cattle with open or postcaval abscess or abscess affecting > 20% liver.

4.3.3.1.2 Mixed breed

Summary statistics for mixed breed cattle for HSCW by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and HSCW are shown in Table 34.

There was no apparent difference in HSCW in mixed breed cattle based on presence/absence of abscess. There was some evidence that HSCW was higher in cattle with non-adhered abscess (3.2 kg [95%CI: -0.3 – 6.7]), abscess affecting < 10% liver (3.2 kg [95%CI: -0.05 – 6.9]), 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter (3.8 kg [95%CI: -0.5 – 8.2]) and chronic abscess compared to no abscess (3.7 kg [95%CI: -0.1 – 7.5]).

4.3.3.1.3 Wagyu

Summary statistics for Wagyu cattle for HSCW by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and HSCW are shown in Table 34.

There was no apparent difference in HSCW in Wagyu cattle based on presence/absence of abscess. However, HSCW was lower in cattle with abscess affecting >20% liver (-27.9 kg [95%CI: -45.7 - -10.1]) compared to those with no abscess. There was some evidence that HSCW was lower in cattle with adhered abscess (-8.1 kg [95%CI: -17.3 - 1.1]), 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter (-22.9 kg [95%CI: -42.0 - -3.8]) and cattle with postcaval abscess (-12.0 kg [95%CI: -22.8 - -1.1]) compared to those with no abscess. The effect estimate for Wagyu cattle with acute abscess was very imprecise and extended far from the null, so no conclusion could be reached.

4.3.3.1 Hydatid

4.3.3.1.1 Angus

Summary statistics for Angus cattle for HSCW by presence/absence of hydatid and by hydatid category are shown in Table 35. As only 22/2,366 (0.9%) Angus cattle had hydatid, no analyses assessing putative associations between hydatid and HSCW were conducted.

4.3.3.1.2 Mixed breed

Summary statistics for mixed breed cattle for HSCW by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and HSCW are shown in Table 35.

There was no evidence of a large difference in HSCW in mixed breed cattle based on presence/absence of hydatid. There was some evidence of reduced HSCW among cattle with unknown cyst status compared to those without hydatid (-9.0 kg [95%CI: -18.1 – 0.1]). The effect estimate for mixed breed cattle with > 20% liver affected was very imprecise and extended far from the null, so no conclusion could be reached.

4.3.3.1.3 Wagyu

Summary statistics for Wagyu cattle for HSCW by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and HSCW are shown in Table 35.

HSCW was lower in cattle with hydatid (-9.1 kg [95%CI: -15.9 – -2.3]), cattle with <10% liver affected (-9.6 kg [95%CI: -16.7 – -2.6]) and cattle with unknown cyst status (-21.1 kg [95%CI: -36.1 – -6.1]) compared to those without hydatid. These findings were consistent when the analyses were restricted to both the 1,158 cattle in the 7 of 44 lots which had at least one animal with hydatid and the 2,022 cattle from 14 of the 51 vendors which had at least one animal with hydatid. Furthermore, there was no evidence of a large difference in weight at induction to the feedlot based on presence/absence of hydatid (-2.1 kg [95%CI: -8.3 – 4.0, p=0.49]), which despite the lack of evidence of a large difference in ADG based on presence/absence hydatid, suggests differential performance at the feedlot. The effect estimate for Wagyu cattle with mixed cyst status was very imprecise and extended far from the null, so no conclusion could be reached.

4.3.3.2 Fluke

4.3.3.2.1 Angus

Summary statistics for Angus cattle for HSCW by presence/absence of fluke and by fluke category and associations between presence/absence of fluke and by fluke category and HSCW are shown in Table 35.

There was no evidence of a large difference in HSCW in Angus cattle based on presence/absence of fluke or bile duct category.

4.3.3.2.2 Mixed breed

Summary statistics for mixed breed cattle for HSCW by presence/absence of fluke and by fluke category are shown in Table 35. As only 22/6,199 (0.4%) mixed breed cattle had fluke, no analyses assessing putative associations between fluke and HSCW were conducted.

4.3.3.2.3 Wagyu

Summary statistics for Wagyu breed cattle for HSCW by presence/absence of fluke and by fluke category are shown in Table 35. As only 29/3,048 (1.0%) Wagyu cattle had fluke, no analyses assessing putative associations between fluke and HSCW were conducted.

4.3.3.3 Fibrosis

4.3.3.3.1 Angus

Summary statistics for Angus cattle for HSCW by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and HSCW are shown in Table 36.

There was no evidence of a large difference in HSCW in Angus cattle based on presence/absence of fibrosis or fibrosis type.

4.3.3.3.2 Mixed breed

Summary statistics for mixed breed cattle for HSCW by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and HSCW are shown in Table 36.

There was some evidence of higher HSCW among cattle with fibrosis (1.5 kg [95%CI: -0.2 – 3.2]) and with parenchymal fibrosis (5.7 kg [95%CI: -0.5 – 11.8]) compared to those without fibrosis.

4.3.3.3.3 Wagyu

Summary statistics for Wagyu cattle for HSCW by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and HSCW are shown in Table 36.

HSCW was higher among cattle with fibrosis (3.8 kg [95%CI: 0.5 – 7.0]) and those with stellate fibrosis (4.5 kg [95%CI: 0.9 – 8.1]) compared to those without.

4.3.3.4 Adhesion

4.3.3.4.1 Angus

Summary statistics for Angus cattle for HSCW by presence/absence of adhesion and associations between presence/absence of adhesion and HSCW are shown in Table 36.

There was no evidence of a large difference in HSCW in Angus cattle based on presence/absence of adhesion.

4.3.3.4.2 Mixed breed

Summary statistics for mixed breed cattle for HSCW by presence/absence adhesion and associations between presence/absence of adhesion and HSCW are shown in Table 36.

There was no evidence of a large difference in HSCW in mixed breed cattle based on presence/absence of adhesion.

4.3.3.4.3 Wagyu

Summary statistics for Wagyu cattle for HSCW by presence/absence of adhesion and associations between presence/absence of adhesion and HSCW are shown in Table 36.

There was no evidence of a large difference in HSCW in Wagyu breed cattle based on presence/absence of adhesion.

4.3.3.5 Melanosis

4.3.3.5.1 Angus

Summary statistics for Angus cattle for HSCW by presence/absence of melanosis and associations between presence/absence of melanosis and HSCW are shown in Table 36.

There was no evidence of a large difference in HSCW in Angus cattle based on presence/absence of melanosis.

4.3.3.5.2 Mixed breed

Summary statistics for mixed breed cattle for HSCW by presence/absence of melanosis and associations between presence/absence of melanosis and HSCW are shown in Table 36.

HSCW was higher among cattle with melanosis compared to those without (5.8 kg [95%CI: 2.7 – 8.9]).

4.3.3.5.3 Wagyu

Summary statistics for Wagyu cattle for HSCW by presence/absence of melanosis and associations between presence/absence of melanosis and HSCW are shown in Table 36.

HSCW was higher among cattle with melanosis compared to those without (9.8 kg [95%CI: 3.8 – 15.9]).

Table 34: Descriptive statistics for hot standard carcase weight by abscess and associated categories for each carcase type. Associations between abscess and abscess categories and hot standard carcase weight by carcase type.

Abscess	Angus[B]			Mixed Breed[C]				Wagyu[D]	
	observed mean (s.d.)	Coefficient	p-value	observed mean (s.d.)	Coefficient	p-value	observed mean (s.d.)	Coefficient	p-value
Presence			**0.252**			**0.171**			**0.552**
No abscess	347.2 (29.3)	Ref		346.2 (33.4)	Ref		406.9 (47.1)	Ref	
Abscess	346.5 (28.3)	-1.7 (-4.7 - 1.2)	0.252	350.8 (37.0)	2.2 (-0.9 - 5.2)	0.171	412.9 (46.5)	-1.6 (-7.0 - 3.7)	0.552
Adhered			***0.027***			**0.188**			**0.201**
No abscess	347.2 (29.3)	Ref		346.2 (33.4)	Ref		406.9 (47.1)	Ref	
No	350.3 (26.4)	0.2 (-3.2 - 3.6)	0.901	351.7 (37.5)	3.2 (-0.3 - 6.7)	0.074	415.9 (43.2)	1.4 (-5.0 - 7.9)	0.666
Yes	*334.6 (30.9)*	*-7.9 (-13.6 - -2.1)*	*0.008*	348.0 (35.7)	-1.0 (-7.0 - 5.0)	0.738	406.6 (52.5)	-8.1 (-17.3 - 1.1)	0.086
% liver			**0.297**			**0.272**			***0.007***
No abscess	347.2 (29.3)	Ref		346.2 (33.4)	Ref		406.9 (47.1)	Ref	
<10%	348.2 (26.9)	-1.21 (-4.9 – 25)	0.520	352.1 (37.5)	3.2 (-0.5 - 6.9)	0.093	418.4 (44.4)	3.6 (-3.0 - 10.1)	0.285
10-20%	346.1 (30.2)	-0.2 (-5.8 – 5.4)	0.952	347.7 (36.4)	-1.5 (-7.4 - 4.5)	0.630	407.3 (46.4)	-6.2 (-16.1 - 3.8)	0.227
>20%	*339.1 (30.1)*	-7.3 (-15.1 – 0.5)	0.067	350.3 (35.7)	4.8 (-5.5 - 15.0)	0.362	387.8 (54.5)	*-27.9 (-45.7 - -10.1)*	*0.002*
Size/number[A]			**0.427**			**0.140**			**0.121**
No abscess	347.2 (29.3)	Ref		346.2 (33.4)	Ref		406.9 (47.1)	Ref	
A	348.7 (28.2)	-0.5 (-5.1 - 4.0)	0.816	351.2 (38.7)	2.2 (-2.4 - 6.8)	0.354	414.5 (43.7)	1.6 (-6.6 - 9.8)	0.704
B	346.0 (27.4)	-1.6 (-5.7 - 2.6)	0.459	353.5 (35.2)	3.8 (-0.5 - 8.2)	0.086	415.3 (46.4)	-1.2 (-8.4 - 6.1)	0.754
C	341.7 (31.5)	-6.1 (-13.9 - 1.8)	0.131	335.9 (35.8)	-6.3 (-15.9 - 3.3)	0.197	386.5 (56.7)	*-22.9 (-42.0 - -3.8)*	*0.019*
Open			**0.147**			**0.243**			**0.757**
No abscess	347.2 (29.3)	Ref		346.2 (33.4)	Ref		406.9 (47.1)	Ref	
No	348.4 (26.2)	-1.1 (-4.2 - 2.0)	0.502	351.4 (37.3)	2.4 (-0.7 - 5.5)	0.130	413.7 (45.2)	-1.3 (-6.9 - 4.2)	0.639
Yes	323.3 (40.0)	-9.6 (-19.7 - 0.5)	0.064	331.1 (18.3)	-6.3 (-23.6 - 11.0)	0.473	401.4 (64.0)	-6.2 (-26.8 - 14.4)	0.555
Postcaval			**0.166**			**0.314**			**0.084**
No abscess	347.2 (29.3)	Ref		346.2 (33.4)	Ref		406.9 (47.1)	Ref	

No	347.7 (28.3)	-0.5 (-3.9 - 2.9)	0.782	351.5 (38.1)	2.6 (-0.8 - 6.0)	0.128	414.9 (44.9)	1.4 (-4.6 - 7.5)	0.644
Yes	342.9 (28.0)	-5.4 (-11.0 - 0.2)	0.059	347.8 (32.1)	0.1 (-6.7 - 6.9)	0.978	406.2 (51.3)	*-12.0 (-22.8 - -1.1)*	*0.031*
Chronicity			***0.011***			**0.185**			**0.616**
No abscess	347.2 (29.3)	Ref		346.2 (33.4)	Ref		406.9 (47.1)	Ref	
Acute	*316.1 (37.7)*	*-23.6 (-38.8 - -8.4)*	*0.002*	355.6 (16.8)	8.9 (-9.9 - 27.8)	0.354	433.8 (42.0)	13.4 (-15.7 - 42.5)	0.366
Chronic	348.5 (27.3)	0.2 (-3.5 - 3.9)	0.904	354.0 (39.6)	3.7 (-0.1 - 7.5)	0.057	411.5 (47.7)	-3.2 (-9.5 - 3.2)	0.334
Mixed	345.5 (27.6)	-3.3 (-8.1 - 1.5)	0.176	344.8 (32.8)	-1.5 (-6.8 - 3.9)	0.591	414.0 (44.1)	0.4 (-9.4 - 10.2)	0.933

[A] A: 4 or fewer abscesses 2-4cm in diameter, B: 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter, C: 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter.

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates

Table 35: Descriptive statistics for hot standard carcase weight by hydatid, fluke and associated categories for each carcase type. Associations between hydatid and associated categories and hot standard carcase weight for Angus and associations between fluke and fluke bile duct status and hot standard carcase weight for mixed breed and Wagyu.

Defect	Angus[B]			Mixed breed[C]			Wagyu[D]		
	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Hydatid									
Presence						**0.220**			***0.009***
No	347.2 (29.1)	n/a		346.5 (33.7)	Ref		408.6 (46.8)	Ref	
Yes	337.1 (35.5)	n/a		345.7 (33.0)	-2.6 (-6.9 - 1.6)	0.220	*375.9 (41.9)*	*-9.1 (-15.9 - -2.3)*	*0.009*
% liver						**0.496**			***0.027***
No hydatid	347.2 (29.1)	n/a		346.5 (33.7)	Ref		408.6 (46.8)	Ref	
<10%	337.4 (36.1)	n/a		345.4 (33.3)	-2.8 (-7.1 - 1.5)	0.209	*375.4 (42.5)*	*-9.6 (-16.7 - -2.6)*	*0.007*
10-20%	334.0 (39.6)	n/a		356.5 (24.8)	3.4 (-17.7 - 24.5)	0.753	384.5 (32.5)	-0.7 (-27.7 - 26.3)	0.958
>20%	n/a	n/a		322.0 (n/a)	-25.5 (-85.0 - 34.0)	0.401	n/a	n/a	
Chronicity						**0.277**			***0.027***
No hydatid	347.2 (29.1)	n/a		346.5 (33.7)	Ref		408.6 (46.8)	Ref	

Mostly cystic	341.3 (35.1)	n/a		344.7 (34.7)	-2.0 (-8.2 - 4.2)	0.533	375.9 (38.5)	-6.0 (-15.2 - 3.2)	0.201
Mostly calcified	339.2 (32.9)	n/a		338.5 (37.4)	-4.7 (-17.2 - 7.8)	0.465	382.9 (41.4)	0.7 (-18.4 - 19.8)	0.944
Mixed	327.9 (40.4)	n/a		351.8 (31.9)	2.9 (-5.8 - 11.7)	0.514	382.2 (45.0)	-12.4 (-29.3 - 4.6)	0.152
Unknown	340.9 (42.0)	n/a		345.0 (27.9)	-9.0 (-18.1 - 0.1)	0.052	*366.6 (49.5)*	*-21.1 (-36.1 - -6.1)*	*0.006*
Fluke									
Presence			**0.941**						
No	347.6 (29.0)	Ref		346.4 (33.6)	n/a		407.2 (47.1)	n/a	
Yes	337.0 (31.3)	-0.2 (-5.1 - 4.7)	0.941	359.8 (48.8)	n/a		416.6 (41.4)	n/a	
Bile ducts			**0.898**						
No fluke	347.6 (29.0)	Ref		346.4 (33.6)	n/a		407.2 (47.1)	n/a	
No obvious thickening	328.5 (28.7)	1.4 (-6.8 - 9.5)	0.745	355.1 (31.2)	n/a		410.2 (46.7)	n/a	
Obvious thickening	341.3 (31.8)	-0.9 (-6.5 - 4.8)	0.767	362.5 (57.5)	n/a		423.4 (35.2)	n/a	

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

Table 36: Descriptive statistics for hot standard carcase weight by fibrosis, fibrosis type, adhesion and melanosis for each carcase type. Associations between fibrosis, fibrosis type, adhesion and melanosis and hot standard carcase weight for each carcase type.

Defect	Angus [B]			Mixed breed [C]			Wagyu [D]		
	observed mean (s.d.)	Coefficient	p-value	observed mean (s.d.)	Coefficient	p-value	observed mean (s.d.)	Coefficient	p-value
Fibrosis									
Presence			**0.320**			**0.084**			***0.022***
No	345.8 (29.8)	Ref		346.0 (34.0)	Ref		406.3 (47.9)	Ref	
Yes	351.8 (26.3)	1.2 (-1.2 - 3.7)	0.320	347.6 (32.8)	1.5 (-0.2 - 3.2)	0.084	*410.8 (43.5)*	*3.8 (0.5 - 7.0)*	*0.022*
Type			**0.565**			**0.198**			**0.094**
No fibrosis	345.8 (29.8)	Ref		346.0 (34.0)	Ref		406.3 (47.9)	Ref	
Stellate	351.7 (26.1)	0.9 (-1.8 - 3.6)	0.534	347.4 (32.7)	1.1 (-0.7 - 2.9)	0.229	*410.4 (43.1)*	*4.5 (0.9 - 8.1)*	*0.013*
Capsular	351.4 (25.5)	0.5 (-6.4 - 7.3)	0.890	347.3 (33.5)	1.9 (-3.7 - 7.4)	0.504	408.6 (45.6)	-0.6 (-9.9 - 8.6)	0.897
Parenchymal	353.3 (28.1)	4.3 (-2.0 - 10.7)	0.183	351.2 (32.7)	5.7 (-0.5 - 11.8)	0.072	416.3 (44.8)	2.6 (-6.2 - 11.3)	0.564
Adhesion									

Presence			**0.345**			**0.815**			**0.686**
No	347.4 (29.0)	Ref		346.5 (33.6)	Ref		407.3 (47.1)	Ref	
Yes	340.7 (33.1)	-2.5 (-7.6 - 2.7)	0.345	345.5 (37.6)	-0.6 (-6.1 - 4.8)	0.815	405.5 (48.2)	-1.7 (-9.9 - 6.5)	0.686
Melanosis									
Presence			**0.166**			***<0.001***			***0.001***
No	346.7 (29.4)	Ref		346.4 (34.2)	Ref		406.4 (47.0)	Ref	
Yes	354.4 (23.2)	3.0 (-1.3 - 7.3)	0.165	*352.3 (30.0)*	*5.8 (2.7 - 8.9)*	*<0.001*	*424.7 (45.1)*	*9.8 (3.8 - 15.9)*	*0.001*

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models for fibrosis and adhesion; 5,894 observations included in model for fibrosis all with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

4.3.4 Modelling analysis results – Dressing percentage

Sex, dentition and non-liver associated illness/injury were included as covariates in all models fitted to assess putative associations between presence/absence of abscess and abscess categories and dressing percentage. Breed was also included in the mixed breed and Wagyu analyses.

Dressing percentage was higher in steers compared to heifers. There was no evidence of an important difference in dressing percentage between those with or without a non-liver associated illness/injury. There was some variability across dentition categories among Angus and mixed breed cattle. Among mixed breed cattle dressing percentage was highest in European/X and higher in Tropical/X cattle than British/X cattle and among Wagyu cattle in was higher in Wagyu X compared to pure-bred.

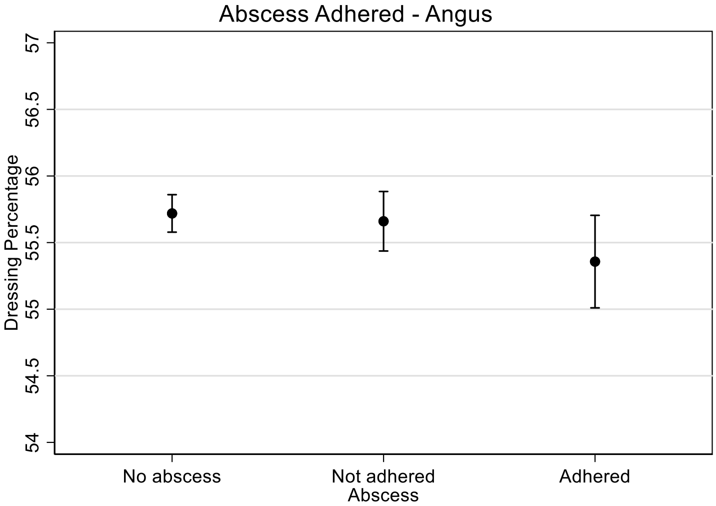
4.3.4.1 Abscess

4.3.4.1.1 Angus

Summary statistics for Angus cattle for dressing percentage by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and dressing percentage are shown in Table 37.

There was no apparent difference in dressing percentage in Angus cattle based on presence/absence of abscess. However, there was some evidence that dressing percentage was lower in cattle with adhered abscess (-0.36% [95%CI: -0.69 - -0.03]; Figure 15), cattle with abscess affecting >20% liver (-0.68% [95%CI: -1.38 – 0.02]) and cattle with 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter (-0.23% [95%CI: -0.47 – 0.00]) compared to those with no abscess.

Figure 15: Predicted dressing percentage of Angus cattle by adhered abscess status.



4.3.4.1.2 Mixed breed

Summary statistics for mixed breed cattle for dressing percentage by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and dressing percentage are shown in Table 37.

Dressing percentage was generally lower in mixed breed cattle with abscess compared to those without (-0.39% [95%CI: -0.57 – -0.21]).

4.3.4.1.3 Wagyu

Summary statistics for Wagyu cattle for dressing percentage by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and dressing percentage are shown in Table 37.

There was no evidence of a large difference in dressing percentage in Wagyu cattle based on presence/absence of abscess. However, dressing percentage was lower in cattle with adhered abscess (-0.50% [95%CI: -0.87 - -0.14]) and cattle with open abscess (-1.20% [95%CI: -2.01 - -0.39]) compared to those with no abscess. There was also some evidence that dressing percentage was lower in cattle with >20% liver affected (-0.66% [95%CI: -1.36 – 0.04]) and cattle with 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter (-0.72% [95%CI: -1.47 - -0.03]).

4.3.4.1 Hydatid

4.3.4.1.1 Angus

Summary statistics for Angus cattle for dressing percentage by presence/absence of hydatid and by hydatid category are shown in Table 38. As only 22/2,366 (0.9%) Angus cattle had hydatid, no analyses assessing putative associations between hydatid and dressing percentage were conducted.

4.3.4.1.2 Mixed breed

Summary statistics for mixed breed cattle for dressing percentage by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and dressing percentage are shown in Table 38.

There was no evidence of a large difference in dressing percentage in mixed breed cattle based on presence/absence of hydatid. There was some evidence of reduced dressing percentage among cattle with mostly cystic hydatid compared to those without hydatid (-0.37% [95%CI: -0.61 – -0.06]). The effect estimates for mixed breed cattle with 10 - 20% and > 20% liver affected were very imprecise and extended far from the null, so no conclusion could be reached.

4.3.4.1.3 Wagyu

Summary statistics for Angus cattle for dressing percentage by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and dressing percentage are shown in Table 38.

Dressing percentage was lower among cattle with hydatid (0.34% [95%CI: -0.60 – -0.07]) and among those with <10% liver affected (-0.34% [95%CI: -0.61 – -0.06]) compared to those without hydatid. Although these trends were consistent when the analyses were restricted to both the 1,158 cattle in the 7 of 44 lots which had at least one animal with hydatid and the 2,022 cattle from 14 of the 51 vendors which had at least one animal with hydatid, the estimates were imprecise.

4.3.4.2 Fluke

4.3.4.2.1 Angus

Summary statistics for Angus cattle for dressing percentage by presence/absence of fluke and by fluke category and associations between presence/absence of fluke and by fluke category and dressing percentage are shown in Table 38.

There was no evidence of a large difference in dressing percentage in Angus cattle based on presence/absence of fluke or bile duct category.

4.3.4.2.2 Mixed breed

Summary statistics for mixed breed cattle for dressing percentage by presence/absence of fluke and by fluke category are shown in Table 38. As only 22/6,199 (0.4%) mixed breed cattle had fluke, no analyses assessing putative associations between fluke and dressing percentage were conducted.

4.3.4.2.3 Wagyu

Summary statistics for Wagyu cattle for dressing percentage by presence/absence of fluke and by fluke category are shown in Table 38. As only 29/3,048 (1.0%) Wagyu cattle had fluke, no analyses assessing putative associations between fluke and dressing percentage were conducted.

4.3.4.3 Fibrosis

4.3.4.3.1 Angus

Summary statistics for Angus cattle for dressing percentage by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and dressing percentage are shown in Table 39.

There was no evidence of a large difference in dressing percentage in Angus cattle based on presence/absence of fibrosis or fibrosis type.

4.3.4.3.2 Mixed breed

Summary statistics for mixed breed cattle for dressing percentage by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and dressing percentage are shown in Table 39.

There was no evidence of a large difference in dressing percentage in mixed breed cattle based on presence/absence of fibrosis or fibrosis type.

4.3.4.3.3 Wagyu

Summary statistics for Wagyu cattle for dressing percentage by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and dressing percentage are shown in Table 39.

There was no evidence of a large difference in dressing percentage in Wagyu cattle based on presence/absence of fibrosis or fibrosis type.

4.3.4.4 Adhesion

4.3.4.4.1 Angus

Summary statistics for Angus cattle for dressing percentage by presence/absence of adhesion and associations between presence/absence of fibrosis and by fibrosis type and dressing percentage are shown in Table 39.

There was no evidence of a large difference in dressing percentage in Angus cattle based on presence/absence of adhesion.

4.3.4.4.2 Mixed breed

Summary statistics for mixed breed cattle for dressing percentage by presence/absence of adhesion and associations between presence/absence of fibrosis and by fibrosis type and dressing percentage are shown in Table 39.

Dressing percentage was lower among cattle with adhesion (-0.48% [95%CI: -0.80 – -0.17]) compared to those without.

4.3.4.4.3 Wagyu

Summary statistics for Wagyu cattle for dressing percentage by presence/absence of adhesion and associations between presence/absence of fibrosis and by fibrosis type and dressing percentage are shown in Table 39.

Dressing percentage was lower among cattle with adhesion (-0.32% [95%CI: -0.64 – 0.00]) compared to those without.

4.3.4.5 Melanosis

4.3.4.5.1 Angus

Summary statistics for Angus cattle for dressing percentage by presence/absence of melanosis and associations between presence/absence of fibrosis and by fibrosis type and dressing percentage are shown in Table 39.

There was no evidence of a large difference in dressing percentage in Angus cattle based on presence/absence of melanosis.

4.3.4.5.2 Mixed breed

Summary statistics for mixed breed cattle for dressing percentage by presence/absence of melanosis and associations between presence/absence of fibrosis and by fibrosis type and dressing percentage are shown in Table 39.

There was no evidence of a large difference in dressing percentage in mixed breed cattle based on presence/absence of melanosis.

4.3.4.5.3 Wagyu

Summary statistics for Wagyu cattle for dressing percentage by presence/absence of melanosis and associations between presence/absence of fibrosis and by fibrosis type and dressing percentage are shown in Table 39.

There was some evidence that dressing percentage was higher among cattle with melanosis (0.22% [95%CI: -0.01 – 0.46]) compared to those without.

Table 37: Descriptive statistics for dressing percentage by abscess and associated categories for each carcase type. Associations between abscess and abscess categories and dressing percentage by carcase type.

