# Combining positional data with climatic and landscape data to understand the interaction of cattle with their environment

Alison SPERA[1], Zoe HALLS[2], David R. STEVENS[3*], Esther D. MEENKEN[4], Warren McG. KING[5], Peter PLETNYAKOV[4], Chandra S. GHIMAIRE[4], Sarah ADAMS[6], and Steve TICKNER[7]

[1]*University of Canterbury, School of Earth and Environmental Science, Private Bag 4800, Christchurch.*
[2]*University of Otago, Department of Mathematics and Statistics, PO Box 56 Dunedin.*
[3]*AgResearch Ltd, Invermay Research Centre, Private Bag 50034, Mosgiel*
[4]*AgResearch Ltd, Lincoln Research Centre, Private Bag, Lincoln*
[5]*AgResearch Ltd, Ruakura Research Centre, Private Bag 3123, Hamilton*
[6]*Gallagher Ltd, 181 Kahikatea Drive, Hamilton*
[7]*Pamu Farms of New Zealand, PO Box 5349, Wellington*
*Corresponding author: David.stevens@agresearch.co.nz

## Abstract
This research provides proof of concept of integrating data from a range of sources by defining landscape use by cattle under different climatic conditions. Digital technologies provided data representing the climatic, geospatial, soil and pasture properties to characterise the grazing environment. Virtual herding technology defined animal position and activity. Data was collected at Waipori Station, a Pamu owned high-country sheep and beef farm of approximately 9,271 effective hectares, located in Otago, New Zealand about 60 kilometres west-northwest of Dunedin (-45.8410008°S, 169.7966283°E). Three hundred and two rising-3-year-old first calving cattle with calves at foot were monitored in two 65 ha paddocks from February to May 2022. Cattle used various parts of the landscape in different climatic conditions. Placement of cattle in sensitive parts of the catchment was identified. Activity patterns were also altered by climatic conditions. These insights, using integrated data sets, can guide farmer decision-making to reduce environmental impact and achieve animal welfare needs while optimising utilisation of the landscape when deploying virtual herding technologies. Further work is required to develop both the data storage systems and the protocols and algorithms to achieve successful integration.

**Keywords** Behaviour, cattle, digital integration, Global information systems, virtual herding

## Background
Smart technologies in tandem with agricultural practices are most recognised in the field of precision agriculture (PA) in which powerful machine learning algorithms are employed to increase crop yield (Aliar et al. 2022; Tantalaki et al. 2019). Sensor based data is also widely incorporated in nutrient management, specifically in the gathering of soil or landscape information (Cammarano et al. 2020).

Although precision farming technologies is not new, their integration in grazing livestock is far less applied (Horn and Isselstein 2022). High resolution movement data is a growing field of movement ecology which can range in scale from individual decision-making to population-level space-use patterns (Seildel 2019). Recent publications within the last decade have studied the use of e-collars on bovines including virtual fencing (Campbell et al. 2019), animal behaviour (Handcock et al. 2009) and oestrus detection (Dela Rue et al. 2013). Several studies have demonstrated the integration of animal movement data in farm management systems using spatial methodologies. For example, Barbari et al. (2006) verified the applications of global positioning systems (GPS) and geographical information system (GIS) technologies to explain the behaviour of grazing animals. Similarly, Netzer et al. (2007) performed a spatial analysis of home range of red deer using minimum convex polygons (MCPs) and distinguished preferences of habitat selection between individuals.

Large farming systems are continuously challenged with the impact of intensive farming on catchment waterways (Hewett et al. 2020). Grasslands in hill country are often under-utilised (Stevens et al. 2021). Changing the grazing intensity to increase utilisation also comes with risk of soil disturbance and potential soil loss, depending on soil type and soil moisture (Donovan and Monaghan 2021), which is a major contributor to water quality degradation in hill country sheep and beef farming (Monaghan et al. 2021). Altering grazing intensity requires precise grazing control of animals. This is challenging in hill country because of large variability in pasture quantity and quality induced by slope, aspect, altitude, and resultant soil fertility distribution (Lambert et al. 2000). If increased

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utilisation is achieved in these environments, it is often accompanied by over-grazing of some parts of the landscape and under-grazing of other parts (Gillingham and During 1973). This then leads to potential further soil degradation and loss, as overgrazing reduces vegetative cover and increases potential hoof damage which play a role in surface erosion (Donovan and Monaghan 2021).

