Grazing Behaviour and the Microbiome of Extensively Managed Australian Alpacas

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2025

A thesis submitted to fulfil the requirements of the degree of Doctor of Philosophy

This is to certify that the content of this thesis is my own work. This thesis has not been submitted for any other degree or purpose.

I certify that the intellectual content of this thesis is the product of my own work, and that all assistance received in preparing this thesis and all sources have been acknowledged.

Imogen Boughey

I Acknowledgements

There are numerous people I would like to thank for their support, expertise and encouragement throughout the duration of this candidature. Without all of you, this thesis would not have been possible, and I can not express how grateful I am for the support and guidance each of you has provided.

Firstly, I would like to thank my primary supervisor, Associate Professor Russell D. Bush, for not only being a supportive supervisor but also for the great mentorship through the entire candidature. I am incredibly grateful for your open-door policy and for always making time for a quick chat, to answer my many questions and for an in-depth discussion whenever it was needed. I would also like to thank you for always encouraging me to step outside my comfort zone to learn new skills. I would also like to thank my co-supervisor, Professor Alex Chaves, for providing a different perspective and encouraging me to expand my project, which has led to valuable professional experiences and a new skill set.

I would like to extend my gratitude to the Australian Alpaca Association (AAA) for the Industry Development Grant 2023, which enabled the purchase of vital equipment for this research project. I would also like to thank the AAA for their support and distribution of the survey included in this thesis to their membership base. In addition, I would like to thank Anne-Marie for her support during my PhD and for her insights into demographic survey methodologies. I would also like to thank the Royal Agricultural Society Foundation (RASF) for supporting me and this project through the RAS Foundation PhD Research Scholarship. Receiving this scholarship enabled me to carry out the fieldwork included in the thesis, and I am incredibly grateful to be a recipient of this award. This research reported in this thesis was supported by the award of a University of Sydney Postgraduate Award and the James Ramage Wright Supplementary Scholarship.

I also owe a huge thank you to the alpaca producers who participated in all the stages of this research project. To all of those who were able to complete the national survey and influence the research that followed, thank you. Also, to the producers who let me come and visit and collect samples for the faecal microbiome component of this research, I appreciate your contribution, time and willingness to be a part of this research. And finally, an absolutely huge thank you to the producer who was involved in the behaviour and real-time tracking tag research. I cannot express how grateful I am for your contribution of animals, property, time and of course, expertise and friendship throughout this whole process. I would not be here without you, so thank you!

I would also like to thank my colleagues at the University of Sydney in the Sydney School of Veterinary Science for their work and support. Dr Evelyn Hall, thank you for the support, easy-to-understand explanations and answering the many, many questions when it comes to statistics. I have thoroughly enjoyed working with you over the past few years. As the faecal microbiome component was an area that required me to do a lot of learning and development, I would like to thank Dr Francisca Samsing Pedrals and Professor Ruth Zadoks for answering all my questions and guiding me through the process. I would also like to extend my thanks to Anna Waldron and the lab in the Sydney School of Veterinary Science for their support with the DNA extraction from the samples.

As a part of this journey, I was able to work with a range of inspirational mentors. I want to thank Dr Rachael Rodney-Harris from the Australian National University for both your friendship and mentorship during my PhD candidature, as well as your reviewing contributions. I am very grateful to learn from you, and I hope to work with you more in the future. I would also like to thank Duncan Kendall for his mentorship and support of my research and PhD candidature, always ensuring that I could do both the work and research that I enjoy and encouraging new skills in areas I would never have expected to work in.

And last, but definitely not least, I would like to thank my friends and family who have supported me through my PhD journey. To my parents, Louise and Alan, for your endless support and encouragement. To my brother Morgan and my friends who have been here through the journey and been my co-pilots in the chaos, thank you for your laughs, encouragement and distraction when I needed it. A special thank you to Jess, Emma, Millie, and Sarah, who not only checked in but also showed interest (even when I was watching hours of videos of alpacas in a paddock) and were there for the ups and downs. I have to give my housemate, Sarah, a special mention for putting up with me charging a ridiculous number of GoPros and batteries all over the house during the field work period and the support during the ups, downs and fatigue in that stage of the process. A thank you to Rubey for the friendship and expertise with the alpacas! And of course, a huge thank you to my partner Josef. Thank you for being my rock, for listening to me rave on, for always showing interest and answering my questions, but mostly for standing by my side during this whole adventure. I could not have done this without you.

II Author Attribution Statement

Chapter 1 of this thesis has been published as Boughey I, Hall E, Bush R. Australian alpaca demographics and management: A national survey. Animals. 2024 Oct;14(19). doi:10.3390/ani14192861. I designed the study, analysed the data alongside E. Hall and wrote the drafts of the manuscript with reviewing done by R. Bush

Chapter 2 of this thesis has been published as Boughey I, Hall E, Bush R. Daytime paddock behaviour of alpacas raised in an Australian extensive production system: A pilot study. Animals. 2025;15:2357. doi:10.3390/ani15162357. Available from: https://www.mdpi.com/2076-2615/15/16/2357. I co-designed the study with F. Samsing, analysed the data alongside E. Hall and wrote the drafts of the manuscript with reviewing done by R. Bush and R. Rodney.

Chapter 3 of this thesis has been published as Boughey, I.; Hall, E.; Bush, R. Using Real-Time GNSS Tracking Tags to Monitor Alpaca Activity in an Australian Extensive Production System. Agriculture 2025, 15, 1839. https://doi.org/10.3390/agriculture15171839. I designed the study, analysed the data alongside E. Hall and wrote the drafts of the manuscript with reviewing done by R. Bush

Chapter 4 of this thesis has been published as Boughey, I.; Samsing, F.; Hall, E.; Rodney, R.; Bush, R. Characterisation of the Faecal Microbiome of Alpacas Raised in South Eastern Australia. Animals 2025, 15, 1748. https://doi.org/10.3390/ani15121748. I designed the study, analysed the data alongside E. Hall and wrote the drafts of the manuscript with reviewing done by R. Bush

No content produced by generative AI tools has been used in the preparation of this thesis.

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As supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statements above are correct.

Lead Supervisor: Russell Bush

III Abstract

The Australian alpaca industry has continued to develop to provide an alternative natural fibre to wool, angora and mohair since their introduction in the 1990's. The production of alpacas in Australia provides an alternative natural fibre industry along a growing eco-tourism industry as well as meat production. This developing industry has an estimated farm gate value of $13.5 million. However, little is known about the demographic structure of the Australian alpaca industry, as well as baseline veterinary, behavioural, and welfare management. This knowledge gap extends to the rumen and faecal microbiome. The aims of this thesis were to:

1. Establish the current Australian alpaca industry demographics relating to herd size and production purpose, identifying common management practices and issues;

2. Create a baseline understanding of alpaca herd paddock behaviour in an extensive production system;

3. Trial on-farm monitoring technology, including cameras and real-time tracking tags, as a tool to research and manage animal behaviour and welfare; and

4. Characterise the faecal microbiome of alpacas raised in south-eastern Australia to create baseline microbiome data that can be utilised in future research on productivity and health factors associated with digestion and microbial communities.

A national industry survey was conducted to characterise the current industry demographics and identify alpaca management practices, identifying areas that require further investigation. The survey consisted of 25 questions grouped across 3 broad topics: demographics, farm production and alpaca nutrition. The east coast of Australia contained the highest concentration (75%) of alpaca producers, with fewer located in South Australia (17.05%), Western Australia (4.55%) and Tasmania (3.41%). Fibre production was identified as the primary purpose of production, with the Huacaya breed accounting for 93% of animal numbers. Although respondents identified 12 key pasture species being grazed by alpacas, the top three were Kikuyu, followed by Subterranean Clover and Phalaris, which is likely due to the suitable environmental conditions for these pasture types. Pasture species being grazed were unable to be identified by 25% of respondents, highlighting an important area for producer education. The results of this survey provide insight into areas that require further research and development to improve alpaca production in Australia, including improved understanding of alpaca paddock behaviour, nutritional requirements and veterinary care.

To gain a better understanding of management influences, the grazing behaviour of extensively managed alpacas was investigated through video monitoring of 64 adult female alpacas (n = 32 Huacaya, n

= 32 Suri) over 3 days across each season, Summer, Autumn, Winter, and Spring. Grazing was the most frequently occurring behaviour, followed by resting and standing, across all seasons. However, key variations in the frequency of these behaviours were found in different seasons and times of day, with alpacas more likely to be grazing throughout the day (0700 - 1500 AEST) in the cooler seasons (autumn and winter) compared to in the afternoon (1300 - 1500 AEST) in the warmer seasons (spring and summer). Understanding the grazing behaviour of healthy alpacas provides the Australian alpaca industry with tools to develop recommended management guidelines, as well as providing a basis for future research to improve alpaca productivity and welfare in grazing systems.

Using the same animals from the grazing behaviour study, 32 alpacas were fitted with collar-mounted GNSS tracking livestock tags across 10 months. An additional 32 alpacas without tags served as a control group to evaluate the suitability and effectiveness of GNSS real-time tracking tags in monitoring alpaca herd behaviour in an extensive production system and assessing their suitability as a future management tool. No impact was found on the body condition score for the treatment group compared to the control. Building on the observed behaviour, the real-time tracking tags indicated Season had a significant impact on the distance travelled each day, with alpacas moving a greater distance in winter (1.57 km, s.e. 0.029) and spring (1.56 km, s.e. 0.013) compared to summer (1.07 km, s.e. 0.007) and a particular wet autumn (0.43 km, s.e. 0.015). The alpacas also displayed an increase in activity between 0600 and 1600, with the majority (60%) of their activity occurring during daylight hours. This study has demonstrated the ability of real-time tracking tags to be utilised with alpacas for live monitoring as well as for behavioural research purposes. The practical adoption of these tags has the potential to improve animal health through early intervention as a result of real-time monitoring where visual observation is not possible, impractical or provide data that cannot be identified visually.

To provide an understanding of the alpaca faecal microbiome which will potentially lead to improved management in Australia, faecal samples were collected from 59 healthy adult female alpacas from 5 herds across New South Wales. Firmicutes were identified as the dominant phylum, accounting for 57.78% of the cumulative abundance, followed by Bacteroidota (29.12%). This is a trend also observed in other ruminant livestock species such as cattle and sheep. Although Firmicutes and Bacteroidota were identified as dominant taxa across all samples, the cumulative abundance differed significantly between locations ($p < 0.05$), potentially due to variations in environmental conditions and feed. The characterisation of the faecal microbiome of alpacas in New South Wales provides important baseline information, with further research needed to investigate the difference in microbiome communities on animal health and productivity, such as nutrient absorption and growth.

Together, the collection of research contained in this thesis characterises the current Australian alpaca industry and provides useful knowledge to enhance alpaca productive and health. The work presented in thesis provides new data on the paddock behaviour of Australian alpacas in an extensive environment as well as highlighting practical examples of the use of livestock monitoring technology to improve alpaca monitoring and management with further opportunities for industry development and adoption. Additionally, a baseline characterisation of the faecal microbiome of Australian alpacas establishes a valuable reference point for future alpaca-focused research and veterinary applications. Further development of alternative fibre industries, including the Australian alpaca industry, provides diversification of products for use in textiles for a wide consumer base as well as an alternative livestock production option for varying environments.

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VI Abbreviations

AEST Australian Eastern Standard Time

ADG Average Daily Gain

BCS Body Condition Score

DM Dry Matter

DSE Dry Sheep Equivalent

FEC Faecal Egg Count

GNSS Global Navigation Satellite System

GPS Global Positioning System

ha Hectare

NSW New South Wales

PEM Protein Energy Malnutrition

QLD Queensland

SAC South American Camelids

SA South Australia

TAS Tasmania

μ**m** Micron

VIC Victoria

VHF Very High Frequency

WA Western Australia

1 Introduction

Alpacas (*Vicunga Pacos*) were first introduced into Australian agriculture as an alternative fibre industry to wool from sheep and mohair from angora goats in the late 1980s [1, 2, 3]. There are two alpaca breeds, the huacaya with fibre diameter ranges between 16 - 40µm, and the suri with a fibre diameter range of 16 - 35µm [4]. Alpaca fleece has become a popular luxury fibre worldwide due to its softness, with similar characteristics and end uses to wool, including jumpers, outerwear, and suiting [3]. Fibre production in the Australian alpaca industry had an estimated farm gate value of $13.5 million in 2022 [2, 5]. In addition to fibre production, alpacas have been used for both meat and leather (hides) [6, 7]; as well as guard animals [6]. However, with limited access to suitable meat processing plants, it is unknown how many alpaca producers are still providing animals for meat in Australia. As the Australian alpaca industry contains a large number of smallholder farms [5, 8, 9], the keeping of alpacas as pets and guard animals is very common, with a suggested farm gate value of $5 million [5, 10]. There is no current data reported on the primary production purpose of alpacas owned in Australia. Current information would be beneficial for key industry bodies in understanding the changing industry structure as well as providing relevant education resources.

Since alpacas' were introduced into Australia, the industry has grown with 788 alpaca breeders registered with the Australian Alpaca Association as of August 2022 (Annemarie Ashton-Wyatt, Personal Communication, August 9th 2022) and an estimated 350,000 alpacas [5]. As of 2022, it was widely considered the Australian alpaca industry comprised mainly small-scale enterprises running between 2 and 50 alpacas, with fewer medium- and large-scale enterprises [6]. The majority of producers at this time were located in the temperate regions of Australia [5]. In 2019, Rashid et al. [6] were able to present key husbandry information collected in an industry survey. It was reported that the average weaning age was less than 5 months, which is consistent with anecdotal evidence in the broader alpaca industry [6]. Despite understanding that the herd numbers vary as low as 2 and up to 1150 [6], it is unclear how husbandry and management practices differ between small-, medium- and large-scale operations. It is very common in Australia and other countries to co-graze alpacas with other ruminants, including sheep, cattle and goats [6, 11]. Co-grazing alpacas with sheep is common and most likely due to their similar management requirements as well as the alpacas' ability to bond well with other livestock species [10]. It is this ability to bond and their innate protective instinct that leads alpacas to be grazed in small numbers with sheep (and goats) as guardian animals [10, 12].

The limited survey data from Australia alpaca producers means further details on husbandry and management practices is needed. Alpaca nutrition practices have previously been referred to as being "short on science and long on art" [13]. The current nutritional requirements for alpacas are mostly extrapolated from other small ruminant species, commonly sheep [13, 14, 15]. More recent research has assessed the safety of feeding supplementary grain to alpacas, concluding that feeding a supplement grain can be a safe method to increase growth rate [16]. Other than the grain supplementation research conducted by Smith et al. 2017 [16], there has been minimal investigation into the feeding management of Australian producers with an exception of the survey conducted by Rashid et al. 2019 that identified feeding supplements was common [6]. Rashid et al. reported 92% of respondents identified providing supplement feed in the form of hay or pellets, particularly during feed gaps in cooler months [6]. However, no further studies have examine supplementary feeding in Australian conditions.

The adoption of husbandry practices in the Australian alpaca industry is largely based on anecdotal evidence due to minimal published reports or literature. However, vitamin D supplementation in lower altitude environments including Australia to correct deficiencies has been one area. [17, 18, 19]. Since understanding the need for vitamin D supplementation has improved in Australia, industry knowledge indicates alpaca producers are regularly providing their animals with vitamin D. Although formal adoption data is not available, anecdotal evidence supports the use of practical based research into husbandry and management for Australian-raised alpacas.

One of the current barriers to improving animal production in alpacas is the lack of scientific baseline information on grazing behaviour and other management practices, including accurate nutritional requirements in the Australian environment. Improving the knowledge available in this field would assist in improving management guidelines specifically formulated for alpacas in the Australian environment as opposed to different environmental conditions worldwide or extrapolated from sheep and cattle practices.

1.1 Alpaca Behaviour

The current understanding of alpaca behaviour, particularly in the Australian environment, is largely based on anecdotal evidence and assumptions based on comparisons with sheep as a similar fibre-producing small ruminant species [11, 20, 21, 22]. Previous research focusing on the selective feeding behaviour of alpacas, including comparisons with other livestock [11, 20, 21, 22], key anatomical differences that influence grazing behaviour [4, 23], and to a more limited extent, diurnal behaviour of alpacas [23, 24]. Grazing, standing and resting are three behaviours that have been consistently identified by studies as common behaviours displayed by alpacas in different environments [22, 23, 24].

1.1.1 Grazing Behaviour

Alpacas have been found to preferentially graze shorter pastures (up to 30cm in height, following grazing by sheep or cattle), instead of taller pastures (over 30cm in height) in both their native environment of Peru as well as in American and Australian studies [11, 20, 22, 25]. In addition to preferring shorter pastures, alpacas display a preference for pastures that have previously been grazed [11]. The preference for shorter pastures persists even when alpacas are sequentially grazed with cattle. However, this differed from their pasture selection during mono-grazing (single-species grazing) with increased tall grasses selected in the mono-grazing trial compared to when sequentially grazed with cattle [20]. The selection of tall grasses in mono-grazing is likely due to an increased pasture availability compared to pastures in which cattle have previously selectively grazed the taller pasture species [20]. The common preference for shorter grasses by alpacas is possibly due to their dental anatomy; the incisor teeth that are fixed to the lower mandible and press against the upper dental pad [4] along with the labial cleft, which splits the upper lip [4]. By independently controlling movement of each side of the upper lip, alpacas can push aside or hold the upper lip away from the dental pad and teeth, enabling the incisors to be moved closer to the ground [26]. The anatomical differences between alpacas and other commonly grazed small ruminants, such as sheep and goats, support some grazing behaviour differences. However, there is limited research into the normal behaviour of extensively raised alpacas in Australia to conclude appropriate management recommendations and tools.

The grazing behaviour of alpacas in their native South American environment changes between the dry (little to no rain, May to October in Peru) and wet seasons (November to April in Peru) [22, 27]. During the wet season, alpacas have been reported to spend between 50% and 60% of their time grazing plants near ground level, also consuming a lower amount of organic matter [22, 27]. In Australia, it is known that seasonal variation in nutritional conditions impact live weight and fibre diameter [11]. In conditions where green pasture availability was reduced (<0.5 t DM/ha), alpacas lost weight, whilst weight gain was recorded when green pasture availability was above 0.5 t DM/ha ([11]. Additionally, alpacas had reduced fibre growth during periods where live weight was negatively impacted [11]. Despite this production and health trait knowledge, there is no published literature on seasonal variation in normal grazing behaviour in Australian extensive production systems, highlighting an area for further research.

Another aspect of alpaca grazing behaviour to note is their grazing habits across a 24-hour period (diurnal grazing habits). A New Zealand study by Sharp et al. [23] compared the timing of grazing activity between sheep and alpacas. Sharp et al. [23] reported that alpacas exhibited increased grazing activity between 0700 h and 1850 h, with minimal rest periods observed in the herd during these hours. This finding is supported by Davies et al. [28] and Robinson et al. [29], who observed that the majority of grazing and feed consumption occurred during daylight hours. Ruminating activity by alpacas at night was observed to be significantly more than that of sheep in the same environment [23]. This behaviour reflects the traditional management practices of alpacas in South America [22]. When farmed in their native environment, alpacas are let out to graze during daylight and corralled at night due to the risk of predation and theft [22]. In extensive livestock production in Australia, animals are generally kept in paddocks day and night, as opposed to being corralled indoors at night. It is essential to determine whether the diurnal behaviour of alpacas is influenced by conditions that promote daylight grazing trends, as observed in other countries, to inform management recommendations for Australian alpaca producers.

The importance of understanding the grazing behaviour of livestock is primarily focused on improving animal health, welfare, and production, as well as land management practices [30, 31, 32]. Evidence of utilising an increased awareness of animal behaviour in livestock production has been well researched in sheep and cattle [30, 32, 33], with early work focusing on reducing stress during handling and husbandry practices [32]. Reducing stress through practices such as low-stress handling techniques and designing infrastructure to complement normal livestock behaviour has been shown to reduce the time it takes cattle return to feed as well as minimising the risk of injury associated with panic or stressed movements [32, 34]. The early detection of illness in livestock species can assist in facilitating early mitigation of the risk of disease spread as well as aiding in faster recovery times and improved health outcomes [33, 35]. However, to detect early signs of illness or the occurrence of injury, the deviation from expected behaviour needs to be recognisable, highlighting the importance of understanding expected livestock behaviour in production systems to optimise production and improve animal health and welfare [32, 33, 35].

1.1.2 Resting Behaviours

Resting behaviours including ruminating (chewing cud), sitting in cush (a specific alpaca behaviour where the legs are tucked under the body) and lying down. The amount of time spent ruminating (rumination time) can be a good indicator of animal health in ruminant species as it is associated with digestion and eating [36]. However, studies that have looked at this in alpacas are limited. In alpacas raised in New Zealand, ruminating occurred more during night hours then daylight [23]. This is also different to sheep where rumination was more evenly spread throughout a 24 hour period [23]. Increased rumination levels during night time periods in alpacas are consistent across different countries and production conditions (extensive vs housed inside at night) [22, 37]. In Australia, the behaviour of alpacas as herd guards in an extensive system has demonstrated a similar trend with with lower activity levels during the night [38]. This indicates the increased resting behaviours in alpacas, including rumination, that occurs during the night differs from other small ruminant species such as sheep [23, 38]. The reason for the night time rumination is possibly due to innate natural behaviour trends of alpacas in native environments where domesticated camelids are housed inside for predator protection, also resulting in grazing occurring to a higher degree during the day [22, 23, 24]. This research is largely based on small herd sizes or alpacas co-grazing with other livestock, highlighting an opportunity to confirm these trends in alpacas managed under extensive conditions more characteristic of Australian production systems.

1.1.3 Standing Behaviours

Standing behaviours, which in some studies includes walking without grazing ([23]), are an important indicator of activity levels as the animals are alert and not in a resting state or displaying other higher activity behaviours such as rolling. Although time spent standing has not been well investigated, Sharp et al. [23] reported that in an extensive grazing production system in New Zealand, alpacas spend more time standing (and walking) during daylight hours. The study by Kapustka and Bydzynska ([24], in which alpacas were housed in a stable overnight, reported that alpacas spent 8% of the morning period (0700 - 1200) standing and only 2% of the afternoon (1200 - 1600). Standing occurred the most during evening periods (12%)(1600 - 2000) [24]. Conversely, alpacas being kept as herd guards for sheep in an Australian production system trended towards a longer standing time in the morning (0900) than in afternoon (1500 and 1800) [38]. As there is a limited amount of research into alpaca behaviour, further research would be beneficial to understand the occurrence of specific behaviour such as standing and the implications for herd management.