Abscess	Angus[B]			Mixed breed[C]				Wagyu[D]	
	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Presence			**0.128**			***<0.001***			**0.835**
No abscess	55.69 (1.41)	Ref		57.15 (1.84)	Ref		57.09 (1.56)	Ref	
Abscess	55.57 (1.56)	-0.13 (-0.30 - 0.04)	0.128	*56.63 (1.94)*	*-0.39 (-0.57 - -0.21)*	*<0.001*	56.87 (1.73)	-0.12 (-0.33 - 0.09)	0.267
Adhered			**0.088**			***<0.001***			***0.019***
No abscess	55.69 (1.41)	Ref		57.15 (1.84)	Ref		57.09 (1.56)	Ref	
No	55.65 (1.42)	-0.06 (-0.25 - 0.13)	0.550	*56.63 (1.83)*	*-0.40 (-0.60 - -0.19)*	*<0.001*	57.04 (1.56)	0.06 (-0.19 - 0.31)	0.623
Yes	55.32 (1.93)	*-0.36 (-0.69 - -0.03)*	*0.031*	*56.63 (2.23)*	*-0.37 (-0.72 - -0.03)*	*0.034*	*56.51 (2.02)*	*-0.50 (-0.87 - -0.14)*	*0.006*
% liver			**0.099**			***<0.001***			**0.112**
No abscess	55.69 (1.41)	Ref		57.15 (1.84)	Ref		57.09 (1.56)	Ref	
<10%	55.51 (1.56)	0.02 (-0.23 - 0.28)	0.851	*56.66 (1.84)*	*-0.37 (-0.58 - -0.15)*	*0.001*	57.05 (1.55)	0.03 (-0.23 - 0.29)	0.809
10-20%	55.82 (1.52)	-0.33 (-0.72 - 0.06)	0.101	*56.34 (2.17)*	*-0.70 (-1.05 - -0.36)*	*<0.001*	56.59 (2.07)	-0.32 (-0.71 - 0.08)	0.113
>20%	55.37 (1.60)	*-0.68 (-1.38 - 0.02)*	*0.058*	57.22 (1.85)	0.36 (-0.23 - 0.95)	0.233	56.36 (1.72)	-0.66 (-1.36 - 0.04)	0.063
Size/number[A]			**0.200**			***<0.001***			**0.143**
No abscess	55.69 (1.41)	Ref		57.15 (1.84)	Ref		57.09 (1.56)	Ref	
A	55.70 (1.51)	0.02 (-0.24 - 0.29)	0.861	56.83 (1.86)	-0.24 (-0.50 - 0.03)	0.079	57.10 (1.53)	0.08 (-0.25 - 0.40)	0.642
B	55.47 (1.65)	*-0.23 (-0.47 - 0.00)*	*0.055*	*56.45 (1.97)*	*-0.57 (-0.82 - -0.31)*	*<0.001*	56.77 (1.84)	-0.19 (-0.47 - 0.10)	0.196
C	55.56 (1.37)	-0.23 (-0.68 - 0.22)	0.318	56.62 (2.09)	-0.20 (-0.76 - 0.35)	0.470	56.29 (1.87)	-0.72 (-1.47 - 0.03)	0.060
Open			**0.310**			***<0.001***			***0.013***
No abscess	55.69 (1.41)	Ref		57.15 (1.84)	Ref		57.09 (1.56)	Ref	
No	55.58 (1.54)	-0.13 (-0.31 - 0.05)	0.155	*56.64 (1.91)*	*-0.39 (-0.57 - -0.21)*	*<0.001*	56.94 (1.53)	-0.05 (-0.26 - 0.17)	0.671
Yes	55.50 (1.81)	-0.18 (-0.76 - 0.40)	0.547	56.19 (2.83)	-0.56 (-1.55 - 0.44)	0.276	*55.86 (3.55)*	*-1.20 (-2.01 - -0.39)*	*0.004*
Postcaval			**0.311**			***<0.001***			**0.305**
No abscess	55.69 (1.41)	Ref		57.15 (1.84)	Ref		57.09 (1.56)	Ref	
No	55.57 (1.60)	-0.13 (-0.32 - 0.07)	0.205	*56.57 (1.93)*	*-0.44 (-0.64 - -0.25)*	*<0.001*	56.90 (1.79)	-0.06 (-0.30 - 0.18)	0.624
Yes	55.58 (1.44)	-0.15 (-0.47 - 0.17)	0.355	56.88 (1.97)	-0.17 (-0.56 - 0.22)	0.393	56.78 (1.53)	-0.32 (-0.75 - 0.10)	0.139
Chronicity			**0.478**			***<0.001***			**0.546**
No abscess	55.69 (1.41)	Ref		57.15 (1.84)	Ref		57.09 (1.56)	Ref	

Acute	55.45 (1.11)	-0.12 (-0.99 - 0.75)	0.790	56.62 (1.47)	-0.45 (-1.54 - 0.63)	0.413	56.46 (1.14)	-0.38 (-1.52 - 0.76)	0.514
Chronic	55.59 (1.58)	-0.11 (-0.32 - 0.10)	0.320	*56.61 (1.91)*	*-0.41 (-0.63 - -0.19)*	*<0.001*	56.80 (1.88)	-0.17 (-0.42 - 0.08)	0.193
Mixed	55.54 (1.57)	-0.18 (-0.45 - 0.10)	0.208	56.62 (2.03)	-0.36 (-0.67 - -0.05)	0.021	57.08 (1.38)	0.02 (-0.36 - 0.41)	0.902

[A] A: 4 or fewer abscesses 2-4cm in diameter, B: 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter, C: 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter.

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

Table 38: Descriptive statistics for dressing percentage by hydatid, fluke and associated categories for each carcase type. Associations between hydatid and associated categories and dressing percentage for Angus and associations between fluke and fluke bile duct status and dressing percentage for mixed breed and Wagyu.

Defect	Angus [B]			Mixed breed [C]			Wagyu [D]		
	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Hydatid									
Presence						**0.194**			***0.013***
No	55.68 (1.43)	n/a		57.13 (1.85)	Ref		57.09 (1.57)	Ref	
Yes	55.35 (1.31)	n/a		56.93 (1.67)	-0.16 (-0.41 - 0.08)	0.194	56.66 (1.59)	-0.34 (-0.60 - -0.07)	0.013
% liver						**0.301**			***0.046***
No hydatid	55.68 (1.43)	n/a		57.13 (1.85)	Ref		57.09 (1.57)	Ref	
<10%	55.25 (1.28)	n/a		56.96 (1.68)	-0.13 (-0.38 - 0.12)	0.304	*56.69 (1.60)*	*-0.34 (-0.61 - -0.06)*	*0.017*
10-20%	56.37 (1.63)	n/a		56.42 (1.26)	-0.71 (-1.93 - 0.51)	0.256	56.26 (1.48)	-0.37 (-1.43 - 0.69)	0.489
>20%	n/a	n/a		54.75 (n/a)	-2.03 (-5.47 - 1.41)	0.248	n/a	n/a	
Chronicity						**0.120**			**0.151**
No hydatid	55.68 (1.43)	n/a		57.13 (1.85)	Ref		57.09 (1.57)	Ref	
Mostly cystic	54.75 (1.44)	n/a		*56.75 (1.58)*	*-0.42 (-0.77 - -0.06)*	*0.023*	*56.61 (1.57)*	*-0.41 (-0.76 - -0.05)*	*0.027*
Mostly calcified	56.13 (1.43)	n/a		57.11 (1.89)	0.10 (-0.62 - 0.82)	0.785	56.96 (1.74)	-0.10 (-0.85 - 0.65)	0.787
Mixed	55.12 (1.36)	n/a		56.82 (1.56)	-0.22 (-0.72 - 0.29)	0.400	56.55 (1.66)	-0.27 (-0.93 - 0.40)	0.433
Unknown	55.56 (0.83)	n/a		57.34 (1.82)	0.31 (-0.22 - 0.83)	0.251	56.74 (1.58)	-0.35 (-0.94 - 0.23)	0.239
Fluke									

Presence			**0.671**						
No	55.68 (1.43)	Ref		57.12 (1.84)	n/a		57.08 (1.57)	n/a	
Yes	55.71 (1.44)	0.06 (-0.22 - 0.33)	0.671	56.39 (2.60)	n/a		57.04 (1.37)	n/a	
Bile ducts			**0.914**						
No fluke	55.68 (1.43)	Ref		57.12 (1.84)	n/a		57.08 (1.57)	n/a	
No obvious thickening	55.75 (1.31)	0.06 (-0.40 - 0.52)	0.805	57.24 (2.03)	n/a		57.09 (1.27)	n/a	
Obvious thickening	55.69 (1.51)	0.06 (-0.26 - 0.38)	0.714	55.91 (2.83)	n/a		56.99 (1.51)	n/a	

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

Table 39: Descriptive statistics for dressing percentage by fibrosis, fibrosis type, adhesion and melanosis for each carcase type. Associations between fibrosis, fibrosis type, adhesion and melanosis and dressing percentage for each carcase type.

Defect	Angus [B]			Mixed breed [C]			Wagyu [D]		
	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Fibrosis									
Presence			**0.396**			**0.860**			**0.123**
No	55.66 (1.46)	Ref		57.12 (1.84)	Ref		57.04 (1.58)	Ref	
Yes	55.75 (1.35)	0.06 (-0.08 - 0.20)	0.396	57.10 (1.86)	0.01 (-0.09 - 0.11)	0.860	57.21 (1.52)	0.10 (-0.03 - 0.23)	0.123
Type			**0.528**			**0.593**			**0.280**
No fibrosis	55.66 (1.46)	Ref		57.12 (1.84)	Ref		57.04 (1.58)	Ref	
Stellate	55.77 (1.33)	0.09 (-0.06 - 0.25)	0.230	57.11 (1.87)	0.00 (-0.10 - 0.11)	0.994	57.21 (1.55)	0.09 (-0.05 - 0.23)	0.197
Capsular	55.50 (1.27)	-0.16 (-0.55 - 0.23)	0.427	57.22 (1.83)	0.19 (-0.13 - 0.51)	0.249	57.38 (1.41)	0.29 (-0.08 - 0.65)	0.122
Parenchymal	55.78 (1.52)	0.02 (-0.35 - 0.38)	0.920	56.81 (1.70)	-0.13 (-0.49 - 0.22)	0.469	57.05 (1.37)	-0.01 (-0.35 - 0.33)	0.957
Adhesion									
Presence			**0.322**			***0.002***			***0.047***
No	55.68 (1.42)	Ref		57.13 (1.84)	Ref		57.08 (1.56)	Ref	
Yes	55.52 (1.75)	-0.15 (-0.44 - 0.15)	0.322	*56.55 (1.92)*	*-0.48 (-0.80 - -0.17)*	*0.002*	*56.78 (1.94)*	*-0.32 (-0.64 - 0.00)*	*0.047*
Melanosis									

Presence			**0.229**			**0.347**			**0.065**
No	55.67 (1.43)	Ref		57.09 (1.85)	Ref		57.06 (1.57)	Ref	
Yes	55.75 (1.43)	0.15 (-0.09 - 0.40)	0.229	57.16 (1.76)	0.09 (-0.09 - 0.26)	0.347	57.32 (1.55)	0.22 (-0.01 - 0.46)	0.065

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates

[C] Mixed breed - 6,198 observations included in models for fibrosis and adhesion; 5,894 observations included in model for fibrosis all with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates

4.3.5 Modelling analysis results – P8 fat

Sex, dentition and non-liver associated illness/injury were included as covariates in all models fitted to assess putative associations between presence/absence of abscess and abscess categories and P8 fat. Breed was also included in the mixed breed and Wagyu analyses. P8 fat was log transformed prior to fitting as the outcome variable as residuals from preliminary analyses using the untransformed variable were right skewed. Consequently, the interpretation of the regression coefficient is different. The exponentiated coefficient for a category of a variable represents the ratio of the expected geometric mean P8 fat for that category of each variable of interest relative to that of the reference category.

P8 fat was higher in heifers compared to steers and those without a non-liver associated illness/injury compared to those with. Among Angus and Wagyu cattle there were some differences in P8 fat across dentition categories but there was no evidence of a marked pattern among mixed breed cattle. Among mixed breed cattle P8 fat was lower in European/X and Tropical/X cattle compared to British/X cattle and among Wagyu cattle P8 fat was higher in pure-bred compared to Wagyu X.

4.3.5.1 Abscess

4.3.5.1.1 Angus

Summary statistics for Angus cattle for P8 fat by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and P8 fat are shown in Table 40.

There was no evidence of a large difference in P8 fat in Angus cattle based on presence/absence of abscess. However, there was some evidence that P8 was lower in cattle with postcaval abscess (6% decrease [95%CI: 1 - 12]) or mixed chronicity (7% decrease [95%CI: 2 - 11]) compared to those with no abscess.

4.3.5.1.2 Mixed breed

Summary statistics for mixed breed cattle for P8 fat by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and P8 fat are shown in Table 40.

P8 fat was higher in cattle with abscess (5% increase [95%CI: 2 - 9]), cattle with unadhered abscess (5% increase [95%CI: 2 - 9]), cattle with abscess affecting <10% liver (5% increase [95%CI: 1 - 9]), cattle with 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter (8% increase [95%CI: 3 - 13]), cattle with closed abscess (5% increase [95%CI: 2 - 9]), cattle with non-postcaval abscess (5% increase [95%CI: 1 - 8]) and cattle with chronic abscess (6% increase [95%CI: 2 - 10]) compared to no abscess.

4.3.5.1.3 Wagyu

Summary statistics for Wagyu cattle for P8 fat by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and P8 fat are shown in Table 40.

There was no evidence of a large difference in P8 fat in Wagyu cattle based on presence/absence of abscess. However, there was some evidence that P8 was lower in cattle with 10-20% liver affected (10% decrease [95%CI: 2 - 18]), cattle with 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter (6% decrease [95%CI: 0 - 12]), cattle with open abscess (16% decrease [95%CI: 30% decrease - 1% increase]) and cattle with postcaval abscess (9% decrease [95%CI: 0 - 17]) compared to those with no abscess. The effect estimate for Wagyu cattle with acute abscess was very imprecise and extended far from the null, so no conclusion could be reached.

4.3.5.2 Hydatid

4.3.5.2.1 Angus

Summary statistics for Angus cattle for P8 fat by presence/absence of hydatid and by hydatid category are shown in Table 41. As only 22/2,366 (0.9%) Angus cattle had hydatid, no analyses assessing putative associations between hydatid and P8 fat were conducted.

4.3.5.2.2 Mixed breed

Summary statistics for mixed breed cattle for P8 fat by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and P8 fat shown in Table 41.

There was no apparent difference in P8 fat in mixed breed cattle based on presence/absence of hydatid or most hydatid categories. The effect estimate for mixed breed cattle with 10 - 20% liver affected was very imprecise and extended far from the null, so no conclusion could be reached.

4.3.5.2.3 Wagyu

Summary statistics for Wagyu cattle for P8 fat by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and P8 fat are shown in Table 41.

P8 fat was lower in cattle with hydatid (8% decrease [95%CI: 2 - 13]) and cattle with hydatid affecting <10% liver (9% decrease [95%CI: 3 - 15]). The effect estimates for Wagyu cattle with 10-20% liver affected and with mixed cyst status were very imprecise and extended far from the null, so no conclusion could be reached. These findings were consistent when the analyses were restricted to both the 1,158 cattle in the 7 of 44 lots which had at least one animal with hydatid and the 2,022 cattle from 14 of the 51 vendors which had at least one animal with hydatid.

4.3.5.3 Fluke

4.3.5.3.1 Angus

Summary statistics for Angus cattle for P8 fat by presence/absence of fluke and by fluke category and associations between presence/absence of fluke and by fluke category and P8 fat are shown in Table 41.

There was no evidence of a large difference in P8 fat in Angus cattle based on presence/absence of fluke or bile duct category.

4.3.5.3.2 Mixed breed

Summary statistics for mixed breed cattle for P8 fat by presence/absence of fluke and by fluke category are shown in Table 41. As only 22/6,199 (0.4%) mixed Breed cattle had fluke, no analyses assessing putative associations between fluke and P8 fat were conducted.

4.3.5.3.3 Wagyu

Summary statistics for Wagyu cattle for P8 fat by presence/absence of fluke and by fluke category are shown in Table 41. As only 29/3,048 (1.0%) Wagyu cattle had fluke, no analyses assessing putative associations between fluke and P8 fat were conducted.

4.3.5.4 Fibrosis

4.3.5.4.1 Angus

Summary statistics for Angus cattle for P8 fat by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and P8 fat are shown in Table 42.

There was no evidence of a large difference in P8 fat in Angus cattle based on presence/absence of fibrosis/fibrosis type.

4.3.5.4.2 Mixed breed

Summary statistics for mixed breed cattle for P8 fat by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and P8 fat are shown in Table 42.

There was no evidence of a large difference in P8 fat in mixed breed cattle based on presence/absence of fibrosis/fibrosis type.

4.3.5.4.3 Wagyu

Summary statistics for Wagyu cattle for P8 fat by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and P8 fat are shown in Table 42.

There was no evidence of a large difference in P8 fat in Wagyu cattle based on presence/absence of fibrosis/fibrosis type.

4.3.5.5 Adhesion

4.3.5.5.1 Angus

Summary statistics for Angus cattle for P8 fat by presence/absence of adhesion and associations between presence/absence of adhesion and P8 fat are shown in Table 42.

There was no evidence of a large difference in P8 fat in Angus cattle based on presence/absence of adhesion.

4.3.5.5.2 Mixed breed

Summary statistics for mixed breed cattle for P8 fat by presence/absence of adhesion and associations between presence/absence of adhesion and P8 fat are shown in Table 42.

There was no evidence of a large difference in P8 fat in mixed breed cattle based on presence/absence of adhesion.

4.3.5.5.3 Wagyu

Summary statistics for Wagyu cattle for P8 fat by presence/absence of adhesion and associations between presence/absence of adhesion and P8 fat are shown in Table 42.

There was no evidence of a large difference in P8 fat in Wagyu cattle based on presence/absence of adhesion.

4.3.5.6 Melanosis

4.3.5.6.1 Angus

Summary statistics for Angus cattle for P8 fat by presence/absence of melanosis and associations between presence/absence of melanosis and P8 fat are shown in Table 42.

There was no evidence of a large difference in P8 fat in Angus cattle based on presence/absence of melanosis.

4.3.5.6.2 Mixed breed

Summary statistics for mixed breed cattle for P8 fat by presence/absence of melanosis and associations between presence/absence of melanosis and P8 fat are shown in Table 42.

There was no evidence of a large difference in P8 fat in mixed breed cattle based on presence/absence of melanosis.

4.3.5.6.3 Wagyu

Summary statistics for Wagyu cattle for P8 fat by presence/absence of melanosis and associations between presence/absence of melanosis and P8 fat are shown in Table 42.

There was no evidence of a large difference in P8 fat in Wagyu cattle based on presence/absence of melanosis.

Table 40: Descriptive statistics for P8 fat by abscess and associated categories for each carcase type. Associations between abscess and abscess categories and P8 fat by carcase type.

Abscess	Angus ^{B}			Mixed breed^{C}			Wagyu^{D}		
	Observed mean (s.d.)	Exponentiated Coefficient^{E}	p-value	Observed mean (s.d.)	Exponentiated Coefficient^{E}	p-value	Observed mean (s.d.)	Exponentiated Coefficient^{E}	p-value
Presence			**0.488**			***0.002***			**0.129**
No abscess	14.8 (3.8)	Ref		12.8 (4.3)	Ref		21.3 (8.1)	Ref	
Abscess	14.8 (4.0)	0.99 (0.96 - 1.02)	0.488	13.5 (4.7)	*1.05 (1.02 - 1.09)*	*0.002*	22.0 (7.9)	0.96 (0.92 - 1.01)	0.129
Adhered			**0.541**			***0.008***			**0.280**
No abscess	14.8 (3.8)	Ref		12.8 (4.3)	Ref		21.3 (8.1)	Ref	
No	14.8 (3.8)	1.00 (0.96 - 1.03)	0.836	13.6 (4.8)	*1.05 (1.02 - 1.09)*	*0.004*	22.0 (6.9)	0.97 (0.92 - 1.03)	0.317
Yes	14.8 (4.7)	0.97 (0.91 - 1.03)	0.272	13.3 (4.3)	1.04 (0.98 - 1.11)	0.191	22.0 (9.8)	0.95 (0.87 - 1.03)	0.200
% liver			**0.110**			***0.022***			**0.107**
No abscess	14.8 (3.8)	Ref		12.8 (4.3)	Ref		21.3 (8.1)	Ref	
<10%	15.0 (3.8)	1.00 (0.94 - 1.05)	0.886	13.5 (4.7)	*1.05 (1.01 - 1.09)*	*0.012*	22.4 (7.5)	1.00 (0.94 - 1.05)	0.873
10-20%	*14.9 (4.0)*	*0.90 (0.82 - 0.98)*	*0.018*	13.6 (4.9)	1.05 (0.99 - 1.12)	0.098	21.4 (8.5)	*0.90 (0.82 - 0.98)*	*0.018*
>20%	13.6 (4.7)	0.94 (0.81 - 1.10)	0.470	13.4 (4.2)	1.06 (0.95 - 1.17)	0.316	21.1 (8.9)	0.94 (0.80 - 1.10)	0.443
Size/number ^{A}			**0.191**			***0.005***			**0.241**
No abscess	14.8 (3.8)	Ref		12.8 (4.3)	Ref		21.3 (8.1)	Ref	
A	14.9 (4.1)	1.00 (0.95 - 1.04)	0.849	12.9 (4.1)	1.03 (0.98 - 1.08)	0.302	22.6 (7.8)	1.00 (0.93 - 1.07)	0.996
B	15.0 (3.8)	1.00 (0.96 - 1.05)	0.829	14.1 (5.1)	*1.08 (1.03 - 1.13)*	*0.001*	*21.7 (7.7)*	*0.94 (0.88 - 1.00)*	*0.043*
C	13.7 (4.3)	0.91 (0.84 - 0.99)	0.031	13.4 (5.0)	1.02 (0.93 - 1.13)	0.674	21.8 (9.7)	0.97 (0.82 - 1.15)	0.748
Open			**0.693**			***0.008***			**0.097**
No abscess	14.8 (3.8)	Ref		12.8 (4.3)	Ref		21.3 (8.1)	Ref	
No	14.8 (4.0)	0.99 (0.96 - 1.02)	0.595	13.6 (4.7)	*1.05 (1.02 - 1.09)*	*0.002*	22.2 (7.8)	0.97 (0.93 - 1.02)	0.269
Yes	14.7 (4.4)	0.96 (0.87 - 1.07)	0.494	11.8 (3.9)	1.03 (0.86 - 1.23)	0.742	19.3 (9.5)	0.84 (0.70 - 1.01)	0.061
Postcaval			**0.067**			***0.007***			**0.134**
No abscess	14.8 (3.8)	Ref		12.8 (4.3)	Ref		21.3 (8.1)	Ref	
No	15.1 (4.1)	1.01 (0.97 - 1.04)	0.644	13.3 (4.4)	*1.05 (1.01 - 1.08)*	0.011	22.7 (7.9)	0.98 (0.93 - 1.03)	0.457
Yes	*13.9 (3.5)*	*0.94 (0.88 - 0.99)*	*0.024*	14.3 (5.8)	1.07 (1.00 - 1.15)	0.054	19.8 (7.7)	0.91 (0.83 - 1.00)	0.059
Chronicity			***0.024***			***0.031***			**0.317**
No abscess	14.8 (3.8)	Ref		12.8 (4.3)	Ref		21.3 (8.1)	Ref	

Acute	14.8 (3.3)	0.97 (0.83 - 1.13)	0.702	13.1 (5.0)	1.04 (0.86 - 1.27)	0.673	26.5 (9.4)	1.10 (0.85 - 1.42)	0.455
Chronic	15.2 (4.1)	1.02 (0.98 - 1.06)	0.268	13.5 (4.6)	*1.06 (1.02 - 1.10)*	*0.005*	22.0 (7.8)	0.95 (0.90 - 1.01)	0.107
Mixed	*13.9 (3.8)*	*0.93 (0.89 - 0.98)*	*0.006*	13.3 (5.0)	1.03 (0.98 - 1.09)	0.278	21.6 (8.0)	0.97 (0.89 - 1.06)	0.523

[A] A: 4 or fewer abscesses 2-4cm in diameter, B: 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter, C: 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter.

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[E] From models with log transformed outcomes the exponentiated coefficient for a category of a variable represents the ratio of the expected geometric mean P8 fat for that category of each variable of interest relative to that of the reference category.

Table 41: Descriptive statistics for P8 fat by hydatid, fluke and associated categories for each carcase type. Associations between hydatid and associated categories and P8 fat for Angus and associations between fluke and fluke bile duct status and P8 fat for mixed breed and Wagyu.

Defect	Angus[B]			Mixed breed[C]			Wagyu[D]		
	Observed mean (s.d.)	Exponentiated Coefficient[E]	p-value	Observed mean (s.d.)	Exponentiated coefficient[E]	p-value	Observed mean (s.d.)	Exponentiated coefficient[E]	p-value
Hydatid									
Presence						**0.603**			***0.007***
No	14.8 (3.8)	n/a		12.9 (4.3)	Ref		21.5 (8.1)	Ref	
Yes	14.3 (3.9)	n/a		13.1 (4.4)	1.01 (0.97 - 1.06)	0.603	*18.6 (6.7)*	*0.92 (0.87 - 0.98)*	*0.007*
% liver						**0.830**			***0.004***
No hydatid	14.8 (3.8)	n/a		12.9 (4.3)	Ref		21.5 (8.1)	Ref	
<10%	14.6 (3.9)	n/a		13.1 (4.5)	1.01 (0.96 - 1.05)	0.722	18.2 (6.5)	*0.91 (0.85 - 0.97)*	*0.002*
10-20%	12.0 (4.2)	n/a		14.1 (3.9)	1.10 (0.89 - 1.37)	0.386	25.0 (8.3)	1.17 (0.92 - 1.48)	0.208
>20%	n/a	n/a		14.0 (n/a)	1.03 (0.56 - 1.92)	0.914	n/a	n/a	
Chronicity						**0.400**			**0.099**
No hydatid	14.8 (3.8)	n/a		12.9 (4.3)	Ref		21.5 (8.1)	Ref	
Mostly cystic	12.3 (3.1)	n/a		13.6 (4.4)	1.05 (0.99 - 1.12)	0.131	18.3 (6.0)	0.93 (0.86 - 1.01)	0.071
Mostly calcified	15.2 (2.5)	n/a		12.5 (4.6)	0.94 (0.83 - 1.07)	0.382	20.4 (9.2)	0.96 (0.81 - 1.14)	0.632
Mixed	15.3 (4.8)	n/a		13.6 (4.7)	1.02 (0.93 - 1.12)	0.671	19.3 (7.5)	0.90 (0.78 - 1.05)	0.183

Unknown	14.6 (4.8)	n/a		12.1 (4.1)	0.96 (0.87 - 1.05)	0.378	17.7 (6.6)	0.89 (0.78 - 1.02)	0.089
Fluke									
Presence			**0.273**						
No	14.8 (3.8)	Ref		12.9 (4.3)	n/a		21.3 (8.1)	n/a	
Yes	15.0 (3.5)	1.03 (0.98 - 1.08)	0.273	13.9 (4.2)	n/a		23.1 (8.1)	n/a	
Bile ducts			**0.402**						
No fluke	14.8 (3.8)	Ref		12.9 (4.3)	n/a		21.3 (8.1)	n/a	
No obvious thickening	15.4 (3.4)	1.06 (0.97 - 1.15)	0.199	13.3 (2.4)	n/a		22.1 (7.2)	n/a	
Obvious thickening	14.8 (3.5)	1.02 (0.96 - 1.08)	0.594	14.2 (5.1)	n/a		24.1 (9.1)	n/a	

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[E] From models with log transformed outcomes the exponentiated coefficient for a category of a variable represents the ratio of the expected geometric mean P8 fat for that category of each variable of interest relative to that of the reference category.

Table 42: Descriptive statistics for P8 fat by fibrosis, fibrosis type, adhesion and melanosis for each carcase type. Associations between fibrosis, fibrosis type, adhesion and melanosis and P8 fat for each carcase type.

Defect	Angus[B]			Mixed breed[C]			Wagyu[D]		
	Observed mean (s.d.)	Exponentiated coefficient[E]	p-value	Observed mean (s.d.)	Exponentiated coefficient[E]	p-value	Observed mean (s.d.)	Exponentiated coefficient[E]	p-value
Fibrosis									
Presence			**0.147**			**0.809**			**0.164**
No	14.8 (3.8)	Ref		12.9 (4.4)	Ref		21.4 (8.1)	Ref	
Yes	15.0 (3.7)	1.02 (0.99 - 1.04)	0.147	12.9 (4.2)	1.00 (0.98 - 1.02)	0.809	21.2 (8.1)	1.02 (0.99 - 1.05)	0.164
Type			**0.528**			**0.596**			**0.235**
No fibrosis	14.8 (3.8)	Ref		12.9 (4.4)	Ref		21.4 (8.1)	Ref	
Stellate	15.0 (3.8)	1.02 (0.99 - 1.05)	0.166	12.9 (4.2)	1.00 (0.98 - 1.02)	0.813	21.1 (8.0)	1.03 (1.00 - 1.06)	0.089
Capsular	14.8 (2.8)	1.01 (0.94 - 1.09)	0.761	12.8 (4.3)	0.98 (0.93 - 1.04)	0.507	20.3 (7.7)	0.96 (0.89 - 1.04)	0.348
Parenchymal	14.9 (3.7)	1.02 (0.96 - 1.09)	0.527	13.2 (4.1)	1.04 (0.97 - 1.11)	0.244	22.9 (9.6)	1.02 (0.95 - 1.11)	0.543
Adhesion									

Presence			**0.580**			**0.593**			**0.409**
No	14.8 (3.8)	Ref		12.9 (4.3)	Ref		21.4 (8.1)	Ref	
Yes	14.5 (3.3)	0.99 (0.93 - 1.04)	0.580	13.1 (4.1)	1.02 (0.96 - 1.07)	0.593	20.9 (8.0)	0.97 (0.90 - 1.04)	0.409
Melanosis									
Presence			**0.453**			**0.338**			**0.485**
No	14.8 (3.8)	Ref		12.8 (4.3)	Ref		21.4 (8.1)	Ref	
Yes	14.9 (3.5)	1.02 (0.97 - 1.06)	0.453	13.2 (4.3)	1.02 (0.98 - 1.05)	0.338	21.0 (6.9)	1.02 (0.97 - 1.07)	0.485

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[E] From models with log transformed outcomes the exponentiated coefficient for a category of a variable represents the ratio of the expected geometric mean P8 fat for that category of each variable of interest relative to that of the reference category.