Virtual herding technologies allow for a non-invasive demarcation of paddock perimeters with minimal discomfort to the animal (Campbell et al. 2019). This innovation enables farmers to control animal grazing dynamics by remotely manipulating computer-generated perimeters (Horn and Isselstein 2022). New coordinates are sent to the GPS receiver unit attached to an animal's neckband which then alerts the animal of the updated fencing. By way of operant conditioning, the animal cognitively maps the boundaries of its environment. Furthermore, it can redirect animals to the most productive paddocks and excludes them from vulnerable ecosystems (Horn and Isselstein 2022).
Thus, the integration of virtual herding with landscape and climatic data sources will advance large-scale farming systems through environmental protection, reduced labour cost and fencing materials and efficient grazing dynamics leading to high precision management at the catchment level.

The grazier must also factor in the behavioural needs of the animal when making decisions regarding improved pasture utilisation in hill country farms where paddock size is large, and terrain is varied. For example, livestock utilise various parts of the landscape in different weather conditions (Fisher 2007). Thus, management decisions regarding the use of the landscape must be aligned to weather forecasting. The use of virtual fencing provides a flexible tool to adapt grazing managements and assignment of livestock to various parts of the landscape depending on the type of thermal stress that the animals may be exposed to. This then requires data from the animal, where it is and what it is doing, from the weather forecasting services, rainfall potential, temperature, and wind, and from Global Information Systems (GIS) identifying elevation, slope, and aspect. Before these can be integrated into decision-making, the farmer also needs to understand where the animals go under different conditions. Often the farmer has tacit knowledge about this from their observations. However, in large-scale enterprises this information is often assumed.

Integrating the information from digital technologies such as animal behaviour, weather and landscape definition to transform farming is complex. A range of technologies are required, operating at different time and spatial scales. They may be used to characterise the resource, predict future performance or as monitoring tools. Integration is crucial as an enabler to allow management decisions to be implemented on appropriate time and spatial scales to deliver improved outcomes.

This research used the integration of animal, climate and landscape data to define the use of the landscape by cattle under free-ranging conditions, demonstrating the opportunity to inform future animal management that improves environmental and animal welfare outcomes when using virtual herding.

## Methods

This case study examined the potential for digital technologies to aid farming by combining a range of data sensors and sources. To do this, digital technologies were used to provide data representing the position and activity of the cattle, the climatic conditions and slope and aspect of the terrain of the system studied. These characterised the environment in which the animal was grazing. Animal position and activity were then related to the climatic conditions and the landscape features. The study was co-designed in partnership with a government-owned farming enterprise, Pāmu farms, and technology partner Gallagher Ltd.

### Site characteristics

Waipori Station is a Pamu owned high-country sheep station located in Otago, New Zealand. It has a farmed area of approximately 9,271 hectares and is situated in the Upper Waipori River catchment, about 60 kilometres west-northwest of Dunedin (-45.8410008°S, 169.7966283°E). The station's landscape features a mix of developed pastures, tussock grasslands, mountainous terrain, and beech forests, and it is home to a variety of native flora and fauna. The farm carries 51,359 stock units that include both sheep and beef animals.

### Project methodology

In 2019 a shared vision of the future and a general progression of technology development was formed (Stevens et al. 2023). This included the steps required for technology development, including production of a minimum viable product, integration of sensors, and the addition of landscape digitisation.

Work from 2019 to 2021 involved the testing of the virtual herding technology (eShepherd™) for containment and herding of cattle under a variety of conditions. Climatic data was also sourced from a local automated weather station (-45.848048 E, 169.837259 S) approximately 2.5 km from the experimental site, and soil data sourced from historic records (Hewitt 1982). Digital representation of the landscape was developed from aerial imagery captured by drone (Mavic 2 Enterprise, pixel size: 20cm$^2$). During this time, a cloud-based database was developed for storage and management of the data. This evolved over time as the ability to store and manage animal location and activity data, and landscape data was added.