1.2 Livestock Behaviour Monitoring Technology

Precision agriculture technology and farming is incorporating the use of technology and on-line or remote systems to improve animal welfare and production efficiency. As precision agriculture technology from water sensors and virtual fencing to animal monitoring devices continues to develop on a global scale, agriculture is continuously working to adopt new technology with the aim of improving livestock health and welfare, production efficiency, crop yields, and environmental management. Prior to the utilisation of remote tracking technologies, animal movement and behaviour were monitored by human observers, often over only a few days [39, 40]. The benefit of adopting this technology in both research and industry is the ability of the technology to track animals over longer periods, including across seasons [39, 40]. For livestock, the primary benefit lies in improved understanding of the distance travelled, enabling more accurate assessment of energy expenditure and adjustment of nutritional requirements, as well as identifying potential health issues or injuries through changes in behavioural trends such as rumination levels [41, 42]. Global Navigation Satellite Systems (GNSS) and accelerometers are two key technologies being used increasingly in livestock production for animal management purposes.

Global Navigation Satellite Systems (GNSS) are systems that estimate the position of a specific device [43]. The first and one of the most well-known types of GNSS systems is the Global Positioning System (GPS), owned and operated by the United States of America [44]. GPS was developed in 1973 and initially named NAVSTAR for military use [43]. It was not until the commercialisation of GNSS technologies that GPS and other technologies were used for animal (including wildlife) tracking in 1991 [43, 45]. Prior to the use of GNSS technology, Very High Frequency (VHF) radio devices, including collars, were used, particularly on wild animals [45]. Key factors that have positively benefited the uptake of modern GNSS tracking devices for animals are the reduction in size of the device and the improvement in cost, performance and reliability (including battery life) [40, 45]. GNSS technologies are advantageous for livestock and animal tracking, as the systems continue to function in poor weather conditions, such as rain and cloud cover, where other technologies, are limited [43]. Another benefit for use in grazing livestock is the technology's ability to detect location in remote and rugged environments [39], where human observation or satellite imagery may be limited. GNSS devices are beneficial in behaviour monitoring for livestock systems as they are operational on a 24-hour basis and do not require human observers to pinpoint location or movement [39, 40].

Accelerometers are another technology commonly used in contemporary livestock monitoring systems. They record movement through measuring the acceleration of animals or object the accelerometer is attached to along one, two or three axis [40] Accelerometers are not a new technology, with the earliest commercialised product in use by 1923 in bridges and infrastructure, with further development leading to the two-axis accelerometer in 1936 for a wider range of uses, including aircraft and military, to elevators [46]. The first version of the modern triaxial accelerometer was developed in the late 1960s [46]. The development of triaxial accelerometers enables the devices to detect changes in movement of the device along the X-axis (forward and backward), Y-axis (side to side), and Z-axis (up and down) [47]. Accelerometers have been used in livestock, mainly sheep and cattle, to research and monitor animal behaviour, including lying down, grazing, standing, walking and even ruminating [47, 48]. One of the valuable types of information regarding livestock behaviour that can be detected by accelerometers for livestock producers is periods of activity versus non-activity [49]. The activity of calves and pigs was successfully detected using accelerometers attached to the animals' bodies by Rodriquez-Baena et al. [49]. However, a limitation was the need to remove the devices to download the collected data. The successful detection of reductions in activity continues to emphasise the practical use of this type of technology, further highlighting the value of commercially accessible technology that has the capacity to remotely transfer data to reduce the need for additional animal handling.

There are substantial benefits to being able to remotely monitor livestock with regard to their location, movement and behaviours. Individually, both GNSS and accelerometer technology provide researchers and producers the ability to monitor livestock for improved health and welfare outcomes [40, 47, 48, 50]. Although the first versions of both devices were developed some time ago, it has not been till relatively recently that there has been an increase in uptake in agricultural production enterprises. In the early development of accelerometers in the 1930s, the cost was prohibitively high for use in livestock research and application, being priced at over USD$400 [46]. As technology and manufacturing of these types of devices have developed, the cost has reduced and become substantially more affordable, with livestock tracking devices utilising both GNSS and triaxial accelerometers on the market in Australia from AUD$69 [51]. The reduction in cost per device for commercially available products coupled with high accuracy suggest that real-time tracking tags or collars provide a real opportunity to enhance for individual animal management in herd-managed livestock, including extensive production systems [52, 53]. The key benefit in moving from traditional visual monitoring is that remote tracking technology has the ability to frequently monitor animal behaviour as well as activity patterns [40, 54]. Technology that has combined both GNSS and triaxial accelerometers in wearable devices for livestock, including collars and ear tags, has provided a valuable and functional monitoring system. Devices using both GNSS and accelerometer technology have been shown to have a high accuracy ($> 98\%$) in monitoring livestock grazing and resting behaviours [52, 53]. From a research perspective, incorporating this technology into behaviour studies enables long-term movement trends and distance travelled averages to be calculated with precision for use in improving the knowledge base on animal behaviour, extending into informing energy requirements and seasonal changes [39]. However, further information needs to be collected to determine the specific suitability and opportunities for use in extensively raised alpacas.

The combined GNSS and accelerometer technology continuously monitors the animal's movement and velocity [39] with digital consumer platforms designed to identify abnormal changes in movement and velocity to alert producers of potential health issues. The obvious health and welfare issues that can be detected are physical injuries that suddenly significantly decrease the level of movement the animal is exhibiting. However, health aspects such as disease detection can also be indicated through changes in movement, but also body placement, such as changes in head movement [55]. Through tracking the coordinate location of each animal, the ability to ascertain where a sick animal has interacted with other animals (and the length of time) can also be determined [40, 55] for the purpose of early quarantine, detection and treatment if required. Examples of practical applications of real-time livestock tracking technology include the use of GNSS and accelerometer collars in intensively raised dairy cattle [50]. For some time now, due to the ability of the technology to detect rumination and movement, this type of technology has been used to detect heat stroke and important health events that may require early intervention, such as calving [28, 56]. The specific alerts and behaviour monitoring that is available for dairy cattle is due to extensive research into cattle behaviour in dairy production systems [50, 57]. Another beneficial aspect of using real-time tracking technology and the associated digital platforms available with commercial products is the ability to identify interactions with points of interest, including water sources or supplement feed (e.g. lick blocks) [39]. This can assist in understanding the amount of time spent consuming supplements or changes in activity when supplements or supplement feed are added to the diet [39, 58].

1.3 Alpaca Digestion and Faecal Microbiome

Alpacas are pseudo-ruminants, having 3 stomach compartments (C1, C2 and C3) compared to the 4 compartments of true ruminants [4, 59, 60]. Despite this difference, they similarly utilise bacterial fermentation in the forestomach region for the breakdown of complex carbohydrates [59, 61]. C1 is the largest compartment, consisting of cranial and caudal sacs divided by a transverse pillar, accounting for approximately 50% of abdominal volume [59, 61]. The C2 compartment is connected to the first compartment, sitting medial to C1 and atop the C3 [59, 61]. These two compartments make up 85 - 80% of gastric volume, accounting for 10% of adult body weight in the alpaca [14, 59]. The C3 compartment is connected to the C2 via a narrow ventricular groove [14, 62]. This tube is what enables the digesta (milk) to bypass C1 and C2, travelling directly to C3 in neonates, similar to the ventricular groove in true ruminants [14, 62]. Compartments C1 and C2, and 80% of C3, are the location for forestomach microbial fermentation in the digestive tract [59]. Compared to other ruminants, South American Camelids (SAC), including alpacas have a high buffering capacity due to an increased saliva production to forestomach volume ratio, providing a suitable dilution environment for cellulolytic bacteria [15, 59, 63]. Although the alpaca digestive tract is similar to a true ruminant, the difference in the functional layout requires further species-specific research for informed management recommendations.

As ruminants rely on microbial fermentation for nutrient extraction and digestion, the ruminant microbiome plays a crucial role in the absorption of nutrients and feed efficiency [64, 65, 66]. It is important to understand the characterisation of the microbiome in a healthy animal, as variation from the healthy characterisation has been linked to metabolic diseases [67] and reduction in growth rates [68]. Across key ruminant species used in livestock production around the world, including sheep, cattle and goats, the Firmicutes and Bacteroidota phyla have been identified as the two dominant phyla [68, 69, 70, 71, 72]. It is important to note that the proportion in which these two groups exist varies [68, 69, 70]. However, bacteria belonging to the Firmicutes phylum are consistently present in a higher proportion compared to Bacteroidota [68, 69, 70]. Further studies in true ruminants have reported that the role of bacteria in the Firmicutes phylum is to break down carbohydrates into energy that is then utilised by the animals [73]. Again, the ratio of the two dominant phyla has displayed importance in production efficiency with a reduced average daily gain of weaning cattle where there was a lower frequency of Firmicutes and higher Bacteroidota [68]. As we understand more about the role of specific bacterial communities in the ruminant microbiome, health and feed management practices can be adapted to improve production and animal health outcomes.

As alpacas are pseudo-ruminants, there is variation in the digestive process compared with true ruminants, raising the question: Does the alpaca microbiome follow similar trends to ruminants? The microbiome of alpacas has been researched to a limited extent in the USA and China [74, 75, 76], with no known Australian based studies. Similar to true ruminants, Firmicutes and Bacteroidetes were the dominant phyla in the populations of alpacas and camels studied [74, 77, 78, 79]. There is some variation in the dominant phylum reported with two studies also noting the presence of Eubacterium [75, 76]. However, there is currently not enough research to draw a conclusion whether this difference is due to management practices or population differences, highlighting the importance of further research in this field across varying environmental conditions.

To analyse microbiome populations, most commonly, rumen fluid samples are collected by either a rumen cannula or oro-esophageal tubing [80]. This has made it difficult to investigate the microbiome, particularly in new species where these collection processes are not common, as it requires specialist expertise for both the collection and processing of samples [74]. There is evidence that the microbial communities found in the lower digestive tract are comparable to those found in faecal samples [81, 82], enabling the gut microbiome to be characterised. The current information on the alpaca microbiome is largely focused on forestomach fluid and digesta samples from various parts of the gastrointestinal tract. However, faecal samples have been used for characterisation and further analysis without the need or invasive tubing [74, 83, 84]. Although previous research had different focal points, studies that used rumen fluid and digesta have yielded similar results, reporting Firmicutes and Bacteroidota as the dominant phyla [74, 83, 84]. The use of faecal samples to characterise microbiome provides a non-invasive option that is more accessible to researchers and for future use in the alpaca industry.

1.4 Aims of This Thesis

Based on current knowledge, several areas worthy of further investigation have been highlighted. The goal of the research presented in this thesis is to assist the Australian alpaca industry in understanding alpaca behaviour and evaluate potential tools to improve alpaca production and management. As there is limited research on alpaca raised in the Australian environment, assessing the current industry demographic information and production knowledge is a crucial starting point. This collection of research aims to create a baseline understanding of alpaca herd behaviour in an extensive production system, trialling monitoring technology that has the potential to be suitable for on-farm adoption as an integrated management tool. Additionally, to improve the knowledge of alpacas in Australia with regards to health and production, this thesis utilised faecal microbiome characterisation as a tool to create baseline microbiome data that can be utilised in future research on productivity and health factors associated with digestion and microbial communities.

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2 Chapter 1: Australian Alpaca Demographics and Management:A National Survey

This Chapter has been published in Animals.
Boughey I, Hall E, Bush R. Australian alpaca demographics and management: A national survey. Animals. 2024 Oct;14(19). doi:10.3390/ani14192861.

The current recommendations for many important alpaca management practices are extrapolated from sheep or other larger camelids (llamas and camels), including vaccinations [1], intestinal parasite control and treatment [2] and nutritional requirements [3, 4]. Gaining an understanding of current common management practices on Australian alpaca farms will provide an important baseline for evaluation and potential recommendations for improvement.

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Australian Alpaca Demographics and Management: A National Survey

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Simple Summary: The Australian alpaca industry is known for fibre production. Despite the growth of alpaca numbers since their introduction in the 1980s, little is known about their distribution or on-farm management practices in Australia. This study used an online survey to gain insight into the current demographics, animal management practices and key knowledge gaps. Of the 88 respondents, the majority were located in the high-rainfall areas of the east coast of Australia, which could be due to consistent year-round pasture availability and market access opportunities. Of the two alpaca breeds, the Huacaya accounted for 93% of the animal numbers reported in this survey. Twelve key pasture species were identified, with Kikuyu the most common, followed by Subterranean Clover and Phalaris, likely due to the high concentration of respondents in suitable high-rainfall environments. Pasture species were not identified by 25% of respondents. The off-label use of veterinary chemicals for disease and parasite control resulted in a variation in dosage rates and administration frequency, raising concerns for effective management. These results highlight important knowledge gaps in nutritional and health management practices that require further research and practical industry recommendations to improve alpaca health and productivity.

Abstract: The Australian alpaca industry has continued to grow since the introduction of alpacas in the 1980s. Little is known about the geographical distribution of alpacas or on-farm management practices. This study aimed to address this and identify key producer knowledge through an online survey. The survey consisted of 25 questions grouped into 3 areas: demographics, farm production and alpaca nutrition. The highest concentration of alpaca producers was along the east coast of Australia, primarily in high-rainfall zones, which could be attributed to more consistent year-round pasture availability and market access opportunities. The Huacaya breed accounted for 93% of the animal numbers reported in this survey. Respondents identified 12 key pasture species being grazed, with Kikuyu being the most common, followed by Subterranean Clover and Phalaris, likely due to the majority of respondents being located in suitable high-rainfall environments. Pasture species were not identified by 25% of respondents. There are no registered anthelmintics or vaccinations for alpacas, resulting in a variation in dosage rates and administration frequency, raising concerns for effective disease and parasite management. This survey has identified key knowledge gaps in alpaca management practices in Australia that will be further investigated to provide industry recommendations to improve alpaca production.

Keywords: alpaca; demographics; survey; farm production; animal management

Citation: Boughey, I.; Hall, E.; Bush, R. Australian Alpaca Demographics and Management: A National Survey. *Animals* **2024**, *14*, 2861. https://doi.org/10.3390/ani14192861

Academic Editor: Laura A. Reese

Received: 28 August 2024
Revised: 26 September 2024
Accepted: 27 September 2024
Published: 4 October 2024

1. Introduction

The Australian alpaca industry began with importations from South America in the 1980s to 1990s to develop an alternative animal fibre industry [1,2]. The Australian alpaca industry has continued to grow in Australia with an approximate current population of 350,000 animals spread across the temperate regions of Australia [3]. Previous survey studies into the Australian alpaca industry have focused on worm control [4], the management of other common diseases such as vitamin D deficiency and staggers [5–8], fibre and meat production [2,9–13] and an overview of smallholders and animal health management across various livestock industries [14]). There has been no previously published general demographic or farm management survey data for the alpaca industry in Australia. Improving livestock productivity can lead to increased farm income and business profitability [15,16]. However, as nutrition and herd management are key factors impacting livestock productivity, limited information for Australian-raised alpacas creates a barrier for future improvement [15]. Improving the productivity and sustainability of the Australian alpaca industry requires identification of current practices and issues. Alpaca management practices in Australia are often derived or extrapolated from recommendations for sheep, including worm control [4,17], vaccination [7] and nutrition and feeding guidelines [18,19]. Prior to 2019, there was no demographic information on the Australian alpaca industry. Rashid et al. [4] included demographic questions in an industry survey in 2019 to determine internal parasite control practices in Australian alpacas. An average herd size of 57 alpacas was determined, with 67% of producers keeping the Huacaya breed [4]. It is important to establish updated data since 2019 to establish the industry's growth and identify issues that have arisen to provide informed research and resources to improve industry productivity. This study aimed to provide current industry demographics on the Australian alpaca industry and identify common management practices and issues. This advanced understanding of current management practices will enable alpaca-specific guidelines that improve productivity to be developed.

2. Materials and Methods

2.1. Survey Participants

The survey was open to any individual or entity owning alpacas in Australia with participation optional. The survey was distributed through industry channels, where members agreed to receive correspondence, as well as social media. The survey was also promoted at industry events, including Agricultural Shows, where the survey electronic link was provided to interested producers. All data collected from submitted responses were non-identifiable, with participants submitting the postcode where their alpacas reside to determine geographical spread. Human ethics approval was granted by The University of Sydney Human Ethics Committee (project number 2022/720).

2.2. Survey

The survey was conducted using the Microsoft Forms online platform. The survey comprised 35 questions grouped into 3 key areas: alpaca nutrition, farm production and farm demographics. Of the questions,10 were close-ended with several options, 7 were semi-open-ended (e.g., with an 'other' option), and 15 were open-ended where providing options was not suitable (e.g., a numerical answer was required). The alpaca nutrition section contained questions on animal health and management to identify common procedures, nutrition, and key animal-related issues. In this section, respondents were asked to select their ideal body condition score (BCS) for different production classifications. BCS is ranked between 1 and 5, with 1 being severely underweight and 5 obese, as BCS is a reflection of nutritional status [20]. Vaccination frequency was divided into 4 categories for statistical analysis; 4 times a year, every 6 months, yearly and never. The frequency of veterinary visits was split into less than once per month, 1 to 5 visits per month, 1 to 5 visits per year. The farm production section contained questions regarding land management, including stocking rate and key pasture species. Stocking rate was measured in number of alpacas per hectare. The farm demographic component focused on the location of properties and herd qualities including breed, sex and animal number. Respondents were asked to identify their production conditions based on annual rainfall amounts. High-rainfall zone areas receive >600 mm annual rainfall, sheep/wheat zone receives 300–600 mm rainfall and pastoral zone <300 mm rainfall.

2.3. Statistical Analysis

Analyses were performed using R Version 4.4.1 [21] and Microsoft Excel 2018 [22]. Survey data was downloaded from Microsoft Forms as an Excel (xlsx) file before being formatted and saved as a comma-delimited (CSV) file to be imported into R (R Core Team, Vienna, Austria, 2022). Farms were categorised in herd size based on the animal numbers provided. Small scale included farms with up to 49 alpacas, medium-scale farms with 50 to 249, and large-scale farms with more than 250 alpacas. These brackets were chosen based on industry structure and similarities within the husbandry and management practices of farms within those brackets. For each variable, descriptive statistics were carried out using Excel [22]. Linear models were used to determine the effect of the production zone on the stocking rate. Generalised linear regression (GLR) models were conducted to assess the impact of production zone and herd size on vaccination frequency, seasonal ill thrift ranking (season in which highest rate of ill thrift occurs), stocking rate, pasture species, supplement types, and frequency of veterinary visits. A *p*-value of <0.05 was considered significant.

3. Results

The database contained 90 responses; 2 responses did not agree to participate and were excluded from the survey, leaving 88 responses.

3.1. Demographic Information

New South Wales (NSW) recorded the highest number of responses, with 35.2% of respondents, followed by Victoria (VIC) with 27.3%, South Australia (SA) 17.0%, Queensland (QLD) 12.5%, Western Australia (WA) 4.5% and Tasmania (TAS) 3.4% (Table 1). There were no respondents from the Northern Territory or the Australian Capital Territory The majority of respondents were located along the east coast of Australia (Figure 1). As the farm scale increases, the properties are located further inland, with the exception of South Australia (Figure 1). The high-rainfall zone (>600 mm) was selected by 52.3% of respondents, followed by 37.5% in the sheep/wheat zone (300–600 mm) and 10.2% of respondents located in the pastoral zone (<300 mm). NSW has the highest number of small- and medium-scalefarms followed by VIC. However, VIC reported three large-scale farms compared to two in NSW.

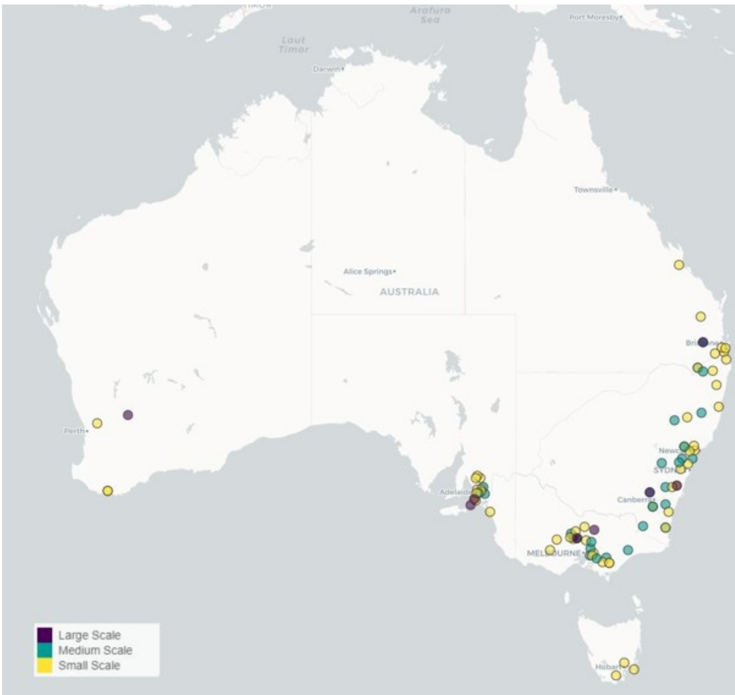

Figure 1. The location of respondents based on postcode. Colours depict farm scale. Small scale ≤49 alpacas, medium scale 50–249 alpacas, large scale ≥250 alpacas.

Table 1. Summary of location (state) and farm scale of survey respondents.

Farm Scale	NSW	QLD	SA	TAS	VIC	WA
Small Scale (≤49 alpacas)	16	7	10	3	13	3
Medium Scale (50–249 alpacas)	13	3	3	0	8	0
Large Scale (≥250 alpacas)	2	1	2	0	3	1
Total	31	11	15	3	24	4
Distribution of Responses (%)	35.23%	12.5%	17.05%	3.41%	27.27%	4.55%

The primary reason for farming alpacas in Australia is for small-scale production or as a smallholder (alpacas are not the primary income source) (69%). Commercial production for fibre was selected by 12% of small-scale producers and 77% of large-scale producers. Stud/Animal Sales were the primary focus for 10% of respondents, with 55% classified as medium scale. The two responses, in other, did not provide enough information to be included in a category. Reasons for primary production are presented in Table 2. Additionally, only 10% of respondents supplied animals for meat.