4.3.6 Modelling analysis results – Rib fat

Sex, dentition and non-liver associated illness/injury were included as covariates in all models fitted to assess putative associations between presence/absence of abscess and abscess categories and rib fat. Breed was also included in the mixed breed and Wagyu analyses. Rib fat was log transformed prior to fitting as the outcome variable for Angus and mixed breed analyses as residuals from preliminary analyses using the untransformed variable were right skewed. Consequently, the interpretation of the regression coefficient is different. The exponentiated coefficient for a category of a variable represents the ratio of the expected geometric mean rib fat for that category of each variable of interest relative to that of the reference category. Even with this transformation the residuals from the Angus analyses were not approximately normally distributed therefore results should be interpreted with caution.

Among mixed breed and Wagyu cattle, rib fat was greater in heifers compared to steers and those without a non-liver associated illness/injury compared to those with, but this pattern was not apparent in Angus cattle. Among Angus and Wagyu cattle, rib fat differed across dentition categories but among mixed breed cattle, there was no evidence of a strong pattern across dentition categories. Among mixed breed cattle, rib fat was lower in European/X and Tropical/X cattle compared to British/X cattle and among Wagyu cattle rib fat was higher in pure-bred compared to Wagyu X.

4.3.6.1 Abscess

4.3.6.1.1 Angus

Summary statistics for Angus cattle for rib fat by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and rib fat are shown in Table 43.

There was no evidence of a large difference in rib fat in Angus cattle based on presence/absence of abscess. However, rib fat was lower in cattle with adhered abscess (5% decrease [95%CI: 0 - 11]) compared to those without abscess.

4.3.6.1.2 Mixed breed

Summary statistics for mixed breed cattle for rib fat by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and rib fat are shown in Table 43.

There was no evidence of a large difference in rib fat in mixed breed cattle based on presence/absence of abscess. However, rib fat was lower in cattle with 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter (8% decrease [95%CI: 0 - 15]) compared to those without abscess and there was some evidence that rib fat was higher in cattle with chronic abscess (3% increase [95%CI: 0 - 6]) compared to those without. The effect estimate for mixed breed cattle with open abscess was very imprecise and extended far from the null, so no conclusion could be reached.

4.3.6.1.3 Wagyu

Summary statistics for Wagyu cattle for rib fat by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and rib fat are shown in Table 43.

There was no evidence of a large difference in rib fat in Wagyu cattle based on presence/absence of abscess or abscess categories.

4.3.6.2 Hydatid

4.3.6.2.1 Angus

Summary statistics for Angus cattle for rib fat by presence/absence of hydatid and by hydatid category are shown in Table 44. As only 22/2,366 (0.9%) Angus cattle had hydatid, no analyses assessing putative associations between hydatid and rib fat were conducted.

4.3.6.2.2 Mixed breed

Summary statistics for mixed breed cattle for rib fat by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and rib fat are shown in Table 44.

There was no evidence of a large difference in rib fat in mixed breed cattle based on presence/absence of hydatid. There was some evidence of reduced rib fat among cattle with unknown cyst status compared to those without hydatid (10% decrease [95%CI: 3 - 16]). The effect estimate for mixed breed cattle with > 20% liver affected was very imprecise and extended far from the null, so no conclusion could be reached.

4.3.6.2.3 Wagyu

Summary statistics for Wagyu breed cattle for rib fat by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and rib fat are shown in Table 44.

Rib fat was lower among cattle with hydatid compared to those without (-1.05 mm [95%CI: -1.75 – -0.34]). These findings were consistent when the analyses were restricted to both the 1,158 cattle in the 7 of 44 lots which had at least one animal with hydatid and the 2,022 cattle from 14 o of the 51 vendors which had at least one animal with hydatid.

4.3.6.3 Fluke

4.3.6.3.1 Angus

Summary statistics for Angus cattle for rib fat by presence/absence of fluke and by fluke category and associations between presence/absence of fluke and by fluke category and rib fat are shown in Table 44.

There was no evidence of a large difference in rib fat in Angus cattle based on presence/absence of fluke or bile duct category.

4.3.6.3.2 Mixed breed

Summary statistics for mixed breed cattle for P8 fat by presence/absence of fluke and by fluke category are shown in Table 44. As only 22/6,199 (0.4%) mixed breed cattle had fluke, no analyses assessing putative associations between fluke and rib fat were conducted.

4.3.6.3.3 Wagyu

Summary statistics for Wagyu cattle for P8 fat by presence/absence of fluke and by fluke category are shown in Table 44. As only 29/3,048 (1.0%) Wagyu cattle had fluke, no analyses assessing putative associations between fluke and rib fat were conducted.

4.3.6.4 Fibrosis

4.3.6.4.1 Angus

Summary statistics for Angus cattle for rib fat by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and rib fat are shown in Table 45.

There was no evidence of a large difference in rib fat in Angus breed cattle based on presence/absence of fibrosis/fibrosis type.

4.3.6.4.2 Mixed breed

Summary statistics for mixed breed cattle for rib fat by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and rib fat are shown in Table 45.

There was no evidence of a large difference in rib fat in mixed breed cattle based on presence/absence of fibrosis/fibrosis type.

4.3.6.4.3 Wagyu

Summary statistics for Wagyu cattle for rib fat by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and rib fat are shown in Table 45.

Rib fat was higher among cattle with fibrosis (0.4 mm [95%CI: 0.06 – 0.73]) compared to those without and there was some evidence that it was higher in those with stellate fibrosis (0.42 mm [95%CI: 0.05–0.79]) compared to those without.

4.3.6.5 Adhesion

4.3.6.5.1 Angus

Summary statistics for Angus cattle for rib fat by presence/absence of adhesion and associations between presence/absence of fibrosis and by fibrosis type and rib fat are shown in Table 45.

There was no evidence of a large difference in rib fat in Angus cattle based on presence/absence of adhesion.

4.3.6.5.2 Mixed breed

Summary statistics for mixed breed cattle for rib fat by presence/absence of adhesion and associations between presence/absence of fibrosis and by fibrosis type and rib fat are shown in Table 45.

There was some evidence that rib fat was higher in those with adhesion (4% increase [95%CI: 0 - 9]) compared to those without.

4.3.6.5.3 Wagyu

Summary statistics for Wagyu cattle for rib fat by presence/absence of adhesion and associations between presence/absence of fibrosis and by fibrosis type and rib fat are shown in Table 45.

There was no evidence of a large difference in rib fat in Wagyu cattle based on presence/absence of adhesion.

4.3.6.6 Melanosis

4.3.6.6.1 Angus

Summary statistics for Angus cattle for rib fat by presence/absence of melanosis and associations between presence/absence of fibrosis and by fibrosis type and rib fat are shown in Table 45.

There was no evidence of a large difference in rib fat in Angus cattle based on presence/absence of melanosis.

4.3.6.6.2 Mixed breed

Summary statistics for mixed breed cattle for rib fat by presence/absence of melanosis and associations between presence/absence of fibrosis and by fibrosis type and rib fat are shown in Table 45.

There was no evidence of a large difference in rib fat in mixed breed cattle based on presence/absence of melanosis.

4.3.6.6.3 Wagyu

Summary statistics for Wagyu cattle for rib fat by presence/absence of melanosis and associations between presence/absence of fibrosis and by fibrosis type and rib fat are shown in Table 45.

There was no evidence of a large difference in rib fat in Wagyu cattle based on presence/absence of melanosis.

Table 43: Descriptive statistics for rib fat by abscess and associated categories for each carcase type. Associations between abscess and abscess categories and rib fat by carcase type.

Abscess	Angus^{B}			Mixed breed^{C}			Wagyu^{D}		
	Observed mean (s.d.)	Exponentiated Coefficient^{E}	p-value	Observed mean (s.d.)	Exponentiated Coefficient^{E}	p-value	Observed mean (s.d.)	Coefficient	p-value
Presence			**0.755**			**0.254**			**0.287**
No abscess	12.7 (3.0)	Ref		10.1 (2.6)	Ref		19.3 (4.0)	Ref	
Abscess	12.6 (3.0)	1.00 (0.97 - 1.02)	0.755	10.4 (2.8)	1.01 (0.99 - 1.04)	0.254	20.1 (4.2)	0.30 (-0.25 - 0.86)	0.287
Adhered			**0.121**			**0.384**			**0.442**
No abscess	12.7 (3.0)	Ref		10.1 (2.6)	Ref		19.3 (4.0)	Ref	
No	12.8 (3.0)	1.01 (0.98 - 1.05)	0.499	10.5 (2.9)	1.02 (0.99 - 1.05)	0.169	20.0 (3.9)	0.17 (-0.50 - 0.84)	0.617
Yes	12.0 (3.2)	0.95 (0.89 - 1.00)	0.057	10.1 (2.4)	1.00 (0.95 - 1.05)	0.931	20.3 (4.7)	0.58 (-0.37 - 1.54)	0.232
% liver			**0.831**			**0.276**			**0.757**
No abscess	12.7 (3.0)	Ref		10.1 (2.6)	Ref		19.3 (4.0)	Ref	
<10%	12.6 (2.9)	1.01 (0.98 - 1.05)	0.508	10.5 (2.7)	1.03 (1.00 - 1.06)	0.065	20.0 (4.2)	0.27 (-0.41 - 0.95)	0.443
10-20%	12.6 (3.3)	1.02 (0.96 - 1.08)	0.546	10.3 (3.0)	0.99 (0.94 - 1.04)	0.622	20.2 (4.3)	0.40 (-0.64 - 1.44)	0.448
>20%	12.4 (3.0)	1.02 (0.92 - 1.13)	0.726	10.1 (2.8)	0.98 (0.91 - 1.07)	0.711	19.9 (4.2)	0.26 (-1.59 - 2.11)	0.782
Size/number^{A}			**0.215**			***0.051***			**0.560**
No abscess	12.7 (3.0)	Ref		10.1 (2.6)	Ref		19.3 (4.0)	Ref	
A	12.3 (3.0)	0.98 (0.93 - 1.02)	0.290	10.5 (2.8)	1.03 (0.99 - 1.07)	0.122	20.4 (4.5)	0.60 (-0.25 - 1.45)	0.170
B	13.0 (3.1)	1.02 (0.98 - 1.07)	0.248	10.4 (2.6)	1.02 (0.98 - 1.06)	0.265	20.0 (3.9)	0.15 (-0.60 - 0.90)	0.697
C	12.0 (2.9)	0.95 (0.88 - 1.02)	0.175	*9.7 (3.3)*	*0.92 (0.85 - 1.00)*	*0.043*	19.1 (4.3)	-0.24 (-2.22 - 1.74)	0.814
Open			**0.911**			**0.358**			**0.564**
No abscess	12.7 (3.0)	Ref		10.1 (2.6)	Ref		19.3 (4.0)	Ref	
No	12.6 (3.0)	1.00 (0.97 - 1.03)	0.826	10.4 (2.8)	1.01 (0.99 - 1.04)	0.327	20.1 (4.1)	0.31 (-0.26 - 0.88)	0.289
Yes	12.6 (3.2)	0.98 (0.89 - 1.08)	0.706	10.6 (2.5)	1.08 (0.94 - 1.24)	0.291	19.7 (5.2)	0.18 (-1.95 - 2.32)	0.865
Postcaval			**0.681**			**0.451**			**0.500**
No abscess	12.7 (3.0)	Ref		10.1 (2.6)	Ref		19.3 (4.0)	Ref	
No	12.6 (2.9)	1.00 (0.97 - 1.04)	0.904	10.4 (2.8)	1.02 (0.99 - 1.05)	0.207	20.2 (4.2)	0.38 (-0.25 - 1.00)	0.240
Yes	12.5 (3.4)	0.98 (0.92 - 1.03)	0.390	10.4 (2.8)	1.00 (0.95 - 1.06)	0.974	19.5 (4.1)	0.05 (-1.08 - 1.18)	0.929
Chronicity			**0.898**			**0.333**			**0.754**
No abscess	12.7 (3.0)	Ref		10.1 (2.6)	Ref		19.3 (4.0)	Ref	

Acute	12.9 (2.4)	1.03 (0.89 - 1.20)	0.693	10.1 (2.8)	1.02 (0.88 - 1.19)	0.784	21.0 (6.7)	0.63 (-2.39 - 3.65)	0.682
Chronic	12.6 (3.2)	1.00 (0.96 - 1.03)	0.891	10.5 (2.7)	1.03 (1.00 - 1.06)	0.099	20.2 (4.1)	0.31 (-0.35 - 0.98)	0.351
Mixed	12.5 (2.9)	0.98 (0.94 - 1.03)	0.517	10.2 (3.0)	0.98 (0.94 - 1.03)	0.471	19.8 (4.1)	0.24 (-0.78 - 1.25)	0.649

[A] A: 4 or fewer abscesses 2-4cm in diameter, B: 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter, C: 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter.

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[E] From models with log transformed outcomes the exponentiated coefficient for a category of a variable represents the ratio of the expected geometric mean rib fat for that category of each variable of interest relative to that of the reference category.

Table 44: Descriptive statistics for rib fat by hydatid, fluke and associated categories for each carcase type. Associations between hydatid and associated categories and rib fat for Angus and associations between fluke and fluke bile duct status and rib fat for mixed breed and Wagyu.

Defect	Angus[B]			Mixed breed[C]			Wagyu[D]		
	Observed mean (s.d.)	Exponentiated coefficient[E]	p-value	Observed mean (s.d.)	Exponentiated coefficient[E]	p-value	Observed mean (s.d.)	Coefficient	p-value
Hydatid									
Presence						**0.627**			**0.004**
No	12.7 (3.0)	n/a		10.1 (2.6)	Ref		19.4 (4.0)	Ref	
Yes	13.0 (3.5)	n/a		10.0 (2.6)	0.99 (0.96 - 1.03)	0.627	17.9 (3.8)	-1.05 (-1.75 - -0.34)	0.004
% liver						**0.126**			**0.013**
No hydatid	12.7 (3.0)	n/a		10.1 (2.6)	Ref		19.4 (4.0)	Ref	
<10%	13.2 (3.4)	n/a		9.9 (2.6)	0.98 (0.95 - 1.02)	0.369	17.9 (3.9)	-1.00 (-1.73 - -0.28)	0.007
10-20%	11.5 (4.9)	n/a		11.8 (2.8)	1.14 (0.96 - 1.35)	0.145	17.6 (2.4)	-1.73 (-4.53 - 1.07)	0.225
>20%	n/a	n/a		15.0 (n/a)	1.51 (0.93 - 2.46)	0.097	n/a	n/a	
Chronicity						**0.030**			**0.028**
No hydatid	12.7 (3.0)	n/a		10.1 (2.6)	Ref		19.4 (4.0)	Ref	
Mostly cystic	11.2 (2.9)	n/a		10.5 (2.7)	1.04 (0.99 - 1.10)	0.108	18.1 (3.8)	-0.62 (-1.57 - 0.33)	0.199
Mostly calcified	15.6 (3.8)	n/a		10.0 (3.0)	1.00 (0.90 - 1.11)	0.993	17.1 (3.7)	*-2.27 (-4.25 - -0.29)*	*0.025*
Mixed	12.7 (2.4)	n/a		9.9 (2.5)	0.98 (0.91 - 1.05)	0.496	17.7 (4.7)	-1.25 (-3.00 - 0.51)	0.164

Unknown	13.0 (4.1)	n/a		9.2 (2.4)	0.90 (0.84 - 0.97)	0.006	17.8 (3.2)	-1.30 (-2.85 - 0.25)	0.100
Fluke									
Presence			**0.542**						
No	12.6 (3.0)	Ref		10.1 (2.6)	n/a		19.4 (4.0)	n/a	
Yes	12.7 (2.5)	1.01 (0.97 - 1.06)	0.542	11.2 (2.8)	n/a		19.4 (3.6)	n/a	
Bile ducts			**0.528**						
No fluke	12.6 (3.0)	Ref		10.1 (2.6)	n/a		19.4 (4.0)	n/a	
No obvious thickening	13.1 (2.4)	1.05 (0.97 - 1.13)	0.260	11.0 (2.7)	n/a		20.1 (3.6)	n/a	
Obvious thickening	12.6 (2.6)	1.00 (0.95 - 1.06)	0.982	11.4 (3.0)	n/a		18.7 (3.5)	n/a	

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[E] From models with log transformed outcomes the exponentiated coefficient for a category of a variable represents the ratio of the expected geometric mean rib fat for that category of each variable of interest relative to that of the reference category.

Table 45: Descriptive statistics for rib fat by fibrosis, fibrosis type, adhesion and melanosis for each carcase type. Associations between fibrosis, fibrosis type, adhesion and melanosis and rib fat for each carcase type.

Defect	Angus[B]			Mixed breed[C]			Wagyu[D]		
	Observed mean (s.d.)	Exponentiated coefficient[E]	p-value	Observed mean (s.d.)	Exponentiated coefficient[E]	p-value	Observed mean (s.d.)	Coefficient	p-value
Fibrosis									
Presence			**0.440**			**0.297**			***0.021***
No	12.7 (3.0)	Ref		10.1 (2.7)	Ref		19.3 (4.0)	Ref	
Yes	12.5 (2.9)	0.99 (0.97 - 1.01)	0.440	10.0 (2.6)	0.99 (0.98 - 1.01)	0.297	*19.5 (3.9)*	*0.40 (0.06 - 0.73)*	*0.020*
Type			**0.681**			**0.294**			**0.140**
No fibrosis	12.7 (3.0)	Ref		10.1 (2.7)	Ref		19.3 (4.0)	Ref	
Stellate	12.6 (2.9)	0.99 (0.97 - 1.02)	0.595	10.0 (2.6)	0.99 (0.97 - 1.00)	0.152	*19.5 (3.9)*	*0.42 (0.05 - 0.79)*	*0.025*
Capsular	12.3 (2.9)	0.96 (0.90 - 1.03)	0.260	10.4 (2.8)	1.02 (0.98 - 1.07)	0.292	19.7 (4.0)	0.31 (-0.64 - 1.27)	0.520
Parenchymal	12.7 (2.6)	1.00 (0.94 - 1.07)	0.913	10.3 (2.6)	1.01 (0.96 - 1.06)	0.680	19.7 (3.7)	0.29 (-0.61 - 1.20)	0.526
Adhesion									

Presence			**0.852**			**0.073**			**0.852**
No	12.7 (3.0)	Ref		10.1 (2.6)	Ref		19.4 (4.0)	Ref	
Yes	12.6 (2.7)	1.00 (0.96 - 1.06)	0.852	10.6 (2.7)	1.04 (1.00 - 1.09)	0.073	19.6 (4.3)	0.08 (-0.76 - 0.93)	0.852
Melanosis									
Presence			**0.230**			**0.423**			**0.331**
No	12.6 (3.0)	Ref		10.1 (2.7)	Ref		19.4 (4.0)	Ref	
Yes	12.9 (3.0)	1.03 (0.98 - 1.07)	0.230	10.0 (2.6)	0.99 (0.97 - 1.02)	0.423	19.5 (3.9)	0.31 (-0.31 - 0.93)	0.331

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[E] From models with log transformed outcomes the exponentiated coefficient for a category of a variable represents the ratio of the expected geometric mean rib fat for that category of each variable of interest relative to that of the reference category.

4.3.7 Modelling analysis results – Eye muscle area

Sex, dentition and non-liver associated illness/injury were included as covariates in all models fitted to assess putative associations between presence/absence of abscess and abscess categories and eye muscle area (EMA). Breed was also included in the mixed breed and Wagyu analyses. Residuals from the Angus analyses were not approximately normally distributed and log transforming did not result in an improved distribution, therefore results should be interpreted with caution.

Among Angus and mixed breed cattle, there was no strong evidence of a difference in EMA between heifers and steers, or between those with and without a non-liver associated illness/injury. However, among Wagyu cattle, EMA was lower in steers compared to heifers and among those with a non-liver associated illness/injury compared to those without. Among mixed breed cattle, EMA was lower in 6 and 8-tooth cattle compared to 0-tooth. Among Angus and Wagyu cattle, estimates for different dentition categories were imprecise so no conclusion could be reached. Among mixed breed cattle, EMA was higher in European/X cattle and lower in Tropical/X cattle compared to British/X cattle but among Wagyu cattle there was no evidence of a large difference in EMA between pure-bred and Wagyu X.

4.3.7.1 Abscess

4.3.7.1.1 Angus

Summary statistics for Angus cattle for EMA by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and EMA are shown in Table 46.

There was no evidence of a large difference in EMA in Angus cattle based on presence/absence of abscess. There was some evidence of reduced EMA among cattle with adhered abscess (-1.49 cm^2 [95%CI: -3.02 – 0.05]) and was increased in those with acute abscess (3.78 cm^2 [95%CI: -0.27 – 7.83]) compared to those without abscess.

4.3.7.1.2 Mixed breed

Summary statistics for mixed breed cattle for EMA by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and EMA are shown in Table 46.

There was no evidence of a large difference in EMA in mixed breed cattle based on presence/absence of abscess or abscess categories.

4.3.7.1.3 Wagyu

Summary statistics for Wagyu cattle for EMA by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and EMA are shown in Table 46.

There was no evidence of a large difference in EMA in Wagyu breed cattle based on presence/absence of abscess or most abscess categories. The effect estimates for Wagyu cattle with 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter or open abscess were very imprecise and extended far from the null, so no conclusion could be reached.

4.3.7.2 Hydatid

4.3.7.2.1 Angus

Summary statistics for Angus cattle for EMA by presence/absence of hydatid and by hydatid category are shown in Table 47. As only 22/2,366 (0.9%) Angus cattle had hydatid, no analyses assessing putative associations between hydatid and EMA were conducted.

4.3.7.2.2 Mixed breed

Summary statistics for mixed breed cattle for EMA by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and EMA are shown in Table 47.

There was no evidence of a large difference in EMA in mixed breed cattle based on presence/absence of hydatid or hydatid category.

4.3.7.2.3 Wagyu

Summary statistics for Wagyu cattle for EMA by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and EMA are shown in Table 47.

There was no evidence of a large difference in EMA in Wagyu cattle based on presence/absence of hydatid or most hydatid categories. The effect estimates for Wagyu cattle with 10 – 20% liver affected and mostly calcified cyst status were very imprecise and extended far from the null, so no conclusion could be reached.

4.3.7.3 Fluke

4.3.7.3.1 Angus

Summary statistics for Angus cattle for EMA by presence/absence of fluke and by fluke category and associations between presence/absence of fluke and by fluke category and EMA are shown in **Error! Reference source not found.**.

There was no evidence of a large difference in EMA in Angus cattle based on presence/absence of fluke or bile duct category.

4.3.7.3.2 Mixed breed

Summary statistics for mixed breed cattle for EMA by presence/absence of fluke and by fluke category are shown in Table 47. As only 22/6,199 (0.4%) mixed breed cattle had fluke, no analyses assessing putative associations between fluke and EMA were conducted.

4.3.7.3.3 Wagyu

Summary statistics for Wagyu cattle for EMA by presence/absence of fluke and by fluke category are shown in Table 47. As only 29/3,048 (1.0%) Wagyu cattle had fluke, no analyses assessing putative associations between fluke and EMA were conducted.

4.3.7.4 Fibrosis

4.3.7.4.1 Angus

Summary statistics for Angus cattle for EMA by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and EMA are shown in Table 48.

There was no evidence of a large difference in EMA in Angus cattle based on presence/absence of fibrosis or fibrosis type.

4.3.7.4.2 Mixed breed

Summary statistics for mixed breed cattle for EMA by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and EMA are shown in Table 48.

There was no evidence of a large difference in EMA in mixed breed cattle based on presence/absence of fibrosis or fibrosis type.

4.3.7.4.3 Wagyu

Summary statistics for Wagyu cattle for EMA by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and EMA are shown in Table 48.

There was some evidence that EMA was higher among cattle with fibrosis compared to those without (0.6 cm^2 [95%CI: 0.0 – 1.3])

4.3.7.5 Adhesion

4.3.7.5.1 Angus

Summary statistics for Angus cattle for EMA by presence/absence of adhesion and associations between presence/absence of fibrosis and by fibrosis type and EMA are shown in Table 48.

There was no evidence of a large difference in EMA in Angus cattle based on presence/absence of adhesion.

4.3.7.5.2 Mixed breed

Summary statistics for mixed breed cattle for EMA by presence/absence of adhesion and associations between presence/absence of fibrosis and by fibrosis type and EMA are shown in Table 48.

There was no evidence of a large difference in EMA in mixed breed cattle based on presence/absence of adhesion.

4.3.7.5.3 Wagyu

Summary statistics for Wagyu cattle for EMA by presence/absence of adhesion and associations between presence/absence of fibrosis and by fibrosis type and EMA are shown in Table 48.

There was no evidence of a large difference in EMA in Wagyu cattle based on presence/absence of adhesion.

4.3.7.6 Melanosis

4.3.7.6.1 Angus

Summary statistics for Angus cattle for EMA by presence/absence of melanosis and associations between presence/absence of fibrosis and by fibrosis type and EMA are shown in Table 48.

There was no evidence of a large difference in EMA in Angus cattle based on presence/absence of melanosis.

4.3.7.6.2 Mixed breed

Summary statistics for mixed breed cattle for EMA by presence/absence of melanosis and associations between presence/absence of fibrosis and by fibrosis type and EMA are shown in Table 48.

There was no evidence of a large difference in EMA in mixed breed cattle based on presence/absence of adhesion.

4.3.7.6.3 Wagyu

Summary statistics for Wagyu cattle for EMA by presence/absence of melanosis and associations between presence/absence of fibrosis and by fibrosis type and EMA are shown Table 48.

EMA was higher among cattle with melanosis compared to those without (1.7 cm^2 [95%CI: 0.5 – 2.9]).

Table 46: Descriptive statistics for eye muscle area by abscess and associated categories for each carcase type. Associations between abscess and abscess categories and eye muscle area by carcase type.