The last step of this project was undertaken from 13 February until 30 April 2022. Three hundred and two rising-3-year-old first calving cattle with calves at foot were fitted with eShepherd™ neckbands (Animal Ethics project 15471, AgResearch Animal ethics committee). These were equally, randomly allocated to one of two 65 ha paddocks. The neckbands logged information on the animal's behaviour (the proportion of time resting, moving, or grazing per recording period of approximately 10 minutes), and location, speed (m/s) and walking distance (m). Data were transmitted from neckband to a LoRa® enabled base station located in one of the paddocks and in turn conveyed data to an online storage service made later available for download. No virtual fencing functions were deployed. The paddocks were improved pasture with bisecting gullies comprising of red tussock interspersed with improved pasture species. The terrain is of low relief with an elevation of 500 to 600 m asl.

Climatic data was continually recorded over this time. Dynamic data of animal location and activity (reported every 10 minutes) and climatic data (recorded hourly) were incorporated into landscape mapping. Soil loss risk was also estimated for each paddock using the protocols of Donovan and Monaghan (2021) and overlayed onto the digital landscape map. Briefly, soil loss risk assessment is developed from soil permeability, structure, clay content and water content, slope, and vegetation cover, along with potential grazing intensity.

These data sources were then interrogated to describe a proof of concept to understand landscape use by the cattle under a range of climatic conditions. Animal activity was summed across the period and average proportion of time spent resting, grazing and walking were reported. Grazing data was further assigned to slope class (flat 0-5º, rolling 6-15º, and moderately steep 16-25º). Data from a subsample of six randomly chosen animals were used to examine how the activities and position in the landscape were influenced by precipitation. Three days in April (12, 16, and 21) with precipitation were paired with the previous day (11,15, and 20). Data of activity was pooled for each hour and analysed using the REML function (Genstat version 23) to detect differences. Heat maps of location were overlayed onto the soil loss risk map of the paddocks. This paper demonstrates the opportunities to understand animal location and activity during different climatic conditions, and the interaction between the cattle and the sensitive parts of the landscape which may be more vulnerable to soil loss.

The data from the 302 cattle, reported at 10-minute intervals over the period of the experiment generated approximately 43,200 location points per day plus the same number of estimates of each activity, totalling approximately 173,000 data points per day. Animal data, climatic data and landscape data were combined into a single data set. ArcGIS was used as the main landscape mapping tool while the software package R was used extensively in collating and interpreting animal activity and location data.

## Results and Discussion

In the first instance the activities of the cattle were compiled. Cattle spent 50.4% of their time resting throughout the study period, 38.5% grazing and 12% walking. However, these behaviours can be affected by several factors including feed quality and availability, management, and the animal's environment (Ramon-Moragues et al. 2021). Further analysis of the grazing data showed that the 38.5% was split into time spent on the flat (27%), rolling (10%) and moderately steep (1.5%) parts of the paddock.

### Influence of climatic conditions on cattle activity

The rainfall on the three days with rain averaged 13.4 (+/-1.0 SE) mm/day. Air temperature averaged 10.3 (+/-3.1 SE) ºC while was modified by wind speed of 5.8 (+/- 2.3 SE) m/s to a wind chill to 3.3 (+/-6.6 SE) ºC, compared with 12.6 (+/-3.8 SE) ºC, 3.4 (+/- 2.5 SE) m/s and 11.5 (+/-3.5 SE) □C on the adjacent days without rain respectively. The variation in rainfall, air temperature and wind speed across the 24-hour period are documented in Figure 1.

General patterns of activity reflected the diurnal behaviours of ruminants, with peak grazing activities occurring around dusk (Gregorini 2012). Disruptions to this general pattern were apparent when days with rain were compared with days without rain (Figure 2). The percentage of time cattle spent moving significantly increased during the period from 11:00 to 24:00 hours (Figure 2; $P<0.05$). This increase parallelled a significant reduction in resting time between 11:00 and 17:00 hours and a reduction in grazing time between 15:00 and 24:00 hours (Figure 2; $P<0.05$). These changes in activity aligned with the decline in temperature and increase in wind speed (Figure 1). Overall, resting declined by approximately 14 minutes/day, moving increase by 57 minute and grazing declined by 43 minutes/day on the days with rain compared with days without rain. This change in behaviour has also been noted in response to cold stress in calves and steers as increased standing time (Kim et al. 2023). The combination of wind and rain has been shown to decrease lying time and feed intake while increasing shelter-seeking behaviours (Schuetz et al. 2010).