Table 2. Primary production reason based on farm scale.

Primary Production Reason	Small Scale	Medium Scale	Large Scale	Total
Commercial production for fibre	6	10	7	23
Guard animals with sheep	2	0	0	2
Other	2	0	0	2
Own as pets	4	0	0	4
Small-scale/smallholder farm	36	12	0	48
Stud/Animal Sales	2	5	2	9

Huacayas accounted for 93% and Suri 7% of the animal numbers reported in this survey. Of the respondents, 92% own Huacayas and 48% own Suri. Furthermore, 60.3% of respondents owned only 1 breed, 52.3% only Huacays and 8% only Suri.

3.2. Farm Management

Respondents identified 12 key pastures used in their grazing systems. Kikuyu was the most common pasture being grazed (37.5%), followed by subterranean clover (30.7%) and Phalaris (29.5%) (Figure 2). Pasture species could not be identified by 25% of respondents. Production zone impacted the occurrence of Kikuyu ($p < 0.05$) with 52.1% (±7%) of farms in high-rainfall zones growing Kikuyu compared to 15.2% (±6%) of sheep/wheat zone farms (Figure 3). White clover was more likely to be grown in high-rainfall zones compared to both the sheep/wheat and pastoral zones (Figure 3).

The stocking rate was recorded as the number of alpacas per hectare. Stocking rate in the high-rainfall zone was 5.5 ± 0.53, the pastoral zone was 7.21 ± 1.29 and the sheep/wheat zone was 3.77 ± 0.63. Stocking rate was significantly affected by production zone ($p = 0.04$). There was no significant difference between the high-rainfall zones and pastoral ($p = 0.31$) or sheep/wheat zone ($p = 0.22$). There was a significant difference in stocking rate between the pastoral and sheep wheat zones ($p < 0.05$), with an estimated difference of 3.44 ± 1.44 (SE) alpacas per hectare. There was no significant difference between the seasonal occurrence of ill thrift and production zone for all seasons (summer [$p = 0.29$], autumn [$p = 0.36$], winter [$p = 0.67$], spring [$p = 0.29$]). Winter was most commonly selected as the season when ill thrift and weight loss was most likely (45.45%), and spring least likely (7.95%).

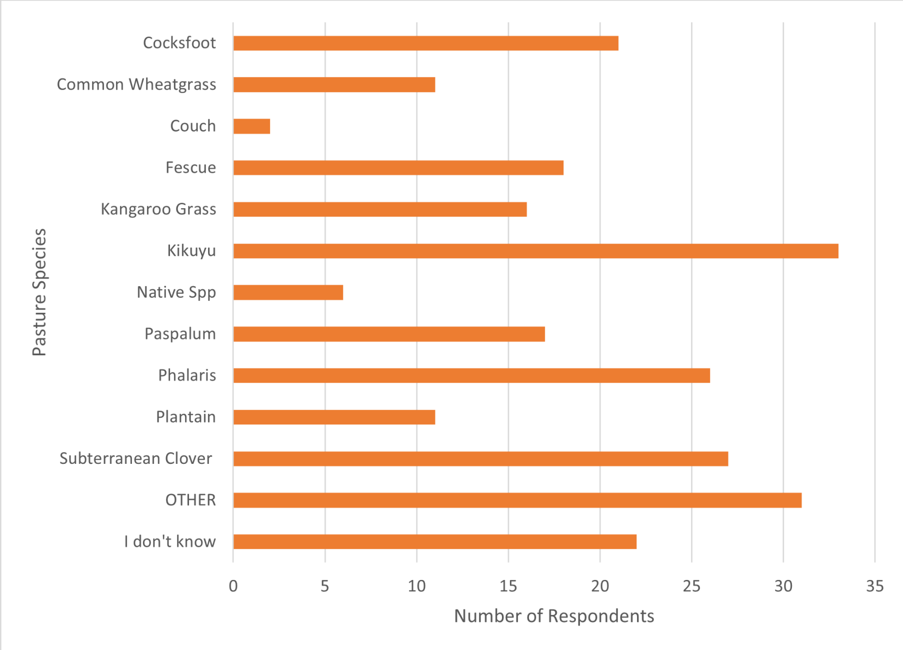

Figure 2. Identified pasture species grazed by alpaca producers throughout the year.

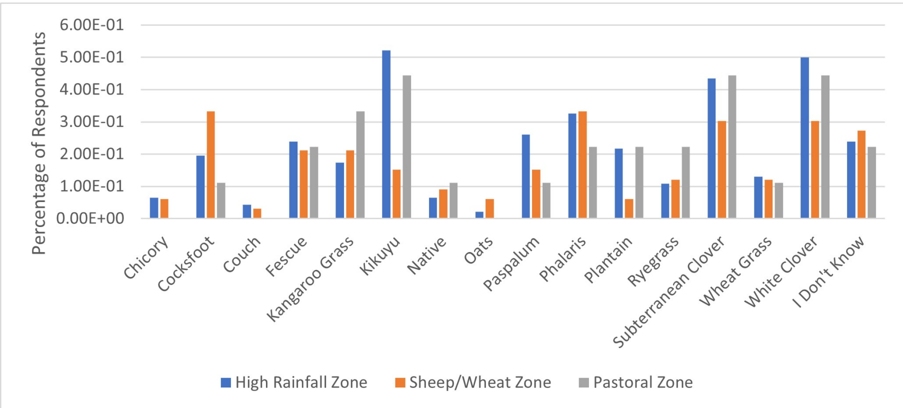

Figure 3. Predicted pasture species occurrence by production zone.

3.3. Animal Management

Forty-nine respondents completed the BCS answers for the categories 'Cria—At Weaning', 'Females—Maintenance', 'Females—At Mating', and 'Working Males'. There were 47 responses for 'Females—Last Trimester Gestation'. The majority of respondents selected three or four as the ideal BCS for most categories (Figure 4).

Fortified pellets were fed by 48.2% of respondents. Alpaca pellets were fed by 88.6% of respondents who fed any pellets, horse pellets by 9.1% and cattle pellets by 2.3%. Neither herd size ($p = 0.63$) nor production zone ($p = 0.10$) significantly impacted whether respondents fed pellets. Respondents were asked if they regularly supplemented with the following commonly used supplements; comprehensive liquid supplement (containing vitamins, minerals and amino acids), vitamins A, D and E, selenium, phosphate, basic liquid supplement, energised nutrition supplement formulated for Australian camelids, vitamin B12 or no additional supplements. Production zone had no significant effect on administering supplements (all $p > 0.05$; Table 3). Herd size significantly impacted supplementing with selenium ($p = 0.0238$), but had no effect on any other supplements included in the survey (Table 3). Vitamin A, D and E were the most commonly administered supplements used by 51.1% of respondents, followed by basic liquid supplements and no supplement provided (30.7% of respondents) (Figure 5).

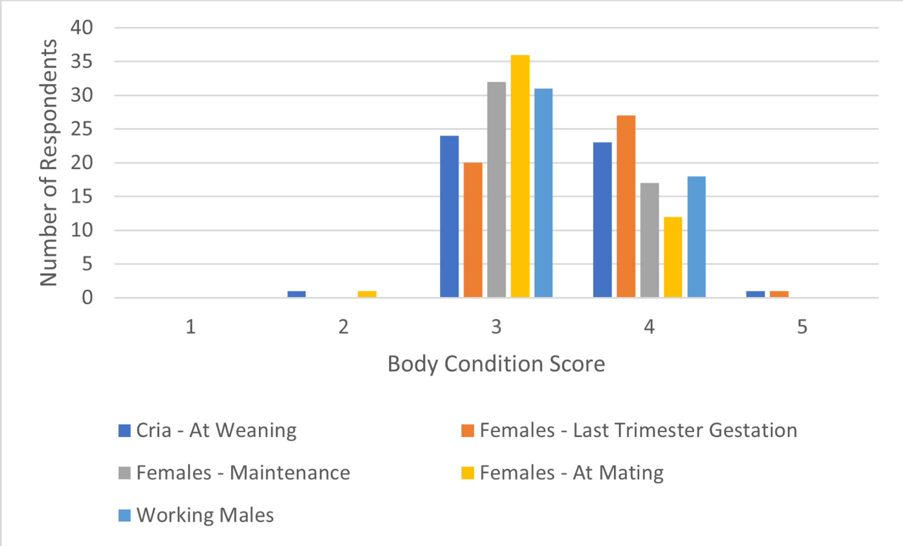

Figure 4. Ideal alpaca body condition score (BCS).

Table 3. Effect of production zone and herd size on administering supplements to alpacas based on survey results.

Primary Factors	Sub Factor	*p* Value
Production Zone	Comprehensive Liquid Supplement	0.62
	ADE	0.55
	Selenium	0.89
	Phosphate	0.94
	Basic Liquid Supplement	0.47
	Energised Nutrition Supplement Formulated For Australian Camelids	0.21
	B12	0.61
	No Supplement	0.23
Herd Size	Comprehensive Liquid Supplement	0.96
	ADE	0.37
	Selenium	0.02
	Phosphate	0.19
	Basic Liquid Supplement	0.26
	Energised Nutrition Supplement Formulated For Australian Camelids	1.00
	B12	0.44
	No Supplement	0.10

The frequency of veterinary visits was not significantly impacted by herd size ($p = 0.13$). However, there was an increased frequency of visits as herd size increased (Figure 6). Birthing complications was the highest-ranked reason for veterinary visits for 43.18% of respondents, followed by external injury for 22.73% (Table 4).

The frequency of drenching for worm prevention or treatment ranged from never to over four times per year, with 55% of respondents identifying that they drench as needed (Figure 7). Of the 48 respondents that drenched as required, 52% noted that they drenched based on a faecal egg count assessment. Respondents that drench as needed also included weather conditions as a key deciding factor, with a trend to increase drenching frequency during increased rainfall. There was 7% of respondents who identified that they never drench the alpacas on their property (Figure 7). Overall, 45 out of 88 respondents identified that they conduct faecal egg counts (FEC) prior to drenching, 12 respondents sometimes conduct FECs and 32 respondents do not conduct FEC. There were no significant effects of the production zone on drenching frequency. Respondents were asked to identify what signs and symptoms they look for before drenching a sick animal: 55% of respondents included descriptions of pale mucous membrane and anaemia symptoms, 50% of respondents considered weight loss or reduced body condition, 30% looked at changes in faecal consistency such as scouring and 40% take into account changes in behaviour, movement and energy levels prior to drenching. Of the respondents that drench their animals, 22% only identified one factor that they looked at prior to drenching; 12% conducted FEC, 5% assessed gum colour, 2% assessed weight or body condition loss, 1% considered changes in animal movement and 1% assessed fecal consistency.

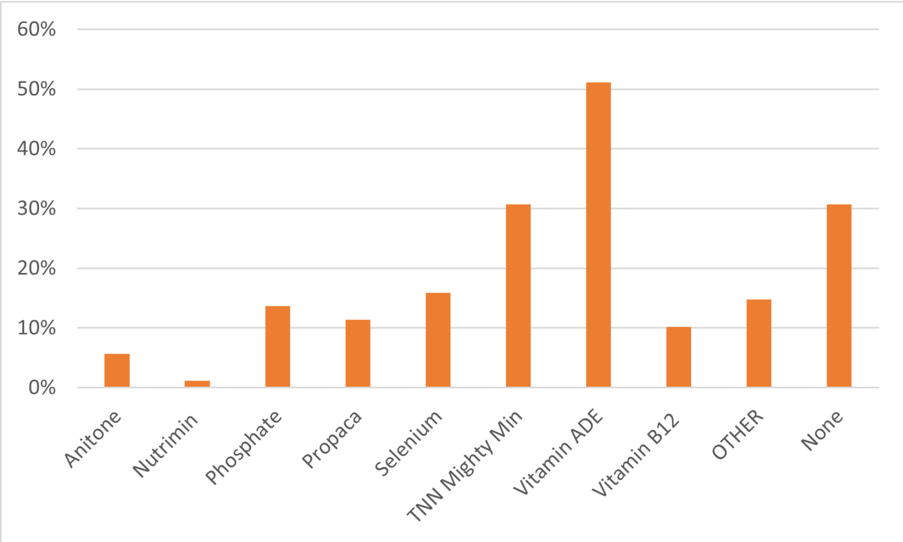

Figure 5. Percentage of respondents providing regular additional supplements for alpaca management.

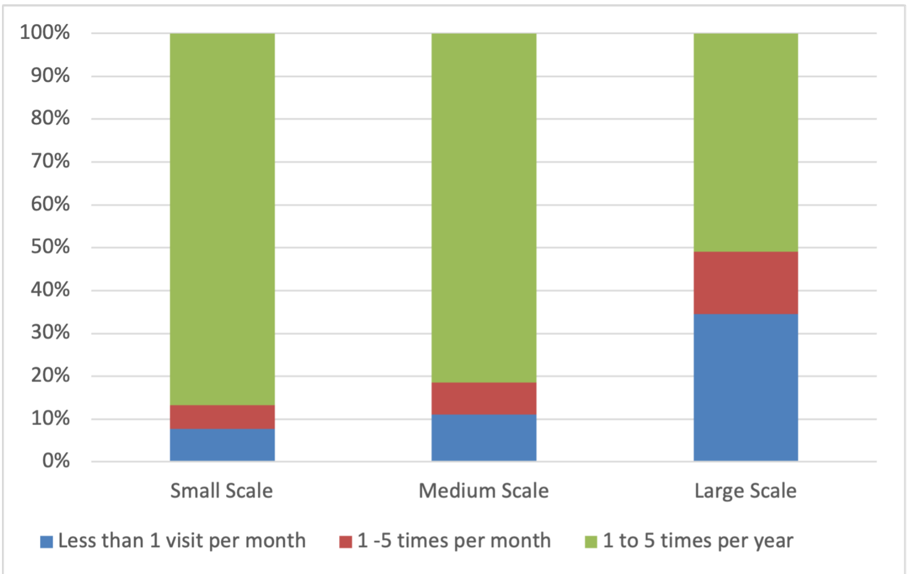

Figure 6. The number of vet visits per year based on herd size.

Herd size did not significantly impact vaccination frequency ($p = 0.23$). There is a trend towards increased vaccination frequency where herd size increases (Figure 8). Large-scale farms are approximately 2.65 times (95% CI, 0.66 to 11) more likely to have a higher rate of vaccination when compared to small-scale farms, while medium-scale farms are 2.1 times more likely Figure 8). The vaccinations identified by respondents w ere: 5in1 (clostridial diseases including enterotoxaemia, tetanus, black disease, malignant oedema and blackleg), 6in1 (clostridial diseases plus cheesy gland) and 7in1 (clostridial diseases plus leptospirosis). The 5in1 vaccination was the most selected (72.7% of respondents), followed by the 6in1 vaccination (22.7%). The 7in1 vaccination was chosen by 2.3%, and the 8in1 or no vaccination options were selected each by 1.1% of respondents. Yearly vaccination frequency was the most common, selected by 48.9% of respondents, followed by vaccination every 6 months (43.2%), 4 times per year (3.4%) and other routines including no vaccination or no regular use (4.6%).

Table 4. First ranked reason for veterinary treatments.

Reason for Veterinary Visit	Number of Respondents
Birthing complications	43.18%
Dental Issues	3.41%
Digestive Issues (bloat, lack of appetite, weight loss)	4.55%
External Injury (e.g., lameness, broken leg, open wound)	22.73%
General husbandry (e.g., vaccinations)	5.68%
Internal Injury (e.g., suspected internal bleeding or trauma)	11.36%
Worms/suspected worms	9.09%

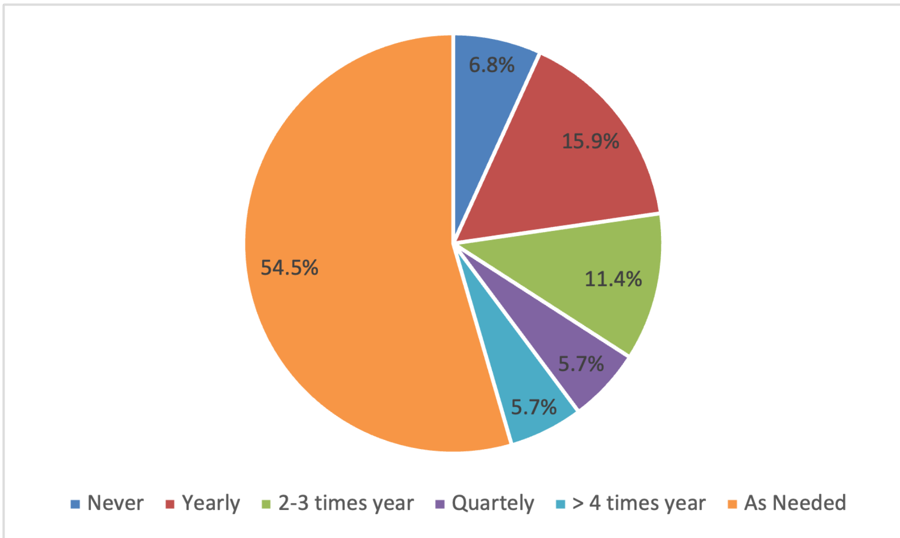

Figure 7. Frequency of drenching alpacas for worm treatment and prevention.

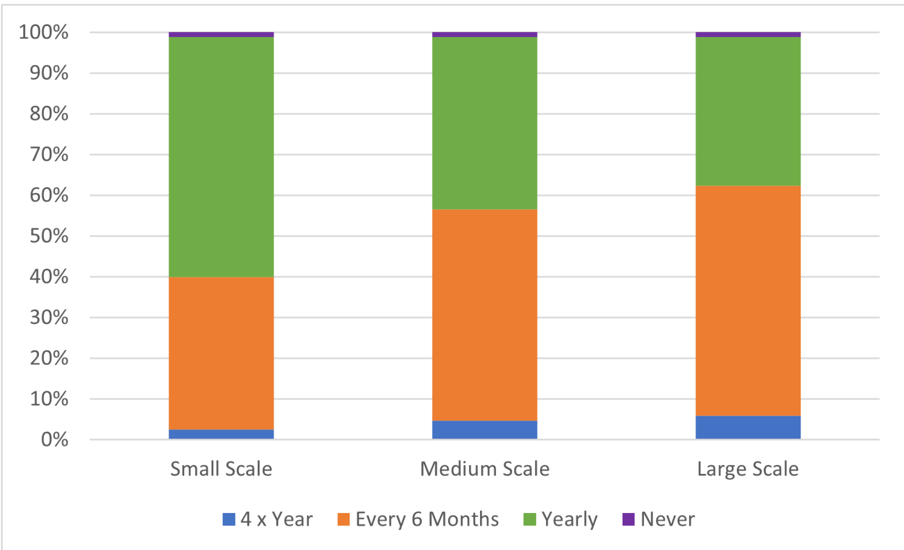

Figure 8. Frequency of vaccination of alpacas based on herd scale.

4. Discussion

4.1. Demographics

The majority of the Australian alpaca survey respondents were located along the east coast of Australia, with smaller numbers in South Australia and Western Australia. This distribution was expected as Hernadez-Jover et al. [14] and Rashid and et al. [4] reported the distributions following a similar distribution. The higher concentration of alpaca producers on the East Coast could be attributed to more consistent year-round pasture availability as producers are in high-rainfall zones. It is also possible that alpaca producers have established enterprises on the east coast due to increased market accessibility, as most alpaca fibre-buying houses are located in NSW, VIC and QLD [23]. Huacayas continue to be the primary breed produced in Australia [4,24]. The popularity of Huacaya alpacas could be linked to the similarity in textile process and end uses as wool [25] and the large range of products available [26]. The number of producers owning both alpaca breeds has increased since 2019 [4], possibly due to increased interest in the Suri breed or a change in market opportunities for Suri fibre. In 2000, 80% of Australian alpaca herds contained less than 6 animals [27]; by 2019, 64% of herds contained less than 50 alpacas [4], and 60% in this study in 2023. In comparison, in a 2019 study by Hernandez-Jover and et al. [14] that also used the Australian Alpaca Association member's database to distribute the survey, the proportion of smallholder farms (<50 animals) keeping alpacas as their primary income has increased from 1.7% to 12%. This change could be attributed to developments in international and domestic market opportunities, shifting the focus to businesses structured around commercial alpaca fibre production. Interestingly, this survey did not determine there was extensive use of alpacas as guard animals within sheep flocks, with only two respondents replying accordingly. This topic has been extensively covered in separate studies [28,29] and will not be addressed here. Currently, only 10% of respondents supply alpacas for meat production, which could be attributed to the few opportunities for animals to be commercially processed in Australia.

4.2. Animal Management

4.2.1. Pasture Management

Twelve key pasture species were identified across Australia. Kikuyu was the most grazed pasture species in the survey. As Kikuyu is suited to the high-rainfall regions of eastern Australia, which have a higher proportion of alpaca producers, it is reasonable to conclude that climatic suitability contributes to the high use of this pasture [30–32]. Subterranean clover (subclover) is often included in a pasture mixture with Kikuyu to improve the nutritional quality of the pasture and provide feed outside of the Kikuyu or summer grass growing periods [32]. The number of respondents who could not identify what pastures they were grazing raises concerns for animal health and environmental management. Inadequate nutritional consumption can lead to a range of nutritional-based diseases, such as protein energy malnutrition (PEM) and mineral deficiency diseases [19,33]. In a pasture-based system, a knowledge gap in pasture identification can result in uninformed administration of supplements and treatment of nutritional deficiencies and diseases, as well as a reduction in feed utilisation impacting animal performance [19,33,34]. Grazing land management practices impact soil properties, including water infiltration, carbon sequestration and nitrogen use globally [35]. Lack of information can lead to inappropriate implementation of grazing practices, which negatively impacts soil health and animal performance, impacting overall farm productivity [34,35]

4.2.2. Supplements

Although there is limited knowledge of alpaca nutrition and supplementation in Australia, it is well established that alpacas are at high risk of vitamin D deficiency when removed from their native high-altitude environment resulting in lameness, slow growth rate, stiff joints and inward-pointing knees [5–7,19,36,37]. This survey found that vitamin D was regularly supplemented via a combination vitamins A, D and E injection by 51.1%

of respondents, which was higher than any other supplements identified in this survey. Vitamin D can also be administered through dietary supplements, which is an option that some producers may favour. There are Australian and international recommendations for vitamin D supplementations to prevent and treat vitamin D deficiency and associated disorders in alpacas and camelids [6,36,37]. This survey did not explore the reasons behind supplementation, and further research is required to confirm the reason for high levels of vitamin D supplementation by Australian alpaca owners. Some of the other supplements identified by this survey, including vitamin B12 and selenium, are administered based on a deficiency in the soil, pasture impacting dietary intake or presentation of symptoms, explaining the lower levels of regular supplementation [23,36]. Although the use of fortified pellets was common among survey respondents, there is minimal knowledge in the scientific and veterinary communities of the effectiveness and suitability of feeding pelleted feed to alpacas as a nutritional supplement [12,38]. Some respondents reported feeding horse pellets regularly. Although alpacas are not true ruminants, many of the nutritional recommendations and digestive processes are similar [18], which raises concerns about the suitability of feed formulated for horses being used in alpacas. Although horse feed contains key nutrition areas (protein and energy), ruminants and horses have different anatomical structures involved in consuming (dentition) and digesting (gastrointestinal tract) feed, resulting in different particle sizes and ingredients required for effective and safe absorption of nutrients [39]. The use of pelleted feed formulated for cattle also needs to be carefully managed, as feeding based on body weight may not account for metabolic differences between the species and result in nutritional imbalances [38]. Further research needs to be conducted to confirm the effectiveness of meeting nutritional requirements for body condition and fibre management through feeding commercial pelleted feeds and mixes formulated for alpacas as a supplement.