Abscess	Angus^B			Mixed breed^C			Wagyu^D		
	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Presence			**0.485**			**0.520**			**0.783**
No abscess	79.3 (6.7)	Ref		78.2 (6.2)	Ref		92.1 (7.7)	Ref	
Abscess	79.0 (6.4)	-0.28 (-1.08 - 0.51)	0.485	77.9 (6.2)	-0.19 (-0.77 - 0.39)	0.519	93.3 (7.9)	0.15 (-0.94 - 1.24)	0.783
Adhered			**0.155**			**0.743**			**0.849**
No abscess	79.3 (6.7)	Ref		78.2 (6.2)	Ref		92.1 (7.7)	Ref	
No	79.4 (5.9)	0.10 (-0.80 - 1.00)	0.822	77.8 (6.1)	-0.26 (-0.92 - 0.40)	0.442	93.0 (8.2)	-0.03 (-1.33 - 1.27)	0.964
Yes	77.9 (7.7)	-1.49 (-3.02 - 0.05)	0.057	78.3 (6.6)	0.02 (-1.11 - 1.15)	0.974	94.1 (7.3)	0.54 (-1.33 - 2.41)	0.570
% liver			**0.656**			**0.811**			**0.656**
No abscess	79.3 (6.7)	Ref		78.2 (6.2)	Ref		92.1 (7.7)	Ref	
<10%	79.4 (6.0)	0.52 (-0.81 - 1.85)	0.442	78.1 (6.1)	-0.13 (-0.83 - 0.57)	0.718	93.6 (7.7)	0.52 (-0.81 - 1.85)	0.441
10-20%	78.4 (6.7)	-0.14 (-2.17 - 1.89)	0.895	77.5 (6.5)	-0.50 (-1.62 - 0.62)	0.380	93.2 (8.2)	-0.14 (-2.17 - 1.89)	0.894
>20%	78.6 (7.2)	-1.81 (-5.43 - 1.81)	0.327	77.8 (6.8)	0.26 (-1.68 - 2.19)	0.794	91.8 (8.9)	-1.81 (-5.44 - 1.81)	0.327
Size/number^A			**0.396**			**0.444**			**0.509**
No abscess	79.3 (6.7)	Ref		78.2 (6.2)	Ref		92.1 (7.7)	Ref	
A	79.0 (6.3)	-0.30 (-1.52 - 0.93)	0.634	78.2 (6.3)	0.01 (-0.86 - 0.87)	0.987	93.5 (6.9)	0.31 (-1.36 - 1.97)	0.719
B	79.5 (6.4)	0.12 (-0.99 - 1.22)	0.835	78.1 (6.2)	-0.11 (-0.93 - 0.72)	0.796	93.6 (8.6)	0.43 (-1.05 - 1.90)	0.568
C	77.4 (6.3)	-1.76 (-3.85 - 0.34)	0.100	75.9 (5.9)	-1.49 (-3.30 - 0.31)	0.106	90.6 (7.8)	-2.68 (-6.56 - 1.20)	0.175
Open			**0.288**			**0.803**			**0.451**
No abscess	79.3 (6.7)	Ref		78.2 (6.2)	Ref		92.1 (7.7)	Ref	
No	78.8 (6.4)	-0.44 (-1.27 - 0.38)	0.292	78.0 (6.2)	-0.18 (-0.77 - 0.41)	0.542	93.2 (8.1)	-0.02 (-1.14 - 1.11)	0.978
Yes	81.7 (5.0)	1.58 (-1.12 - 4.27)	0.251	75.3 (6.3)	-0.45 (-3.71 - 2.81)	0.788	95.8 (4.0)	2.69 (-1.49 - 6.87)	0.207
Postcaval			**0.733**			**0.806**			**0.913**
No abscess	79.3 (6.7)	Ref		78.2 (6.2)	Ref		92.1 (7.7)	Ref	
No	78.9 (6.5)	-0.36 (-1.27 - 0.54)	0.430	77.9 (6.1)	-0.21 (-0.85 - 0.43)	0.524	93.2 (7.5)	0.06 (-1.17 - 1.29)	0.924
Yes	79.3 (5.9)	-0.05 (-1.54 - 1.45)	0.952	78.1 (7.0)	-0.12 (-1.40 - 1.17)	0.858	93.6 (9.2)	0.47 (-1.74 - 2.68)	0.675
Chronicity			**0.193**			**0.593**			**0.697**
No abscess	79.3 (6.7)	Ref		78.2 (6.2)	Ref		92.1 (7.7)	Ref	

Acute	83.6 (4.1)	3.78 (-0.27 - 7.83)	0.067	79.5 (5.7)	1.51 (-2.05 - 5.06)	0.406	96.8 (7.8)	3.52 (-2.39 - 9.42)	0.243
Chronic	78.8 (6.7)	-0.48 (-1.47 - 0.51)	0.341	78.0 (6.4)	-0.14 (-0.86 - 0.58)	0.698	92.8 (7.6)	-0.05 (-1.34 - 1.25)	0.945
Mixed	78.9 (5.8)	-0.43 (-1.71 - 0.84)	0.506	77.3 (6.0)	-0.53 (-1.54 - 0.47)	0.300	94.1 (8.5)	0.27 (-1.71 - 2.25)	0.789

[A] A: 4 or fewer abscesses 2-4cm in diameter, B: 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter, C: 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter.

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

Table 47: Descriptive statistics for eye muscle area by hydatid, fluke and associated categories for each carcase type. Associations between hydatid and associated categories and eye muscle area for Angus and associations between fluke and fluke bile duct status and eye muscle area for mixed breed and Wagyu.

Defect	Angus[B]			Mixed breed[C]			Wagyu[D]		
	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Hydatid									
Presence						**0.687**			**0.196**
No	79.3 (6.6)	n/a		78.2 (6.2)	Ref		92.2 (7.7)	Ref	
Yes	80.0 (6.0)	n/a		77.9 (5.8)	-0.2 (-1.0 - 0.6)	0.687	90.2 (7.8)	-0.9 (-2.3 - 0.5)	0.196
% liver						**0.870**			**0.289**
No hydatid	79.3 (6.6)	n/a		78.2 (6.2)	Ref		92.2 (7.7)	Ref	
<10%	80.6 (5.8)	n/a		77.9 (5.9)	-0.1 (-0.9 - 0.7)	0.807	90.3 (8.0)	-0.8 (-2.2 - 0.7)	0.296
10-20%	75.0 (7.1)	n/a		78.1 (4.5)	-1.5 (-5.5 - 2.4)	0.445	87.9 (5.0)	-3.3 (-8.8 - 2.1)	0.232
>20%	n/a	n/a		75.0 (n/a)	-1.6 (-12.8 - 9.7)	0.785	n/a	n/a	
Chronicity						**0.906**			**0.320**
No hydatid	79.3 (6.6)	n/a		78.2 (6.2)	Ref		92.2 (7.7)	Ref	
Mostly cystic	80.5 (6.8)	n/a		77.4 (5.8)	-0.5 (-1.7 - 0.7)	0.396	89.5 (8.9)	-1.5 (-3.4 - 0.4)	0.113
Mostly calcified	78.8 (3.9)	n/a		77.6 (5.4)	-0.4 (-2.7 - 2.0)	0.745	88.6 (6.1)	-2.7 (-6.6 - 1.2)	0.171
Mixed	78.2 (4.6)	n/a		78.9 (6.9)	0.3 (-1.3 - 2.0)	0.689	92.0 (6.3)	0.7 (-2.8 - 4.1)	0.709
Unknown	83.0 (8.2)	n/a		78.3 (4.8)	0.2 (-1.6 - 1.9)	0.859	91.5 (6.5)	0.6 (-2.4 - 3.7)	0.695

Fluke									
Presence			**0.987**						
No	79.2 (6.6)	Ref		78.2 (6.2)	n/a		92.1 (7.7)	n/a	
Yes	80.0 (6.2)	0.0 (-1.3 - 1.3)	0.987	78.7 (6.8)	n/a		93.3 (8.7)	n/a	
Bile ducts			**0.700**						
No fluke	79.2 (6.6)	Ref		78.2 (6.2)	n/a		92.1 (7.7)	n/a	
No obvious thickening	81.2 (5.1)	0.7 (-1.4 - 2.9)	0.502	83.0 (4.6)	n/a		91.1 (6.3)	n/a	
Obvious thickening	79.4 (6.6)	-0.3 (-1.8 - 1.2)	0.655	76.3 (6.7)	n/a		95.6 (10.6)	n/a	

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

Table 48: Descriptive statistics for eye muscle area by fibrosis, fibrosis type, adhesion and melanosis for each carcase type. Associations between fibrosis, fibrosis type, adhesion and melanosis and eye muscle area for each carcase type.

Defect	Angus[B]			Mixed breed[C]				Wagyu[D]	
	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Fibrosis									
Presence			**0.998**			**0.543**			***0.056***
No	79.3 (6.6)	Ref		78.3 (6.2)	Ref		92.1 (7.7)	Ref	
Yes	79.1 (6.5)	0.0 (-0.7 - 0.7)	0.998	78.0 (6.2)	-0.1 (-0.4 - 0.2)	0.543	*92.5 (7.8)*	*0.6 (0.0 - 1.3)*	*0.056*
Type			**0.989**			**0.553**			**0.202**
No fibrosis	79.3 (6.6)	Ref		78.3 (6.2)	Ref		92.1 (7.7)	Ref	
Stellate	79.1 (6.5)	0.0 (-0.7 - 0.7)	0.948	77.9 (6.2)	-0.2 (-0.5 - 0.2)	0.335	92.4 (7.9)	0.7 (0.0 - 1.4)	0.061
Capsular	79.2 (6.9)	-0.3 (-2.1 - 1.6)	0.780	78.2 (6.2)	0.3 (-0.7 - 1.3)	0.577	93.2 (8.1)	1.1 (-0.8 - 3.0)	0.259
Parenchymal	79.4 (6.5)	0.2 (-1.5 - 1.9)	0.851	78.5 (5.2)	0.5 (-0.7 - 1.6)	0.423	92.7 (7.5)	-0.1 (-1.9 - 1.7)	0.899
Adhesions									
Presence			**0.541**			**0.173**			**0.810**
No	79.3 (6.6)	Ref		78.2 (6.1)	Ref		92.1 (7.7)	Ref	
Yes	79.1 (6.5)	-0.4 (-1.8 - 0.9)	0.541	77.1 (7.2)	-0.7 (-1.7 - 0.3)	0.173	92.7 (6.5)	-0.2 (-1.9 - 1.5)	0.810

Melanosis									
Presence			**0.503**			**0.264**			***0.006***
No	79.3 (6.6)	Ref		78.2 (6.2)	Ref		92.1 (7.7)	Ref	
Yes	78.7 (7.2)	-0.4 (-1.5 - 0.8)	0.503	77.6 (5.8)	-0.3 (-0.9 - 0.3)	0.264	*93.9 (7.5)*	*1.7 (0.5 - 2.9)*	*0.006*

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

4.3.8 Modelling analysis results – Marbling

Sex, dentition and non-liver associated illness/injury were included as covariates in all models fitted to assess putative associations between presence/absence of abscess and abscess categories and marbling score being <2 / ≥ 2 in Angus cattle, <1 / ≥ 1 in mixed breed cattle and <5 / ≥ 5 among Wagyu cattle. Breed was also included in the mixed breed and Wagyu analyses.

Among Angus cattle the marbling score was more likely to be ≥ 2 in those without compared to those with a non-liver associated illness/injury and there was an indication that it might be more likely to be ≥ 2 in heifers compared to steers.

Among mixed breed cattle the marbling score was more likely to be ≥ 1 in British/X compared to European/X or Tropical/X cattle and those without compared to those with a non-liver associated illness/injury. The marbling score was more likely to be ≥ 1 in 4-tooth compared to 0-tooth cattle. There was an indication that it might be more likely to be ≥ 1 in heifers compared to steers.

Among Wagyu cattle the marbling score was more likely to be ≥ 5 in pure-bred compared to Wagyu/X cattle and heifers rather than steers. The likelihood of marbling score being ≥ 5 increased with dentition category.

4.3.8.1 Abscess

4.3.8.1.1 Angus

Summary statistics for Angus cattle for marbling score < 2/ ≥ 2 by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and marbling score < 2/ ≥ 2are shown in Table 49.

There was no evidence of a large difference in likelihood of a marbling score < 2/ ≥ 2 in Angus cattle based on presence/absence of abscess. However, marbling score was less likely to be ≥ 2 in cattle with chronic abscess (odds ratio [OR]: 0.2 [95%CI: 0.1 – 0.8]) compared to those without abscess. The effect estimate for Angus cattle with open abscess was very imprecise and extended far from the null, so no conclusion could be reached.

4.3.8.1.2 Mixed breed

Summary statistics for mixed breed cattle for marbling score < 1/ ≥ 1 by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and marbling score < 1/ ≥ 1 are shown in Table 49.

There was no evidence of a large difference in likelihood of a marbling score < 1/ ≥ 1 in mixed breed cattle based on presence/absence of abscess. However, there was some evidence that marbling score was more likely to be ≥ 1 in cattle with postcaval abscess (OR: 2.0 [95%CI: 1.0 – 4.0]) compared to those without abscess.

4.3.8.1.3 Wagyu

Summary statistics for Wagyu cattle for marbling score < 5/ ≥ 5 by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and marbling score < 5/ ≥ 5 are shown in Table 49.

There was no evidence of a large difference in likelihood of a marbling score < 5/ ≥ 5 in Wagyu cattle based on presence/absence of abscess or most abscess categories. The effect estimate for Wagyu cattle with > 20% liver affected was very imprecise and extended far from the null, so no conclusion could be reached.

4.3.8.1 Hydatid

4.3.8.1.1 Angus

Summary statistics for Angus cattle for marbling score < 2/ ≥ 2 by presence/absence of hydatid and by hydatid category are shown in Table 50. As only 22/2,366 (0.9%) Angus cattle had hydatid, no analyses assessing putative associations between hydatid and marbling score were conducted.

4.3.8.1.2 Mixed breed

Summary statistics for mixed breed cattle for marbling score < 1/ ≥ 1 by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and marbling score < 1/ ≥ 1 are shown in Table 50.

There was no evidence of a large difference in likelihood of a marbling score < 1/ ≥ 1 in mixed breed cattle based on presence/absence of hydatid or most hydatid categories. The effect estimates for mixed breed cattle with < 10 and 10 – 20% liver affected were very imprecise and extended far from the null, so no conclusion could be reached.

4.3.8.1.3 Wagyu

Summary statistics for Wagyu cattle for marbling score < 5/ ≥ 5 by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and marbling score < 5/ ≥ 5 are shown in Table 50.

There was no evidence of a large difference in likelihood of a marbling score < 5/ ≥ 5 in Wagyu cattle based on presence/absence of hydatid or most hydatid categories. The effect estimate for Wagyu cattle with 10 - 20% liver affected was very imprecise and extended far from the null, so no conclusion could be reached.

4.3.8.2 Fluke

4.3.8.2.1 Angus

Summary statistics for Angus cattle for marbling score < 2/ ≥ 2 by presence/absence of fluke and by fluke category and associations between presence/absence of fluke and by fluke category and marbling score < 2/ ≥ 2 are shown in Table 50.

There was no evidence of a large difference in likelihood of a marbling score < 2/ ≥ 2 in Angus cattle based on presence/absence of fluke or bile duct category.

4.3.8.2.2 Mixed breed

Summary statistics for mixed breed cattle for marbling score < 1/ ≥ 1 by presence/absence of fluke and by fluke category are shown in Table 50. As only 22/6,199 (0.4%) mixed breed cattle had fluke, no analyses assessing putative associations between fluke and marbling score were conducted.

4.3.8.2.3 Wagyu

Summary statistics for mixed breed cattle for marbling score < 5/ ≥ 5 by presence/absence of fluke and by fluke category are shown in Table 50. As only 29/3,048 (1.0%) Wagyu cattle had fluke, no analyses assessing putative associations between fluke and marbling score were conducted.

4.3.8.3 Fibrosis

4.3.8.3.1 Angus

Summary statistics for Angus cattle for marbling score < 2/ ≥ 2 by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and marbling score < 2/ ≥ 2 are shown in Table 51.

Marbling score was less likely to be ≥ 2 in cattle with fibrosis (OR: 0.7 [95%CI: 0.6 – 1.0]) compared to those without.

4.3.8.3.2 Mixed breed

Summary statistics for mixed breed cattle for marbling score < 1/ ≥ 1 by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and marbling score < 1/ ≥ 1 are shown in Table 51.

There was some evidence that marbling score was less likely to be ≥ 1 in cattle with fibrosis (OR: 0.9 [95%CI: 0.8 – 1.0]) compared to those without.

4.3.8.3.3 Wagyu

Summary statistics for Wagyu cattle for marbling score < 5/ ≥ 5 by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and marbling score < 5/ ≥ 5 are shown in Table 51.

There was no evidence of a large difference in likelihood of a marbling score < 5/ ≥ 5 in Wagyu cattle based on presence/absence of fibrosis or fibrosis type.

4.3.8.4 Adhesion

4.3.8.4.1 Angus

Summary statistics for Angus cattle for marbling score < 2/ ≥ 2 by presence/absence of adhesion and associations between presence/absence of adhesion and marbling score < 2/ ≥ 2 are shown in Table 51.

There was no evidence of a large difference in likelihood of a marbling score < 2/ ≥ 2 in Angus cattle based on presence/absence of adhesion.

4.3.8.4.2 Mixed breed

Summary statistics for mixed breed cattle for marbling score < 1/ ≥ 1 by presence/absence of adhesion and associations between presence/absence of adhesion and marbling score < 1/ ≥ 1 are shown in Table 51.

There was no evidence of a large difference in likelihood of a marbling score < 1/ ≥ 1 in mixed breed cattle based on presence/absence of adhesion.

4.3.8.4.3 Wagyu

Summary statistics for Angus cattle for marbling score < 5/ ≥ 5 by presence/absence of adhesion and associations between presence/absence of adhesion and marbling score < 5/ ≥ 5 are shown in Table 51.

There was no evidence of a large difference in likelihood of a marbling score < 5/ ≥ 5 in Wagyu cattle based on presence/absence of adhesion.

4.3.8.5 Melanosis

4.3.8.5.1 Angus

Summary statistics for Angus cattle for marbling score < 2/ ≥ 2 by presence/absence of melanosis and associations between presence/absence of melanosis and marbling score < 2/ ≥ 2 are shown in Table 51.

There was no evidence of a large difference in likelihood of a marbling score < 2/ ≥ 2 in Angus cattle based on presence/absence of melanosis.

4.3.8.5.2 Mixed breed

Summary statistics for mixed breed cattle for marbling score < 1/ ≥ 1 by presence/absence of melanosis and associations between presence/absence of melanosis and marbling score < 1/ ≥ 1 are shown in Table 51.

There was no evidence of a large difference in likelihood of a marbling score < 1/ ≥ 1 in mixed breed cattle based on presence/absence of melanosis.

4.3.8.5.3 Wagyu

Summary statistics for Wagyu cattle for marbling score < 5/ ≥ 5 by presence/absence of melanosis and associations between presence/absence of melanosis and marbling score < 5/ ≥ 5 are shown in Table 51.

There was no evidence of a large difference in likelihood of a marbling score < 5/ ≥ 5 in Wagyu cattle based on presence/absence of melanosis.

Table 49: Descriptive statistics for marbling by abscess and associated categories for each carcase type. Associations between abscess and abscess categories and marbling by carcase type using marble score < 2/ ≥2 for Angus, < 1/ ≥ 1 for mixed breed, < 5/ ≥ 5 for Wagyu. Percentage refers to the percentage of cattle in that category with the higher marbling score.

Abscess	Angus[B]			Mixed breed[C]			Wagyu[D]		
	Percentage	Odds ratio	p-value	Percentage	Odds ratio	p-value	Percentage	Odds ratio	p-value
Presence			**0.391**			**0.766**			**0.466**
No abscess	85.8	Ref		79.1	Ref		76.8	Ref	
Abscess	87.2	1.2 (0.8 - 1.7)	0.391	81.0	1.0 (0.8 - 1.4)	0.766	85.6	1.2 (0.8 - 1.8)	0.466
Adhered			**0.630**			**0.796**			**0.766**
No abscess	85.8	Ref		79.1	Ref		76.8	Ref	
No	88.1	1.2 (0.8 - 1.9)	0.337	81.5	1.1 (0.8 - 1.5)	0.580	84.8	1.2 (0.7 - 2.0)	0.546
Yes	84.7	1.0 (0.5 - 2.0)	0.929	79.4	0.9 (0.6 - 1.5)	0.711	87.1	1.2 (0.5 - 2.6)	0.665
% liver			**0.225**			**0.221**			**0.245**
No abscess	85.8	Ref		79.1	Ref		76.8	Ref	
<10%	90.2	1.5 (0.9 - 2.5)	0.114	82.4	1.2 (0.8 - 1.6)	0.344	86.5	1.4 (0.8 - 2.4)	0.243
10-20%	80.3	0.7 (0.4 - 1.3)	0.259	75.0	0.7 (0.4 - 1.1)	0.125	80.8	0.6 (0.3 - 1.3)	0.240
>20%	87.2	1.4 (0.5 - 3.6)	0.529	88.2	1.7 (0.6 - 5.1)	0.306	93.8	3.3 (0.4 - 26.0)	0.249
Size/number[A]			**0.375**			**0.975**			**0.905**
No abscess	85.8	Ref		79.1	Ref		76.8	Ref	
A	90.5	1.6 (0.8 - 3.0)	0.184	80.7	1.0 (0.7 - 1.5)	0.877	84.8	1.1 (0.6 - 2.2)	0.696
B	84.0	0.9 (0.6 - 1.4)	0.657	81.5	1.1 (0.7 - 1.6)	0.700	86.1	1.2 (0.7 - 2.2)	0.518
C	89.5	1.8 (0.6 - 5.2)	0.291	79.5	0.9 (0.4 - 2.1)	0.832	85.7	1.1 (0.2 - 5.1)	0.910
Open			**0.221**			**0.949**			**0.739**
No abscess	85.8	Ref		79.1	Ref		76.8	Ref	
No	88.0	1.3 (0.9 - 1.9)	0.219	80.9	1.0 (0.8 - 1.4)	0.785	85.7	1.2 (0.7 - 1.8)	0.525
Yes	78.3	0.5 (0.2 - 1.5)	0.233	83.3	1.2 (0.2 - 5.8)	0.858	83.3	1.5 (0.3 - 7.8)	0.647
Postcaval			**0.692**			**0.138**			**0.692**
No abscess	85.8	Ref		79.1	Ref		76.8	Ref	
No	87.4	1.2 (0.8 - 1.8)	0.442	79.2	0.9 (0.7 - 1.2)	0.553	85.3	1.1 (0.7 - 1.8)	0.672
Yes	86.8	1.2 (0.6 - 2.3)	0.673	*88.6*	*2.0 (1.0 - 4.0)*	*0.059*	86.4	1.4 (0.6 - 3.5)	0.447
Chronicity			***0.033***			**0.902**			**0.623**
No abscess	85.8	Ref		79.1	Ref		76.8	Ref	

Acute	60.0	*0.2 (0.1 - 0.8)*	*0.018*	100.0	n/a	n/a	83.3	0.7 (0.1 - 6.4)	0.752
Chronic	89.6	1.6 (0.9 - 2.6)	0.084	80.0	1.0 (0.7 - 1.3)	0.888	84.2	1.0 (0.6 - 1.7)	0.898
Mixed	85.8	1.0 (0.6 - 1.8)	0.991	82.2	1.1 (0.7 - 1.8)	0.670	89.1	1.8 (0.7 - 4.4)	0.199

[A] A: 4 or fewer abscesses 2-4cm in diameter, B: 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter, C: 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter.

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

Table 50: Descriptive statistics for marbling by hydatid, fluke and associated categories for each carcase type. Associations between hydatid and associated categories and marbling for Angus and associations between fluke and fluke bile duct status and marbling for mixed breed and Wagyu. All analyses were based on a marble score < 2/ ≥ 2 for Angus, < 1/ ≥ 1 for mixed breed, < 5/ ≥ 5 for Wagyu.

Defect	Angus[B]			Mixed breed[C]			Wagyu[D]		
	Percentage	Odds ratio	p-value	Percentage	Odds ratio	p-value	Percentage	Odds ratio	p-value
Hydatid									
Presence						**0.769**			**0.692**
No	85.9	n/a		79.2	Ref		77.5	Ref	
Yes	90.9	n/a		79.9	1.1 (0.7 - 1.5)	0.769	73.3	0.9 (0.6 - 1.5)	0.692
% liver						**0.503**			**0.520**
No hydatid	85.9	n/a		79.2	Ref		77.5	Ref	
<10%	90.0	n/a		79.5	0.5 (-1.9 - 2.9)	0.686	72.6	0.9 (0.5 - 1.4)	0.511
10-20%	100.0	n/a		87.5	2.5 (-9.2 - 14.2)	0.677	85.7	2.9 (0.3 - 28.7)	0.353
>20%	n/a	n/a		100.0	n/a	0.156	n/a	n/a	
Chronicity						**0.909**			**0.759**
No hydatid	85.9	n/a		79.2	Ref		77.5	Ref	
Mostly cystic	100.0	n/a		81.1	0.9 (0.3 - 2.7)	0.784	75.4	1.0 (0.5 - 1.9)	0.985
Mostly calcified	80.0	n/a		78.3	0.9 (0.4 - 2.3)	0.904	64.3	0.6 (0.2 - 2.1)	0.453
Mixed	83.3	n/a		80.9	0.6 (0.3 - 1.6)	0.344	83.3	1.7 (0.4 - 7.1)	0.458
Unknown	100.0	n/a		77.3	0.8 (0.5 - 1.4)	0.516	65.2	0.7 (0.3 - 1.7)	0.381
Fluke									

Presence			**0.164**						
No	86.1	Ref		79.2	n/a		77.3	n/a	
Yes	83.2	0.7 (0.4 - 1.2)	0.164	95.5	n/a		86.2	n/a	
Bile ducts			**0.380**						
No fluke	86.1	Ref		79.2	n/a		77.3	n/a	
No obvious thickening	82.5	0.7 (0.3 - 1.7)	0.392	87.5	n/a		80.0	n/a	
Obvious thickening	83.5	0.7 (0.4 - 1.3)	0.236	100.0	n/a		92.9	n/a	

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

Table 51: Descriptive statistics for marbling by fibrosis, fibrosis type, adhesion and melanosis for each carcase type. Associations between fibrosis, fibrosis type, adhesion and melanosis and marbling for each carcase type. All analyses were based on a marble score < 2/ ≥ 2 for Angus, < 1/ ≥ 1 for mixed breed, < 5/ ≥ 5 for Wagyu.

Defect	Angus[B]			Mixed breed[C]			Wagyu[D]		
	Percentage	Odds ratio	p-value	Percentage	Odds ratio	p-value	Percentage	Odds ratio	p-value
Fibrosis									
Presence			***0.037***			***0.059***			**0.861**
No	86.1	Ref		80.1	Ref		78.1	Ref	
Yes	*83.2*	*0.7 (0.6 - 1.0)*	*0.037*	*77.2*	*0.9 (0.8 - 1.0)*	*0.059*	74.4	1.0 (0.8 - 1.2)	0.860
Type			**0.122**			**0.274**			**0.783**
No fibrosis	86.1	Ref		80.1	Ref		78.1	Ref	
Stellate	*82.3*	*0.7 (0.5 - 0.9)*	*0.017*	77.4	0.9 (0.8 - 1.0)	0.135	73.1	1.0 (0.8 - 1.3)	0.828
Capsular	86.3	0.9 (0.4 - 2.1)	0.803	75.8	0.8 (0.5 - 1.2)	0.275	73.8	0.8 (0.4 - 1.5)	0.491
Parenchymal	86.4	1.1 (0.5 - 2.3)	0.866	77.3	0.8 (0.5 - 1.3)	0.311	84.1	1.3 (0.6 - 2.6)	0.469
Adhesions									
Presence			**0.909**			**0.504**			**0.637**
No	86.0	Ref		79.2	Ref		77.2	Ref	
Yes	85.7	1.0 (0.6 - 1.9)	0.909	83.1	1.2 (0.7 - 1.9)	0.504	82.3	1.2 (0.6 - 2.2)	0.637
Melanosis									

Presence			**0.572**			**0.465**			**0.932**
No	85.8	Ref		79.8	Ref		77.4	Ref	
Yes	88.1	1.2 (0.7 - 2.0)	0.572	76.9	0.9 (0.7 - 1.2)	0.465	77.5	1.0 (0.6 - 1.5)	0.932

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

4.3.9 Modelling analysis results – Ossification

Sex, dentition and non-liver associated illness/injury were included as covariates in all models fitted to assess putative associations between presence/absence of abscess and abscess categories and ossification. Breed was also included in the mixed breed and Wagyu analyses.

Ossification was higher in heifers compared to steers and increased progressively with increasing dentition. Among mixed breed cattle it was higher in those without a non-liver associated illness/injury with some evidence of a similar trend among Angus cattle. Among mixed breed cattle ossification was higher in British/X compared to European/X and Tropical/X cattle but among Wagyu cattle there was no evidence of an important difference in ossification between pure-bred and Wagyu X cattle.

4.3.9.1 Abscess

4.3.9.1.1 Angus

Summary statistics for Angus cattle for ossification by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and ossification are shown in Table 52.

There was no evidence of a large difference in ossification in Angus cattle based on presence/absence of abscess. However, ossification was lower in cattle with adhered abscess (-3.7 [95%CI: -6.8 - -0.6]) compared to those without and there was some evidence that it was lower in cattle with open abscess (-4.9 [95%CI: -10.4 - -0.6]) compared to those without.

4.3.9.1.2 Mixed breed

Summary statistics for mixed breed cattle for ossification by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and ossification are shown in Table 52.

There was no evidence of a large difference in ossification in mixed breed cattle based on presence/absence of abscess. However, there was some evidence that it was higher in cattle with acute abscess (11.3 [95%CI: 0.8 – 21.7]) compared to those without.