Some variation in individual animal responses were recorded (data not presented). Several factors may

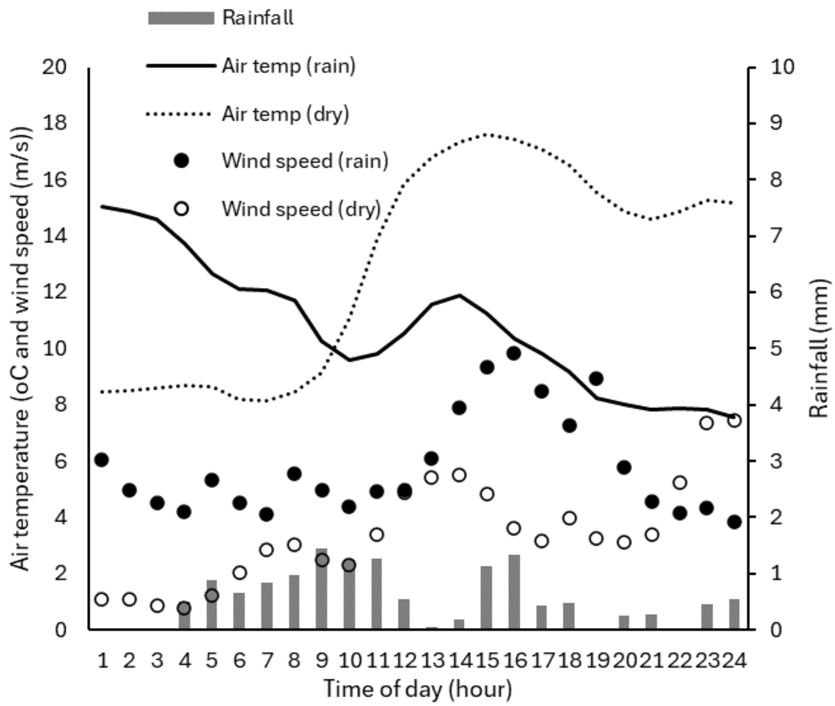


**Figure 1** Average hourly air temperature, wind speed and rainfall on three days with rain or adjacent days without rain during April 2022 at Waipori Station.

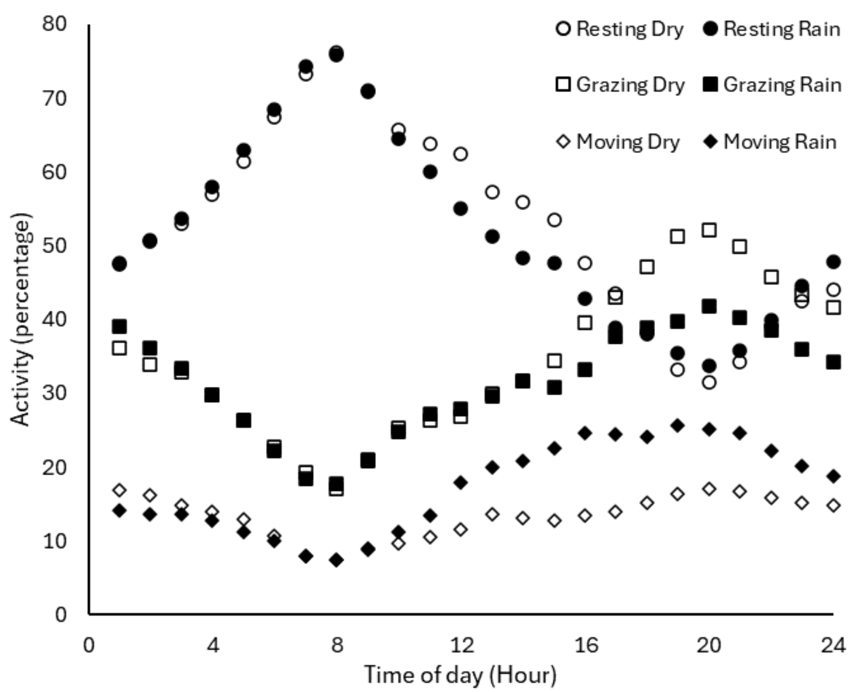


**Figure 2** Average resting, grazing and moving activity of cattle on three days with rain or adjacent days without rain during April 2022 at Waipori Station. Sunrise occurred at 07:16 and sunset occurred at 18:06. Least significant differences (P<0.05) for resting, grazing, and moving were 2.5, 2.0 and 2.7 % respectively.