4.2.3. Internal Parasite Control

Despite internal parasites, particularly gastrointestinal nematodes, causing significant health and production issues in alpacas in Australia and globally [40–43], there are no comprehensive guidelines for intestinal worm control or registered anthelmintic treatments [42]. Regardless of this, the majority of alpaca producers in this survey were practising intestinal parasite control. This survey found that 55% of respondents drenched without a regular schedule, with 52% basing their decisions on FECs. This amount has increased slightly from a 2019 survey, where 43% of respondents drenched as needed [42]. Comparatively, a 2021 survey of Australian sheep producers showed a different trend, with 74% following planned preventative treatments [44]. The frequency of drenching for producers following a schedule was varied, with more respondents drenching yearly (16%) and 2–3 times a year (11%) than quarterly (6%) or more (6%). In Australia, adult ewes, lambs and weaners, on average, were treated for worms 2.1 times/year [44]; goats were similar, being administered an anthelmintic on average 2.5 times/year [45], which is reflected in the trend seen in the alpaca industry. A common practice in sheep internal parasite control is spelling paddocks and moving stock to spelled or 'cleaner' pastures after drenching [44]. This practice was only performed by 23% of respondents in the study conducted by Rashid et al. [4], and additional methods of worm control were not looked at in this study. The difference in internal parasite management could be linked to the higher proportion of smallholder farms than commercial farms [14]. Internal parasite management guidelines and the registration of anthelmintic treatments for alpacas are important areas for future development to improve alpaca management and productivity.

4.2.4. Vaccination

There are also no licenced vaccinations for use in alpacas. However, it is generally recommended by veterinarians and industry to use a 5in1 or 7in1 vaccination developed for sheep and cattle for the prevention of clostridial diseases and leptospirosis as these have been developed for similar livestock species (sheep and cattle) [46,47]. The "Code of Welfare for Alpacas and Llamas Australia, 2016" only contains a recommendation to vaccinate pregnant alpacas 4–6 weeks prior to unpacking or at 300 days of gestation with a 5in1 vaccination to support antibody levels in colostrum [46]. However, globally, recommendations are highly variable and often include initial vaccinations prior to/at weaning and annual boosters [33]. Across the world, the most common vaccination given to alpacas is to protect against Clostridial diseases [33,36,46,48,49]. The 5in1 vaccination was the most commonly used in this survey reflecting the key diseases identified by previous studies. The frequency of vaccination was significantly affected by herd size, with 1.1% of respondents indicating that they were not vaccinating compared to 6% in New Zealand in 2015 [49] and 12.2% of South American Camelid (SAC) owners in Germany in 2021 [36]. A recent UK survey of alpaca owners was similar and reported that 95.7% of respondents' animals were vaccinated against clostridial diseases [50]. Overall, although there are minimal recommendations for alpaca-specific vaccination schedules, it is a common practice globally to maintain the health of alpaca herds. Future research in Australia is needed to confirm appropriate doses and vaccination schedules for alpacas to improve production, including reducing the need for excess veterinary chemicals where possible.

4.2.5. Production Zone, Stocking Rate and Seasonal Variation

In this study, the production zone significantly influenced the stocking rate between the pastoral and sheep/wheat zones. This was expected due to general livestock management practices based on annual average rainfall and feed availability. In comparison, sheep are commonly grazed at a higher stocking rate (e.g., 14–24 DSE (dry sheep equivalent) in coastal regions with improved pasture) [51] in high-rainfall zones due to smaller property sizes and increased amounts of available feed [52]. One DSE equals the feed required to maintain one 50 kg non-pregnant or lactating castrated male (weather) sheep [51]. There are currently no stocking rate calculation guides for alpacas in Australia. Still, suggestions are that alpacas should be grazed at similar or lower stocking rates compared to sheep due to similar performance or more efficient pasture utilisation of alpacas [11,42]. The ability of the current study to calculate stocking rates in the Australian production system was limited as many producers were unsure how to calculate stocking rates or only owned small numbers where all were run together in one mob.

4.2.6. Veterinary Services

This survey found that the most common reason for visiting a vet was due to birthing complications (43%), followed by external injury (23%). Although respondents were not asked to expand on this, it is reasonable to assume that these are the key areas that require additional expertise or tools beyond what is available on-farm for most producers. From this survey, Australian alpaca producers utilise veterinary services infrequently, with most respondents visiting a vet between 1 and 5 years, with fewer going multiple times a month. However, the frequency of visits did increase as herd size increased. This is to be expected as more animals are to be cared for. When surveying livestock small-holders in Australia, Hernandez-Jover et al. [14] found that where most other livestock species considered veterinarians a valuable source of information, less than half of the surveyed alpaca owners considered veterinarians a helpful information source. Interestingly, a similar viewpoint was taken by SAC owners in Germany [36]. The common feedback from alpaca owners is that few veterinarians have experience or the appropriate knowledge of alpaca or SAC-specific care, basing recommendations on other small ruminant species. The limited use of veterinary services by alpaca producers, based on the low number of visits from survey respondents and the perceived lack of specialised alpaca experience in Australia and overseas, indicates that future training needs to be provided to large animal veterinarians on alpacas and other SAC species to ensure appropriate veterinary care and improve overall animal treatment.

5. Conclusions

The Australian alpaca industry largely consists of small to medium-sized herds that keep alpacas as a smallholder farm. The number of commercial alpaca enterprises is increasing, raising concerns about the lack of management guidelines to outline best practices and improve overall herd health and productivity. Further research surrounding paddock behaviour and nutritional requirements in the Australian environment is needed to facilitate the development of industry guidelines and address the producer and veterinary knowledge gap. Addressing these critical knowledge gaps will provide an opportunity to increase the health and productivity of Australian alpaca herds.

Author Contributions: Conceptualization, project administration, investigation, writing—original draft preparation, visualisation, I.B., methodology, I.B. and R.B.; formal analysis, data curation, I.B. and E.H.; writing—review and editing, R.B. and E.H.; supervision, R.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study protocol was approved by the The University of Sydney Human Ethics Committee (project number 2022/720, 7 October 2023).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data are contained within the article.

Acknowledgments: The authors would like to thank the alpaca producers across Australia who participated in this survey and the assistance of the Australian Alpaca Association for distribution to their members.

Conflicts of Interest: The authors declare no conflicts of interest.

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3 Chapter 2: Daytime Paddock Behaviour of Alpacas Raised in an Australian Extensive Production System: A Pilot Study

This Chapter has been published in Animals.
Boughey I, Hall E, Bush R. Daytime paddock behaviour of alpacas raised in an Australian extensive production system: A pilot study. Animals. 2025;15:2357. doi:10.3390/ani15162357. Available from: https://www.mdpi.com/2076-2615/15/16/2357

The previous chapter focused on surveying the Australian alpaca industry to identify normal paddock behaviour as a starting point to address both producer and veterinary knowledge gaps. As the Australian alpaca industry continues to grow with large-scale enterprises [1, 2], it is important to understand normal alpaca behaviour in an extensive production system in order to identify potential areas for better management to optimise production and improve alpaca health.

Australian-based research has previously focused on alpacas co-grazed with sheep, including their use as herd guards [3, 4]. Although this has provided information on management practices of the Australian alpaca industry as it has developed, understanding the normal paddock behaviour of alpacas farmed as a sole species in an extensive production system is required to confirm or improve current management practices.

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Daytime Paddock Behaviour of Alpacas Raised in an Australian Extensive Production System: A Pilot Study

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Simple Summary

The alpaca industry in Australia began in the 1980s and 1990s and continues developing as an alternative natural fibre industry. This study aimed to create a baseline for alpaca herd behaviour in an extensive production system in southeastern Australia. Sixty-four adult female alpacas, 32 Huacaya and 32 Suri, were inducted into the trial and kept together across 10 months. Visual monitoring occurred using GoPro cameras for 3 days in the middle of every season in the same paddock to record paddock behaviour without a human presence. Videos were taken five times per day at 0800, 1000, 1100, 1300, 1500 for 60 min with behaviour observations recorded every 5 min. Grazing, resting and standing were the most common behaviours. Alpacas were more likely to be seen grazing at any time throughout the day in the cooler seasons (autumn and winter) and resting in the warmer parts of the day during summer and spring. The time of day impacted the number of alpacas seen resting or grazing at any point in time, but not the number of alpacas standing still. This study has outlined the common paddock behaviours for alpacas in southeastern Australia, highlighting that alpacas spend the majority of daylight grazing compared to other observed behaviour.

Abstract

The Australian alpaca industry is continuing to develop as an alternative fibre industry to the traditional merino or angora industries. This study aimed to investigate herd behaviour in an extensive system in south eastern Australia. Healthy adult female alpacas (Huacaya n = 32, Suri n = 32) over two years old were inducted into the trial and kept together across a 10 month period. A total of 5 animals were removed during the study due to illthrift or death unrelated to the study. GoPro cameras were set up at 5 locations in the paddock for 3 days in the middle of every season (Summer, Autumn, Winter, Spring) to record alpaca behaviour without a human observer present. Visual observations were taken at 0800, 1000, 1100, 1300, 1500 for 60 min. Behaviour observations were taken every 5 min from the videos according to a prepared ethogram. A count of animals exhibiting each behaviour was recorded at each time point within each of the designated 60-minute periods. A generalised linear mixed-effects model (GLMM) was run on binary data for each behaviour. Behaviours that returned a predicted proportion of over 0.10 for all seasons were used in an ordinal logistic regression that was then utilised to determine the effect of the season, time of day, and weather conditions on the number of animals. Season significantly impacted the number of alpacas grazing, resting, and standing ($p < 0.0001$). Alpacas were more likely to be grazing throughout the day in cooler seasons (autumn, winter) and resting in the warmer parts of the day in summer and spring. The time of day impacted the proportion of alpacas resting and grazing ($p < 0.05$) but not standing ($p = 0.4432$). This study highlights that alpacas spend the majority of the daylight hours grazing, with some variability across

Received: 1 July 2025
Revised: 8 August 2025
Accepted: 9 August 2025
Published: 11 August 2025

Citation: Boughey, I.; Hall, E.; Bush, R. Daytime Paddock Behaviour of Alpacas Raised in an Australian Extensive Production System: A Pilot Study. *Animals* **2025**, *15*, 2357. https://doi.org/10.3390/ani15162357

different seasons, which may impact ideal management practices to optimise production in an extensive system.

Keywords: alpaca; camelid; grazing system; paddock behaviour

1. Introduction

Alpacas (*Vicugna pacos*) are New World Camelids that are the domesticated descendants of the vicugna and are closely related to llamas and the guanaco [1]. Alpacas originate from South America in high-altitude regions, where they are used for both meat and fibre production [2]. The alpaca industry began to develop in Australia from the 1980s as an alternative fibre industry and continues to grow in size, with an estimated 350,000 alpacas currently in Australia [3,4]. The Australian alpaca population is mainly comprised of small- (≥250 alpacas) to medium-scale (50–249 alpacas) properties with an increasing number of larger-sized enterprises (≥250 alpacas) operating as an extensive production system [5].

Understanding the grazing patterns and pasture utilisation of sheep and cattle in pasture-based systems has enabled the development of long-term sustainable management strategies to improve animal productivity and land management [6,7]. Developing a great understanding of normal animal behaviour enables us to recognise behaviours that deviate from normal and may indicate early signs of illness [8,9]. Early recognition of illness facilitates early intervention and improved health outcomes, as well as mitigating the spread of disease [8,9]. Improving the knowledge of sheep and cattle behaviour regarding handling has led to the development of low-stress handling techniques and systems and infrastructure designed to minimise stress [8,10]. Reducing stress associated with handling and husbandry practices improves animal welfare and production outcomes, as animals that experience lower stress levels are more likely to go back to feed faster, negating negative impacts on production [8,10]. A large portion of the existing literature on the grazing behaviour of alpacas is focused on feed selection in South American environments [11–13]. Identifying that alpacas have the ability to consume and thrive on a higher level of low-quality forage compared with other small ruminants in their native environments has provided valuable insight into managing alpacas when low-quality feed is available. However, this information is specific to South American production systems [11,13], highlighting the need for further research in other production systems to improve management recommendations.

Across the world, it is common for alpacas to co-inhabit with sheep, as well as llamas [11,14,15]. The ability of alpacas to successfully co-inhabit and guard other grazing species, such as sheep, has led to their increased use in Australia [16]. Early research during the development of the alpaca industry was focused on cohabitation studies with sheep [15]. When alpacas co-inhabit with sheep, they spend most of their time grazing (57%), with less time spent on other activities such as resting (27%) [17]. Zabek et al. [18] also reported that alpacas with cria at foot displayed grazing as the dominant behaviour. These results, despite different production conditions (herd guardians, smallholder farms, and being housed inside at night), highlight that grazing behaviours occur more frequently than other behaviours, including resting and standing.

However, there is limited information on the grazing and paddock behaviour of alpacas in an extensively raised system, especially in Australia. Current research has focused primarily on alpaca behaviour with regards to sheep, either in a co-grazing scenario [15,17] or as guardian animals [16,19,20]. As the Australian alpaca industry continues to develop with an increase in larger-scale properties [5], it is important to understand baseline herd behaviour in an extensive production system of both alpaca breeds to improve management recommendations and producer education resources. This study aimed to provide a baseline of herd paddock behaviours of alpacas raised in an extensive production system in Southeastern Australia.

2. Materials and Methods

2.1. Animal Usage and Location

A total of 64 adult female alpacas (32 Suri and 32 Huacaya) were inducted into the trial conducted at a property located in the Southern Highlands, New South Wales, Australia. At the time of induction, animals were over 2 years old and had a body condition score (BCS) greater than 2 (scale 1–5). The study was conducted across a 10-month period from January to October 2024 to collect data across all seasons. A total of 5 animals were removed from the study at different time points due to ill-thrift (2) or death due to causes unrelated to the study (3). The animals used in this study experienced regular interactions with humans and had two (2) days of acclimatisation to the presence of the cameras in a smaller paddock prior to starting the behaviour monitoring. The alpacas remained together for the duration of the study. The University of Sydney Animal Ethics Committee (ethics number 2023/2333) granted animal ethics approval. The weather conditions were recorded at each time point based on visual observations in the video recordings. The weather was classified as overcast, raining, or sunny.

2.2. Behaviour Monitoring

Visual behaviour measurements were taken between 0800 and 1500 AEST during the middle of each season for 3 days. The paddock used for the behaviour monitoring was 1.01 ha. Natural alpaca behaviour without the impact of human presence was recorded through 5 wide-lens cameras placed at each corner of the paddock and an additional camera at a high vantage point (Figure 1). In summer, 2 GoPro Hero 11 Black (GoPro Inc., San Mateo, CA, USA) and 3 GoPro Hero 4 (GoPro Inc.) cameras were used. Malfunctions with the GoPro Hero 4 cameras due to overheating resulted in some missing data due to date-limited usable footage. These cameras were replaced with 3 GoPro Hero 12 Black cameras for the remainder of the study. Video collection occurred in the middle of each season. Recordings ran for 60 min across 5 time periods, starting at 0700, 0900, 1100, 1300, and 1500 AEST in the middle of each season. In summer, the GoPro Hero 4 cameras were manually started, resulting in the first and last 5 min measurements being removed due to human presence for some recordings. In all other seasons, GoPro Hero 11 and 12 cameras were used with preset start times and duration limits, allowing the collection of SD cards and the reset of cameras between monitoring periods without influencing alpaca behaviour during monitoring.

Behaviour observations were taken every 5 min from the videos, checking all camera footage. Observations were conducted by a trained observer familiar with presentations of alpaca behaviour on a prepared ethogram (Table 1). The behavioural states included in this study were developed based on the authors' extensive experience working within the Australian alpaca industry. Behaviour states were defined as behaviours occurring for more than one minute to ensure that clear identification was impossible for moving behavioural states [21]. The following behaviours were included in the ethogram: cush (a seated position where the legs are folded under the body that is specific to the alpaca), lying down, standing still, walking, grazing, chewing cud while standing, chewing cud while in cush, drinking, rolling, urinating or defecating, scratching, other (with description), and out of sight (Table 1). A count of animals exhibiting each behaviour was recorded at each time point within each of the designated 60 min periods. Any animals that could not be seen or were displaying behaviour that was not distinguishable were recorded as out of sight. For further analysis, cush, lying down, chewing cud in cush, and chewing cud while standing were all grouped together to be analysed as resting behaviours.

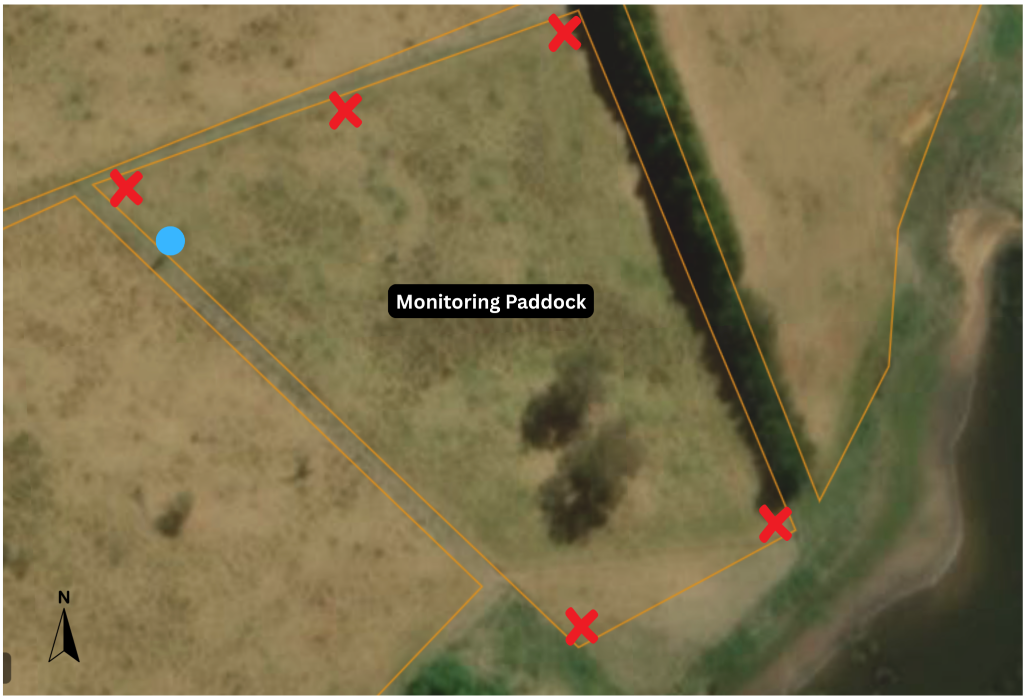

Figure 1. Locations of cameras and water sources in the monitoring paddock. A red X indicates approximate camera locations, and the blue circle indicates the approximate water trough location.

Table 1. Definition of behavioural states used in behaviour observations of alpacas raised in an extensive production system in Australia.

Behaviour	Description
Chewing Cud in Cush	The alpaca is seated in cush, and a chewing motion can be seen without the presence of grazing.
Chewing Cud Standing	The alpaca is standing, and a chewing motion can be seen without the presence of grazing.
Cush	A seated position where the legs are folded under the body and the alpaca's body remains upright. The head/neck may be up or down.
Lying Down	The alpaca is lying on its side with legs out (not under its body). The head/neck is commonly on the ground but may be lifted.
Standing Still	The alpaca is standing still (not chewing cud).
Grazing	The alpaca is actively grazing (may include slowly walking while the head is down). The alpaca can be seen taking "bites" of the pasture or feed.
Walking	The alpaca is walking without grazing.
Drinking	The alpaca is drinking (from a trough or water source).
Rolling	The alpaca is seen actively moving on its back, generally side to side, commonly in dirt or short grass.
Urinating or Defecating	The alpaca is seen urinating or defecating.
Scratching	The alpaca is using either its back legs or teeth to scratch another area of its body.

2.3. Statistical Analysis

Statistical analyses were conducted in R (Version 4.4.2 [22]) and Excel (Version 16.98 [23]). A generalised linear mixed-effects model (GLMM) was run on binary data for each behaviour using the lm4 package [24]. A GLMM was run to assess the effect of the season on the binary (yes/no observed) data obtained for each behaviour to generate predicted proportions for each behaviour at each season (summer/autumn/winter/spring). Behaviours that returned a predicted proportion of over 0.10 for all seasons were considered common and were used for further analysis. The data for the selected common behaviours (resting, grazing, and standing still) were categorised into groups that indicated the percentage of the herd observed performing a behaviour. The categories were 0%, ≤25%, 26–50%, 51–75%, and 75–100%. Ordinal logistic regression was then utilised to determine the effect of the season, time of day, and weather conditions on the number of animals exhibiting the behaviours using the ordinal package in R [25]. A *p*-value of >0.05 was considered significant.