4.3.9.1.3 Wagyu

Summary statistics for Wagyu cattle for ossification by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and ossification are shown in Table 52.

There was no evidence of a large difference in ossification in Wagyu cattle based on presence/absence of abscess or abscess category.

4.3.9.2 Hydatid

4.3.9.2.1 Angus

Summary statistics for Angus cattle for ossification by presence/absence of hydatid and by hydatid category are shown in Table 53. As only 22/2,366 (0.9%) Angus cattle had hydatid, no analyses assessing putative associations between hydatid and ossification were conducted.

4.3.9.2.2 Mixed breed

Summary statistics for mixed breed cattle for ossification by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and ossification are shown in Table 53.

There was no evidence of a large difference in ossification in mixed breed cattle based on presence/absence of hydatid. There was some evidence of that ossification was reduced among cattle with mostly calcified cysts compared to those without hydatid (-7.0 [95%CI: -13.9 – 0.0]). The effect estimate for mixed breed cattle with > 20% liver affected was very imprecise and extended far from the null, so no conclusion could be reached.

4.3.9.2.3 Wagyu

Summary statistics for Wagyu cattle for ossification by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and ossification are shown in Table 53.

Ossification was higher in cattle with hydatid (4.1 [95%CI: 1.5 – 6.6]) compared to those without. These findings were consistent when the analyses were restricted to both the 1,158 cattle in the 7 of 44 lots which had at least one animal with hydatid and the 2,022 cattle from 14 o of the 51 vendors which had at least one animal with hydatid.

4.3.9.3 Fluke

4.3.9.3.1 Angus

Summary statistics for Angus cattle for ossification by presence/absence of fluke and by fluke category and associations between presence/absence of fluke and by fluke category and ossification are shown in Table 53.

There was no evidence of a large difference in ossification in Angus cattle based on presence/absence of fluke however there was some evidence that ossification was higher in cattle with no obvious bile duct thickening (4.3 [95%CI: -0.1 – 8.7]) compared to those without fluke.

4.3.9.3.2 Mixed breed

Summary statistics for mixed breed cattle for ossification by presence/absence of fluke and by fluke category are shown in Table 53. As only 22/6,199 (0.4%) mixed breed cattle had fluke, no analyses assessing putative associations between fluke and ossification were conducted.

4.3.9.3.3 Wagyu

Summary statistics for Wagyu cattle for ossification by presence/absence of fluke and by fluke category are shown in Table 53. As only 29/3,048 (1.0%) Wagyu cattle had fluke, no analyses assessing putative associations between fluke and ossification were conducted.

4.3.9.4 Fibrosis

4.3.9.4.1 Angus

Summary statistics for Angus cattle for ossification by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and ossification are shown in Table 54.

There was no evidence of a large difference in ossification in Angus cattle based on presence/absence of fibrosis or fibrosis type.

4.3.9.4.2 Mixed breed

Summary statistics for mixed breed cattle for ossification by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and ossification are shown in Table 54.

There was no evidence of a large difference in ossification in mixed breed cattle based on presence/absence of fibrosis or fibrosis type.

4.3.9.4.3 Wagyu

Summary statistics for Wagyu cattle for ossification by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and ossification are shown in Table 54.

Ossification was lower among cattle with fibrosis (-1.5 [95%CI: -2.8 – -0.3]) compared to those without.

4.3.9.5 Adhesion

4.3.9.5.1 Angus

Summary statistics for Angus cattle for ossification by presence/absence of adhesion and associations between presence/absence of adhesion and ossification are shown in Table 54.

There was no evidence of a large difference in ossification in Angus cattle based on presence/absence of adhesion.

4.3.9.5.2 Mixed breed

Summary statistics for mixed breed cattle for ossification by presence/absence of adhesion and associations between presence/absence of adhesion and ossification are shown in Table 54.

There was no evidence of a large difference in ossification in mixed breed cattle based on presence/absence of adhesion.

4.3.9.5.3 Wagyu

Summary statistics for Wagyu cattle for ossification by presence/absence of adhesion and associations between presence/absence of adhesion and ossification are shown in Table 54.

There was no evidence of a large difference in ossification in Wagyu cattle based on presence/absence of adhesion.

4.3.9.6 Melanosis

4.3.9.6.1 Angus

Summary statistics for Angus cattle for ossification by presence/absence of melanosis and associations between presence/absence of melanosis and ossification are shown in Table 54.

There was no evidence of a large difference in ossification in Angus cattle based on presence/absence of melanosis.

4.3.9.6.2 Mixed breed

Summary statistics for mixed breed cattle for ossification by presence/absence of melanosis and associations between presence/absence of melanosis and ossification are shown in Table 54.

There was no evidence of a large difference in ossification in mixed breed cattle based on presence/absence of melanosis.

4.3.9.6.3 Wagyu

Summary statistics for Wagyu cattle for ossification by presence/absence of melanosis and associations between presence/absence of melanosis and ossification are shown in Table 54.

There was no evidence of a large difference in ossification in Wagyu cattle based on presence/absence of melanosis.

Table 52: Descriptive statistics for ossification by abscess and associated categories for each carcase type. Associations between abscess and abscess categories and ossification score by carcase type.

Abscess	Angus[B]			Mixed breed[C]			Wagyu[D]		
	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Presence			**0.872**			**0.797**			**0.111**
No abscess	140.9 (14.6)	Ref		162.2 (18.3)	Ref		163.0 (16.0)	Ref	
Abscess	141.1 (14.1)	-0.1 (-1.8 - 1.5)	0.872	161.6 (18.6)	0.2 (-1.5 - 1.9)	0.797	162.5 (15.3)	-1.6 (-3.6 - 0.4)	0.111
Adhered			***0.032***			**0.964**			**0.281**
No abscess	140.9 (14.6)	Ref		162.2 (18.3)	Ref		163.0 (16.0)	Ref	
No	142.0 (13.5)	1.0 (-0.8 - 2.8)	0.278	161.5 (18.3)	0.2 (-1.8 - 2.1)	0.855	162.3 (15.2)	-1.7 (-4.1 - 0.8)	0.178
Yes	138.1 (15.7)	*-3.7 (-6.8 - -0.6)*	*0.020*	161.8 (19.4)	0.4 (-3.0 - 3.7)	0.835	163.1 (15.6)	-1.6 (-5.0 - 1.8)	0.365
% liver			**0.303**			**0.543**			**0.304**
No abscess	140.9 (14.6)	Ref		162.2 (18.3)	Ref		163.0 (16.0)	Ref	
<10%	141.9 (14.3)	-1.7 (-4.2 - 0.7)	0.166	161.0 (18.4)	-0.6 (-2.6 - 1.5)	0.592	162.0 (15.0)	-1.7 (-4.2 - 0.7)	0.166
10-20%	139.5 (14.0)	-0.5 (-4.3 - 3.2)	0.787	163.7 (18.7)	2.3 (-1.1 - 5.6)	0.182	165.0 (15.8)	-0.5 (-4.3 - 3.2)	0.788
>20%	140.5 (13.8)	-4.5 (-11.2 - 2.1)	0.183	159.7 (19.3)	0.4 (-5.3 - 6.1)	0.886	158.8 (16.3)	-4.5 (-11.2 - 2.1)	0.183
Size/number[A]			**0.996**			**0.855**			**0.326**
No abscess	140.9 (14.6)	Ref		162.2 (18.3)	Ref		163.0 (16.0)	Ref	
A	140.8 (14.8)	-0.2 (-2.7 - 2.3)	0.848	161.3 (17.9)	0.0 (-2.6 - 2.5)	0.984	161.4 (14.7)	-2.5 (-5.6 - 0.5)	0.104
B	141.5 (13.9)	-0.1 (-2.4 - 2.1)	0.900	162.8 (19.4)	0.8 (-1.6 - 3.2)	0.513	163.4 (15.6)	-0.7 (-3.5 - 2.0)	0.593
C	140.5 (13.3)	0.2 (-4.0 - 4.5)	0.910	156.9 (17.0)	-1.6 (-6.9 - 3.8)	0.564	162.9 (17.3)	-3.0 (-10.1 - 4.2)	0.416
Open			**0.197**			**0.899**			**0.277**
No abscess	140.9 (14.6)	Ref		162.2 (18.3)	Ref		163.0 (16.0)	Ref	
No	141.6 (14.0)	0.3 (-1.4 - 2.0)	0.740	161.9 (18.4)	0.2 (-1.6 - 1.9)	0.849	162.5 (15.1)	-1.7 (-3.7 - 0.4)	0.113
Yes	135.2 (14.1)	-4.9 (-10.4 - 0.6)	0.078	152.5 (23.0)	2.1 (-7.5 - 11.7)	0.673	162.5 (18.6)	-1.0 (-8.7 - 6.7)	0.794
Postcaval			**0.978**			**0.943**			**0.281**
No abscess	140.9 (14.6)	Ref		162.2 (18.3)	Ref		163.0 (16.0)	Ref	
No	141.2 (14.1)	-0.2 (-2.0 - 1.7)	0.837	161.4 (18.7)	0.1 (-1.8 - 2.0)	0.890	163.3 (15.5)	-1.6 (-3.9 - 0.6)	0.162
Yes	140.7 (14.3)	0.0 (-3.0 - 3.1)	0.978	162.5 (17.9)	0.6 (-3.2 - 4.4)	0.751	160.0 (14.5)	-1.7 (-5.8 - 2.4)	0.414
Chronicity			**0.888**			**0.176**			**0.423**
No abscess	140.9 (14.6)	Ref		162.2 (18.3)	Ref		163.0 (16.0)	Ref	

Acute	140.0 (20.5)	-3.3 (-11.6 - 5.0)	0.434	170.0 (24.0)	*11.3 (0.8 - 21.7)*	*0.035*	161.7 (20.4)	-4.1 (-15.0 - 6.7)	0.455
Chronic	141.5 (13.4)	0.0 (-2.0 - 2.0)	0.992	162.3 (18.3)	0.5 (-1.6 - 2.6)	0.660	163.2 (15.3)	-1.4 (-3.8 - 1.0)	0.248
Mixed	140.3 (14.8)	-0.2 (-2.8 - 2.4)	0.865	160.0 (17.9)	-0.8 (-3.8 - 2.1)	0.586	161.1 (14.9)	-1.9 (-5.6 - 1.7)	0.306

[A] A: 4 or fewer abscesses 2-4cm in diameter, B: 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter, C: 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter.

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

Table 53: Descriptive statistics for ossification by hydatid, fluke and associated categories for each carcase type. Associations between hydatid and associated categories and ossification for Angus and associations between fluke and fluke bile duct status and ossification for mixed breed and Wagyu.

Defect	Angus[B]			Mixed breed[C]			Wagyu[D]		
	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Hydatid									
Presence						**0.706**			***0.002***
No	140.9 (14.5)	n/a		162.1 (18.2)	Ref		162.8 (16.0)	Ref	
Yes	139.5 (12.9)	n/a		163.7 (20.1)	0.5 (-1.9 - 2.8)	0.706	*167.6 (14.0)*	*4.1 (1.5 - 6.6)*	*0.002*
% liver						**0.503**			***0.007***
No hydatid	140.9 (14.5)	n/a		162.1 (18.2)	Ref		162.8 (16.0)	Ref	
<10%	141.5 (11.8)	n/a		163.6 (20.3)	0.5 (-1.9 - 2.9)	0.686	*167.4 (13.9)*	*4.0 (1.4 - 6.6)*	*0.003*
10-20%	120.0 (0.0)	n/a		168.8 (11.3)	2.5 (-9.2 - 14.2)	0.677	170.0 (16.3)	5.4 (-4.7 - 15.5)	0.296
>20%	n/a	n/a		140.0 (n/a)	-23.9 (-57.0 - 9.1)	0.156	n/a	n/a	
Chronicity						**0.227**			***0.018***
No hydatid	140.9 (14.5)	n/a		162.1 (18.2)	Ref		162.8 (16.0)	Ref	
Mostly cystic	141.7 (7.5)	n/a		163.2 (18.6)	0.6 (-2.9 - 4.0)	0.745	*167.7 (13.8)*	*3.9 (0.5 - 7.3)*	*0.025*
Mostly calcified	136.0 (15.2)	n/a		*153.9 (14.7)*	*-7.0 (-13.9 - 0.0)*	*0.049*	*171.4 (12.9)*	*8.1 (1.0 - 15.3)*	*0.026*
Mixed	138.3 (17.2)	n/a		168.1 (27.5)	2.8 (-2.1 - 7.7)	0.260	170.0 (14.1)	4.6 (-1.8 - 10.9)	0.157
Unknown	142.0 (13.0)	n/a		165.2 (14.2)	1.6 (-3.5 - 6.6)	0.545	163.0 (14.6)	1.6 (-4.0 - 7.1)	0.587
Fluke									

Presence			**0.619**						
No	141.0 (14.6)	Ref		162.2 (18.3)	n/a		162.9 (16.0)	n/a	
Yes	139.0 (13.6)	0.7 (-2.0 - 3.3)	0.619	159.5 (20.6)	n/a		165.2 (16.2)	n/a	
Bile ducts			**0.117**						
No fluke	141.0 (14.6)	Ref		162.2 (18.3)	n/a		162.9 (16.0)	n/a	
No obvious thickening	140.5 (12.2)	4.3 (-0.1 - 8.7)	0.055	160.0 (26.7)	n/a		162.0 (17.8)	n/a	
Obvious thickening	138.2 (14.2)	-0.9 (-4.0 - 2.1)	0.545	159.3 (17.3)	n/a		168.6 (14.1)	n/a	

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

Table 54: Descriptive statistics for ossification by fibrosis, fibrosis type, adhesion and melanosis for each carcase type. Associations between fibrosis, fibrosis type, adhesion and melanosis and ossification for each carcase type.

Defect	Angus[B]			Mixed breed[C]				Wagyu[D]	
	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Fibrosis									
Presence			**0.401**			**0.588**			***0.013***
No	140.8 (14.6)	Ref		162.3 (18.3)	Ref		163.4 (16.1)	Ref	
Yes	141.4 (14.1)	0.6 (-0.8 - 1.9)	0.401	162.0 (18.3)	-0.3 (-1.2 - 0.7)	0.588	*161.1 (15.5)*	*-1.5 (-2.8 - -0.3)*	*0.013*
Type			**0.233**			**0.933**			**0.060**
No fibrosis	140.8 (14.6)	Ref		162.3 (18.3)	Ref		163.4 (16.1)	Ref	
Stellate	141.7 (14.0)	0.7 (-0.7 - 2.2)	0.319	162.0 (18.2)	-0.2 (-1.2 - 0.8)	0.647	161.4 (15.5)	-1.2 (-2.6 - 0.1)	0.069
Capsular	138.0 (17.0)	-2.5 (-6.2 - 1.2)	0.193	161.9 (19.6)	-0.5 (-3.6 - 2.5)	0.727	159.8 (14.5)	-2.4 (-5.9 - 1.0)	0.167
Parenchymal	142.7 (11.1)	2.1 (-1.3 - 5.6)	0.223	162.0 (17.2)	-0.7 (-4.1 - 2.7)	0.687	160.4 (16.3)	-2.9 (-6.2 - 0.4)	0.080
Adhesions									
Presence			**0.987**			**0.942**			**0.370**
No	140.9 (14.5)	Ref		162.2 (18.3)	Ref		162.9 (16.0)	Ref	
Yes	141.5 (14.9)	0.0 (-2.8 - 2.8)	0.987	161.0 (19.2)	0.1 (-2.9 - 3.1)	0.942	164.4 (15.8)	1.4 (-1.7 - 4.4)	0.370
Melanosis									

Presence			**0.581**			**0.939**			**0.948**
No	140.9 (14.5)	Ref		162.3 (18.3)	Ref		163.0 (16.0)	Ref	
Yes	141.7 (14.5)	0.7 (-1.7 - 3.0)	0.581	162.7 (16.9)	0.1 (-1.6 - 1.8)	0.939	162.4 (14.9)	-0.1 (-2.3 - 2.2)	0.948

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

4.3.10 Modelling analysis results – Fat colour

Fat colours in the range of 0 to 3 are generally considered acceptable (Meat & Livestock Australia, 2013).

As all carcases, except one in the mixed breed carcase type, had a fat colour within this acceptable range (Table 20), no analyses assessing putative associations between liver defects and fat colour were conducted.

4.3.11 Modelling analysis results – Meat colour

Meat colours in the range of 1B to 3 are generally considered acceptable (Meat & Livestock Australia, 2013).

As all carcases, except 39 in the mixed breed carcase type, had a meat colour within this acceptable range (Table 20), no analyses assessing putative associations between liver defects and meat colour were conducted.

4.3.12 Modelling analysis results – pH level

Meat with a pH of >5.7 is classified as “dark cutting” (Meat & Livestock Australia, 2013).

As all carcases, except 41 in the mixed breed carcase type (all 39 carcases with a meat colour > 3 and 2 with a meat colour of 2), had a pH ≤ 5.7, no analyses assessing putative associations between liver defects and pH level were conducted.

4.3.13 Modelling analysis results – Exit timing

As only 8/2,366 (0.3%) Angus, 14/6,199 (0.2%) mixed breed and 28/3,048 (0.9%) Wagyu cattle were late exiting relative to the median number of days on feed for their lot (Table 20), no analyses assessing putative associations between liver defects and exit timing were conducted. These cattle were from 8, 10 and 9 different lots, respectively.

4.3.14 Modelling analysis results – Carcase value

Sex, dentition and non-liver associated illness/injury were included as covariates in all models fitted to assess putative associations between presence/absence of abscess and abscess categories and carcase value. Breed was also included in the mixed breed and Wagyu analyses.

Carcase value was higher in steers compared to heifers and, among Angus and mixed breed cattle, those without a non-liver associated illness/injury compared to those with.

Among Angus cattle carcase value was higher in 2-tooth and 4-tooth cattle compared to 0-tooth. Among mixed breed cattle it was higher in 2-tooth cattle compared to all other categories and markedly lower in 8-tooth cattle. Among Wagyu cattle carcase value increased progressively with increasing dentition categories.

Among mixed breed cattle carcase value was higher in European/X compared to British/X and lower in Tropical/X cattle compared to British/X cattle but among Wagyu cattle there was no evidence of an important difference in carcase value between pure-bred and Wagyu X cattle.

4.3.14.1 Abscess

4.3.14.1.1 Angus

Summary statistics for Angus cattle for carcase value by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and carcase value are shown in Table 55.

There was no evidence of a large difference in carcase value in Angus cattle based on presence/absence of abscess. However, carcase value was lower in cattle with adhered abscess (-$60.30 [95%CI: -103.20 - -17.40]) and cattle with acute abscess (-$179.70 [95%CI: -292.80 – -66.60]) compared to those with no abscess. There was some evidence that carcase value was lower in cattle with abscess affecting >20% liver (-$53.80 [95%CI: -111.80 – 4.20]), cattle with open abscess (-$75.90 [95%CI: -151.30 – -0.40]) and cattle with postcaval abscess (-$40.80 [95%CI: -82.60- 1.00]) compared to those with no abscess.

4.3.14.1.2 Mixed breed

Summary statistics for mixed breed cattle for carcase value by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and carcase value are shown in Table 55.

There was no evidence of a large difference in carcase value in mixed breed cattle based on presence/absence of abscess. However, there was some evidence carcase value was higher in cattle with non-adhered abscess ($20.90 [95%CI: -3.10 – 45.00]), cattle with 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter ($27.20 [95%CI: -2.70 – 57.00]) and cattle with chronic abscess ($22.50 [95%CI: -3.60 – 48.60]).

4.3.14.1.3 Wagyu

Summary statistics for Wagyu cattle for carcase value by presence/absence of abscess and by abscess categories and associations between presence/absence of abscess and abscess categories and carcase value are shown in Table 55.

There was no evidence of a large difference in carcase value in Wagyu cattle based on presence/absence of abscess. However, there was some evidence carcase value was lower in cattle with abscess affecting >20% liver (-$395.50 [95%CI: -792.20 - -1.10]). The effect estimate for Wagyu cattle with acute abscess was very imprecise and extended far from the null, so no conclusion could be reached.

4.3.14.2 Hydatid

4.3.14.2.1 Angus

Summary statistics for Angus cattle for carcase value by presence/absence of hydatid and by hydatid category are shown in Table 56. As only 22/2,366 (0.9%) Angus cattle had hydatid, no analyses assessing putative associations between hydatid and carcase value were conducted.

4.3.14.2.2 Mixed breed

Summary statistics for mixed breed cattle for carcase value by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and carcase value are shown in Table 56.

There was no evidence of a large difference in carcase value in mixed breed cattle based on presence/absence of hydatid or hydatid category.

4.3.14.2.3 Wagyu

Summary statistics for Wagyu cattle for carcase value by presence/absence of hydatid and by hydatid category and associations between presence/absence of hydatid and by hydatid category and carcase value are shown in Table 56.

The effect estimate for Wagyu cattle with hydatid was very imprecise and extended far from the null, so no general conclusion could be reached. However, there was some evidence carcase value was lower in cattle with unknown cyst status (-$377.70 [95%CI: -711.40 - -43.90]).

4.3.14.3 Fluke

4.3.14.3.1 Angus

Summary statistics for Angus cattle for carcase value by presence/absence of fluke and by fluke category and associations between presence/absence of fluke and by fluke category and carcase value are shown in Table 56.

There was no evidence of a large difference in carcase value in Angus cattle based on presence/absence of fluke or bile duct category.

4.3.14.3.2 Mixed breed

Summary statistics for mixed breed cattle for carcase value by presence/absence of fluke and by fluke category are shown in Table 56. As only 22/6,199 (0.4%) mixed breed cattle had fluke, no analyses assessing putative associations between fluke and carcase value were conducted.

4.3.14.3.3 Wagyu

Summary statistics for Wagyu cattle for carcase value by presence/absence of fluke and by fluke category are shown in Table 56. As only 29/3,048 (1.0%) Wagyu cattle had fluke, no analyses assessing putative associations between fluke and carcase value were conducted.

4.3.14.4 Fibrosis

4.3.14.4.1 Angus

Summary statistics for Angus cattle for carcase value by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and carcase value are shown in Table 57.

There was no evidence of a large difference in carcase value in Angus cattle based on presence/absence of fibrosis or fibrosis type.

4.3.14.4.2 Mixed breed

Summary statistics for mixed breed cattle for carcase value by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and carcase value are shown in Table 57.

There was some evidence carcase value was higher in cattle with fibrosis ($11.30 [95%CI: -0.50 – 23.10]).

4.3.14.4.3 Wagyu

Summary statistics for Wagyu cattle for carcase value by presence/absence of fibrosis and by fibrosis type and associations between presence/absence of fibrosis and by fibrosis type and carcase value are shown in Table 57.

There was no evidence of a large difference in carcase value in Wagyu cattle based on presence/absence of fibrosis or fibrosis type.

4.3.14.5 Adhesion

4.3.14.5.1 Angus

Summary statistics for Angus cattle for carcase value by presence/absence of adhesion and associations between presence/absence of adhesion and carcase value are shown in Table 57.

There was no evidence of a large difference in carcase value in Angus cattle based on presence/absence of adhesion.

4.3.14.5.2 Mixed breed

Summary statistics for mixed breed cattle for carcase value by presence/absence of adhesion and associations between presence/absence of adhesion and carcase value are shown in Table 57.

Carcase value was higher in cattle with adhesion ($39.40 [95%CI: 18.10 – 60.60]) compared to those without.

4.3.14.5.3 Wagyu

Summary statistics for Wagyu cattle for carcase value by presence/absence of adhesion and associations between presence/absence of adhesion and carcase value are shown in Table 57.

There was no evidence of a large difference in carcase value in Wagyu cattle based on presence/absence of adhesion.

4.3.14.6 Melanosis

4.3.14.6.1 Angus

Summary statistics for Angus cattle for carcase value by presence/absence of melanosis and associations between presence/absence of melanosis and carcase value are shown in Table 57.

There was no evidence of a large difference in carcase value in Angus cattle based on presence/absence of melanosis.

4.3.14.6.2 Mixed breed

Summary statistics for mixed breed cattle for carcase value by presence/absence of melanosis and associations between presence/absence of melanosis and carcase value are shown in Table 57.

4.3.14.6.3 Wagyu

Summary statistics for Wagyu cattle for carcase value by presence/absence of melanosis and associations between presence/absence of melanosis and carcase value are shown in Table 57.

The effect estimate for Wagyu cattle with melanosis was very imprecise and extended far from the null, so no conclusion could be reached.

Table 55: Descriptive statistics for carcase value by abscess and associated categories for each carcase type. Associations between abscess and abscess categories and carcase value by carcase type.

Abscess	Angus^B			Mixed breed^C				Wagyu^D	
	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Presence			**0.230**			**0.194**			**0.887**
No abscess	2,562 (220)	Ref		2,407 (230)	Ref		4,217 (940)	Ref	
Abscess	2,556 (214)	-13.6 (-35.8 - 8.6)	0.230	2,439 (252)	13.9 (-7.1 - 35.0)	0.194	4,396 (880)	-8.7 (-128.2 - 110.8)	0.887
Adhered			***0.022***			**0.215**			**0.852**
No abscess	2,562 (220)	Ref		2,407 (230)	Ref		4,217 (940)	Ref	
No	2,586 (199)	1.3 (-23.8 - 26.4)	0.917	2,446 (254)	20.9 (-3.1 - 45.0)	0.088	4,403 (861)	13.3 (-129.7 - 156.4)	0.855
Yes	*2,464 (232)*	*-60.3 (-103.2 - -17.4)*	*0.006*	2,420 (247)	-7.3 (-48.3 - 33.8)	0.729	4,383 (927)	-55.2 (-259.7 - 149.4)	0.597
% liver			**0.306**			**0.289**			**0.219**
No abscess	2,562 (220)	Ref		2,407 (230)	Ref		4,217 (940)	Ref	
<10%	2,570 (206)	-8.5 (-36.1 - 19.1)	0.548	2,448 (253)	20.8 (-4.6 - 46.3)	0.109	4,437 (835)	50.0 (-95.8 - 195.8)	0.501
10-20%	2,550 (220)	-5.4 (-47.2 - 36.4)	0.801	2,418 (256)	-10.8 (-51.5 - 29.8)	0.602	4,422 (971)	-32.1 (-254.4 - 190.2)	0.777
>20%	2,504 (232)	-53.8 (-111.8 - 4.2)	0.069	2,440 (237)	33.8 (-36.3 - 104.0)	0.345	*3,990 (873)*	*-395.5 (-792.2 - 1.1)*	*0.051*
Size/number^A			**0.413**			**0.129**			**0.482**
No abscess	2,562 (220)	Ref		2,407 (230)	Ref		4,217 (940)	Ref	
A	2,573 (218)	-4.1 (-38.3 - 30.2)	0.816	2,439 (262)	12.5 (-18.9 - 43.9)	0.435	4,369 (833)	-25.6 (-207.9 - 156.8)	0.783
B	2,552 (203)	-13.1 (-43.9 - 17.8)	0.406	2,460 (236)	27.2 (-2.7 - 57.0)	0.075	4,463 (894)	46.4 (-115.2 - 208.0)	0.574
C	2,523 (241)	-44.8 (-103.4 - 13.9)	0.135	2,336 (272)	-45.5 (-111.1 - 20.0)	0.173	4,068 (1,025)	-309.6 (-734.0 - 114.8)	0.153
Open			**0.116**			**0.296**			**0.931**
No abscess	2,562 (220)	Ref		2,407 (230)	Ref		4,217 (940)	Ref	
No	2,571 (196)	-8.2 (-31.3 - 14.9)	0.486	2,443 (254)	15.5 (-5.8 - 36.8)	0.155	4,403 (879)	-14.0 (-137.1 - 109.1)	0.824
Yes	*2,377 (315)*	*-75.9 (-151.3 - -0.4)*	*0.049*	2,312 (128)	-37.5 (-155.8 - 80.8)	0.535	4,300 (938)	70.6 (-387.3 - 528.4)	0.763
Postcaval			**0.157**			**0.372**			**0.906**
No abscess	2,562 (220)	Ref			Ref		4,217 (940)	Ref	
No	2,565 (213)	-4.2 (-29.6 - 21.1)	0.744	2,444 (257)	16.7 (-6.6 - 39.9)	0.160	4,408 (884)	4.6 (-130.0 - 139.3)	0.946

Yes	2,531 (215)	-40.8 (-82.6 - 1.0)	0.056	2,422 (235)	2.5 (-44.0 - 49.0)	0.916	4,356 (877)	-53.7 (-295.4 - 188.0)	0.663
Chronicity			***0.011***			**0.299**			**0.784**
No abscess	2,562 (220)	Ref		2,407 (230)	Ref		4,217 (940)	Ref	
Acute	*2,319 (296)*	*-179.7 (-292.8 - -66.6)*	*0.002*	2,470 (143)	53.0 (-75.9 - 182.0)	0.420	4,772 (736)	179.6 (-467.0 - 826.2)	0.586
Chronic	2,571 (204)	0.2 (-27.5 - 27.9)	0.988	2,458 (264)	22.5 (-3.6 - 48.6)	0.090	4,362 (897)	-46.6 (-188.6 - 95.4)	0.520
Mixed	2,551 (211)	-23.4 (-59.0 - 12.3)	0.199	2,403 (238)	-6.6 (-43.1 - 29.9)	0.722	4,439 (857)	63.0 (-154.4 - 280.3)	0.570

[A] A: 4 or fewer abscesses 2-4cm in diameter, B: 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter, C: 3 or more abscesses >4cm in diameter or >8 abscesses >2cm in diameter.