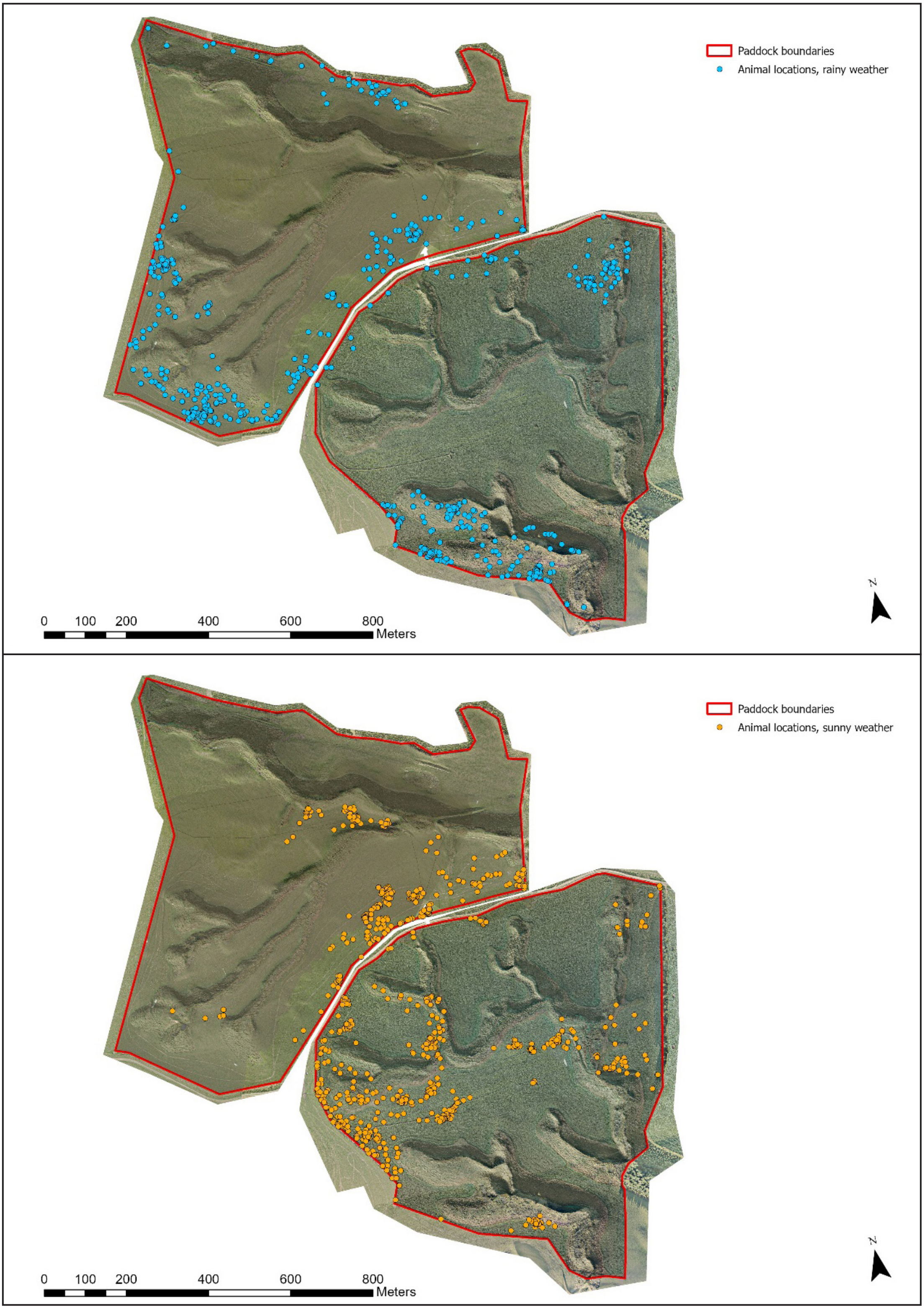


**Figure 3** Location of cattle during days with rain (a) or without rain (b)

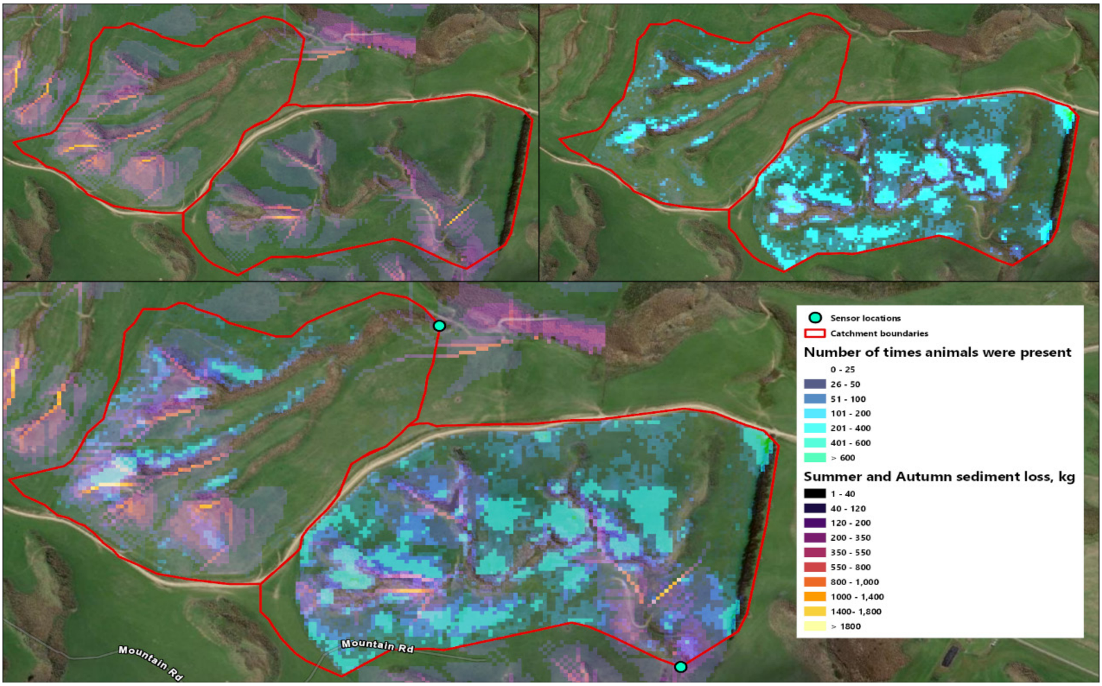


**Figure 4** Mapping of soil loss risk (a; upper left), cattle concentrations (b; upper right) and the overlay of both (c; lower) to demonstrate the potential of integrating a range of digital data sources for improved landscape management.

influence individual variation in behaviour. The cattle may range in robustness as depicted by, for example, condition score as an indicator of ability to withstand cold (Webster 1973). The physiological and nutritional needs of these cows rearing calves may vary with, for example, lactational output differences driving hunger to a lesser or greater extent (Friggens et al. 1998). Their potential genetic make-up may also influence their response to cold as breeds vary in their natural interaction with the environment (Bailey et al. 2015).

**Influence of climatic conditions on cattle position**

We also examined the position of the animals within the environment during days with or without precipitation. This demonstrated that the placement of cattle within the landscape was altered (Figure 3). The cattle used areas within each paddock which were sheltered from the predominant direction of the weather (south-west), using areas which were north-east facing during wet weather. This aligns with the wind speed data presented in Figure 1.