3. Results

Walking, drinking, rolling, urinating, defecating, and scratching behaviours returned a predicted proportion under 0.10 and were not included in further analysis. Resting (including cush, lying down, chewing cud in cush, and chewing cud while standing), grazing, and standing still returned predicted proportions greater than 0.10 and were used in further analysis.

3.1. Resting Behaviours

There was a significant impact of the season on the number of animals displaying resting behaviours ($p < 0.001$) (Table 2). Alpacas were more likely to spend more time resting in the middle of the day during summer and spring compared to winter and autumn (Figure 2). Alpacas were 2.07 times (95% CI 1.43–2.97) more likely to exhibit resting behaviours in rain compared to overcast conditions, and they were 5.04 (95% CI 3.95–6.42) times more likely to show resting behaviours in sunshine compared to overcast conditions. Odds ratios and *p*-values can be seen in Table 2.

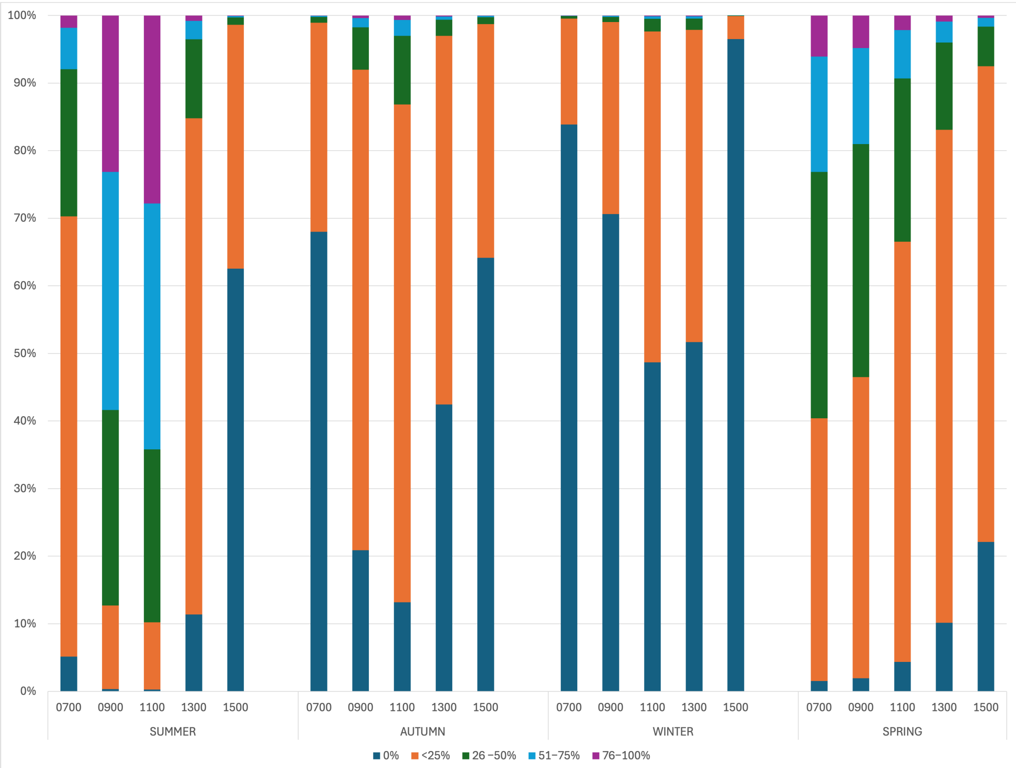

Figure 2. The effect of the time of day and season on the percentage of the herd exhibiting resting behaviours.

Table 2. The effects of the season, time, and weather on resting, grazing, and standing behaviours.

			Odds Ratio	LCI	UCI	*p*-Value
Resting	Season	WINTER	-	-	-	<0.001
		AUTUMN	0.26	0.11	0.62	
		SPRING	0.03	0.01	0.06	
		SUMMER	0.01	0.00	0.02	
	Time	0700	-	-	-	<0.001
		0900	2.00	1.43	2.81	
		1100	2.10	1.51	2.93	
		1300	0.93	0.68	1.27	
		1500	0.31	0.22	0.42	
	Weather	Overcast	-	-	-	<0.001
		Rain	2.07	1.43	2.97	
		Sun	5.04	3.96	6.42	
Grazing	Season	WINTER	-	-	-	<0.0001
		AUTUMN	0.26	0.11	0.62	
		SPRING	0.03	0.01	0.06	
		SUMMER	0.01	0.00	0.02	
	Time	0700	-	-	-	<0.0001
		0900	1.04	0.74	1.47	
		1100	1.08	0.76	1.53	
		1300	3.48	2.34	5.18	
		1500	5.73	3.68	8.92	
	Weather	Overcast	-	-	-	<0.0001
		Rain	0.55	0.34	0.89	
		Sun	0.19	0.13	0.26	
Standing	Season	WINTER	-	-	-	<0.0001
		AUTUMN	0.90	0.57	1.42	
		SPRING	1.11	0.72	1.73	
		SUMMER	2.96	1.97	4.46	
	Time	0700	-	-	-	0.4432
		0900	1.26	0.78	2.05	
		1100	1.47	0.91	2.36	
		1300	1.00	0.62	1.62	
		1500	1.21	0.76	1.92	
	Weather	Overcast	-	-	-	0.4354
		Rain	0.74	0.40	1.38	
		Sun	1.12	0.79	1.57	

3.2. Grazing

The season significantly impacted the number of alpacas grazing ($p < 0.0001$), with a higher proportion of the herd being more likely to be grazing at any time point during autumn and winter (Figure 3). The time of day had a significant impact on the proportion of alpacas grazing ($p < 0.0001$). Alpacas were 3.48 (95% CI 2.43–5.18) times more likely to be grazing at 1300 than at 0700 and 5.73 times more likely at 1500 (95% CI 3.86–8.92). They were more likely to graze later (1300–1600) in the day (Table 2). Weather significantly affected the proportion of alpacas grazing ($p < 0.001$). Alpacas were 0.55 times (95% CI 0.34–0.89) more likely to be grazing in rain compared to overcast conditions and 0.19 (95% CI 0.13–0.26) times more likely to graze in sunshine compared to overcast conditions. Odds ratios and p-values can be seen in Table 2.

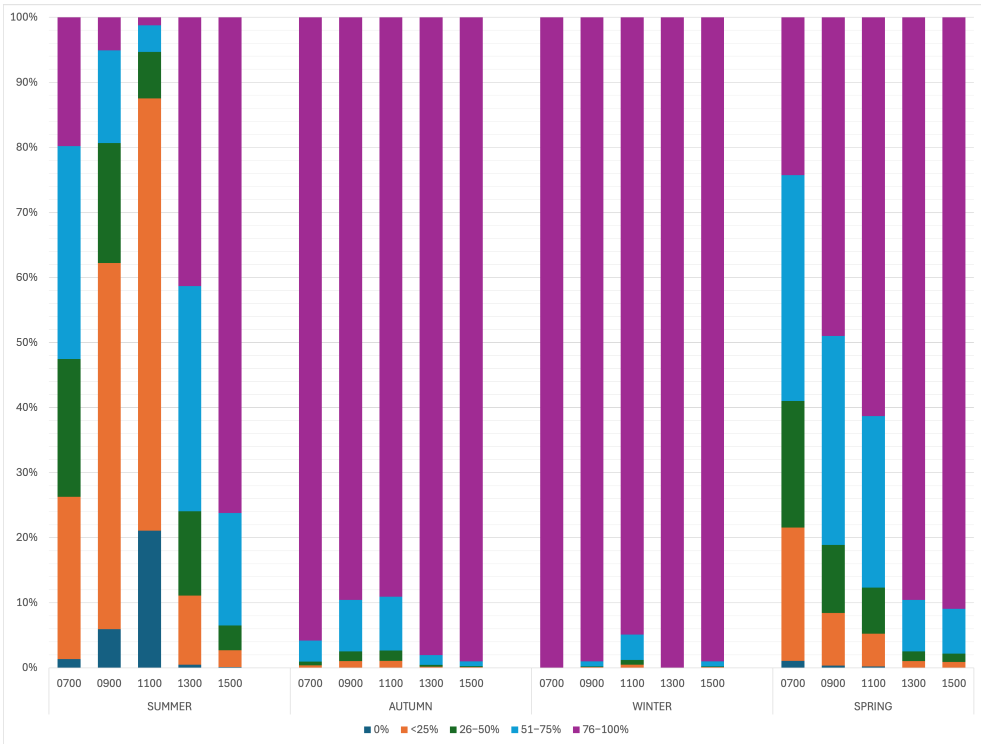

Figure 3. The effect of the time of day and season on the percentage of the herd grazing.

3.3. Standing Still

The proportion of alpacas standing was impacted by the season ($p < 0.0001$), with more animals standing still in the warmer seasons compared to winter and autumn (Figure 4). The number of alpacas standing still was not impacted by the time of day ($p = 0.4432$) or weather conditions ($p = 0.4354$) (Table 2).

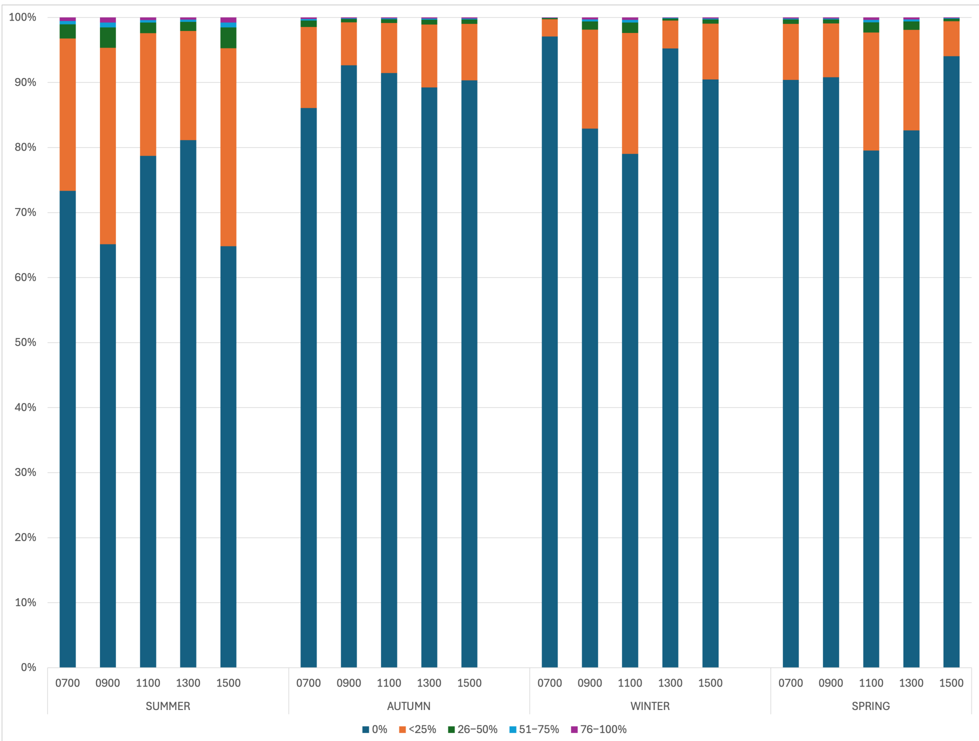

Figure 4. The effect of the time of day and season on the percentage of the herd standing still.

4. Discussion

Alpaca paddock behaviour at an independent herd level has not previously been researched in Australia. Prior research has focused on alpaca behaviour when used as herd guardians for sheep [17], whereas this pilot study investigated alpaca behaviour when grazed on their own in an extensive production system. In another first, this study utilised GoPro cameras to record alpacas on video for 60 min periods during daylight hours to assess their behaviour without human presence. This provided an opportunity to assess the feasibility of using this technology for behaviour monitoring in an extensive system, particularly where access to power is limited. From this, it was found that grazing is the dominant behaviour of alpacas during daylight hours, with resting and standing also being common. Grazing is also reported to be one of the dominant daytime behaviours observed in sheep, but sheep conduct grazing consistently over a 24 h period with more discrete meal times compared to alpacas, highlighting the differences between the two species, which are commonly grazed together [16,26]. Anecdotal evidence from alpaca producers suggests that their understanding of behaviour and appropriate management practices are often based on sheep, as they are a similar small ruminant species.

4.1. Grazing Behaviour

This study found that alpacas spent more time grazing compared to resting or standing during the day. Alpacas do the majority of their grazing during daylight, which differs slightly from the behavior of sheep, as sheep spread their grazing over a longer time frame, including at night [7,27]. Sheep have been reported to have distinct grazing peaks at sunrise and sunset, whilst alpacas are observed to be resting or ruminating in these timeframes [26,27].

In Poland and New Zealand, alpacas were found to do most of their grazing during daylight hours (0700–1850) [26,28]. In a study by Kapustka and Budzynska [28], alpacas were housed in stables overnight, which is a key difference in management practices compared to this study. However, in a New Zealand study by Sharp et al. [26], alpacas were observed in a paddock for 24 h periods, the authors reported a similar trend with minimal grazing occurring after sunset. It is expected that there will be minimal to no grazing at night in Australian alpacas in a similar extensive production system. However, this would require further research to confirm this herd behaviour under Australian conditions.

Understanding grazing behaviour and key grazing time periods can assist in improving production and maintaining animal health. This especially applies during periods where adjustments to uninterrupted grazing occur, such as during dry periods when pasture is limited and a supplement is supplied [29]. Developing supplement feeding regimes, including those considering the feed type and timing to cause minimal disruption to the animals' digestive system, is important for maintaining health [29,30]. In alpacas, strategically aligning feeding times with natural peaks in grazing activity will likely best fit with alpaca behavioural routines and may also minimise supplement waste, as the feed is supplied at a time when alpacas would naturally prefer to eat.

Other factors shown to influence grazing behaviour in other grazing livestock, including sheep, include the amount and location of shade and water troughs [6]. However, there is no research on this in alpacas in Australia. This study found that alpacas were more likely to be resting in sunny conditions than overcast or rainy conditions; however, the amount of time spent in the shade or sun was not recorded. As this study collected baseline herd behaviour across the four seasons, all observations were collected in the same paddock. Hence, factors such as varying water locations and shade locations were not investigated. It is also worth noting that time spent drinking was not regularly recorded on the cameras in this study. The impact of paddock layout, including differing shade and water locations, is an area for future research on alpaca behaviour to optimise production and animal welfare.

4.2. Effect of the Season on Alpaca Herd Behaviour

In this study, alpacas were more likely to be grazing in the afternoon between 1300 and 1500 than early in the morning. In the warmer seasons (summer and spring), alpacas were more likely to graze in the late afternoon compared to the morning and the middle of the day, which is similar to what happens in New Zealand [26]. Alpacas in Australia are likely to graze more frequently and for longer periods when the conditions are cooler, such as in autumn and winter. The season had a significant effect ($p < 0.001$) for all behaviours, and this is likely due to changes in daily temperatures, as well as the length of daylight. As alpacas graze predominantly during daylight [26,28] and are more likely to graze in rainy than in sunny conditions, it is plausible that grazing occurred more often in the winter and autumn monitoring periods due to the more favourable conditions (lower daily temperatures), as well as shorter days, leading to a more condensed grazing period, which was able to be captured on camera. Although resting behaviours were commonly observed in this study, the proportion of alpacas resting at any one time was lower than that of those engaging in grazing behaviours, except in Summer, which has also been observed in sheep [31] and is likely due to the warmer weather and increased shade-seeking behaviours.

4.3. Resting and Standing Behaviours

Resting behaviour in this study included ruminating (chewing cud), cush, and standing, as well as lying down and sitting in cush, as the alpacas were at rest and not in an alert state. Standing was treated as a separate behaviour, as animals were still in an alert state. Alpacas in this study were about twice as likely to be resting at 0900 and 1100 compared to 0700, and they were one-third as likely to be resting in the afternoon (1500) compared to the morning (0700). This differs from New Zealand, where alpacas spent significantly more time ruminating early in the morning (0100–0650) [26]. Sharp et al. [26] found that alpacas and sheep grazed together in New Zealand spent more time ruminating and standing compared to grazing [7], which was not seen in this study.

Weather conditions impacted resting behaviours, with alpacas being more likely to be resting when conditions were sunny compared to being overcast. These effects have also been reported in sheep, with routine grazing and ruminating behavioural trends being impacted by changes in weather and climatic conditions [7]. The impact of weather conditions on alpacas raised in Australia would benefit from further research across different climate regions to assess the degree of the impact of weather on herd behaviour.

4.4. Technology Use and Limitations

Cameras used in this study were unable to record behaviours during the night. In addition, older GoPro models overheated in the summer period, resulting in some footage not being recorded. Replacing these with newer cameras ensured footage capture in subsequent seasons, but night vision was not possible. Future research would benefit from trialling additional technology, such as GPS tracking technology, to monitor alpaca behaviour on farms. Although there were challenges with camera use, there were clear benefits in the ability to observe alpaca behaviour in an extensive paddock environment without constant human presence and limited human interaction. This provided a cohesive account of natural herd behaviours in an extensive production system.

5. Conclusions

Alpacas raised in an extensive production system in Australia exhibit resting, grazing, and standing as the most frequently observed behaviours. Alpacas are more likely to spend time grazing in winter and autumn compared to summer, showing a preference for grazing for longer periods in cooler conditions. They are also more likely to graze in the afternoon (between 1300 and 1600 AEST) compared to the morning, when they are most likely resting (between 0900–1200 AEST). Understanding the grazing behaviour of Australian-raised alpacas enables the future development of suitable management practices, such as supplement feeding times, to optimise health and productivity.

Author Contributions: Conceptualization, project administration, investigation, writing—original draft preparation, visualisation, I.B.; methodology, I.B. and R.B.; formal analysis, data curation, I.B. and E.H.; writing—review and editing, R.B. and E.H.; supervision, R.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the Australian Alpaca Association, Industry Development Grant 2023.

Institutional Review Board Statement: The study protocol was approved by the the University of Sydney Animal Ethics Committee (Project Number 2023/2333, 1 August 2023).

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Acknowledgments: The authors wish to thank the Australia alpaca producer involved for providing the animals and location for this research. The authors would also like to acknowledge Myrna Bakhit and Ella Harris (University of Sydney) for their assistance in data collection.

Conflicts of Interest: The authors declare no conflicts of interest.

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4 Chapter 3: Using Real-time GNSS Tracking Tags to Monitor Alpaca Activity in an Australian Extensive Production System

This chapter has been published in Agriculture.

Boughey, I.; Hall, E.; Bush, R. Using Real-Time GNSS Tracking Tags to Monitor Alpaca Activity in an Australian Extensive Production System. Agriculture 2025, 15, 1839. https://doi.org/10.3390/agriculture15171839

Chapter 2 presented a pilot study into the normal behaviour of alpacas in an extensive production system to confirm or improve current management practices. The following chapter builds on this, utilises real-time tracking livestock tags containing Global Navigation Satellite Systems (GNSS) and triaxial accelerometer technology to report on the activity levels, including average hourly and daily distances travelled livestock [1, 2, 3]. The benefit of expanding the understanding of alpaca paddock behaviour based on the visual observations discussed in Chapter 2 is the ability to collect data over extended periods of time [4] with the Smart Paddock Bluebell tags (Smart Paddock, Melbourne, Australia). This study was able to record movement data across 24 hours for the same 10-month period and production conditions outlined in the previous chapter (Chapter 2).

Gaining an understanding of the suitability of these tags for both future alpaca behaviour research and industry adoption may provide valuable insight for improving alpaca health outcomes through enhanced management.

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Using Real-Time GNSS Tracking Tags to Monitor Alpaca Activity in an Australian Extensive Production System

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Abstract

Australian alpacas contribute to a developing alternative fibre industry with an increasing number of larger-scale enterprises requiring real-time management options. This study aimed to investigate the ability of GNSS real-time tracking tags to monitor alpaca herd behaviour in an extensive production system and assess their suitability as a future management tool. A total of 32 alpacas were fitted with collar-mounted GNSS tracking livestock tags, and an additional 32 alpacas were used as a control group without tags. Both Huacaya (n = 32) and Suri (n = 32) breeds were included. There was no effect of treatment on body condition score change (p = 0. 3648). Breed had a significant effect on distance travelled ($p < 0.0184$), with Suri alpacas travelling 1.03 (±0.058) km and Huacayas 0.9 (±0.058) km per day. Season significantly impacted the distance travelled each day ($p < 0.0001$), with alpacas moving a greater distance in winter and spring compared to summer and autumn. The alpacas displayed an increase in activity between 0600 and 1600, with the majority (60%) of their activity occurring during daylight hours. This study outlines normal paddock behaviour for extensively raised alpacas in Australia and showcases the potential for GNSS remote monitoring technology to be utilised as a management tool.

Keywords: alpaca; camelid; GNSS; real-time tracking; behaviour

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Received: 12 August 2025
Revised: 27 August 2025
Accepted: 27 August 2025
Published: 29 August 2025

Citation: Boughey, I.; Hall, E.; Bush, R. Using Real-Time GNSS Tracking Tags to Monitor Alpaca Activity in an Australian Extensive Production System. *Agriculture* **2025**, *15*, 1839. https://doi.org/10.3390/agriculture15171839

1. Introduction

Technology is becoming an increasingly common tool for understanding and monitoring livestock behaviour worldwide. Global Navigation Satellite Systems (GNSS) estimate the positional location of the device [1]. GPS (Global Position System) is a common type of GNSS device used in agriculture. GNSS and accelerometers have a high accuracy of >98% (calculated as the percentage of well-classified instances [2]) when monitoring grazing and resting behaviours as well as movement tracking [2,3]. GNSS technology, when used with GIS or motion sensors, has a slightly reduced accuracy (still above 90%) [4], suggesting GNSS-based technology can provide accurate animal tracking for individual livestock in an extensive herd system. As this technology tracks movement, the technology and associated digital platforms have the ability to track and identify a variety of aspects to improve health and management, an example being their use in the dairy industry for real-time monitoring of health traits for animals. This includes rumination and movement, to identify abnormal behaviour (including heat stress) or important events such as calving [5,6] to advocate early intervention where needed for improved welfare outcomes. Outside of animal health and behaviour monitoring, GNSS tracking technology can assist producers in identifying grazing patterns and making informed grazing manangement decisions, saving both time and money [7,8]. GNSS tracking devices attached to sheep collars have also been successfully used to detect changes in individual and flock movements, determine activity patterns, and monitor animal welfare in extensively managed flocks [8–11]. The use of GNSS technology in extensive production systems extends beyond monitoring activity, as it can enable producers to see the location of their animals. In herds grazing large areas, using GNSS technology and digital platforms, producers can see where in the paddock individual animals from the herd are located, providing real-time information on pasture or vegetation being grazed, distance to water access, and commonly used areas (for example, for resting or birthing) [12].