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

Table 56: Descriptive statistics for carcase value by hydatid, fluke and associated categories for each carcase type. Associations between hydatid and associated categories and carcase value for Angus and associations between fluke and fluke bile duct status and carcase value for mixed breed and Wagyu.

Defect	Angus[B]			Mixed breed[C]			Wagyu[D]		
	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Hydatid									
Presence						**0.231**			**0.250**
No	2,562 (219)	n/a		2,410 (231)	Ref		4,242 (938)	Ref	
Yes	2,484 (273)	n/a		2,402 (230)	-17.7 (-46.6 - 11.3)	0.231	3,902 (867)	-89.2 (-241.1 - 62.6)	0.249
% liver						**0.453**			**0.512**
No hydatid	2,562 (219)	n/a		2,410 (231)	Ref		4,242 (938)	Ref	
<10%	2,485 (279)	n/a		2,399 (231)	-19.2 (-48.7 - 10.4)	0.203	3,908 (883)	-91.2 (-247.5 - 65.1)	0.253
10-20%	2,472 (293)	n/a		2,489 (179)	39.9 (-104.3 - 184.1)	0.587	3,799 (584)	-57.6 (-658.5 - 543.3)	0.851
>20%	n/a	n/a		2,254 (n/a)	-174.4 (-581.2 - 232.4)	0.401	n/a	n/a	
Chronicity						**0.292**			**0.232**
No hydatid	2,562 (219)	n/a		2,410 (231)	Ref		4,242 (938)	Ref	

Mostly cystic	2,518 (273)	n/a		2,393 (234)	-16.9 (-59.3 - 25.5)	0.434	4,005 (859)	0.7 (-203.6 - 205.1)	0.995
Mostly calcified	2,501 (259)	n/a		2,349 (277)	-31.0 (-116.5 - 54.5)	0.477	3,917 (881)	57.4 (-368.3 - 483.1)	0.791
Mixed	2,414 (309)	n/a		2,451 (222)	24.0 (-35.8 - 83.8)	0.431	3,969 (879)	-150.8 (-527.8 - 226.3)	0.433
Unknown	2,510 (320)	n/a		2,397 (198)	-56.9 (-118.9 - 5.1)	0.072	*3,549 (835)*	*-377.7 (-711.4 - -43.9)*	*0.027*
Fluke									
Presence			**0.971**						
No	2,565 (218)	Ref		2,409 (231)	n/a		4,228 (939)	n/a	
Yes	2,485 (234)	-0.7 (-37.0 - 35.6)	0.971	2,485 (320)	n/a		4,286 (754)	n/a	
Bile ducts			**0.846**						
No fluke	2,565 (218)	Ref		2,409 (231)	n/a		4,228 (939)	n/a	
No obvious thickening	2,423 (221)	13.8 (-47.2 - 74.8)	0.658	2,485 (218)	n/a		4,174 (710)	n/a	
Obvious thickening	2,517 (235)	-7.0 (-49.1 - 35.2)	0.746	2,484 (374)	n/a		4,405 (807)	n/a	

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

Table 57: Descriptive statistics for carcase value by fibrosis, fibrosis type, adhesion and melanosis for each carcase type. Associations between fibrosis, fibrosis type, adhesion and melanosis and carcase value for each carcase type.

Defect	Angus[B]			Mixed breed[C]			Wagyu[D]		
	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value	Observed mean (s.d.)	Coefficient	p-value
Fibrosis									
Presence			**0.277**			**0.060**			**0.125**
No	2,551 (225)	Ref		2,406 (234)	Ref		4,226 (938)	Ref	
Yes	2,598 (195)	10.1 (-8.1 - 28.4)	0.277	2,419 (225)	11.3 (-0.5 - 23.1)	0.060	4,238 (932)	56.6 (-15.7 - 128.8)	0.125
Type			**0.528**			**0.132**			**0.472**

No fibrosis	2,551 (225)	Ref		2,406 (234)	Ref		4,226 (938)	Ref	
Stellate	2,597 (195)	7.6 (-12.5 - 27.7)	0.458	2,417 (224)	8.4 (-4.0 - 20.8)	0.185	4,213 (937)	60.0 (-19.6 - 139.5)	0.139
Capsular	2,592 (177)	2.1 (-48.8 - 53.1)	0.934	2,416 (232)	15.0 (-22.9 - 53.0)	0.437	4,242 (931)	17.2 (-188.5 - 222.9)	0.870
Parenchymal	2,610 (209)	32.7 (-14.7 - 80.1)	0.177	2,447 (228)	*42.1 (0.0 - 84.1)*	*0.050*	4,410 (892)	68.2 (-126.3 - 262.7)	0.492
Adhesion									
Presence			**0.344**			**0.768**			**0.684**
No	2,563 (218)	Ref		2,410 (231)	Ref		4,227 (938)	Ref	
Yes	2,510 (247)	-18.6 (-57.0 - 19.9)	0.344	2,399 (257)	-5.6 (-42.6 - 31.5)	0.768	4,310 (916)	37.7 (-144.0 - 219.4)	0.684
Melanosis									
Presence			**0.150**			***<0.001***			**0.169**
No	2,558 (222)	Ref		2,409 (234)	Ref		4,219 (937)	Ref	
Yes	2,618 (172)	23.6 (-8.5 - 55.6)	0.150	*2,450 (208)*	*39.4 (18.1 - 60.6)*	*<0.001*	4,410 (930)	94.2 (-40.0 - 228.4)	0.169

[B] Angus - 2,366 observations included in models with sex, dentition and non-liver associated illness/injury fitted as covariates.

[C] Mixed breed - 6,198 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

[D] Wagyu - 3,047 observations included in models with sex, dentition, breed type and non-liver associated illness/injury fitted as covariates.

5. Conclusions

5.1 Key findings

The liver's key functions include bilirubin, carbohydrate, lipid and xenobiotic metabolism, the production and excretion of bile, protein and urea synthesis, and immune functions (Brown et al. 2017). The liver has significant functional reserve and regenerative capacity, and in normal animals up to two thirds could be removed without significant impairment in hepatic function, with regeneration occurring within days (Brown et al. 2017). This functional reserve capacity means that clinical signs will only manifest in an animal with significant liver damage. Despite this, liver disease is frequently observed in feedlot and slaughter cattle and is known to be associated with production and economic impacts. This study's aims were to examine the effect of liver defects on growth performance, carcase characteristics, and health of feedlot cattle, and explore the economic impact of liver defects in the context of an Australian feedlot beef supply chain.

5.1.1 Pilot study

- The initial pilot study by veterinary pathologists of 1006 livers at abattoir A defined the types of pathology prevalent in slaughtered beef cattle, creating morphologic criteria for each defect that could be observed on the slaughter floor. This involved detailed evaluation of the gross pathology and examination of representative areas of the lesions by histopathology to definitively identify the pathologic changes in the tissue. **Types of liver lesions identified during the pilot study were as previously described in multiple studies on pathology of the viscera of slaughter cattle** (Brown et al. 2017; Rezac 2014; Lehreena et al. 2010; Roberts, 1982).
- Categories of lesion severity as a percentage of affected liver parenchyma were set as <10%, 10-20%, and >20% to explore if a threshold for subclinical impact on production performance could be defined in the prospective study. Thresholds (10 and 20%) were chosen based on the professional experience of the pathologists in the team.
- The pathological analysis in the pilot study determined the most significant defects relative to likely impact on animal health, production and economics to be abscess, hydatid, and fluke. This was based on frequency, the extent of the pathology, and also the aetiopathogenesis and prior research indicating impacts on animal health or productivity.
- Major lesions identified in the pilot study by frequency included **abscess (8.4%), fibrosis (4.4%), fluke (4.2%), adhesion (3.4%), hydatid (1.8%), hepatitis (1.6%)**. Other defects occurring at a frequency of less than 1% included telangiectasia, cyst, melanosis, steatosis/ glycogen, neoplasia and cirrhosis. **Diseases/defects noted in the pilot study are all established as liver disease entities in production cattle.** A study in the early 1980s in a Queensland abattoir by Roberts (1982) examining both grain-fed (80 and 120 day) and grass-fed cattle identified similar defects. In that study, the prevalence of disorders in grain fed cattle was 5.6% (80 days) and 11.1% (120 days) for abscesses, telangiectasis 8.4%, hydatid (*Echinococcus granulosus)* 3.3.%, fluke (*Fasciola hepatica)* 0.4%, unclassified lesions 7.4% and contamination 3.2% (Roberts 1982). In Roberts (1982), grass fed cattle unsurprisingly had a much lower prevalence of abscesses (0.2%) as the aetiology of this defect is ruminal acidosis associated with grain-feeding (Roberts 1982; Nagaraja and Changappa 1998; Nagaraja and Lechenberg 2007). However, grass fed cattle had a higher prevalence of

hydatid (18.9%) and fluke (5.4%), again as expected as the exposure to these metazoan parasites is during grazing (Roberts, 1982).

- Another major outcome of the pilot study was the **development of a rigorous high throughput data collection and grading scheme for liver defects in beef cattle**. This applied a more detailed and rigorous scheme than used by the meat inspectors at abattoir A or B, and the Elanco scheme, but could be deployed accurately at chain speed. This allowed very detailed data collection to define the production and economic impacts of liver diseases to be collected in industry settings. The grading scheme was supported by a liver defect training guide to harmonise diagnoses across pathologists performing the liver grading in the prospective study.
- Data were entered in real time using hand-held tablets and the CommCare (Dimagi, https://www.dimagi.com/commcare/) data entry platform. CommCare is an application that combines mobile-based timestamped data entry with web-based management and data storage. Thus, data collected offline on tablets can then be synchronised to cloud-based data storage and exported when required in spreadsheet format. The grading scheme (Appendix 8.1) was set up in the application in questionnaire format using skip logic, as applicable, to facilitate rapid data entry required as approximately one minute was available for examination and data entry for each liver. Most questions were closed but additional free text fields enabled entry of notes on unusual findings. The timestamp function allowed ease of review and management of inconsistencies, for example accidental duplication of carcase numbers or typographical errors.

5.1.1.1 Liver abscessation

- Liver abscessation is the most common and severe pathology likely to impact production and economics seen in feedlot cattle. In the pilot study abscesses were detected in 8.4% of livers. Abscesses in feedlot cattle are associated with high grain rations causing ruminal acidosis, and subsequent inflammation and damage to the rumen mucosa termed ruminitis, which allows the penetration of bacteria through the rumen wall and into the portal blood supply that drains to the liver (Nagaraja and Changappa 1998). Bacteria then embolise to the liver parenchyma and may establish an infection, which subsequently results in abscessation (Nagaraja and Changappa 1998). The correlation of ruminitis with liver abscessation in cattle reported by Rezac et al. (2014) was 20.6% of mild, 21.6% of moderate, and 9.24% of severely abscessed livers correlated with mild or severe rumenitis at slaughter.
- After seeding of bacteria within the liver, the initial lesion is a microabscess, which would have been identified and classified as hepatitis in this pilot study. Prior studies have suggested the initial hepatitis, accompanied by coagulative necrosis of hepatocytes progresses gradually to a true pus-filled abscess within 3 to 10 days (Nagaraja and Lechtenberg 2007). Over time a fibrous capsule surrounds the abscess with immature fibrosis in the centre progressing to more mature fibrous tissue peripherally (Nagaraja and Lechtenberg 2007). Abscesses near the liver capsule will induce fibrinous peritonitis and may result in adhesions, in a chronic timeframe, between the liver and adjacent viscera as the fibrin organises into fibrous tissue (Nagaraja and Lechtenberg 2007). Some abscesses will eventually become sterile and be resorbed and replaced by a fibrous scar, which occurred between 45-180 days in experimentally inoculated cattle (Jensen et al. 1954). Thus, there is likely to be a strong association between abscesses, fibrosis and adhesions in terms of

aetiology, though it should be noted that many other liver diseases will resolve leaving fibrosis in the liver, such as migrating fluke or resolved hydatids.

- Observational studies have suggested that liver abscess formation predominates in the last 60 days on feed in the finishing phase, with smaller abscesses that form early in the feeding period tending to resolve within 60 days (Nagaraja and Lechtenberg 2007). Prior studies have demonstrated that liver abscess numbers can range from one to hundreds but the typical range is two to ten per liver (Nagaraja and Lechtenberg 2007).
- In the case of abscesses, size and number of the abscesses were also graded as an indicator of severity as indicated in the methods. Further, additional disease severity modifiers were assessed for this defect. Abscess was the most complex defect assessed, with **parameters such as adhesion, open to the peritoneal cavity, postcaval and acute considered to indicate a more severe disease** process likely to affect the animal's health, welfare and productivity. Conversely, **no adhesions, closed abscesses and those that were chronic and not postcaval were considered likely to have a less severe impact on animal health** and productivity. Previous work has indicated that liver abscessation of Elanco grade A-, A+, A+AD, and A+OP had reduced dressed yields, hot carcase weight and longissimus muscle (LM) area than normal livers to varying degrees (Brown and Lawrence 2010). A study by Brink et al. (1990) only demonstrated impacts on performance means in cattle with A+ graded liver abscesses, including final live weight, hot carcase weight, dry matter intake, and daily gain. These studies suggest variable impacts on liver abscess severity on performance parameters, but indicate severity grading of abscesses was an important criteria to include in the prospective study.
- **Microbiological results**: The established most common bacterial species associated with liver abscessation in cattle are *Fusobacterium necrophorum* and *Trueperella pyogenes* (formerly *Arcanobacterium pyogenes*) (Nagaraja and Changappa 1998; Nagaraja and Lechenberg 2007). However, our pilot study did not identify either of these organisms in the 29 condemned livers that were cultured for detailed microbiological examination in the pilot study from abattoir A, with the most frequent isolations by bacterial genus being *Escherichia spp., Aeromonas, Staphylococcus, Enterococcus, Acinetobacter, Clostridium perfringens, Pasteurella multicoda*, and *Citrobacter*, with lesser frequency of *Enterobacter, Klebsiella, Mannheimia haemolytica, Bacillus cereus* and *Streptoccus bovis*. This means the microbiological profile in our study differed markedly from the previously reported studies and inferred pathogenesis of liver abscesses. After determining this finding, technical reasons for not isolating *Fusobacterium necrophorum* and *Trueperella pyogenes* were explored, and it was deemed highly unlikely that the result would be a false negative as both organisms are considered robust, and the sampling and culture methods would be highly likely to detect them if they were present. Further, the feedlot associated at abattoir A did not use antimicrobials as standard in the ration, though due to study methodology the environment, source and prior exposure to antimicrobials or microbiome altering feed additives of the cattle that had liver abscesses cultured could not be determined. Nonetheless, the organisms cultured in our study have either been previously reported as isolated from liver lesions in cattle, or are common pathogens associated with cattle disease (Nagaraja and Changappa 1998; Stotland et al. 2001; Lehreena et al. 2010; Amachawadi and Nagaraja 2016). **Thus, a recommendation of this study is that further exploration of the microbiological causes of liver abscessation in feedlot cattle is strongly warranted to**

explore the generalisability of this finding, understand currently important causal organisms in feedlot cattle, and further investigate the pathogenesis of liver abscesses. Further, alterations in abscess causing microorganisms under different production conditions, and with various interventions to reduce abscessation would be of value.

5.1.1.2 Hydatid

- Hydatid (*Echinococcus granulosus*) disease was graded by percentage of liver affected as well as chronicity, with cystic lesions indicating acute or active disease, and calcified lesions indicating chronic and inactive disease. Hydatid disease is a parasitic zoonosis, involving a canid definitive host and an herbivorous or omnivorous intermediate host in which fluid-filled cysts develop in the offal (Wilson et al. 2019^{B}). Hydatid cysts, even when present in large numbers, rarely cause overt clinical signs in domestic animals (Brown et al. 2017). Typically, the disease is subclinical in cattle but results in condemnation and downgrading of affected viscera, typically liver and lungs, although many organs can contain the cysts (Wilson et al. 2019^{B}). It is important to explore the economic impact of both the condemnation of viscera, and the productivity of affected cattle in an Australian context (Wilson et al. 2019^{A}; Wilson et al. 2019^{B}). In this pilot study, hydatid was detected at 1.8% prevalence, which is considerably below a prior prevalence of 3.3% reported by Roberts (1982) in a Queensland abattoir in a study of over 5000 cattle conducted in the early 1980s.

5.1.1.3 Fluke

- Liver fluke *(Fasciola hepatica)* are leaf-shaped flukes that inhabit the biliary system. Their lifecycle involves *Lymnaea* aquatic snails, which serve as intermediate hosts. After ingestion of metacercariae juvenile flukes migrate within liver parenchyma causing haemorrhagic tracts, which repair by fibrosis (Brown et al. 2017). Disease impacts associated with juvenile fluke migration include acute peritonitis, widespread hepatic necrosis with heavy infestations, and necrosis of the liver triggering baciliary haemoglobinuria (*Clostridium haemolyticum*) or infectious necrotic hepatitis (*Clostridium novyi*) (Brown et al. 2017). Mature flukes within the bile ducts cause chronic cholangitis, which may progress to ectasia (dilation) or stenosis (constriction). The bile ducts may fill with abnormal bile, cell debris and iron porphyrin fluke pigment, and chronic disease may progress to significant fibrosis and mineralisation resulting in a ‘pipe-stem’ appearance to the liver (Brown et al. 2017). Chronic liver fluke disease is associated with poor body condition in adult cattle. In this pilot study flukes were detected at 4.2% prevalence, which is considerably above a prior prevalence of 0.4% reported by Roberts (1982) in a Queensland abattoir in a study of over 5000 cattle conducted in the early 1980s. Another abattoir survey conducted in southern Queensland reported an overall prevalence of 1.1%, though prevalence varied markedly by geographic location with 36% in the Stanthorpe shire, with distribution and prevalence impacted by the presence of the intermediate snail host (Baldock and Arthur 1985)

5.1.1.4 Other lesions

- An explanation of the causes and appearance of liver injury is presented in Brown (2017). In the pilot study fibrosis (4.4%), adhesion (3.4%), hepatitis (1.6%) occurred at a prevalence of over 1%. Other defects occurring at a frequency of less than 1% included telangiectasia, cyst, melanosis, steatosis/ glycogen, neoplasia and cirrhosis.

- Fibrosis and adhesions are some of the most common responses to chronic liver injury and represent a scarring reaction, which could have different inciting causes such as abscess, or juvenile fluke migration. Localised fibrosis or adhesions (fibrosis on the surface of the liver capsule extending to adjacent viscera) generally have minimal impact on health due to their localised nature and the extensive functional reserve capacity of the organ. However extensive hepatic fibrosis extending into cirrhosis, or perisinusoidal fibrosis can have serious health effects, though both conditions would be very rare in feedlot cattle. Likewise, severe peritoneal adhesions can result in strictures and dysmotility in the gastrointestinal tract, which could impact digestion and animal productivity, again likely to be rare in feedlot cattle.
- Hepatitis is inflammation of the hepatic parenchyma, which in cattle is mostly caused by bacterial species similar to those described as causing abscesses, with parasites, fungi and non-infectious causes possible. In feedlot cattle, hepatitis is likely part of the ruminitis-bacterial abscess complex either presenting as hepatitis rather than an abscess due to low severity or being in the early/acute part of the disease complex. Histologically hepatitis is characterised by various types of inflammation, hepatocellular necrosis and apoptosis of cells. Random foci of acute neutrophilic hepatitis occur as a consequence of embolization of bacteria and are relatively common in all species. If acute hepatitis fails to resolve, chronic features including fibrosis, mononuclear cells and hepatocellular regeneration may be present. In the pilot study histopathology of hepatitis demonstrated both acute and chronic features as reported in prior literature.
- Telangiectasia, also known as bovine hepatic telangiectasia (BHT) is one of the most common lesions reported in bovine livers and reported to cause >10% of liver condemnations due to aesthetics in federal inspected slaughter facilities in the United States (Stotland et al. 2001). Telangiectasia grossly presents as single or multiple 1-5mm red-brown foci and histologically as irregular cystic dilations of the hepatic sinusoids (Yousef et al. 2011). The cause of telangiectasia unknown, but it is considered incidental by pathologists with no health consequences for the animal (Stotland et al. 2001).
- Cysts, exclusive of hydatid as a cause, are likely to be due to congenital abnormalities often of the biliary tree and are unlikely to impact the health of the animal due to their focal nature. Non-hydatid cysts were rare.
- Melanosis is the visible presence of endogenous pigment that is dark brown or black, typically in animals with black or red coat colour and can occur in many organs such as the lung, liver, brain, kidneys and muscle. In cattle the melanosis pigment is endogenous melanin, identical to that which imparts coat and eye colours, that has no adverse impact on organ function, or animal health. Melanosis is characterised as a pigmentation for meat inspection purposes, it is a cosmetic defect of no public health importance, and affected livers can be diverted to pet food due to the cosmetic impact of the defect.
- Steatosis (fatty accumulation) and glycogenosis are accumulations of fat or sugar, respectively, in hepatocytes, which can result in focal or more extensive areas of pallor in the liver parenchyma. Apart from cosmetic impact they are not of animal health or public health significance. In slaughter cattle, steatosis is usually focal and associated with ligaments or adhesions, which place tension on the liver capsule. This is not the same entity as bovine fatty liver syndrome that results in generalised pathological hepatic fat accumulation in ruminants, more commonly dairy cattle, with ketosis. Glycogen

accumulation in slaughter cattle would be physiologic and of no consequence. Both steatosis and glycogenosis were rare.

- Neoplasia (cancer) and cirrhosis, a diffuse process of late-stage fibrosis and destruction of the normal liver architecture into abnormal lobules with vascular shunting, in slaughter cattle are expected to be extremely rare. Both because the frequency of these diseases in cattle is extremely low, and because both are likely to result in significant illness that would result in the animal being diverted from routine processing.

5.1.2 Retrospective study

The retrospective study was conducted to assess seasonal trends and temporal patterns in the liver defects recorded by meat inspectors in abattoir B over consecutive years between 2014-2020. This study was conducted using this retrospective dataset, as COVID19 impacted access to abattoir B over a full 12-month period preventing the analysis of the impact of season on liver disease prevalence. However, the retrospective data allowed multiple years to be compared, which would not have been feasible with a prospective study methodology. The methodology of using meat inspector terminal data to explore the seasonal and annual trends in the prevalence of liver diseases of importance to the feedlot industry was successful. This methodology is cost-effective, as it only requires access to pre-existing data sets for analysis. However, the recording of defects is likely dependent on local meat inspector and processing plant standard operating procedures, which would affect both data availability and reliability. The retrospective data showed a general decreasing trend in the major defects assessed (abscess, fluke, hydatid and adhesion); however, it was beyond the scope of the study to model the causal factors influencing these annual variations, which are likely to include management and environmental factors. Further, data was linked to the group level not individual animals, precluding consideration of animal-level factors.

5.1.2.1 Abscess

As mentioned in the pilot study discussion, abscessation is strongly associated with grain feeding and would be acquired during the feeding period, thus would not be expected to show clear annual or seasonal trends based on its aetiopathogenesis. Consequently, it is unsurprising that there is no strong seasonal pattern in the data across the three cattle classes. There was, however, a variation in abscessation prevalence with 6.2% in Angus, 3.8% in mixed breed and 3.9% in Wagyu over the study period. What is notable, however, is the dramatic reduction in adhesions over the study period with a decline from 2017-2020. As adhesions are likely to be a sequelae of severe abscessation, this suggests that a management factor within the lot reduced the severity of abscessation over the herd, resulting in the decline of adhesion prevalence.

5.1.2.2 Fluke

Climatic effects such local rainfall and temperature would be predicted to have a significant effect on the prevalence of metazoan parasites, particularly fluke, which has an aquatic snail intermediate host. Fluke showed a general trend across cattle class to be more prevalent in cooler seasons at slaughter, versus summer. However, as animals are unlikely to pick up fluke whilst in a feedlot, the factors contributing to this distribution require further investigation. Given mixed breed and Angus cattle were on 100-day feeding programs, the must have logically predominantly acquired the fluke at least a full climatic season ahead of slaughter (a season being 3 months in duration or approximately 90 days). The total prevalence of fluke also varied considerably between cattle classes in the retrospective study with a very high 10.2% in Angus, very low 0.8% in mixed breed and 2.1% in Wagyu. Notably, prevalence of fluke reduced between early in the data set (2014-2016) to later year periods in Angus (2019-2020) and mixed breed cattle (2017-2020). Data from a 1985 study demonstrated a major variation in prevalence based on geographic region in Queensland, being 36% around Stanthorpe but <1% in more arid western regions of south Queensland (Baldock and Arthur, 1985). So, in addition to climate, geography is likely to have a major influence on fluke prevalence. A study that investigates how the geographic origin and management practices of cattle relates to fluke prevalence would be of benefit in defining the factors driving the prevalence of this defect.

5.1.2.3 Hydatid

Hydatid prevalence was more consistent between cattle classes, with Angus 1.6%, mixed breed 2.7% and Wagyu 2.1%, with no strong seasonal pattern but again a strong decrease in prevalence over the time of the study between the early years (2014-2016) to later periods (2017-2020). Acquisition of hydatid cysts requires exposure to the faeces of an intermediate canid host, with grass-fed cattle showing a much higher prevalence than grain fed (Wilson et al. 2019[A]). Hydatid is less likely to be affected by climatic factors due to the different parasitic lifecycle, but the strong downward trend in the later half of the study period in hydatid prevalence suggests a management intervention or factor is responsible for the reduced prevalence rather than weather or climate.

5.1.2.4 Interpretations and considerations

In general, 2013-2015 had low rainfall throughout Queensland due to an El Niño weather pattern, 2017 was El Niño southern oscillation (ENSO) neutral with higher western district rainfall and drier coastal conditions, but much of QLD remained drought declared until early 2020. However, there were notable flooding events in far north Queensland in 2019, which killed hundreds of thousands of cattle in the Carpentaria gulf plains. (https://www.stateoftheenvironment.des.qld.gov.au/climate/climate-observations/annual-rainfall). Based on this superficial climatic summary the fluke and hydatid prevalence was actually higher during the earlier portions of the study period (2014-2016) during the El Niño event and decreased over time to be much lower particularly from 2018-2020. This poor correlation with weather patterns may indicate that management factors are the primary determinant of fluke and hydatid prevalence. **A recommendation for future research would be to model the geographic source of the cattle prior to entering the lot against the prevalence of metazoan parasites, fluke and hydatid, to determine if particular regions have a higher prevalence and therefore may see economic benefit (reduced liver condemnations) from parasite mitigation strategies. Further, a broader epidemiological study of climate, geography and heard health practices on metazoan parasite prevalence, involving multiple supply chains, could provide more information on the influence of these factors on fluke and hydatid prevalence, and the interplay with breed, sex and age of cattle.**

Overall, the retrospective study showed a decreased trend in fluke, hydatid and adhesions over the study period suggesting management factors may be improving animal health within the supply chain by reducing the prevalence of these diseases. The method of using meat inspector gathered terminal data provided abundant data, which was collected cost-effectively through standard operating procedures at abattoir B. **This means at an industry level, other supply chains could consider the analysis of defect prevalence over time courses and seasons, in order to determine the prevalence and therefore economic impact of various liver defects in their specific supply chains. Further, a large-scale study could be deployed more widely across different supply chains to determine the impact of the various defects across different classes of cattle under varying climatic, geographic and production parameters.** However, as this data cannot be reliably linked to individual animal production parameters and does not include the defect severity criteria of the prospective data collection system, its utility in assessing economic impact is limited to determining the number/ cost of condemned livers due to each defect. Furthermore, the level of detail on defects, accuracy of reporting, and duration of available data captured in meat inspector terminal data will vary from processor to processor and with individual meat inspector practices. However, give the cost effectiveness of the methodology the value of its application should be considered by individual supply chains.

