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# Individual-based remote walk-over weighing: improving current performance of RFID-linked in-paddock sheep weight data

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**Abstract**

Management of livestock in extensive grazing systems can be improved by monitoring smaller production units more at an increased frequency. Sheep liveweight is a crucial indicator of nutritional status, health and welfare, productivity and performance to list a few. The current industry standard level of monitoring is at a mob-based level; largely restricting the precision of management. Remote walk-over weighing (WOW) allows more timely and frequent observation of sheep in-paddock, providing a mob-based average liveweight (MBWOW). Incorporating radiofrequency identification (RFID) into WOW provides individual-based liveweight estimations (RFID-linked WOW), capable of monitoring temporal changes in liveweight of individual sheep. At present, RFID-linked WOW data is reported having low repeatability (<0.22) and frequency of accurate predictions (± 2 kg, 95% CI) within a suitable timeframe for management (1, 5 days), when processed using basic filtering methods. RFID-linked WOW data was collected and analysed from a mob of weaned lambs, using alternative system designs and more sophisticated data analysis methods, for the purpose of evaluating the usefulness of this information to assist with management decision making. Liveweight data analysis was compared to similar published reports to gauge whether an improvement was realised. Repeatability of RFID-linked WOW data across three filter levels; raw, coarse and fine, were 0.917, 0.965 and 0.995 respectively. Analysed data was successfully manipulated to produce mob, sub-group and individual-based records allowing both statistical and subjective associations to be drawn between individual liveweight and the effects of animal, management and environmental factors. This study gives evidence of high performance from RFID-linked WOW technology, suitable for assisting management. However further progression is still required to develop a more robust and easy-to-use commercial system.

**Additional Keywords**

electronic identification EID, precision sheep management, weighing system design

***Introduction***

The importance of collecting objective liveweight measurements of production animals to monitor performance is well accepted. It is widely agreed that liveweight and liveweight change are key production measurements within sheep production systems, as indicators of not only production performance, but also health, welfare and reproductive traits amongst others (Richards et al. 2010). Technology aiding in the frequent and timely capture of these observations has been recognised to improve management decision making accuracy and increase profitability on-farm. However, conventional liveweight monitoring procedures are time consuming, labour intensive, cause production losses and often impose risks to the welfare of livestock and stock handlers. Currently, liveweight change (growth rate) calculations are restricted to an estimated linear average between two weighing events over an extended period of time; yet this is rarely a correct interpretation of the liveweight change history of a mob, let alone an individual animal (Brown et al. 2014a). The advancement and implementation of remote monitoring technology within the sheep industry is lagging behind other livestock production enterprises such as dairy, beef, pork and poultry (Burke et al. 2004).

Walk over weighing (WOW) technology has been widely used across other livestock industries since early development in the late 1960's (Clarke et al. 1967); however literature reporting on the effectiveness of WOW in sheep is limited. The process of collecting liveweight records remotely to produce a mob average weight is known as mob-based walk over weighing (MBWOW). Brown et al. (2012) concluded MBWOW to be a low-stress and cost effective method of monitoring sheep performance, with accuracy comparable to static weighing ($R^2 > 0.82$) and a high observation frequency; however it was also stated that further research was necessary into both data collection and analysis. Difficulties presented during the implementation of remote monitoring technologies within sheep production systems include large variation between individuals' behaviour, a high level of mobility and flightiness, as well as disruption from growing fleeces (Burke et al. 2004; Richards et al. 2006).

Morris et al. (2012) described benefits of utilising radio frequency identification (RFID) technology in the collective practice known as "precision sheep management", as a means to better monitor large numbers of sheep to improve production efficiency and animal welfare. RFID technology allows rapid and cost effective collection and storage of data over the lifetime of individual animals, aiding in many decisions such as breeding and culling selection (Young et al. 2011). When electronic identification (EID) ear tags are used to compliment WOW monitoring, an individual RFID-linked WOW data record is created; able to be stored to generate a liveweight history of individual animals. Both Charmley et al. (2006) and Alawneh et al. (2011) concluded that in cattle, RFID-linked WOW was an improved non-invasive method of monitoring liveweight; comparable to static weighing with the advantage of more frequent observations allowing for better identification of early liveweight change. However, although comparable to static weighing; Brown et al. (2014a; 2014b) found RFID-linked WOW data in sheep to have significant limitations in repeatability and frequency within a commercial management timeframe of 5 days, when processed using the Australian Sheep Industry CRC's *WeighMatrix* program with a filter of ± 25% from a predetermined estimate (either a recent mob average or predicted likely mean liveweight). It is hypothesised however, that an improved filtering system that also draws on an individual's previous RFID-linked WOW liveweight records could significantly increase system repeatability (Lee et al. 2008).