**Cattle position in relation to the vulnerability of the landscape to soil loss.**

Heat maps of animal location were imposed on a modelled estimate of soil loss risk (Figure 4). Soil loss risk mapping (Figure 4a) highlights the vulnerability of steeper slopes with lower vegetative cover within each of the two paddocks. A heat map of cattle use of the paddocks (Figure 4b) provides data on the concentrations of cattle in the various parts of the landscape. Overlaying the two maps (Figure 4c) provides insight into where the potential high soil loss risk areas of the paddocks are being exposed to high concentrations of cattle. With further interrogation of the data sets we may be able to highlight the climatic conditions under which greater exposure occurs. This initial examination of the data provides information which can be used to inform the use of virtual herding options within the eShepherd™ hardware, to restrict grazing or access if soil damage may occur, or loss risk may be increased by hoof damage and reduced vegetative cover.

**Data integration**

Integration of data into agricultural systems research provides a novel but innovative approach to re-configure systematic farming practices and enhance ecosystems services with waterway, biodiversity, and cultural feature protection. Utilising wireless sensor networks and GPS collars is a common technique for research in wild animal habitat use (Barbari et al. 2006). A refocus to this approach enables researchers to determine farm animal movement and behaviour for optimal managerial practices within an agricultural context (Bailey et al. 2018; Campbell et al. 2019;

Handcock et al. 2009).

The data collected in this case study provided insight into the activity of cattle (Figure 2) when exposed to rain, temperature and wind factors in this extensive environment (Figure 1). Collection of this type of data has often been restricted to very controlled conditions or small plot experiments due to the labour-intensive recording process. Having devices on animals which can regularly collect and interpret this type of data will aid farmer decision-making in times of inclement weather. While cattle actively moved to sheltered positions in this landscape (Figure 3), the use of virtual fencing will enable the potential exclusion of animals from sensitive areas (Figure 4) within those sheltered zones. This research provides a proof-of-concept which supports the emerging literature promoting precision livestock farming (PLF) technologies for herd monitoring (Aquilani et al. 2022; Hostiou et al. 2017; Trezubov et al. 2023)).

Data sharing to enable the accelerated development of opportunities, such as those demonstrated here, is essential to enabling use of data and implementation of precision farming. The long-standing nature of relationships between AgResearch, Pamu and Gallagher provided several opportunities. It allowed for the sharing of resources with Pāmu committing land, animals, labour, and data access to support the development. Sharing of data with Agersens, a start-up company, was initially more limited due to intellectual property (IP) concerns, and a much newer relationship. Once Gallagher became sole owner the range of data available increased, though again within the bounds of IP limitations.

The development of virtual herding technologies provides a tool to implement precision practices in cattle farming. This is because we can now control the placement of the animal within the landscape without the restrictions of physical fence layouts. Physical fencing cannot segregate diverse hill country landscapes into the fine resolution that is required to enable precision grazing management. While enabling this level of precision is now within our grasp, we still need to understand animal behaviours and how they are influenced by the landscape and climatic events to ensure that animal behaviours and animal wellbeing needs are met. Farmers develop an understanding of these principles through observing animals in many conditions. Translating these experiences into actions can now be enhanced through the addition of digital technology layers. Data from these layers can be then developed into tools to direct the animals in the landscape, depending on circumstance, for improved outcomes for both the animal and the environment. However, challenges remain in the acceptance of such technologies by the wider community, and in the complexity of data processing and interpretation. Nevertheless, the potential of wearable technologies in precision grazing systems is immense and warrants further investigation into its long-term implementation.

## Conclusions

This research demonstrated the use of integrated data sets to understand the activity of cattle in various parts of the landscape, activity under different climatic conditions, and their potential interaction with vulnerable parts of the landscape. It also provided an example of where cattle reside in the landscape in different climatic conditions.

These insights can guide farmer decision-making regarding the utilisation of the landscape when deploying virtual fencing technologies. Improvements in environmental outcomes will come from managing access to vulnerable parts of the landscape at critical times. Animal welfare needs will be met through ensuring that natural shelter-seeking behaviours are optimised. Combining these different data sources can also be used to provide 'proof of placement' for quality assurance programmes and regulatory needs.

It is not until data integration is achieved that these insights are realised. However, this comes at significant cost in developing both the data storage systems and the integration protocols and algorithms that are required. While we compiled a set of research questions on the concept of e-collar technology and animal movement studies, this is a beginning to identify themes that will help farming management and a broader scientific audience to exploit the opportunities wearable technologies provide to pastoral agriculture.

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