5.1.3 Prospective study

The prospective study combined the detailed high throughput grading and analysis of liver defects with detailed analysis of animal and carcase performance characteristics. This allowed a summary of the detailed interplay of liver defect, breed and performance parameter to be defined across a large data set of 11,600 animals that were eligible for inclusion. Thus, this is one of the largest prospective studies to interrogate the impact of liver disease on animal performance, health and economics to date done either globally or in an Australian context. Further, the impact on a large number of production parameters including ADG, HSCW, dressing percentage, P8 fat, rib fat, EMA, marbling ossification and carcase value was conducted. A summary of associations between defects and performance/ carcase parameters by carcase type is presented in Table 58.

5.1.3.1 Abscess

- Liver abscesses as a defect varied by cattle class with a prevalence of 12.6% in Angus, 6.6% in mixed breed, and 6.4% in Wagyu cattle in the prospective study in abattoir B. The retrospective study also demonstrated a low prevalence with 6.2% in Angus, 3.8% in mixed breed and 3.9% in Wagyu over the 2014-2020 study period in abattoir B. This range of prevalence is lower than the reported incidence of 12 to 32% in most feedlots (Nagaraja and Changappa 1990). Management parameters in the feedlot are likely successfully reducing the incidence of abscessation in this supply chain.
- Based on the production chain protocols of abattoir B, only animals that were clinically well were included in the prospective data set, thus all identified parameters must be considered subclinical as animals were certified healthy prior to slaughter. This differs from the pilot study conducted at abattoir A, where sick animals culled at the end of the day as emergency slaughters were deliberately included as part of the research methodology to gauge the full severity of disease that could be present in slaughter cattle.
- Notably, the prospective study was clearly able to define a series of lesion and defect parameters associated with abscessation that, while subclinical, resulted in production and economic impacts important in feedlot beef cattle. **These included abscesses that were adhered, open, acute, postcaval and affecting >20% of liver parenchyma, all of which can be considered pathological parameters that indicate more severe disease**.
- The impact on carcase or animal performance parameters varied by breed with Angus cattle most severely impacted. In these cattle, the severe abscess parameters were definitively ($p<0.05$) associated with reductions in ADG, HSCW, marbling and carcase value, with some evidence of negative impact on dressing percentage, and rib fat. In Wagyu, HSCW, dressing percentage, P8 fat and carcase value also showed variable negative impacts. However, the pattern was more complex in mixed breed cattle with some parameters like ADG, HSCW, P8 fat and carcase value appearing to improve if the abscess was of lower severity (non-adhered, chronic, <10%). Potentially, as the aetiopathogenesis of abscessation is strongly associated with ruminal acidosis and finisher rations, the improved performance represents a balance between animals that have strong production performance due to high feed intake causing acidosis, but low enough liver disease to not have an adverse impact.

Compensatory weight gain or performance after a previous or intermittent period of ruminal acidosis is also a plausible explanation. Determining the causal association and if this is a consistent pattern requires more research.

- Previous studies have reported that liver abscessation affects the performance of feedlot beef cattle. Brink et al. (1990) reported that severe liver abscesses were associated with reduced carcase gain and dressing percentage, as well as reduced feed intake, particularly in A+ cattle with active abscesses. In a review of liver abscesses in feedlot cattle, liver condemnation, reduced feed intake, reduced weight gain, decreased feed efficiency and decreased carcase yield were notable economic impacts (Nagaraja and Chengappa 1998; Nagaraja and Lechtenberg 2007). Severe liver abscesses (A+) may also result in increased carcase trimming due adhesions, condemnation of the viscera, or disruption of the processing chain and slaughter floor workflows due to accidental rupture of abscesses contaminating the carcase (Nagaraja and Lechtenberg 2007).
- Conversely, in our research study mixed breed cattle with less severe liver abscessation had improvements in ADG, HSCW, P8 fat and carcase value. Notably, Brink et al. (1990) also reported the heaviest final weights and hot carcase weight in A- liver abscess cattle. We hypothesize that this is due to increased feed intake in these animals predisposing them to ruminal acidosis, which then produces liver abscesses, but the degree of liver injury is below a threshold that causes production impacts. Determining the causal association and if this is a consistent pattern requires more research.
- Multiple mitigation strategies can be used to control liver abscesses in feedlot cattle. It was out of scope in this study to consider the management practices influencing liver abscess prevalence in the supply chains enrolled in the study. In the USA bacitracin methylene disalicylate, chlortetracycline, oxytetracycline, neomycin in combination with oxytetracycline, tylosin and virginiamycin have been approved for the prevention of liver abscesses in feedlot cattle (Nagaraja and Chengappa 1998; Amachawadi and Nagaraja 2016). Previous work has shown antibiotics in the feed can reduce abscessation with tylosin, a macrolide, generally seen as the most effective and most commonly used, reducing incidence by 40-70% (Nagaraja and Chengappa, 1998). However, concerns over antimicrobial resistance have heightened awareness of antimicrobial stewardship, and from 2017 tylosin use in the USA must be under veterinary oversight as mandated by the United States Food and Drug Administration (Amachawadi and Nagaraja 2016). Virginiamycin has also demonstrated reduced liver abscessation and improved ADG (Tedeschi and Gorocica-Buenfil 2018). Alternatives to antibiotics include the probiotic Lactipro® (BECBiotech https://becfeed.com/wp-content/uploads/BECBiotech-Beef.pdf) a live culture of a patented strain of *Megasphaera elsdenii* a lactic acid utilizing bacterium registered to aid transition onto grain rations.
- Other management strategies to reduce liver abscessation include proper bunk management to minimise rumen imbalance, such as gradual adaptation of cattle to high grain diets, avoiding over or under feeding, providing feed multiple times a day to spread intake, increasing roughage content in the ration, ration quality control, and providing adequate bunk space and fresh clean water for cattle (Nagaraja and Chengappa 1998).

5.1.3.2 Hydatid

- Hydatid had a prevalence of 0.9% in Angus, 3.4% in mixed breed and 3.9% in Wagyu cattle in the prospective study. Hydatid prevalence in the retrospective study was more consistent between cattle classes, with Angus 1.6%, mixed breed 2.7% and Wagyu 2.1%, with no strong seasonal pattern but again a strong decrease in prevalence over the time of the study between the early years (2014-2016) to later periods (2017-2020). The apparent prevalence of hydatid in any organ in a retrospective study of over 1 million cattle slaughtered in eastern Australia was 8.8%, with the true prevalence modelled at 33%, with 75% of animals having both liver and lung infected (Wilson et al. 2019[B]).
- Hydatid disease in the prospective study predominantly involved <10% of the liver (90.9% Angus, 95.7% mixed and 94.2% Wagyu), with the chronicity showing a complex pattern between cystic acute, calcified chronic and mixed chronicity infections, though in 19.2-22.7% the chronicity could not be determined.
- Hydatid disease has been previously reported to show increased prevalence with age, with <3% in animals under 1 year but up to 39.5% in animals four years or older (Wilson et al. 2019[B]). Prevalence also varies with feed type, with prevalence significantly associated with grass feeding, and an inconsistent influence of sex is reported (Wilson et al. 2019[B]; Wilson et al. 2019[C]). Geography also plays a significant role in prevalence with higher prevalence (52.2%) east of the Great Dividing Range versus west (10.8%) in Queensland, attributable to the climate, presence of wild dogs and macropods, particularly wallabies (Wilson et al. 2019[B]).
- The Wagyu cattle showed a higher prevalence of hydatid in both the prospective and retrospective analyses, so determining if these cattle were sourced from an area with higher prevalence compared to Angus and mixed breed cattle would be important to determine if the higher prevalence was relative to geography or a potential breed specific effect. Further, in Wagyu cattle there was a negative association between hydatid and HSCW, dressing percentage, P8 fat, rib fat and ossification. Hydatid is generally considered to be asymptomatic in cattle, so production impacts are predominantly from condemnation and downgrading of offal, though some hints of production impact were noted in older literature (Wilson et al. 2019[A]). So the negative association between hydatid and multiple production parameters in Wagyu is an important finding of this study. **Further investigation to determine if Wagyu cattle are more susceptible or sensitive to hydatid disease to confirm if the negative production impacts in Wagyu cattle extend into other contexts is warranted.**
- Hydatid disease is an important zoonotic disease, with canid (dingoes, domestic and feral dogs, and foxes) faeces contaminated with *Echinococcus granulosus* eggs posing a significant public health risk. However, cysts in offal are of no risk to public health, particularly abattoir workers (Wilson et al. 2019[c]). **Geographic determinates of clustering of hydatid disease via property identification codes (PIC) and post codes with increased prevalence may identify certain regions where public health interventions are warranted to reduce risk.** Previous work by Wilson et al. (2019[B]), has demonstrated that this methodology can identify spatio-temporal clusters of hydatid based on PIC region. However, preventive measures by farmers, including canine anthelmintics and preventing dog access to raw offal, may not prevent cattle infections and suggest that sylvatic cycles are an important source of infection in cattle (Wilson et al. 2019[C]).

5.1.3.3 Fluke

- Fluke had a prevalence of 5.0% in Angus, 0.4% in mixed breed and 1.0% in Wagyu cattle in the prospective study. The total prevalence of fluke also varied considerably between cattle classes in the retrospective study with a very high 10.2% in Angus, very low 0.8% in mixed breed and 2.1% in Wagyu.
- No obvious production impact was noted on any class of cattle by fluke; however, the low prevalence in mixed breed and Wagyu cattle meant a detailed modelling was not possible. However, affected livers are condemned meaning there is a minor economic impact from this defect.
- The chronicity pattern varied between cattle class with 33.6% acute and 66.4% chronic in Angus, 36.4% acute and 63.6% chronic in mixed breed and 51.7% acute and 48.3% chronic in Wagyu. The proportion of cattle with acute disease, defined as no obvious remodelling and fibrosis of the bile ducts, was interesting given the research group hypothesize that the infection likely occurred prior to introduction to the feedlot. This is even more intriguing considering Wagyu cattle showed an almost 50% distribution between acute and chronic fluke, despite being 300 days on feed. **This suggests further investigation is warranted into the kinetics of chronic change in the bile ducts from fluke infection. However, the lack of production impacts on feedlot cattle would suggest this work is low priority**.
- A study by Mazeri et al. (2017) indicated that under conditions in the United Kingdom cattle with fluke had 10 days greater slaughter age, which correlated with increased liver fibrosis compared to fluke-free cattle. Other negative effects of liver fluke include lower carcase weights and lower carcase conformation scores than non-infected animals (Sanchez-Vazquez and Lewis 2013). The absences of a negative effect in our study may be due to local effects as both these studies were conducted in Scotland, or reflect the larger datasets in both these studies having a high sensitivity for detecting production impacts, as both incorporated larger cattle numbers in their datasets.

5.1.3.4 Fibrosis

- Unexpectedly, liver fibrosis was correlated with evidence of, or some evidence of, improvement in multiple positive carcase parameters across the three classes of cattle except for negative effects on marbling in Angus and mixed breed cattle. This is unlikely to be a causal association, but likely reflects that fibrosis is a sequela to healing of hepatic damage. The research group believes this is most likely correlated with the positive production parameters associated with mild hepatic abscessation, and thus associated with the ruminal acidosis-abscess complex and potentially animals that are good eaters or have compensatory weight gain after a period of acidosis, resulting in abscessation.

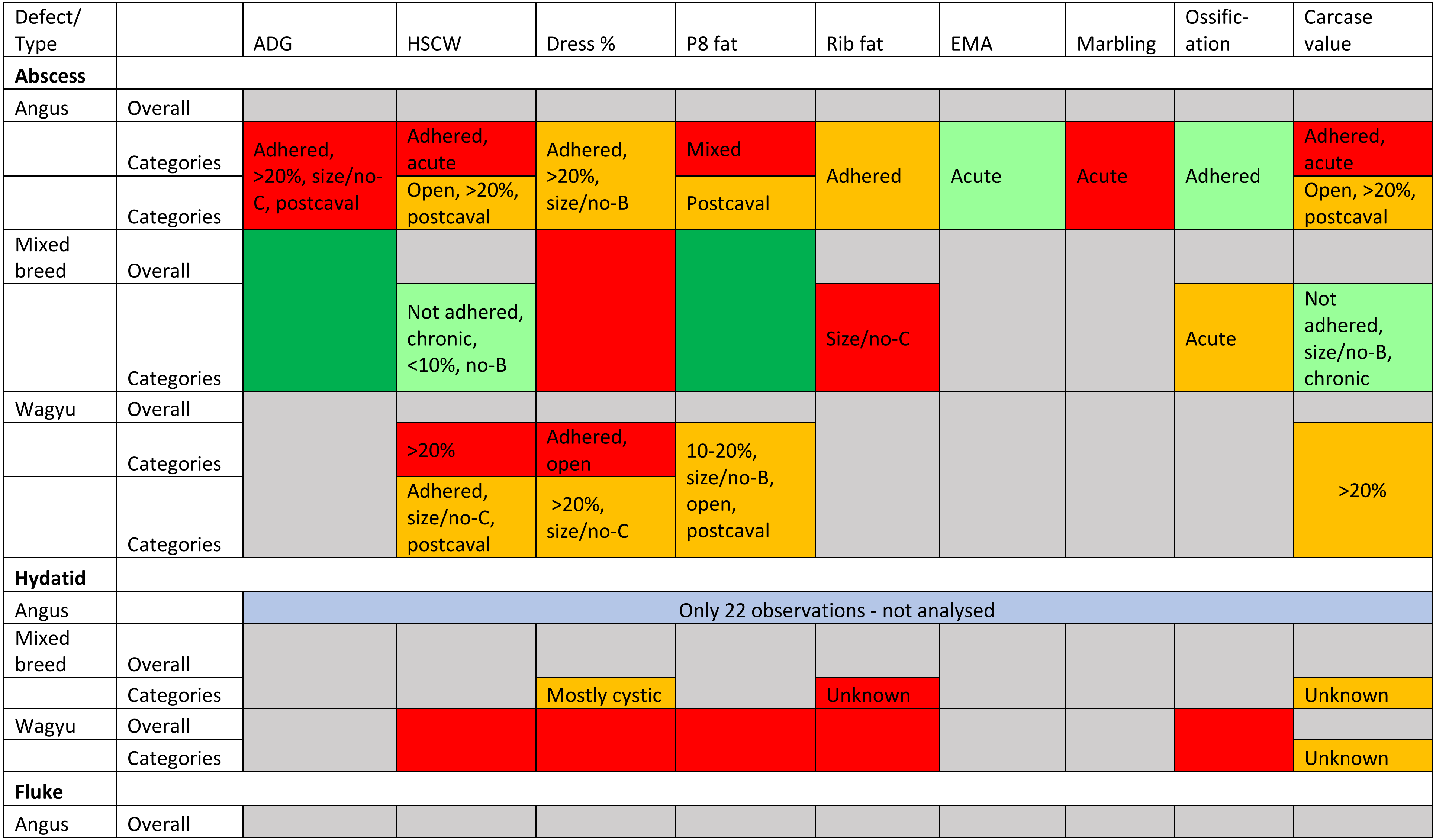
5.1.3.5 Adhesions

- Adhesions are most likely associated with severe degrees of the ruminal acidosis-liver abscess complex. There was a negative association with adhesions and dressing percentage in mixed breed and Wagyu cattle. Conversely there was a mild positive association of adhesions with rib fat in mixed breed cattle, again reflecting the complex interplay of positive and negative effects on cattle performance from the ruminal acidosis-liver abscess complex due to the positive effects of increased dietary intake balancing the negative effects of more severe liver abscessation.

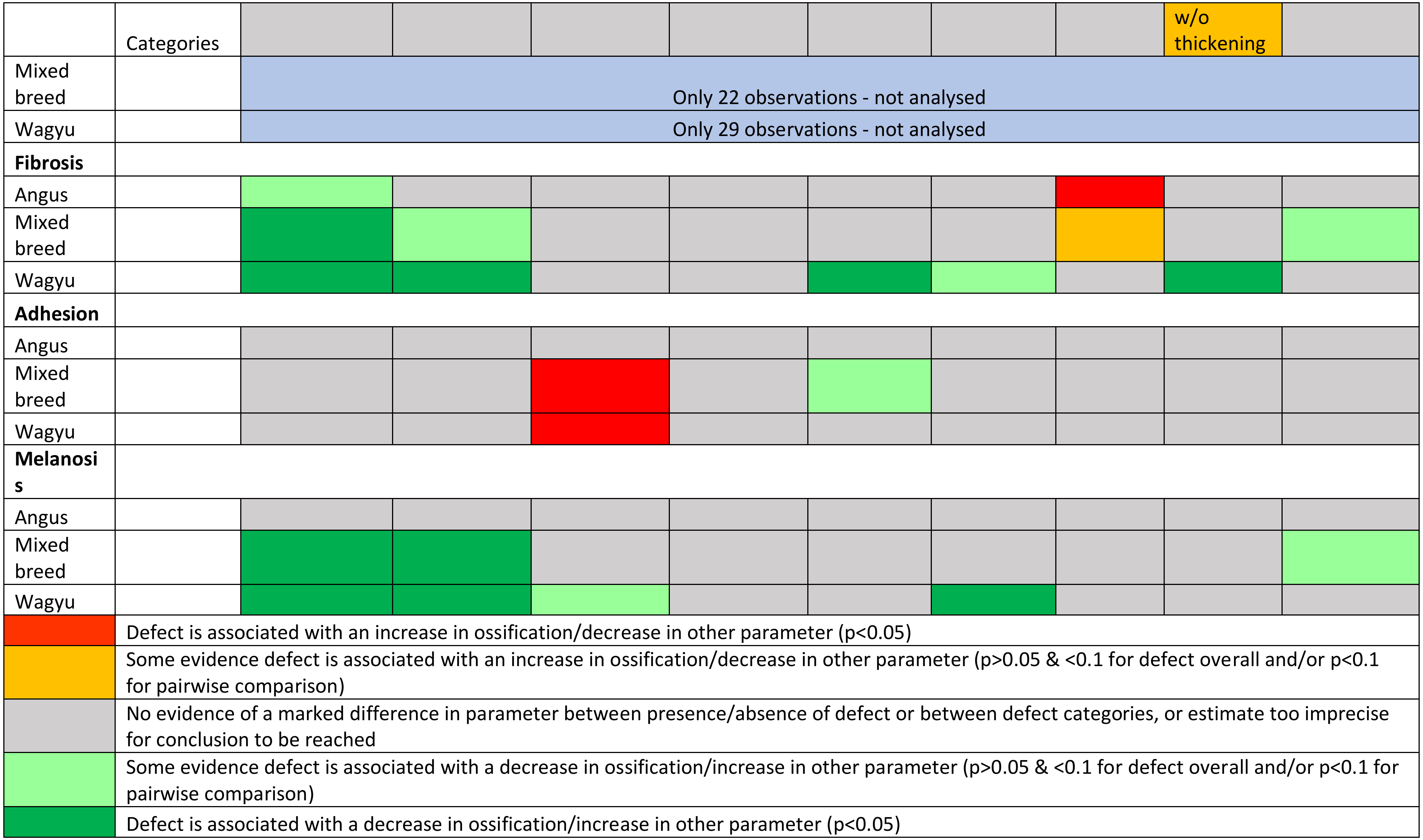
5.1.3.6 Melanosis

- Melanosis, which is the physiological deposition of pigment in organs in black and red-coated cattle, was positively correlated with improvements in multiple parameters in mixed breed and Wagyu cattle. The research group believes this is not a causal association but reflects the co-association of these coat colours and pigments with genes that are associated with good production performance in the mixed breed or Wagyu cattle. This effect was not observed in Angus cattle.

Table 58: Summary of associations between defects and performance/carcase parameters by carcase type.



Defect/ Type		ADG	HSCW	Dress %	P8 fat	Rib fat	EMA	Marbling	Ossific-ation	Carcase value
Abscess										
Angus	Overall									
	Categories	Adhered, >20%, size/no-C, postcaval	Adhered, acute	Adhered, >20%, size/no-B	Mixed	Adhered	Acute	Acute	Adhered	Adhered, acute
	Categories		Open, >20%, postcaval		Postcaval					Open, >20%, postcaval
Mixed breed	Overall	🟩		🟥	🟩					
	Categories		Not adhered, chronic, <10%, no-B			Size/no-C			Acute	Not adhered, size/no-B, chronic
Wagyu	Overall									
	Categories		>20%	Adhered, open	10-20%, size/no-B, open, postcaval					>20%
	Categories		Adhered, size/no-C, postcaval	>20%, size/no-C						
Hydatid										
Angus		Only 22 observations - not analysed								
Mixed breed	Overall									
	Categories			Mostly cystic		Unknown				Unknown
Wagyu	Overall		🟥	🟥	🟥	🟥			🟥	
	Categories									Unknown
Fluke										
Angus	Overall									



	Categories								w/o thickening	
Mixed breed		Only 22 observations - not analysed								
Wagyu		Only 29 observations - not analysed								
Fibrosis										
Angus		🟢	▨	▨	▨	▨	▨	🟥	▨	▨
Mixed breed		🟩	🟢	▨	▨	▨	▨	🟧	▨	🟢
Wagyu		🟩	🟩	▨	▨	🟩	🟢	▨	🟩	▨
Adhesion										
Angus		▨	▨	▨	▨	▨	▨	▨	▨	▨
Mixed breed		▨	▨	🟥	▨	🟢	▨	▨	▨	▨
Wagyu		▨	▨	🟥	▨	▨	▨	▨	▨	▨
Melanosis										
Angus		▨	▨	▨	▨	▨	▨	▨	▨	▨
Mixed breed		🟩	🟩	▨	▨	▨	▨	▨	▨	🟢
Wagyu		🟩	🟩	🟢	▨	▨	🟩	▨	▨	▨
🟥	Defect is associated with an increase in ossification/decrease in other parameter (p<0.05)									
🟧	Some evidence defect is associated with an increase in ossification/decrease in other parameter (p>0.05 & <0.1 for defect overall and/or p<0.1 for pairwise comparison)									
▨	No evidence of a marked difference in parameter between presence/absence of defect or between defect categories, or estimate too imprecise for conclusion to be reached									
🟢	Some evidence defect is associated with a decrease in ossification/increase in other parameter (p>0.05 & <0.1 for defect overall and/or p<0.1 for pairwise comparison)									
🟩	Defect is associated with a decrease in ossification/increase in other parameter (p<0.05)									

5.2 Key benefits to industry

- This study has proposed and validated a high throughput data collection methodology and grading scheme that covers all liver defects of economic importance, allowing detailed data to be collected on the slaughter floor at chain speed. This scheme significantly extends on the previously reported classification schemes such as the Elanco liver abscess grading method, correlating the pathogenesis and health impacts on animals with observable criteria on the slaughter floor. This scheme can be applied by research groups, producers and processes to gain a detailed picture of liver defects impacting beef feedlot stakeholders.
- The retrospective study indicated that meat inspector-collected data on liver defects can serve as a cost-effective data set for determining disease prevalence and patterns over years and seasons within a beef feedlot production system.
- Further, the scheme when applied in the prospective study, has identified a clear subclinical threshold for production impacts by liver abscessation with adhered, postcaval, acute and >20% parenchymal involvement impacting numerous carcase performance criteria including average daily gain, hot standard carcase weight, dressing percentage, P8 fat, rib fat, marbling, ossification and carcase value. These impacts were variable but showed a consistent trend of this severity threshold impacting performance in the 3 classes of cattle in the study, particularly 100-day Angus and 300-day Wagyu. It is recommended that producers and processors use this severity threshold for liver abscessation to assess for economic impacts on their supply chain and determine if interventions to reduce liver abscessation will have production, economic and animal health benefits based on their specific circumstances.
- The prospective study provided detailed results as a tabulated ‘traffic light system’, which correlated the major defects noted at liver inspection on the kill floor to impacts on parameters of animal/ carcase performance across three classes of feedlot cattle, with two feeding durations (100 days, 300 days) and breed effects (Angus, mixed-breed, Wagyu).

6. Future research and recommendations

6.1 Future research and development

1. Further exploration of the microbiological causes of liver abscessation in feedlot cattle is warranted to explore the generalisability of our finding of the lack of *Fusobacterium and Trueperella spp* in the pilot study. This would further understanding of currently important causal organisms in feedlot cattle, and further investigate the pathogenesis of liver abscesses. Also, alterations in abscess causing microorganisms under different production conditions and with various interventions to reduce abscessation would be of value to understand aetiopathogenesis and intervention benefits.
2. The retrospective study indicated seasonal and temporal trends in defects like fluke, which was generally more common in winter and spring, but this was more overt in some classes of cattle i.e., Angus. Given the animals are unlikely to acquire new infections of fluke once in a feedlot, the geographic, climatic, and sources of animals being inducted into the feedlot at specific times of year should be explored to gain a greater understanding about the epidemiological factors driving the defect. As indicated by the literature, the prevalence of

liver fluke is highly dependent on the distribution of the intermediate snail host, so the relative importance of this defect will vary across Australia's various beef production zones.

3. Parasitic defects in the prospective study including fluke and hydatid are likely impacted by climatic and geographic factors, but these were not explored within this study. Defining climatic, seasonal or geographic regions that result in a higher prevalence of these parasites may indicate specific supplier/ producer geographic regions that would benefit from interventions to reduce the burden of parasites and subsequently reduce the number of liver condemnations from parasitic causes. The economic benefit of interventions to reduce fluke and hydatid may be highly regional but this could be explored by a more detailed analysis involving cattle origin.
4. The prospective study identified across three cattle classes (Angus, mixed breed and Wagyu) and two feed durations (100-day and 300-day) the complex interaction of liver disease with multiple production parameters. Exploration of the interactions in other breeds, feed programs and production systems, particularly on the impact of liver abscesses would determine the generalisability of results.
5. The breed-specific negative association between hydatid and several performance characteristics in Wagyu cattle should be explored to determine if it is a true breed-specific effect.
6. Geographic determinates of clustering of hydatid disease via property identification codes and post codes with increased prevalence may identify certain regions where public health interventions are warranted to reduce risk.
7. Further investigation is warranted into the kinetics of chronic change in the bile ducts from fluke infection. However, the lack of production impacts on feedlot cattle would suggest this work is low priority.
8. Future R&D should extend the prospective collection methodology across different supply chains in other geographic areas to determine a more holistic impact of liver disease on the Australian beef feedlot supply chain, as only two supply chains were examined in this study, and both were located within Queensland. Notably, the prevalence of disease in the abattoir B supply chain was lower than previously reported in other studies, so the impact of liver disease in other Australian supply chains may be higher.
9. Based on this body of work, an economic calculator could be developed allowing various supply chains and producers to input their price grids to assess the economic impact of liver disease, thus guiding management decisions.

6.2 Practical applications of the project's insights

1. This study has proposed and validated a high throughput data collection methodology and grading scheme that covers all liver defects of economic importance, allowing detailed data to be collected on the slaughter floor at chain speed. This scheme can be applied by research groups, producers and processes to gain a detailed picture of liver defects impacting beef feedlot stakeholders.
2. The retrospective study indicated that meat inspector collected data on liver defects can serve as a cost-effective data set for determining disease prevalence and patterns over years and seasons within a beef feedlot production system.
3. The prospective study defined a threshold for production impacts of liver abscesses impacting production, economics and animal health parameters (open, adhered, postcaval,

acute, >20% parenchyma). Thus, interventions that reduce the severity of liver abscessation above this threshold should be explored as these are likely to have benefits for all stakeholders in the supply chain by improving productivity, animal health and resulting in economic benefit.

6.3 Development and adoption activities that would ensure the red meat industry achieves full value from the project's findings

- Supply chains could consider the periodic analysis of meat inspector terminal data to determine trends and patterns in the prevalence of liver defects.
- The new liver defect grading scheme developed can be applied at chain speed and could be deployed as part of meat inspector data collection. The grading parameters for abscesses severity could be incorporated into this routine data collection to flag cattle classes where mitigation strategies would be of economic benefit.
- Supply chains should assess the percentage of animals in the severe liver abscess category to determine the likely economic and animal health impact for their specific circumstances and if interventions to reduce liver abscessation are warranted.
- Correlating defects, particularly metazoan parasite prevalence, to specific supply sources may indicate geographic areas that would benefit from interventions to reduce defect prevalence.
- Improved communication between all stakeholders—particularly producers and/or feedlots and processors—on the prevalence of liver defects would allow coordinated interventions to reduce liver defects, thus improving economic outcomes to all stakeholders.