The Australian alpaca industry is a growing industry focused on fibre production from small to large-scale enterprises [13]. It is largely unknown how alpacas raised in Australia behave in a grazing environment, particularly in an extensive production system, and as the primary livestock species in the herd (i.e., not as herd guardians). Despite alpacas commonly being compared to and co-grazed with sheep, the daytime grazing behaviour between the two species varies in the published literature [14–16]. Additionally, it is known that alpacas in higher altitude environments in their native habitat travel more distance then those at slightly lower altitudes to meet their nutritional requirements [17]. However, information on the distances travelled by alpacas raised out of their native habitat is limited, with minimal published literature for Australian production systems, particular across 24 h periods [16]. As the Australian alpaca industry continues to develop, understanding paddock behaviour is crucial to developing maagement and handling recommendations for optimal animal welfare outcomes [18,19]. Previously, GNSS technology has been mounted on alpaca collars to monitor the guardian behaviour when cohabitating with sheep [11]. In the Australian alpaca industry, alpacas are commonly kept with collars or neckbands as an additional method of identification, suggesting GNSS device attachment is a suitable option for real-time animal monitoring if reliable information can be collected. It is important to gain an understanding of alpaca grazing behaviour as this will assist producers in considering ways to improve animal health, welfare and production efficiency [7]. This study aimed to use GNSS real-time tracking tags to investigate baseline alpaca herd activity in an extensive production system and assess the suitability of the technology for future use in real-time monitoring and improved management through early identification of illness or injury.

2. Materials and Methods

2.1. Animal Usage and Location

A total of 64 adult female alpacas (32 Suri and 32 Huacaya) were inducted into the trial at a commercial alpaca property in the Southern Highlands, NSW, Australia. At the time of induction, animals were over 2 years old and had a body condition score (BCS) greater than 2 (scale 1–5). The study was conducted across 10 months from January to October 2024 to collect data across all seasons. A total of 5 animals were removed from the study at different time points due to ill-thrift (2) or death due to causes unrelated to the study (3). Body condition score measurements were collected by the same trained person in the middle of summer, autumn, winter and spring in the study year. The animals used in this study experienced regular interactions with humans. The University of Sydney Animal Ethics Committee (ethics number 2023/2333) granted animal ethics approval.

2.2. Herd Management

The alpacas were run together as one herd for the duration of the study, moving between four paddocks. Paddock size ranged from 0.89 ha to 2.38 ha, with all paddocks being used for this study located in the same area of the property. Paddock rotation was conducted by the producer based on pasture availability. This study was conducted concurrently with Boughey et al. [16]. The alpacas were housed in the same paddock for a period of 3 days in the middle of each season for visual behaviour monitoring [16]. The methodology and results of the visual behaviour monitoring component are reported in detail in Boughey et al. [16].

2.3. Real Time Tracking Tags

Smart Paddock Bluebell Cattle Tags (Smart Paddock, Melbourne, Australia) were used to monitor the behaviour of alpacas in a treatment group (n = 16 Huacaya, n = 16 Suri). The tags require a standard male button pin for application (to the ear or collar) and contain a small solar panel that provides power for the tags. The tags are also encased in a water-tight moulding. The tags were applied to a buckle collar, with the collar fitted to the alpaca (Figure 1). Collar fit was determined by ensuring two fingers could move between the collar and the alpaca's neck. A control group (n = 16 Huacaya, n = 16 Suri) was included to assess any negative impacts on body condition. The control group had a Velcro neckband without a tag. The neckbands on the control group were lighter as they did not contain a tag to assess if the presence of the tags had an impact on the alpacas' body condition score. Collars and neckbands were commonly used on the property as part of normal management practice, with the alpacas used in the study wearing long-term collars. All tags were replaced in late June due to a product fault with the initial batch of tags, due to the moulding on the tags not being water-tight. This resulted in some missing data due to the tags malfunctioning after significant rain events that the property experienced in late autumn. Replacement with new tags resolved this issue.

Figure 1. Smart Paddock Bluebell tag with prominent solar panel (**left**) and the collar with tag on the treatment group alpacas (**right**).

The tags were programmed to update the location (GPS ping) every 15 min to 1 h, depending on the tag's battery voltage. Higher battery voltage, usually due to direct sunlight on the tag, increased the update frequency. With every update, the tags recorded the location coordinates (degrees), date, time, battery voltage, tag temperature, average and standard deviation acceleration data for the *X*-, *Y*-, and *Z*-axes. A LoRaWAN (Long Range Wide Area Network) gateway from Smart Paddock was used to receive data pings from the tags (Smart Paddock, Melbourne, Australia). Tag location and movement were visualised on the Smart Paddock online producer platform.

2.4. Spatio-Temporal Patterns

Density heat maps were generated using R (Version 4.4.2 [20]) from coordinate data points during a 3-day monitoring period in the middle of each season when the alpacas were in the same paddock (in line with the methodological approach published by [16], conducted concurrently with this study). The ggmap [21], ggplot2 [21] and sf [22] packages were utilised to conduct the base mapping and plotting the paddock outlines and coordinate points.

2.5. Statistics

Statistical analyses were conducted in R (Version 4.4.2 [20]) and Excel (Version 16.98 [23]). Data were pulled from the Smart Paddock Platform using AzureTableStor in R [20]. Data were cleaned in Excel [23], removing incomplete tag readings (latitude and longitude values equalling zero) and assigning each tag to a unique animal ID number to account for the change in tags during the trial. Data were categorised as day or night based on a day being between 0700 and 1700 and night between 1700 and 0500 inclusive. Distance travelled was calculated using the Haversine equation [24] via the distHaversine function in R, for every recorded latitude and longitude for each animal throughout the trial. Grouped average distance calculations were completed for the hour of the day and period (day and night) in R [20] for qualitative analysis. Linear models (LM) were run to investigate the effect of the tags on body condition score change between the treatment and control groups. LMs were also run on the distance data generated from the tags to investigate the effect of season, period (day and night) and breed on average distance travelled. A p-value of <0.05 was considered significant.

3. Results

3.1. Alpaca Health

There was no significant difference in body condition score (BCS) between the treatment and control groups ($p = 0.3648$). However, season had a significant impact on BCS change ($p = 0.0066$). The change in BCS between autumn and winter significantly differed compared to between summer and autumn ($p = 0.0016$), with a small increase between autumn and winter. Summer to autumn and winter to spring both indicated marginal increases. No other seasonal comparison displayed a difference.

3.2. Alpaca Activity Levels

The alpacas moved 1.08 (±0.72) km per day on average for the duration of the study. The average daily distance travelled (km) significantly varied between seasons ($p < 0.0001$) with higher activity levels in winter and spring (Table 1). There was a significant effect of breed on the distance travelled ($p = 0.0108$). On average, Huacaya alpacas travelled a shorter distance, moving 0.9 km (±0.058) compared to the Suri alpacas, who travelled 1.03 km (±0.058) per day.

Table 1. Average daily distance travelled per season.

Season	Average Daily Distance (km)	SE
Summer	1.07	0.007
Autumn	0.43	0.015
Winter	1.57	0.029
Spring	1.56	0.013

The distance travelled per hour varied significantly ($p < 0.001$). The activity record increased between 0400 and 0600, with high activity levels between 0600 and 1600 when levels decreased (Figure 2).

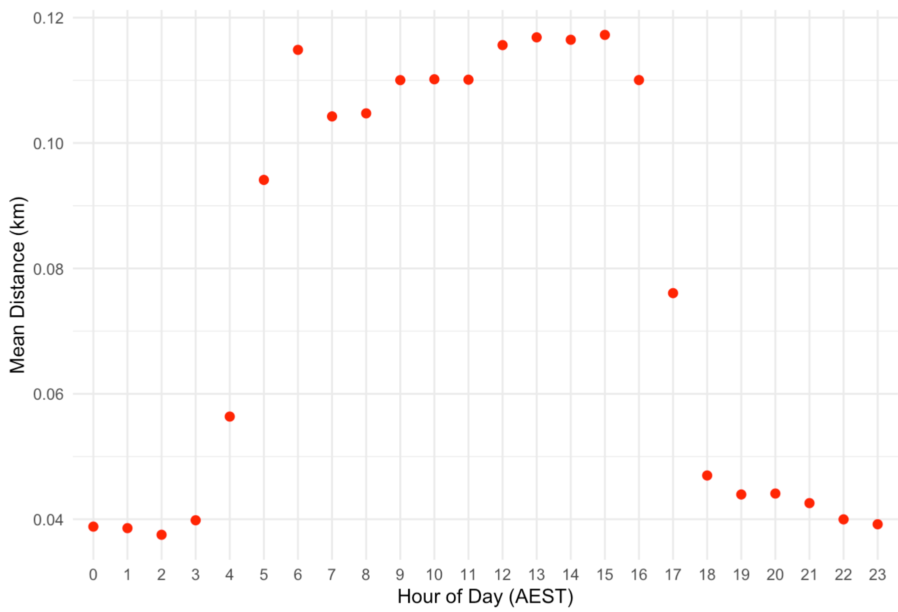

Figure 2. Average distance travelled per hour.

The difference in distance travelled between day and night periods (kilometres) was significant ($p < 0.0001$). The majority (60%) of the movement occurred during the day, with 40% during the night (Figure 3).

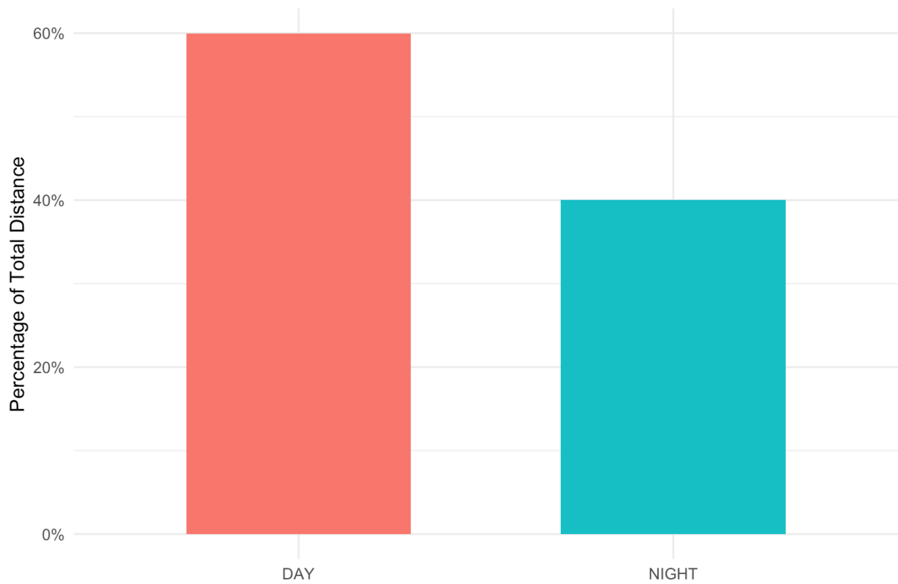

Figure 3. Comparison between day and night activity in alpacas.

3.3. Spatio-Temporal Patterns

There was a change in the spatio-temporal pattern trends between seasons over the 3-day periods where the alpacas were monitored in the same paddock (Figure 4). There was a higher density in summer located on the right-hand side of the paddock, which is the location of a treeline providing shade. The locations were more widely spread in the cooler seasons of autumn and winter. Spring showed more variation in location compared to summer; however, animal location was more concentrated at the top of the paddock compared to the cooler seasons.

Figure 4. Density heat maps of alpacas during 3-day periods in the middle of each season. Increases in density are represented by an increase from purple to red.

4. Discussion

With an increase in precision farming technologies available for use in livestock [8,10,25], it is relevant to explore opportunities to improve livestock health and welfare, as well as to reduce labour costs for producers [6–8]. Although precision farming and livestock monitoring technology includes satellite imagery for pasture management, water sensors, fence sensors, GNSS and accelerometer tags [4,10], this study focused on the use of GNSS tags to monitor alpaca behaviour in an extensive grazing system.

4.1. Alpaca Activity in an Extensive Production System

The use of GNSS tags across four seasons enabled changes in movement distances to be compared, a first in Australian alpacas. A significant effect of season was observed through the average daily distance travelled, with higher activity in winter and spring compared with summer. It is plausible to conclude that the reduced activity in summer could be due to higher temperatures and coincide with the higher amounts of resting, which was also reported in [16]. In the summer season, the alpacas in this study were also more concentrated in one area of the paddock, near the fence and treeline compared to being more uniformly distributed in the other seasons. This highlights that in warmer periods, alpacas display increases levels of resting as seen through reduced walking activity and grazing [16]. Interestingly, there was a significant drop in activity in autumn, indicated by almost half the daily distance travelled compared to summer and one-third of winter and spring. This could be attributed to adverse weather conditions experienced by the region, with large amounts of rain that resulted in localised flooding on the property. However, a study by Lachica et al. [26] also reported that grazing goats displayed a significant reduction between summer and autumn in the daily distance travelled while grazing, most likely due to seasonal variation in feed availability. As the grazing conditions and species are different, more research is required to understand if the reduction in movement by the alpacas seen in this study is a common occurrence or due to unexpected external conditions.

Matthews et al. [11] used a collar-mounted GNSS device to monitor the behaviour of two herd guardian alpacas cohabitating with sheep, reporting similar behaviour trends and diurnal activity between the species. It has been previously reported that alpacas feed regularly, interspersed with resting periods during the day [27,28]. Although in both of these studies, the alpacas were housed indoors overnight [27,28], a similar trend was observed in this study where alpacas remained in the paddock overnight. Activity levels, measured by the average distance travelled, began to increase between 0400 and 0500 before peaking at 0600 and remaining high for the duration of the daylight hours. Alpacas displayed a steep reduction in activity reaching minimal movement by 1800, which is reflected in the study by Scheibe et al. [27] despite the differences in nighttime housing. This study also found that even with the same space to move during the night, the alpacas conducted 60% of their movement between 0600 and 1600, which is supported by the trends reported for alpacas in other countries and production systems [28,29]. Understanding peak activity periods may assist in planning on-farm management practices, such as aligning supplement feeding with peak grazing times.

Understanding the spatio-temporal pattern of grazing livestock enables the visualisation of land use and herd movement [30], which is important for both animal and sustainable land management [31,32]. In this study, there were clear visual seasonal differences for paddock usages, which could be attributed to the location of shade and shelter as well as pasture availability. The spatio-temporal movement of grazing cattle has been shown to vary with the availability of feed or feed type preferences [32]. Improving the knowledge of paddock and environment use by grazing livestock has the potential to guide paddock design, pasture management practices, and improve environmental management through understanding the factors that drive livestock movement [31–33]. Currently, there are no comparable data for the spatio-temporal movement of alpacas, highlighting an area for further research to improve production efficiency and environmental management of alpacas in extensively raised systems.

This study examined both Suri and Huacaya behaviour, research which has been limited previously in Australian extensive production systems. In this study, there was a significant difference between the average daily distance travelled between the breeds, with Suri alpacas travelling further than Huacayas. Differentiated behaviour between different sheep breeds grazed in extensive production systems has been reported previously [34,35]. In sheep, it has been found that factors including selection pressure of predators, exposure to humans and body size can influence behaviour with regards to social spacing in herds, resulting in differences in grazing behaviour [34]. The social behaviour of alpacas in extensive systems, as the sole species being grazed, is not well researched, highlighting an area for future development to understand alpaca herd social structure in a commercial production setting. Variations in behaviour between breeds have been reported in other livestock, with cattle grazing in a mountainous grassland environment displaying differences in movement and travel distances between three cattle breeds [36]. However, in the study by Pauler et al. [36], the behavioural differences were attributed to variation in anatomical structures such as hoof size. In alpacas, it is unlikely that this explains differences in activity, as the breeds are similar in adult size and anatomical attributes aside from fleece structure. Further research is required to understand if this difference is a recurring trend and to identify the external and animal-related factors influencing the distance travelled per day.

4.2. Effect of Real-Time Tracking Technology on Animal Health

GNSS and accelerometer technology in ear tags or collars are becoming increasingly common in livestock production to improve animal health and optimise productivity [3,6,8,10]. A vital aspect to consider when trialling new technology for livestock management is ensuring that the technology does not result in negative impacts on health and welfare. The use of the collar mounted tags in this study displayed no significant reduction in body condition scores between the treatment and control groups, suggesting that the use of the tags has minimal negative impact on alpaca health when applied to the animal via a collar, supporting the continued use of this technology based on the information available from this study.

Real-time and continuous tracking technology can identify unwell or injured animals by using changes from normal behaviour [10,37]. This type of information can also be used to identify animals that are showing early signs of illness or ill-thrift [10]. The benefit of early detection is improved recovery rates, reduced disease spread and it can also reduce the economic burden of treating late-stage or widely spread issues. As the normal behaviour of cattle and sheep is more widely documented compared to alpacas, the real-time monitoring systems have been able to be used to create production associations with live movement data, such as comparing levels of rumination and with milk yield and quality in dairy cattle [38]. Furthering this, collar-mounted accelerometers were able to measure how long dairy cattle were experiencing heat stress through increased breathing motions, providing a practical application of early heat stress detection [6]. The benefit of remote animal monitoring technology in extensive livestock systems extends into utilising this tool to make informed production decisions, including in reproductive management [9]. Through understanding and identifying changes in normal behaviour, not only can producers identify health issues such as heat stress [6], but the information can also be used to detect oestrus as both cows and ewes are found to show increased activity in the mornings during the oestrus period [9,37]. Accelerometer technology, which is often paired with GNSS in monitoring tags and collars has also been successfully used to detect calving times [38], which enables producers to be aware of animal activity and provide early intervention if needed. The implementation of real-time monitoring collars in other livestock industries provides a starting point to base industry adoption and future development for this technology in other species including alpacas. However, it is crucial to have an understanding of normal behaviours in order to use real-time monitoring to detect behavioural changes for welfare or reproductive management.

4.3. Research Learnings and Future Opportunities

For GNSS and similar technology for real-time alpaca behaviour tracking to be implemented on-farm, key information around deviations from normal behaviour is required to alert a producer of the need for potential intervention [10]. The moulding issue impacting the water tightness of the tags resulted in false alerts due to the tags' failure to send data to the gateway. The false alerts, alongside poor weather conditions in autumn, resulting in localised flooding, prevented visual observations of the animals, limiting this study's ability to validate the accuracy of the low activity alerts. This was resolved with replacement tags. Future research and technology development in alpacas would benefit from focusing on the accuracy of detecting specific behaviours, such as low activity and inactivity, to alert producers to an issue. The results of this study have showcased that real-time tracking tags are a valuable tool for assessing the natural behaviour of alpacas in a free grazing environment as the tags supported longitudinal monitoring across 24-h periods, which has not previously been reported for alpacas in Australia. The potential benefits for day-to-day alpaca care and management include the capacity to remotely monitor herd and individual animal health and welfare, facilitating immediate remediation when required.

5. Conclusions

GNSS technology has previously been limited in monitoring alpaca behaviour. The Smart Paddock Bluebell tag highlighted the capacity for GNSS remote monitoring technology to be used as a research tool to investigate alpaca behaviour under commercial grazing conditions. The remote-monitoring technology resulted in no negative impacts on body condition score and possesses the ability to enable producers to monitor alpacas for illness or injury through absence of normal movement when visual observation is not possible. The results of this study showcase the potential for GNSS remote monitoring technology to be utilised in a practical, extensive production system for alpacas raised in Australia.

Author Contributions: Conceptualization, project administration, investigation, writing—original draft preparation, visualisation, I.B.; methodology, I.B. and R.B.; formal analysis, data curation, I.B. and E.H.; writing—review and editing, R.B. and E.H.; supervision, R.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the Australian Alpaca Association, Industry Development Grant 2023.

Institutional Review Board Statement: The study protocol was approved by the The University of Sydney Animal Ethics Committee (Project Number 2023/2333, 1 August 2023).

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Acknowledgments: The authors wish to thank the Australia alpaca producer involved for providing the animals and location for this research.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

BCS	Body Condition Score
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System

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5 Chapter 4: Characterisation of the Faecal Microbiome of Alpacas Raised in South Eastern Australia

This chapter has been published in Animals.

Boughey, I.; Samsing, F.; Hall, E.; Rodney, R.; Bush, R. Characterisation of the Faecal Microbiome of Alpacas Raised in South Eastern Australia. Animals 2025, 15, 1748. https://doi.org/10.3390/ani15121748

Microbiome analysis can be a valuable tool in understanding and managing animal health as well as improving the understanding of how specific microorganisms can influence growth and productivity [1, 2, 3, 4]. Whereas the real-time livestock tracking tags discussed in Chapter 3 are a valuable tool for producers to improve livestock management on the farm, understanding the microbiome of alpacas is a tool that can be used to compare and improve productivity through nutrition and digestive health.

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Article

Characterisation of the Faecal Microbiome of Alpacas Raised in South Eastern Australia

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Simple Summary: There is a large health and production knowledge gap for alpacas raised in Australia and further abroad with regard to their microbiome. This study aimed to characterise the faecal microbiome of alpacas raised in south-eastern Australia and identify variations across geographic regions. Faecal samples were collected from 59 healthy adult female alpacas, aged between 15 months and 17 years in NSW, Australia. Firmicutes were identified as the dominant phyla, followed by Bacteroidota. These two phyla accounted for 90% of the taxa, with the cumulative abundance of Firmicutes and Bacteriodota significantly differing across locations ($p < 0.05$). Age did not have any effect on the frequency of microbes identified at either phyla or class levels. The alpaca's production status only significantly affected the abundance of Firmicutes *Clostridia Oscillospirales* ($p = 0.0026$). The characterisation of the alpaca faecal microbiome identified here is consistent with previous ruminant and camelid studies. This study provides a valuable baseline for the microbiome characterisation of alpacas in south-eastern Australia and can be used as a reference point for further microbiome studies.