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8. Appendix

8.1 CommCare data collection scheme – Liver grading

Meat inspector assessment

1. Non-condemned
2. Trimmed
3. Condemned

Percentage liver trimmed by meat inspector

1. Less than 10%
2. 10-20%
3. More than 20%

Trimmed part examined by UQ pathologists?

1. No
2. Yes

UQ pathology assessment

1. No defect
2. Defect
3. Not Examined

Pathology observed (check all that apply)

1. Abscess
    a. Abscess adhered?
        i. Yes
        ii. No
    b. Abscess percentage tissue?
        i. Less than 10%
        ii. 10-20%
        iii. More than 20%
    c. Abscess size and number?
        i. 4 or fewer abscesses 2-4cm in diameter
        ii. 1-2 abscesses >4cm in diameter or 4-8 abscesses >2cm in diameter
        iii. 3 or more abscesses >4cm in diameter or > 8 abscesses > 2cm in diameter
    d. Abscess open
        i. Not open
        ii. Open
    e. Abscess postcaval?
        i. Not postcaval
        ii. Postcaval
    f. Abscess chronicity
        i. Acute
        ii. Chronic
        iii. Mixed
2. Adhesions

3. Hydatid
    a. Hydatid percentage tissue
        i. Less than 10%
        ii. 10-20%
        iii. More than 20%
    b. Hydatid cystic/ calcified
        i. Mostly cystic
        ii. Mostly calcified
        iii. Mixed
        iv. Unknown/ uncertain
4. Fluke
    a. Fluke- thickened bile ducts?
        i. Fluke on opening bile duct but bile duct thickening not obvious more peripherally
        ii. Obvious bile duct thickening in at least one lobe
5. Fibrosis
    a. Fibrosis type
        i. Stellate scar(s) only
        ii. Capsular fibrosis regional
        iii. Parenchymal fibrosis
    b. Parenchymal fibrosis- percentage tissue
        i. Less than 10%
        ii. 10-20%
        iii. More than 20%
6. Hepatitis
    a. Hepatitis percentage tissue?
        i. Less than 10%
        ii. 10-20%
        iii. More than 20%
7. Telangiectasia
8. Cyst
9. Steatosis
10. Cirrhosis
11. Neoplasia
12. Melanosis
13. Paunch rupture
    a. Cause of paunch rupture
        i. Technical
        ii. Disease
        iii. Condemnation of viscera due to technical paunch rupture
            1. None
            2. Partial
            3. All
        iv. Condemnation of viscera due to disease related paunch rupture
            1. None
            2. Partial
            3. All
14. Severe non-liver pathology

Reason why not examined -include details such as contamination with digesta/ ruptured lung abscess and any gross liver pathology observed (free text)

Describe severe non-liver pathology (free text)

Additional notes (free text)

8.2 Liver defect training guide

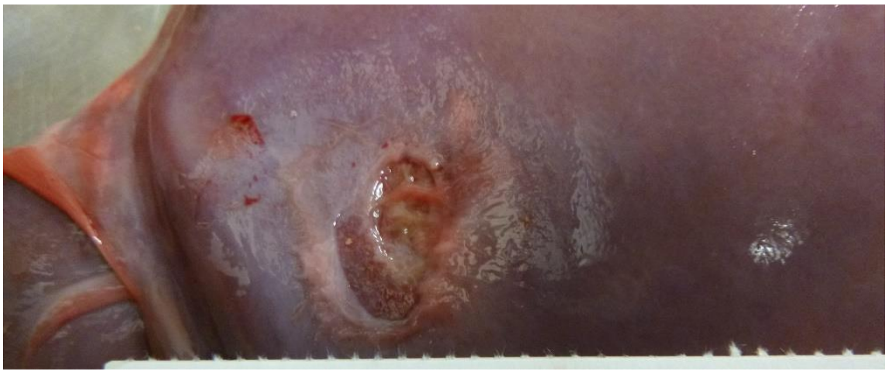
8.2.1 Procedure

Examiner will stand down the chain from the meat inspector. The meat inspector will palpate the liver on both sides (cranial/ diaphragmatic and caudal/ visceral) and incise into and open up the common hepatic bile duct. Examiner will then also palpate the liver on both sides and examine the incised bile duct. Care should be taken to carefully palpate small lesions—in particular, small mineralised lesions can be difficult to differentiate from small abscesses without careful palpation.

Livers will be assessed as normal or as having defects as listed and described in Figure 16 - Figure 25. Abscess, hydatid, fluke and hepatitis will also be graded as per the criteria outlined in Section 8.1. Data will be recorded electronically using a handheld tablet and the data collection app CommCare (https://www.dimagi.com/commcare/). Carcase number, normal versus defect and type of defect and grade(s), if relevant will be recorded for each liver.

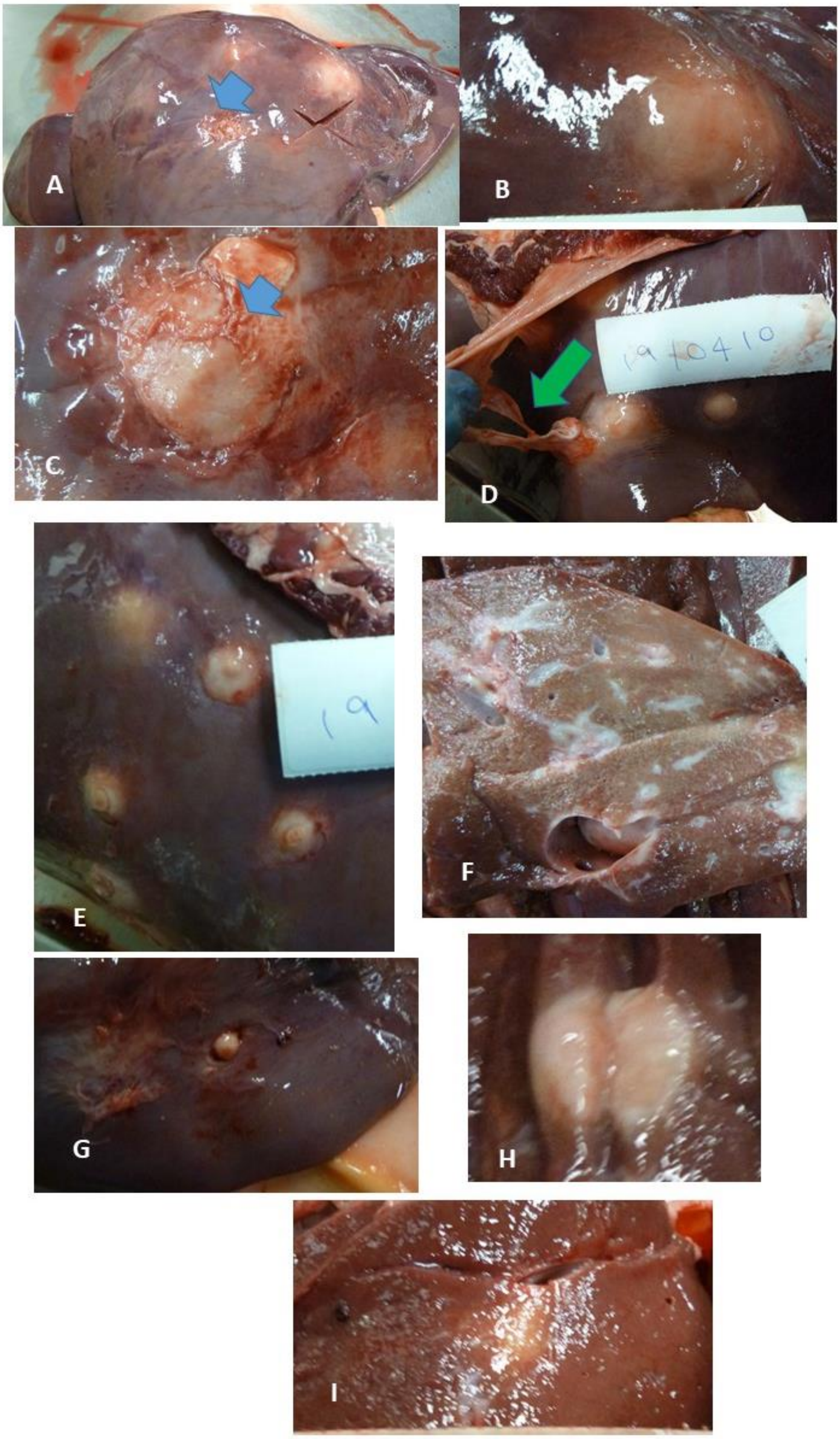
8.2.2 Adhesion

Figure 16: Adhesion. Circular lesions on capsule, depressed up to 1cm, often with fibrous tags. Usually less than 3cm diameter.



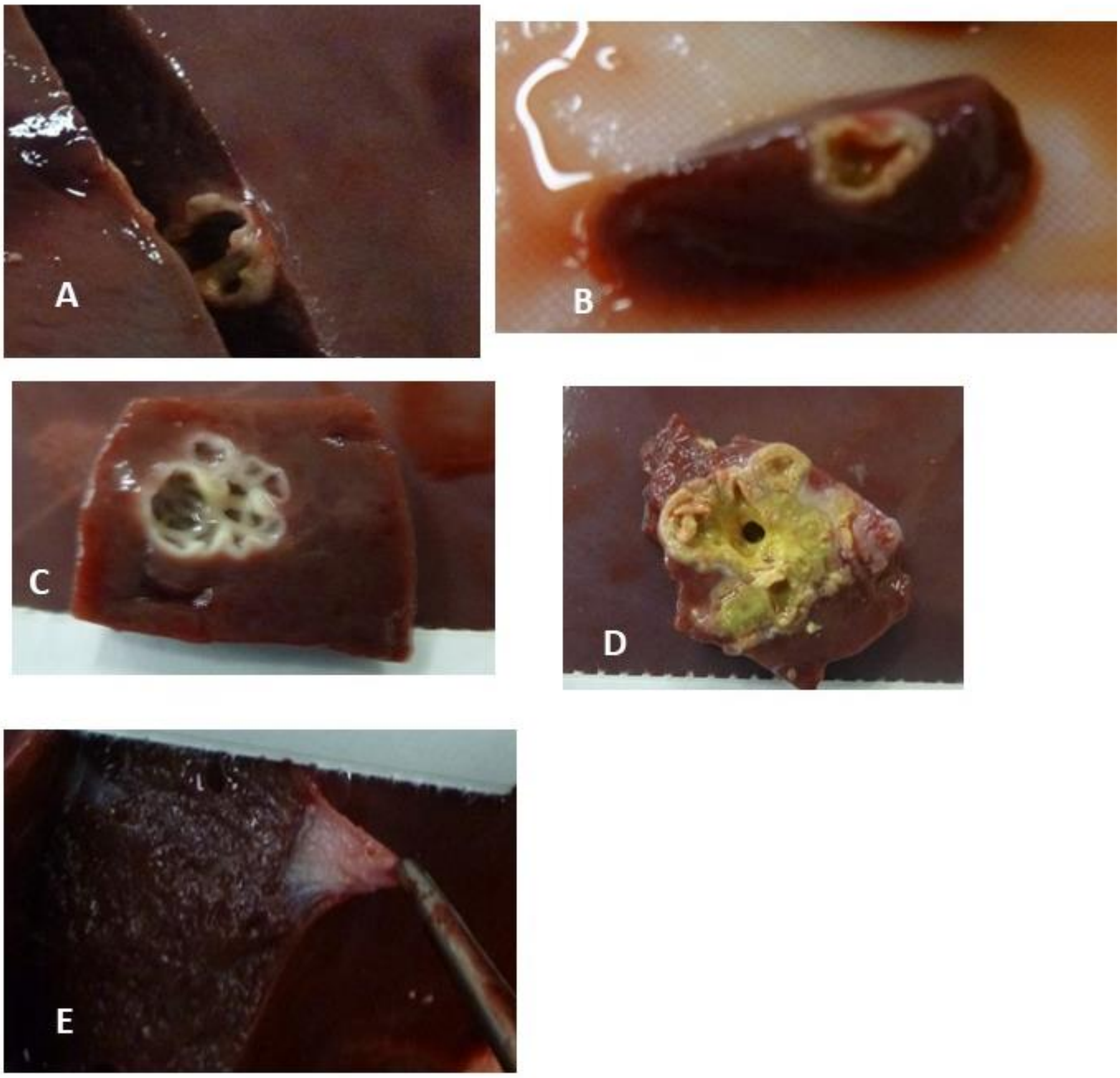
8.2.3 Abscess

Figure 17: Hepatic abscess. Focal to multifocal, pale, firm, well demarcated, raised nodule with fibrous capsule and purulent (A-E, G) or solid (H, I) centre. They can have fibrous tags (blue arrow) on the capsular surface, these can be attached to the diaphragm (green arrow). These can have a central area discharging purulent material (E). Surrounding tissue can be paler and firmer than normal liver and be transected by bands of fibrous tissue (inflammation and fibrosis, F). They can be pale, firm, well demarcated (+/- pale, firm subjacent tissue), pedunculated nodule within a circular depressed area (G).


A
B
C
19+0410
D
19
E
F
G
H
I

8.2.4 Hydatid

Figure 18: Hydatid. Circular +/- multilocular nodule with pale, often hard (mineralised) capsule of varying thickness containing clear fluid (A-C). Irregular lesion that is pale to yellow and hard (mineralised) this can be solid or have areas of cavitation (D). In contrast, cysts, have a thin, flaccid capsule (E).

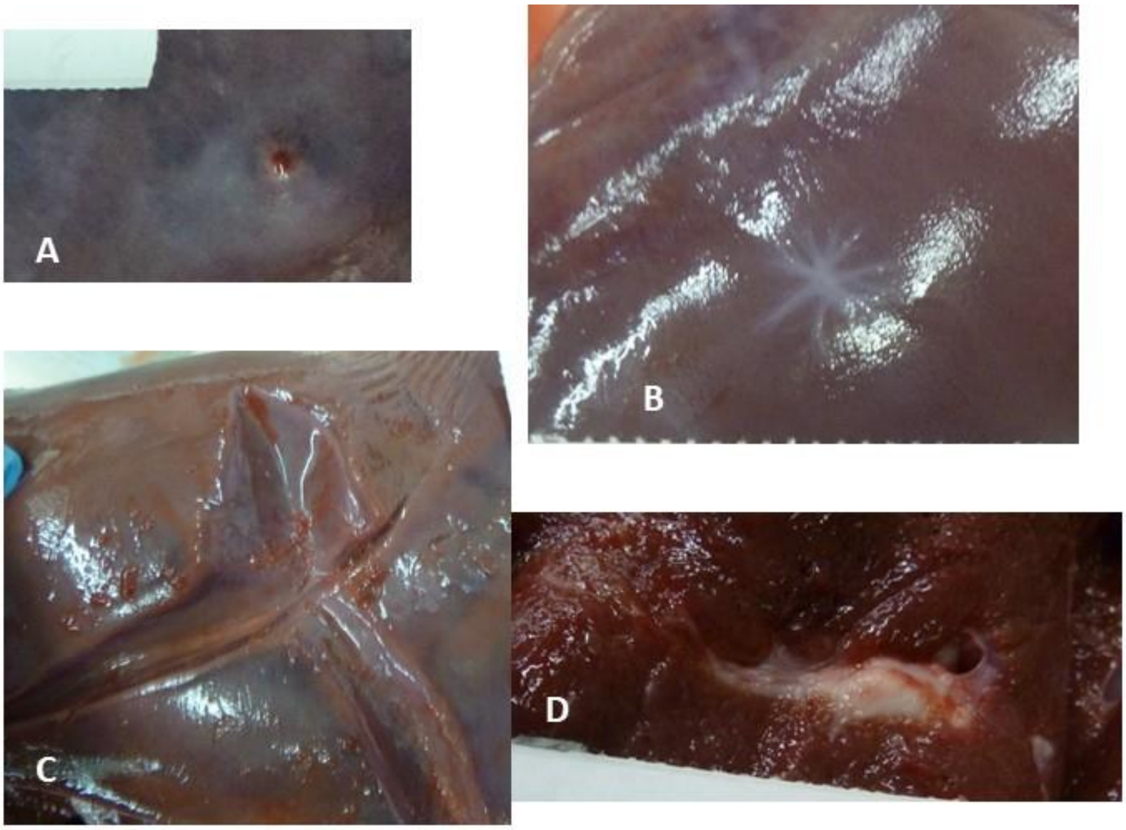


8.2.5 Fluke

Figure 19: Fluke. Variably thickened bile ducts (A, B) +/or presence of adult fluke (C) in bile ducts, finely granular, dark pigment in bile ducts.

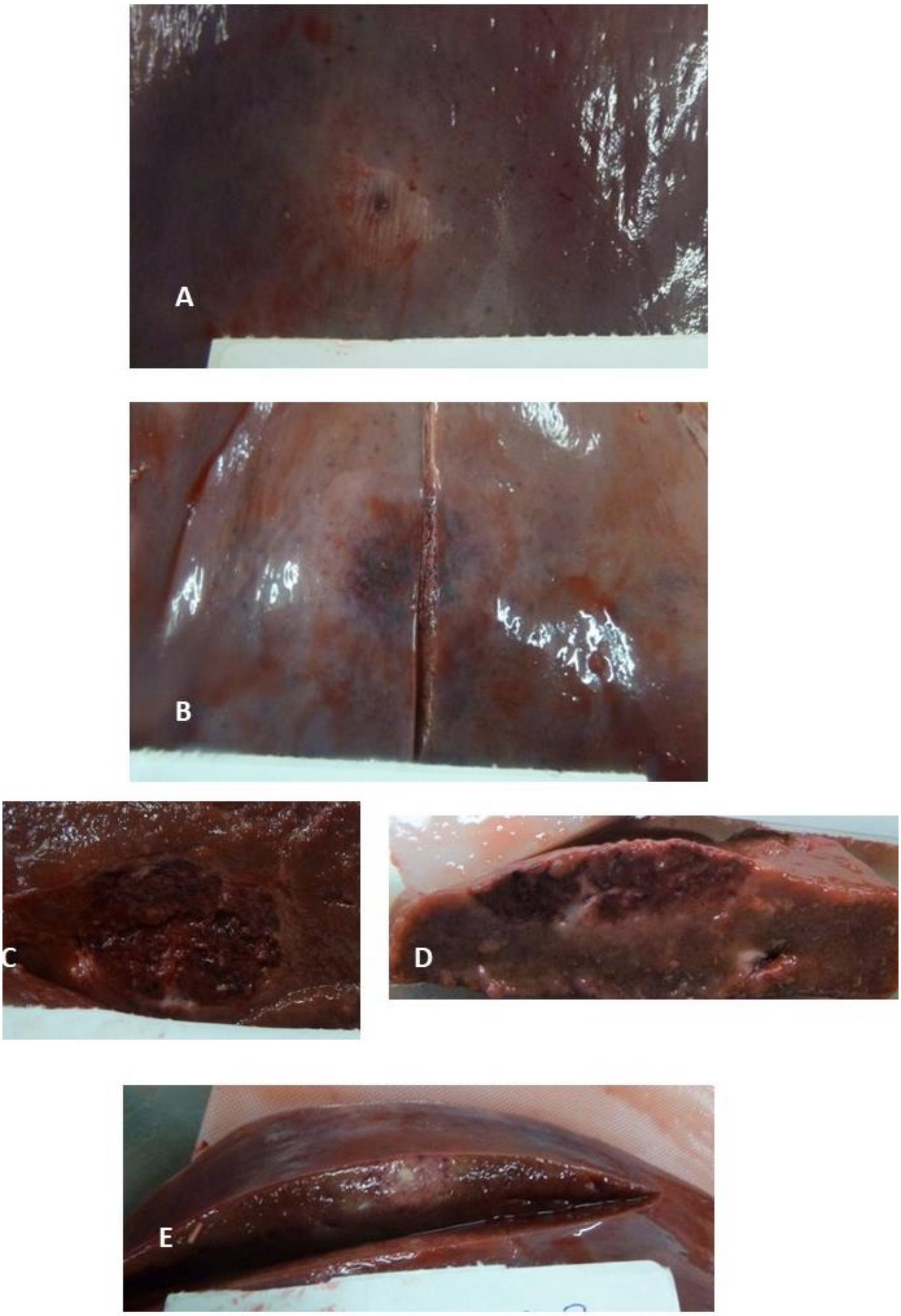
8.2.6 Fibrosis

Figure 20: Fibrosis. Depressed circular, linear or curved, smooth edged lesions in capsule +/- pale, firm, fibrous bands in subjacent parenchyma (A, C). Confluent to slightly depressed, pale, intersecting bands on the capsule without any adhesion (B). Pale, firm, fibrous bands in parenchyma (D).



8.2.7 Hepatitis

Figure 21: Hepatitis. Multifocal dark (often consisting of coalescing pinpoint dark areas, B) and pale, firm, roughly circular confluent lesions (A, B). On cross section, dark-red, confluent areas surrounded by and transected by pale zones (C, D) or dark-red and pale mottling (E).

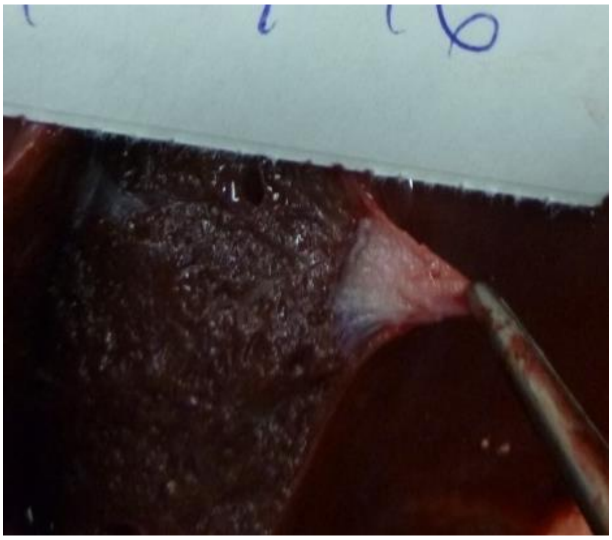


8.2.8 Telangiectasia

Figure 22: Telangiectasia. Pinpoint (not substantially coalescing), confluent, red. No evidence of inflammatory lesions.

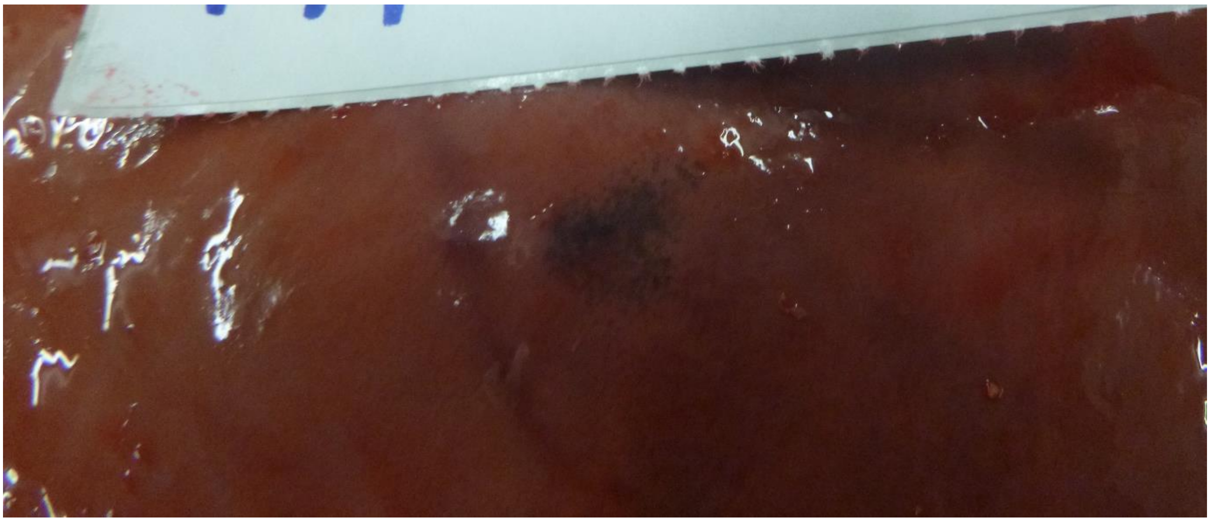
8.2.9 Cyst

Figure 23: Cyst. Circular lesion with pale, thin (not hard) capsule, contains colourless fluid.



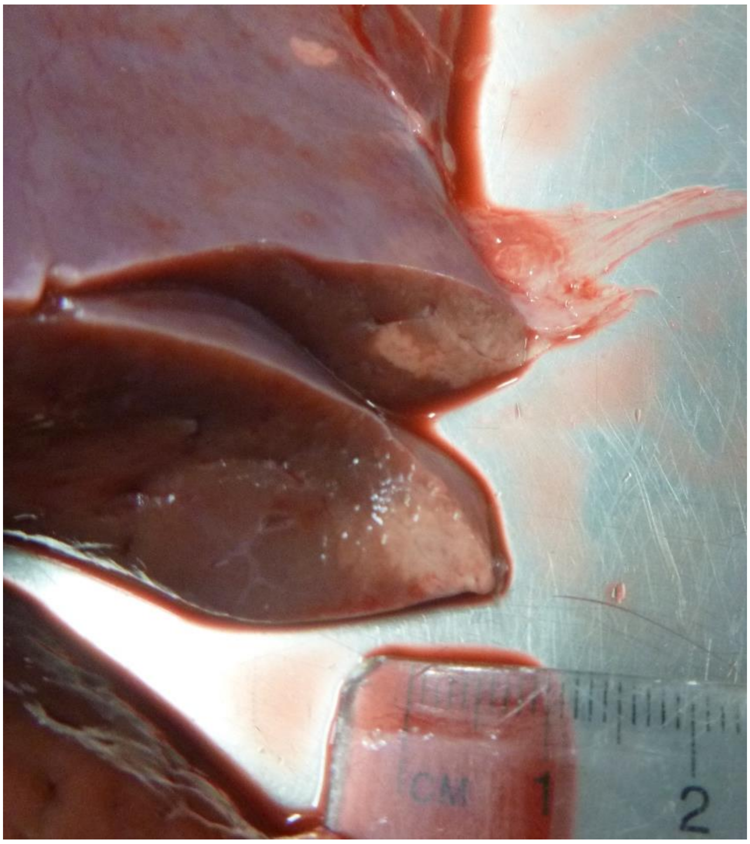
8.2.10 Melanosis

Figure 24: Melanosis. Focal or multifocal, confluent areas of black pigmentation.



8.2.11 Steatosis / glycogen

Figure 25: Steatosis/ glycogen Focal, multifocal or diffuse and confluent areas of pallor with similar patterning and texture to normal liver.



8.3 Prospective study data

8.3.1 Collection dates, breed and numbers of livers graded.

Visit Date	Angus	Wagyu	Mixed	Total
11/02/2020	0	0	308	308
17/02/2020	66	240	0	306
3/03/2020	0	0	215	215
16/03/2020	199	74	0	273
30/10/2020	0	287	0	286
3/11/2020	0	0	470	470
10/11/2020	0	0	424	424
17/11/2020	166	0	300	466
25/11/2020	0	0	206	206
27/11/2020	0	282	0	282
1/12/2020	0	0	475	475
9/12/2020	0	0	411	411
18/12/2020	0	208	0	208
22/12/2020	0	0	440	440
25/01/2021	171	0	6	177
27/01/2021	0	0	368	368
1/02/2021	239	0	240	479
2/02/2021	0	0	320	320
3/02/2021	0	0	307	307
5/02/2021	0	357	0	357
8/02/2021	242	0	281	523
9/02/2021	0	0	535	535
12/02/2021	0	240	0	240
15/02/2021	360	101	118	579
16/02/2021	0	0	497	497
17/02/2021	0	0	320	320
19/02/2021	0	359	0	359
22/02/2021	360	0	0	360
23/02/2021	0	0	541	541
26/02/2021	0	240	0	240
1/03/2021	480	120	0	600
2/03/2021	120	0	108	228
5/03/2021	0	311	0	311
12/03/2021	0	359	0	359
Total	2403	3178	6890	12470
% by carcase type	**19.3**	**25.5**	**55.3**	