Abstract: There is limited investigation of the alpaca microbiome on a global scale, with no previous research conducted in Australia characterising the faecal microbiome. The microbiome composition in other ruminants has been shown to impact feed efficiency, average daily gain and methane production. This study aimed to characterise the faecal microbiome of alpacas raised in south-eastern Australia and identify variation across geographic regions. Faecal samples were collected from 59 healthy adult female alpacas, aged between 15 months and 17 years in NSW, Australia. Firmicutes were identified as the dominant phyla, accounting for 57.78% of the cumulative abundance, followed by Bacteroidota (29.12%). These two phyla accounted for 90% of the taxa, with the cumulative abundance of Firmicutes and Bacteriodota significantly differing ($p < 0.05$) across locations. There was no effect of age on the frequency of microbes identified at either phyla or class levels. The alpaca's production status only significantly affected the abundance of Firmicutes *Clostridia Oscillospirales* ($p = 0.0026$). The breakdown of the alpaca faecal microbiome identified here is consistent with previous ruminant and camelid studies. This study provides a valuable baseline for the microbiome characterisation of alpacas in south-eastern Australia and can be used as a baseline for further microbiome studies.

Keywords: alpaca; camelid; faecal microbiome

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Academic Editor: Chunqi Gao

Received: 15 April 2025
Revised: 19 May 2025
Accepted: 11 June 2025
Published: 13 June 2025

Citation: Boughey, I.; Samsing, F.; Hall, E.; Rodney, R.; Bush, R. Characterisation of the Faecal Microbiome of Alpacas Raised in South Eastern Australia. *Animals* **2025**, *15*, 1748. https://doi.org/10.3390/ani15121748

1. Introduction

The ruminant microbiome plays an essential role in the absorption of nutrients and the feed efficiency [1,2]. In ruminants, the microbiome composition has been seen to impact weight gain and feed efficiency due to the role of key taxa in carbohydrate metabolism [3,4]. Variation from a healthy microbiome is linked to metabolic diseases, with an understanding of the role of taxa in the microbiome informing management practices and optimising animal health and growth [4,5]. As methane production from agriculture contributes to greenhouse gas emissions, understanding the composition of the ruminant microbiome and factors that influence metabolic function has become a focus, specifically the functional and compositional microbiome [5–7].

Alpacas are pseudo-ruminants, with 3 compartments in their foregut, relying on gut microbial communities to break down plant cell wall carbohydrates, similar to true ruminants [8]. Microbiome compositions in ruminant species are highly variable and can be impacted by a variety of factors, including diet composition and husbandry practices [2,9,10]. Understanding the alpaca microbiome is important for improving management practices for optimal alpaca health and production. The proportion of Firmicutes and Bacteroidota as the dominant phyla in ruminants influences feed efficiency and average daily gain [4]. As pseudo-ruminants, the limited research on the alpaca microbiome globally has indicated similarities with the dominant microbiome of true ruminants. American-based studies determined that Firmicutes and Bacteroidetes are the dominant phyla found in the faecal and gut microbiome of alpacas and camels [8–11]. However, there is variation in the dominant taxa, as species in the Eubacterium phyla have also been highlighted in both the USA and China [12,13]. The variation in findings across different geographical locations highlights the need to investigate environment-specific microbiome communities in alpacas. Understanding the composition of the microbial communities in alpacas presents an opportunity to improve nutritional management and gastrointestinal care to benefit the animals and production system. Understanding the microbiome of ruminants has had increased interest recently due to the role of methanogenic archaea in the production of methane in the rumen [6]. Alpacas have been identified to have lower methane emissions compared to sheep raised in the same environments due to the differences in the microbiome [12]. Identifying these changes across different locations and conditions may provide insight for future management of other ruminant species.

The microbiome has traditionally been difficult to investigate as it requires specialist expertise to collect and process rumen samples. Studies such as [11] have started to characterise the microbiome using faecal samples, providing a non-invasive option for analysing microbiome communities. The faecal microbiome in ruminants is comparable to the microbial community found in the lower digestive tract [14,15]. To our knowledge, no studies have been conducted that examine the faecal microbiome of alpacas in Australia, and there are varying microbial populations reported between the USA and China. This study aimed to characterise the faecal microbiome of alpacas raised on the east coast of Australia to create a reference base for future research and veterinary applications.

2. Materials and Methods

2.1. Faecal Collections

Faecal samples were collected from healthy, breeding female alpacas aged between 15 months and 17 years from 5 farms across New South Wales, Australia, in September 2023. The farms were located in the Southern Highlands, Far South Coast, Central West, Greater Sydney and New England regions (Figure 1). The locations were selected as representative distribution of Australian alpaca farms based on survey data [16]. Table 1 oulines the primary pasture species and supplement feed on offer at each location. All alpacas were female and categorised into one of the following production status categories: Empty (not pregnant), Empty with Cria at Foot (not pregnant and lactating), Pregnant, and Pregnant with Cria at Foot (pregnant and lactating). A total of 60 samples were collected, 12 from each location. Table 2 presents data on the individual alpacas. Faecal samples were collected from animals restrained in a purpose-built race using a lubricated glove to scoop faecal pellets from the rectum. Faeces were collected in accordance with procedures approved by the University of Sydney Animal Ethics Committee (Project Number 2023/2333).

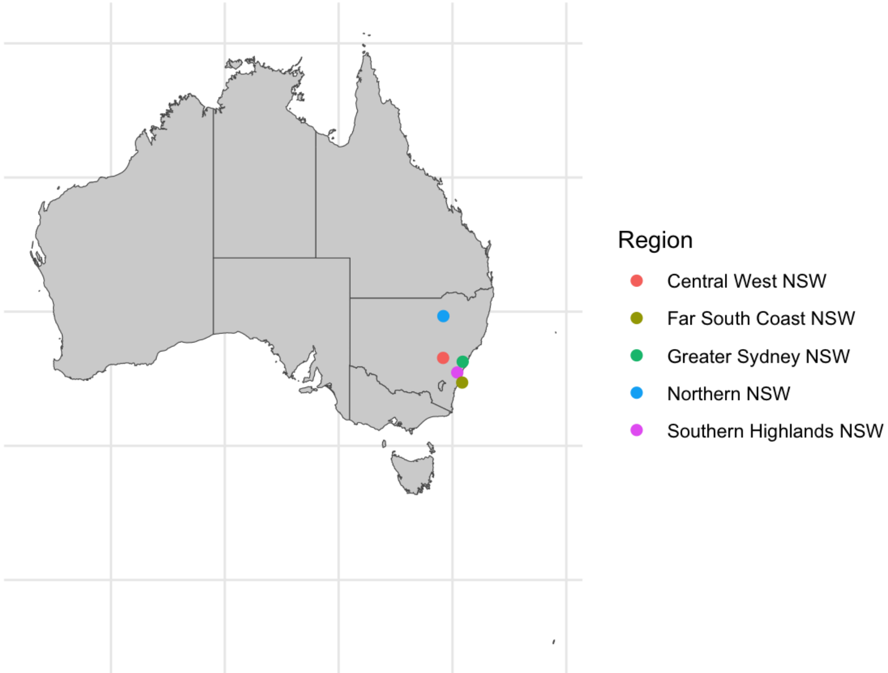

Figure 1. Distribution of alpaca faecal sample collection locations in Australia.

Table 1. Primary pasture species and supplementary feed.

Region	Primary Pasture Species	Supplemental Feed
Central West	Phalaris (*Phalaris aquatica*), Cocksfoot (*Dactylis glomerata*), Wallaby Grass (*Rytidosperma* spp), Microlena (*Microlena stipoides*), Tussock Grass (*Poa labillardierei*), White Clover (*Trifolium repens*), Subterranean Clover (*Trifolium subterraneum*), Perennial Ryegrass (*Lolium perenne*)	
Far South Coast	Kikuyu (*Cenchrus clandestinus*), Phalaris (*Phalaris aquatica*), Cocksfoot (*Dactylis glomerata*), Wallaby Grass (*Rytidosperma* spp.), Microlena (*Microlena stipoides*), Tussock Grass (*Poa labillardierei*)	Ad Lib Access to Hay Mix: Lucerne (Alfalfa) Hay (*Medicago sativa*), Oaten Hay, Clover Hay
Greater Sydney	Kikuyu (*Cenchrus clandestinus*), Microlena (*Microlena stipoides*), Couch (Cynodon dactylon)	Ad Lib Access to Hay Mix: Lucerne Alfalfa) Hay (*Medicago sativa*), Oaten Chaff, Horse Pellet Mix
Northern NSW	Phalaris (*Phalaris aquatica*), Cocksfoot (*Dactylis glomerata*), White Clover (Trifolium repens), Perennial Ryegrass (*Lolium perenne*)	
Southern Highlands	Kikuyu (*Cenchrus clandestinus*), Perennial Ryegrass (*Lolium perenne*)	

Table 2. Metadata for sample collection including basic husbandry practices.

Region	Age (Months)	N	Production Status	N	Vaccination	Drench	Recent Supplements
Far South Coast	13–18 19–29 30–47 48+	0 1 2 9	Empty with Cria Pregnant Empty Pregnant with Cria	1 9 2 0	5in1	STARTECH	ADE and Phosphorus Injection
Central West	13–18 19–29 30–47 48+	0 1 2 9	Empty with Cria Pregnant Empty Pregnant with Cria	2 0 9 1	5in1	NA	Selenium 1 mL
Greater Sydney	13–18 19–29 30–47 48+	0 3 0 9	Empty with Cria Pregnant Empty Pregnant with Cria	2 5 5 0	5in1	AVERMEC Dual	
Southern High-lands	13–18 19–29 30–47 48+	0 0 2 10	Empty with Cria Pregnant Empty Pregnant with Cria	0 1 11 0	5in1	Startech	ADE Injection
Northern NSW	13–18 19–29 30–47 48+	2 2 0 8	Empty with Cria Pregnant Empty Pregnant with Cria	1 5 6 0	5in1	Ivermectin Injectable (Cattle)	

NA-not applicable.

2.2. DNA Extraction and Bioinformatics

Samples were frozen at −20 °C on the day of collection and until undergoing freeze drying for 72 h. Freeze-dried samples were stored at −20 °C until DNA extraction. DNA was extracted using the QIAamp Powerfaecal Kit (Qiagen, Hilder, Germany) per the manufacturer's instructions. PCR products were further processed at the Ramaciotti Centre for Genomics (UNSW, Sydney, Australia). Illumina MiSeq 2 × 300 bp (Illumina, San Diago, CA, USA) sequencing was used to amplify the 16S rRNA, V3–V4 regions using the forward primer 'CCTACGGGNGGCWGCAG' and reverse primer 'GACTACHVGGGTATCTAATCC'. Quality control was >70% sequences above Q30. Microbiome bioinformatics analysis was performed with QIIME2 2024.10 [17]. Primers were removed with cutapdat, trimming was conducted with the quality filter q-score [18] and denoising was completed with DADA3 [19] (via dada2 denoise-paired). One sample was removed during filtering due to a frequency below 2000. Taxonomy was assigned using classify-sklearn [20], naïve Bayesian classifier [21] and the SILVA NR 99 database. OTUs (operational taxonomic units) classified as mitochondria, Eukaryota and chloroplast were filtered before analysis. Abundance calculations and the bacterial community structure were assessed using the Bray–Curtis distance calculation with a principal coordinate analysis plot using R [22]. The original data presented in the study are openly available in the Sequence Read Archive (SRA) at PRJNA1264719.

2.3. Statistical Analysis

Analyses were performed using R Version 4.4.1 (R Core Team 2024) and Microsoft Excel 2018 [23]. Linear models were used to determine the effect of the location, production status and age on the presence of the microbial communities identified in the bioinformatics steps down to an order level. Linear modelling was conducted on the top OTUs,which included the populations contributing up to 90% or greater of the cumulative abundance when sequencing results were pooled. A p-value of <0.05 was considered significant.

3. Results

3.1. Faecal Microbiome Population

The average number of 16S rRNA gene sequences per sample was 24,082.27 (±9572.91). Firmicutes were the dominant phyla identified, accounting for 55.35% of the taxa in the pooled samples, followed by Bacteroidota (31.30%) (Table 3). A detailed breakdown of the taxa found at phyla, class and order levels that account for the top OTUs is presented in Table 3.

Table 3. Relative abundance of top OTUs in alpaca faecal microbiome.

Phylum	
Firmicutes	57.78%
Bacteroidota	29.12%
Class	
Firmicutes Clostridia	51.76%
Bacteroidota Bacteroidia	29.16%
Firmicutes Bacilli	5.48%
Verrucomicrobiota Verrucomicrobiae	2.90%
Order	
Bacteroidota Bacteroidia Bacteroidales	29.05%
Firmicutes Clostridia Lachnospirales	21.41%
Firmicutes Clostridia Peptostreptococcales-Tissierellales	11.99%
Firmicutes Clostridia Oscillospirales	10.19%
Verrucomicrobiota Verrucomicrobiae Verrucomicrobiales	5.12%
Firmicutes Bacilli Erysipelotrichales	2.89%
Desulfobacterota Desulfovibrionia Desulfovibrionales	2.71%
Firmicutes Clostridia Christensenellales	2.40%
Verrucomicrobiota Kiritimatiellae WCHB1-41	2.00%
Proteobacteria Alphaproteobacteria Rhodospirillales	1.29%

3.2. Effect of Location, Age and Production Status

All the top OTUs at a phylum, class and order level were significantly affected by region ($p < 0.05$). The phylum Firmicutes accounted for between 53.9% and 61.5% of the alpaca biome, whilst Bacterioda contributed between 27.3% and 33.7%. The distribution of the top taxa for Class and Order levels can be seen in Figures 2 and 3.

The principal coordinate analysis calculated using the Bray–Curtis distance accounted for 17.4% of the variation between groups. The limited clustering indicates that Northern NSW, Southern Highlands and, to a lesser degree, the Central West regions were more similar compared to the Far South Coast and Greater Sydney (Figure 4).

At an order level, Firmicutes Clostridia Oscillospirales ($p = 0.0026$) was the only taxa significantly impacted by status with Empty animals displaying a significantly higher abundance of Firmicutes Clostridia compared to animals that were Pregnant and Pregnant with Cria at Foot. No other taxa displayed significance. There was no effect of age displayed at the phyla, class or order levels ($p > 0.05$).

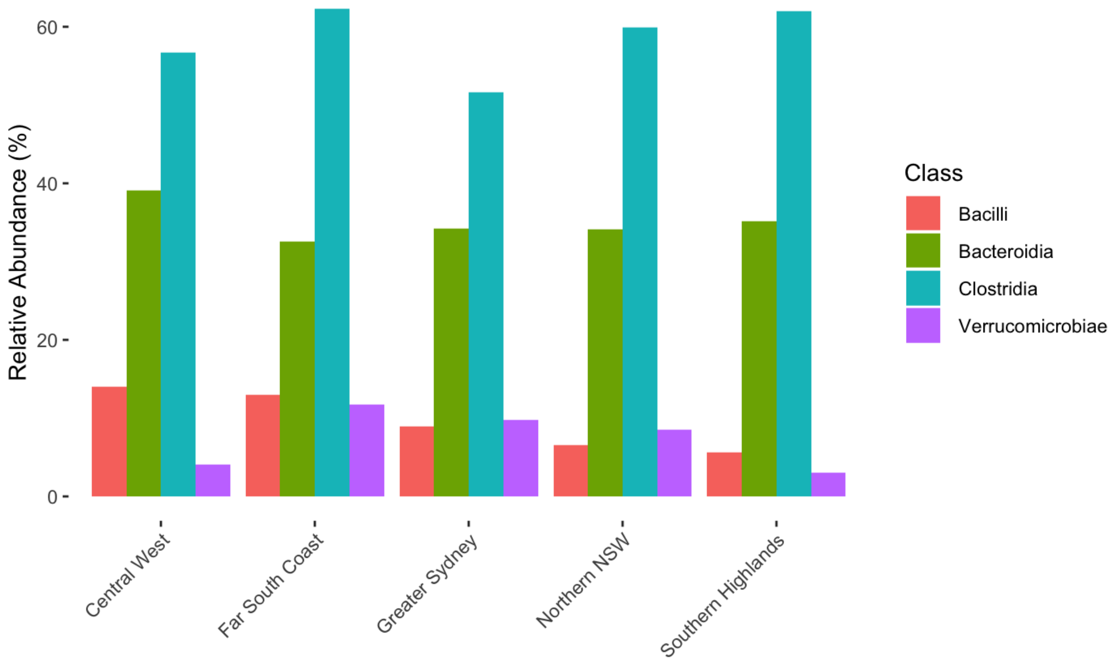

Figure 2. Variation of relative abundance of class OTUs making up top 90% by region in alpaca faecal microbiome.

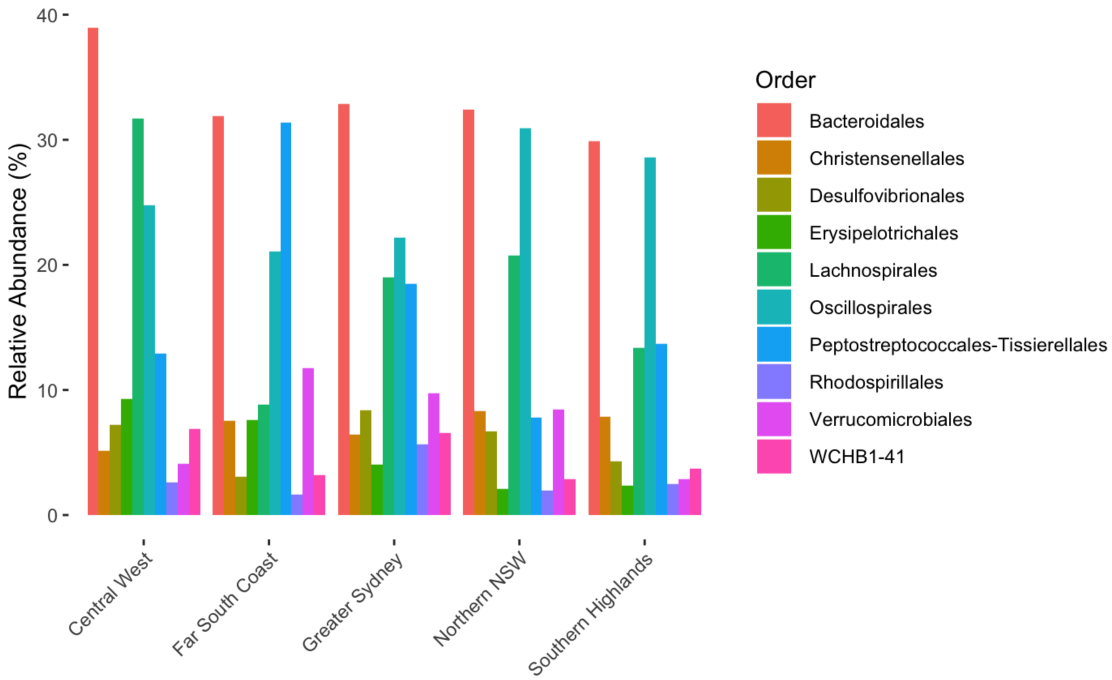

Figure 3. Variation of relative abundance of order OTUs making up top 90% by region in alpaca faecal microbiome.

3.3. Methanogens Present in Alpaca Faecal Microbiome

The Archaea Euryarchaeota phyla accounted for 0.17% of the taxa in the alpacas studied. At a class level, from the Euryarchaeota phylum, *Methanobacteriales* accounted for 0.18% of the total taxa, *Methanomassiliicoccales* 0.09% and *Methanomicrobiales* 0.01%.

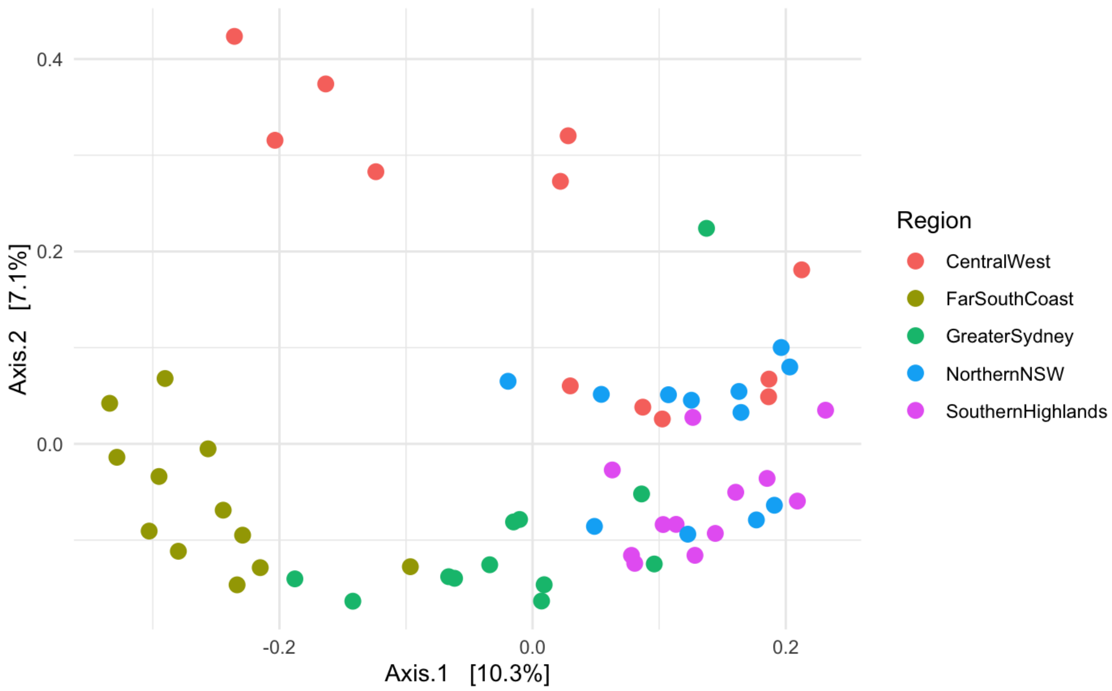

Figure 4. Principal coordinate analysis showing the analysis of faecal microbiome in alpacas across different regions of NSW.

4. Discussion

There is a paucity of information on the microbial community in alpacas with a small number of studies globally, mainly in the USA and China, exploring alpaca microbiome composition and diversity. In other species, including cattle, changes in taxa have been associated with desired improvement in health and production such as higher weight gain during weaning. The dominant taxa now identified in Australian alpacas display similar ratios when compared to other ruminants. Future research building upon this characterisation of the alpaca microbiome in Australia will provide a new pathway for veterinary management of alpacas in small-scale and commercial production systems.

The majority of alpaca microbiome studies have sampled forestomach fluid and digesta from other areas along the gastrointestinal tract with only three studies using faecal samples for analysis. Of these, [24,25] focus on isolating novel species of Bacteroides and Clostridium, respectively, whilst [11] looked at the association between the microbiome and endoparasitism making it difficult to meaningfully compare this characterisation with these studies. Although prior use of faecal samples to analyse alpaca microbiome had different focal points, the results support Firmicutes and Bacteroidota being the dominant two taxa in alpacas despite different geographical locations [9,11,24,25]. Firmicutes and Bacteroidota have been widely reported as dominant taxa in other common ruminant species, including cattle, sheep and goats [4,26–29]. The proportion of these two groups of taxa varies, with Firmicutes consistently displaying a higher proportion than Bacteriodota, aligning with the results in this study [4,26,28]. The faecal microbiome of camels has been studied more widely compared to alpacas exhibiting similar results to the microbial composition of this study, despite different locations and environmental conditions. Firmicutes (59.7%), Bacteroidota (24.3%), as well as Verrucomicrobiota (8.09%), have been reported as the three dominant taxa in adult Bacterian camels raised in Mongolia, with similar levels of relative frequency as reported here [30]. The similarity across the different environments indicates that at a phlya level, the Firmicutes and Bacteroidota are consistently the dominant taxa [9,11,24,25]. This study also indicates that the environment can impact the proportion of both phyla present in the faecal samples. This trend was also reported in India in camels where the faecal microbiome was compared between two different management and feeding systems [10]. Conversely, that study found that in an extensive system most similar to Australia, Proteobacteria was the most abundant phyla followed by Firmicutes, then a smaller proportion of Bacteroidota, highlighting a potential difference in camelid species that requires further research [3,30]. The variation among locations needs to be researched further to investigate the impact of environmental factors due to location or the contribution of management practices on microbiome composition.

Pregnancy and lactation have various effects on the physiology of female ruminants, including altering metabolic rate and nutritional requirements along with the composition of the rumen microbiome fluid [31–33]. Lima at al. [31] found that the structure of the microbial communities present in the rumen fluid of dairy cows changed between prepartum and 1 week postpartum (lactation) and that certain bacterial taxa were associated with differences in milk production and composition. The abundance of Firmicutes in Hu sheep has been found to be higher during pregnancy and lactation whilst the abundance of Bacteroidota was lower when compared to non-pregnant (empty) sheep [32]. However, this trend is not consistent with breed, as Suffolk sheep in the same study showed higher levels of Bacteroidota taxa during pregnancy and lactation [32]. Although the taxa reported vary between studies in different ruminant species (cattle, sheep and goats), differences in the microbiome are consistently identified between pregnant, lactating and empty animals [32–34]. Further understanding the impact of variation at different production status' could provide opportunities to improve management recommendations and health using faecal samples as a minimally invasive sample collection method. Furthermore, studies conducted in camels have identified different key taxa in animals at 2 months of age vs. adult animals between 1 and 3 years [30]. This variation has been connected to the changes in diet and/or physiology as alpacas/camels age, which in turn influence microbial communities and their role in digestion and immune system development [30]. However, in this study, only adult female alpacas were examined, and age did not have any impact. This suggests a need for future studies to compare alpacas of different ages.

Alpacas have been reported to produce less methane compared to other domesticated ruminants such as sheep and cattle [12,35]. The Archaea *Methanbrevibacter* clade has been identified as the key methanogen from the Euryarchaeota phyla responsible for ruminant methane production [6,36]. Both *Methanbrevibacter* and *Methanosphaera* have previously been identified as methanogens present in the forestomach of alpacas, with *Methanbrevibacter* as the dominant methanogen [13], which is consistent with the results of this study using faecal samples. In this study, the Euryarchaeota taxa only accounted for 0.17% of phyla, with *Methanbrevibacter* the dominant taxa in this phyla, which is less than what has been reported in sheep [12] and other ruminants [35]. Pei et al. [12] reported that methanogens accounted for 1.38% of the microbial forestomach community in alpacas, which was lower than the 1.92% they reported in sheep, following a similar trend reported by [37]. This variation in the proportion of methanogens identified between these studies could be attributed to the difference in location and management conditions and requires a more detailed investigation. The lower percentage of methanogens, alongside nutrition and other physiological differences in the gastro-intestinal tract has been postulated as the reason for the reduced methane production in alpacas compared to other ruminants [35,37,38].

The practical applications of understanding the alpaca microbiome at a global and local scale are important in improving the overall knowledge base of alpaca health and management in their context as a farmed production animal. The impact of endoparasites on the faecal microbiome has been investigated with endoparasite presence linked to a small proportion of variation between microbial composition and stronglyid egg populations [11]. Firmicutes have been identified to breakdown carbohydrates into energy [3], with the Firmicutes-to-Bacteroidota proportion impacting feed efficiency in ruminants and average daily gain (ADG) in cattle [3,4]. Maslen et al. [4] reported that in weaning cattle, the individuals with a lower production efficiency (reduced ADG) had a lower frequency of Firmicutes and higher Bacteroidota compared to those with a higher efficiency, highlighting that understanding the microbiome communities is important in managing ruminant nutrition and production efficiency.

The similarity of microbiome key taxa at a phylum level across common ruminant species in agriculture has been acknowledged, supporting the theory of a core rumen microbiome [3]. The similar key taxa among sheep, cattle and alpacas, across a variety of locations suggests that other ruminant models such as sheep, cattle or camels may be useful for basic knowledge in alpacas; however, as there is variation in physiology, more species-specific models and research needs to be conducted to improve alpaca welfare, veterinary care and management practices.

5. Conclusions

The faecal microbiome of alpacas in Australia is consistent with ruminant and camelid studies from across the globe. Firmicutes and Bacteroidota were the key phyla identified by this study and align with other ruminants including cattle, providing a baseline for further research into the production implications of changes in microbiome composition. The results of this study support the theory of a core rumen microbiome at a phylum level, indicating that other ruminant models may be the suitable starting point for alpaca-based care. However, species-specific knowledge still needs to be established.

Author Contributions: Conceptualization, project administration, investigation, writing—original draft preparation, visualisation, I.B.; methodology, I.B., F.S. and R.B.; formal analysis, data curation, I.B. and E.H.; writing—review and editing, R.B., F.S., R.R. and E.H.; supervision, R.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study protocol was approved by the University of Sydney Animal Ethics Committee (Project Number 2023/2333, 1 August 2023).

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw sequencing data for this genome is publicly available in the SRA(PRJNA1264719).

Acknowledgments: We would like to thank Anna Waldron and the Sydney School of Veterinary Science for conducting the DNA extraction. We also wish to acknowledge Ruth Zadoks [University of Sydney, Sydney School of Veterinary Science] for their support in the DNA extraction and sequencing component of this work. Thank you to the Australian alpaca producers that participated in this study.

Conflicts of Interest: The authors declare no conflicts of interest.

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6 General Discussion

This research presents the first data on the herd paddock behaviour of alpacas raised in an Australian extensive production system. It outlines a plausible use case for the adoption of livestock monitoring technology to improve health and productivity outcomes. The previous information published for Australian alpacas was focused on addressing vitamin D deficiency [1] and intestinal parasites [2] as well as comparisons of alpacas co-grazed with sheep [3, 4]. The novel research in this thesis provides valuable information and recommendations for the Australian alpaca industry, focusing on the documentation and improvement of alpaca management practices, as well as identifying areas for further investigation.

6.1 Australian Alpaca Industry Demographics

The results of a nationwide survey of Australian alpaca owners set the foundation for the research conducted in this thesis. There is little known about the current demographics of the Australian alpaca industry. This survey has provided an opportunity to assess the current demographic information, including industry structure. The survey conducted in 2024 (Chapter 1) confirmed the majority of alpaca producers are located on the east coast of Australia, with smaller numbers in South Australia and Western Australia, similar to what was reported by Rashid et al. [5] and Hernandez-Jover et al [6]. This survey also collected information on herd size with the number of medium (50–249 alpacas) and large (250 alpacas) scale enterprises increasing as the industry continues to develop [5]. In 2015, 64% of herds contained less then 50 alpacas, compared with 60% in 2023 (Chapter 1). With the gradual increase of larger-scale properties, the primary purpose of owning alpacas is focused on fibre production [5], which in 2022 had an estimated farm gate value of AUD $13.5 million [7] . However, compared to respondents in the 2015 survey, farming alpacas for meat has dropped from 16% [5] to 10% of respondents in this study (Chapter 1). This difference could be due to the reduction in meat processing plants that are accepting alpacas in recent years. Using alpacas for meat production is one of the lower sources of income generation across the industry, with an estimated farm gate value of AUD $0.45 million, compared to selling alpacas as pets, which has an estimated farm gate value of AUD $5 million. [7].

A trait of the Australian alpaca industry that continues to remain constant is the dominant use of the Huacaya breed (93%) compared to the Suri breed (7%) (Chapter 1)[5]. The higher popularity of the Huacaya breed could be linked to market access with the Huacaya fibre possessing similar traits and processing requirements to wool [8]. Further to this, the majority of respondents (60%) in this survey only owned one breed. However, the reason for this is unclear and would require further investigation to determine breed preference.

6.1.1 On-Farm Management Practices

A key outcome from the survey is producer knowledge with regard to nutrition and grazing management. In this survey, 25% of respondents were unable to identify the pasture species that was being grazed by the alpacas they owned. This is the first time this data has been reported for the Australian alpaca industry. This low level of knowledge is a concern as inadequate or imbalanced nutritional intake can be detrimental to alpaca, with potential for reduced production (slower wool growth, weight loss, tender fleece) due to malnourishment or even death in severe cases where conditions such as protein energy malnutrition (PEM) occur [9, 10]. Providing supplemental feeds such as fortified pellets is quite common in the alpaca industry (48.2%). However, with many respondents feeding pelleted feed designed for other ruminants (including sheep and cattle) as well as horses, alongside the uncertainty of what pasture is being grazed, there is a risk of inappropriate feed types and nutritional intake. A contributing factor to the guesswork that occurs with feeding alpacas worldwide [9] can be attributed to the lack of knowledge available, including grazing behaviour, as well as consistent and detailed management guidelines. Published practical solutions have previously been provided to identify issues such as vitamin D deficiency and the development of rickets, and have had a positive influence and successful adoption in the Australian alpaca industry [1, 11, 12].The information contained within Chapter 1 provides a foundation for similar management recommendations to be developed. This would be especially relevant to the increasing numbers of large-scale (> 250 alpacas) enterprises for management practices related to pasture utilisation.

Internal parasites, particularly gastrointestinal nematodes, are a common and potentially severe problem for livestock health in Australia, including alpacas [5, 13, 14, 15]. Gastrointestinal nematodes are typically managed through the use of anthelmintics for both prevention and treatment [5, 13, 14]. The key issue identified previously by Rashid et al [5] and again in the survey conducted here, is the lack of licensed anthelmintic treatments for alpacas, resulting in inconsistent schedules and dosages. This leads to anthelmintic resistance of gastrointestinal worms which is on the rise in livestock [16], with timing of treatments and underdosing among the top contributors [17]. Further research and development into the efficacy and safety of commonly used off-label veterinary chemicals is required to develop clear guidelines for appropriate chemical use, dosage rate and schedules to benefit alpaca health.

The current survey determined less than half of Australian alpaca owners consider veterinarians as a beneficial source of information for alpaca care and treatment of disease [6]. The lack of formal knowledge available to veterinarians and producers alike contributes to veterinary and health care being based on principles inferred from other small ruminant species, namely sheep and goats. This lack of information extends to vaccination recommendations with limited licensed veterinary chemicals and dosages on commonly used products. Although 5in1 and 7in1 vaccinations are regularly recommended for the prevention of clostridium disease and leptospirosis in alpacas, as is common practice in other livestock species in Australia, there is no vaccination schedule or dosage formally available [18, 19]. The only current recommendation is made in the "Code of Welfare for Alpacas and Llamas Australia 2016" prepared by the Australian Alpaca Veterinarians [18] and refers to vaccination of pregnant alpacas at 300 days gestation (4 − 6 weeks prior to unpacking). Despite this, this survey (Chapter 1) identified alpaca owners are following a regular annual or biannual vaccination schedule, similar to the schedule defined for sheep on the vaccination product. The success of these vaccination schedules has not been documented. Improving access to information for the relevant professional sectors, including veterinary care and on-farm management, as well as further investment into research and development of suitable vaccinations or vaccination regulation, has the potential to improve veterinary training in camelid care and, in turn, the trust and relationships between alpaca owners and the veterinary sector. Further clarification of suitable disease prevention options available to alpaca producers may help address the variation in vaccination use, including instances where there is no routine use as found in the survey (Chapter 1).

6.2 Alpaca Behaviour

6.2.1 Improving Alpaca Paddock Behaviour Knowledge

In an extensive production system in Australia, alpaca grazing activity is mainly during daylight hours (0700 - 1500). In addition, grazing is the most commonly observed behaviour [20, 21, 22] with resting and standing behaviours, including chewing cud (rumination), regularly observed albeit to a lesser extent [21, 22]. In Peru [20, 23] and Poland [21], alpacas are seen resting more during night hours compared to daylight hours. However, these observations were conducted in production systems in which alpacas were corralled or moved in stables for safety purposes overnight [21, 23], removing the opportunity for alpacas to display grazing behaviours. The research contained in Chapters 2 and 3 of this thesis, investigated the behaviour of alpacas management in a paddock environment without being corralled or housed inside at night. Even with this management difference, the visual observations and activity levels recorded by GNSS and accelerometer technology in real-time tracking tags reveal a similar trend in extensively raised alpacas that remain in the paddock during night hours in Australia. Understanding the diurnal behavioural trends of alpacas has the potential to provide owners with a valuable tool for the early and remote detection of illness and injury. Combining the video observations and data from the real-time tracking tags, the normal paddock behaviour of alpacas in an extensively raised system has been documented enabling future technology development to detect reductions in activity [24, 25] to facilitate the early detection of health conditions that cause reduced activity levels. The importance of understanding natural grazing behaviour also applies to the development of management guidelines, particularly with regard to supplement feeding or drought feeding. When providing supplement feed to livestock it is important to consider not only the type of feed but also the timing in order to reduce disruption to the digestive system [26, 27]. Based on the insights gleaned from this research, it is recommended to provide supplement feeds during the afternoon between 1300 and 1500 based to align with observed peak grazing times. However, during warmer months, as alpacas tend to graze later in the day, this should be later (1300-1600) to accommodate for seasonal differences.

With an increasing number of large-scale alpaca enterprises, it is important to understand how alpacas interact with their environment. Most pre-existing knowledge of alpaca behaviour in Australia has been in co-grazing situations with sheep, both for fleece production [3] and as herd guardians [4, 28]. These studies have provided valuable information, particularly in comparison to sheep, as most of the current management practices have evolved from successful sheep applications. However, the key differences between sheep and alpacas appear to be the continuous daytime grazing and lower activity levels during the night in alpacas compared to the discrete peaks in grazing that have been recorded in sheep every 8 hours [22, 29]. Although the reason for this is not known, it is plausible that management strategies applied in South America, where the alpaca was domesticated, have resulted in the species displaying the same behaviour. Domesticated cattle have been observed displaying natural grazing behaviours in agricultural production systems [30], indicating that is could explain the behavioural trend across different systems. The baseline behaviour trends reported in both Chapters 2 and 3 provide an introduction into alpaca grazing behaviour in Australia, where alpacas are the sole species being farmed. This contribution of knowledge can be utilised in the Australian alpaca industry to optimise on-farm production through aligning management practices, such as supplement feeding and handling, to cause minimal disruption to normal behaviour. The behavioural trends reported within this thesis provide a comparison for future studies in different environments both within Australia and globally as well as for further research identifying abnormal behaviour for use in health management and early detection systems.

6.2.2 Technology as a Tool for Animal Behaviour

Using real-time tracking tags mounted to collars has provided valuable baseline behaviour information as well as displayed promising potential for alpaca industry adoption. In this research, real-time tracking tags and video footage were successfully used to monitor alpaca paddock behaviour. The benefit of tracking and collecting video without the close presence of human observers cannot be understated, as normal behaviour can be researched over longer periods of time [31, 32]. In addition, the successful use of this technology in a research setting highlights the potential for future development for industry adoption. Real-time tracking technology has the potential to optimise animal welfare practices in extensive production systems, where daily visual observation may not be possible or practical. Utilising GNSS and accelerometer technology also has the potential to enhance the understanding of alpaca activity budgets (the proportion of time spent on defined behaviours or moving in a set period of time) and movement trends on a larger scale [31, 33, 34]. This information can be utilised to create specialised nutrition guidelines and improve industry management recommendations, including paddock size and potentially stocking rate if paired with further pasture studies to establish recommended stocking rates for optimal health and production such as growth in young animals and fibre production [34].

Although a technology validation trial could not be conducted within the scope of this thesis, the results from the GNSS and accelerometer technology using the Bluebell tags (Smart Paddock, Melbourne, Australia) align with reported behaviours from visual observations of alpacas raised outside of Australia [21, 22, 23]. The daylight activity recorded by the tags in this research is also supported by the herd behaviour recorded through the GoPro cameras, providing another basis for future validation projects. The adoption of real-time tracking tags for Australian alpacas could provide improved animal health and welfare management for small to large-scale enterprises through the early detection of illness and remote detection of injury. It is important to note that this research was limited it its ability to investigate if the application of the tags impacted behavioural trends, highlighting an area for further research. The normal behaviour trends reported in this thesis (Chapter 2 and 3) have provided the first data for normal levels of alpaca activity. Further development of real-time tracking technology can utilise these normal activity levels for the detection and alert systems for abnormal activity. Another area that requires further investigation for both industry adoption and further use in research trials is the cost of using the tags. Although the producer's financial willingness to spend was not investigated in this trial, it is important to note that individual tags cost ranges from $59 (Smart Paddock, Melbourne, Australia) to over $466 (Ceres Tag, Queensland, Australia). Future research investigating cost as a factor that influences decision making in the adoption of real-time tracking tags would provide valuable information for the development of suitable devices for the alpaca industry. Overall, this trial of remote tracking technology in alpacas presents a plausible use-case for industry adoption and further technology development, including investigating the suitable size and weight of tags for the alpaca ear.

6.3 Alpaca Faecal Microbiome

The microbiome plays a vital part in ruminant and pseudo-ruminant health and absorption of nutrients [35, 36, 37]. Characterising the faecal microbiome of alpacas raised in Australia has provided a novel insight into the similarity and differences of Australian alpacas with alpacas, camels and ruminant species worldwide. Although the ratio may vary at a phylum level, Firmicutes and Bacteroidota are consistently the dominant taxa in the alpaca microbiome [38, 39, 40]. The results of this study support the theory of a core rumen microbiome [41] and provides a baseline characterisation of the healthy microbiome of alpacas raised in south-eastern Australia. While this study was representation of the Australia alpaca industry, it is expected to see some variation based on environmental conditions. This area would benefit from further development to investigate the variation across other production regions of Australia to develop a comprehensive record of the Australian alpaca microbiome.

Research into the microbiome of ruminants, particularly cattle, provides an understanding of differences in key phyla that can be used as a tool to improve productivity, such as average daily gain in weaner cattle [38]. Baseline characterisation of healthy adult alpacas is required before utilising the microbiome as a tool for improving productivity. The work of Henderson et al. [41] and Maslen et al. [38] highlight the role of specific taxa in feed efficiency and the potential for understanding microbiome interactions to facilitate industry application. Further research is required on the effect the proportion of Firmicutes and Bacteroidota in alpacas may have on nutrient absorption, carbohydrate metabolism and liveweight change [38, 41]. A better understanding of the interaction between microbiome composition and environment will potentially provide practical applications for improved nutrient absorption and feed efficiency. As the move to reduce methane produced by livestock continues to be a focal point in sustainable agricultural production [42, 43], improving knowledge on the role of the *Methanbrevibacter* genus in ruminant and pseudo-ruminant methane production and nutrient absorption has the potential to be a vital next step in reducing methane production in both fibre and meat production [42, 43]. Alpacas have been identified to have lower concentrations of *Methanbrevibacter* taxa compared with sheep [44, 45, 46, 47]. Further understanding of the microbiome may present a future tool for mitigating methane production in ruminant species used in agriculture through careful manipulation of rumen microbiome environments [46, 47, 48].

The microbiome research included in this thesis was representative of Australian conditions, despite limitation in the geographic range due to funding and logistics. However, the successful characterisation using faecal samples opens the opportunity for future research from alpacas distributed around Australia and to investigate how nutritional interventions alter or interact with the microbiome.

7 Conclusion

The Australian alpaca industry continues to develop, with an increased number of large-scale properties comprising >250 animals focused on commercial fibre production. However, small-holder farms with <50 animals remain important. Continual industry development requires improved producer education in the areas of nutritional management, alpaca behaviour and veterinary care. Baseline information on alpaca behaviour under Australian extensive production systems and tools for real-time monitoring provide practical information for improving Australian alpaca health and production.

Real-time tracking technology provided the first insight into Australian alpaca behaviour when farmed as the sole species and not co-grazed with sheep. Extensively grazed alpacas in south-eastern Australia display similar grazing trends to other countries. Despite differences in management, including corralling overnight, grazing is the dominant daytime behaviour. Future research into the use of this technology will be beneficial in informing Australian alpaca management guidelines, such as recommended supplement feed timings.

Characterising the alpaca faecal microbiome has provided a baseline and enables future comparisons with healthy animals. This opens the potential for use as a tool for investigating nutrient absorption, methane production and production factors such as weight gain in growing animals. In addition, this research demonstrates the successful use of faecal samples as a non-invasive sample collection method for microbiome analysis. The identification of Firmicutes and Bacteroidota as the dominant phyla aligns with prior camelid research in different environments and other livestock species, including cattle. The sample collection methods display promising results for industry adoption, with further research required to validate the results across a broader geographical range.

This thesis provides novel information on both alpaca paddock behaviour and faecal microbiome creating a baseline for future use in research focused on improving alpaca productivity and welfare. Importantly, the work contained in thesis provides practical examples of how to utilise livestock monitoring technology designed to improve alpaca monitoring and management with further industry development and adoption.

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