Data analysis is a further challenge when faced with large datasets gained from high frequency liveweight collection. Brown et al. (2014a; 2014b) stated that RFID-linked WOW data requires complex analysis and processing due to large and often noisy records. As a result of the scarcity of literature in sheep production fields regarding either MBWOW or RFID-linked WOW, there is little information available on successful data analysis techniques. It is likely however, that similar approaches to WOW data handling can be appropriated from other literature regarding RFID-linked WOW in other species; particularly extensive beef cattle (Gonzalez et al. 2014).

The objectives of this study were firstly to report on the repeatability and frequency of remote RFID-linked WOW data, using new weighing system design and data processing techniques, for the purpose of generating liveweight histories for individual lambs. Additionally, the effectiveness of the analysed RFID-linked WOW data was evaluated on its use to monitor temporal changes in individual daily liveweight as a result of both environmental and management factors, to assess the suitability of RFID-linked WOW for commercial use.

## Materials and methods

All procedures undertaken during this trial were performed in accordance with the guidelines of the *Australian code of practice for the care and use of animals for scientific* *purposes* and were first approved by the University of Sydney Animal Ethics Committee (Project number: 2016/983)

*Sheep and management*

A single mob of 181 mixed-sex weaner lambs (129 Merino and 52 Merino x White Suffolk/Border Leicester) aged 5-7 months were grazed under commercial conditions at Catombal Park, 20 km south of Wellington, New South Wales (longitude 148.974465 and latitude -32.693205; annual rainfall 620 mm). Allflex reusable RFID button tags were applied before lambs commenced a 14-day conditioning process to encourage use of the WOW system, as commercially recommended by the Australian Sheep Industry CRC. This process consisted of gradually reducing the gap between either sides of the WOW system so that animals were eventually traversing the apparatus voluntarily.

The enclosure design was developed to allow one-way access for lambs, utilising spear trap gates at the end of the entrance race as well as the exit. During the preliminary enclosure designing period, additional alterations to the conventional design were made including a bent entrance race, with a 90° angle both before and after the weighing platform, to further manipulate the uniformity and frequency of individuals crossing the platform, preventing multiple lambs from simultaneously standing on the platform, moving too quickly across the platform or jumping over it entirely. Monitoring using CCTV was also used to subjectively assess the movement of lambs through the bent race before deeming the design suitable.

Once conditioned to the apparatus, lamb liveweights were captured and stored autonomously using TRU-TEST weighing equipment. As per commercial management, sheep were subject to occasional mustering/yarding events for husbandry events including drenching, shearing, and paddock changes. Over the trial supplementary feed was provided when deemed necessary by the farm manager. Supplement feed consisted of Barley grain (1 kg /hd/week), Lucerne hay (*ad libitum*) or Barley straw (*ad libitum*), or a combination of these feeds. Although each lamb was only shorn once, all lambs underwent two shearing events, where lambs were mustered, yarded and spent one night off feed in the shearing shed before either being shorn or held in the yards till the mob was returned to their paddock. Lambs were recorded as being shorn in either early April or late May. Lambs were rotated paddocks 4 times as part of the grazing plan of the property and the remote RFID-linked WOW system was rebuilt at each paddock's water source.

*Walk over weighing system*

The RFID-linked WOW system consisted of a self-fabricated weighing platform, 120 cm long with rubber gauze to reduce slipping and noise while being traversed. IRONBARK 1.1 m Farm Gate Infill mesh was shaped as necessary and held with star pickets, so that the race width could be adjusted to suit the width of the lambs. Liveweights and EID numbers were collected using TRU-TEST MP600 load cells and a XRP2 panel reader, and were paired and stored with time and date on an XR3000 head unit indicator. Power was supplied using an ADVENTURE KINGS 120 W portable solar panel and with a 12 V deep cycle battery. The use of temporary yarding material allowed ease of minor alterations to be made to suit multiple paddock scenarios when the system was relocated.

*Data analysis*

Data analysis procedures were adapted from Gonzalez *et al*. (2014), with appropriations from Brown *et al*. (2014a). In summary, all data collected on the XR3000 unit was analysed both periodically and at the conclusion of the trial to assess the repeatability and frequency of data, as well as temporal changes in lamb liveweight and liveweight change, and factors affecting these values.

Repeatability and frequency of RFID-linked WOW data was assessed by firstly determining the success rate, as a percentage of the total observed dataset, for each filter group (Raw, Coarse and Fine). The Mob-based WOW success rate was also determined. Final predicted liveweights were a result of multiple filter levels; the first (Raw) included all weight values successfully linked to an RFID number. Next were all RFID-linked weights within predetermined real mob parameters of 15-55 kg (Coarse). Data was then fitted to a B-spline, penalised by the coefficients of each individual animal based on its developing history (5-day rolling average); smoothing was then carried out using a ± 1.5 x residual filter for each individual lamb before a final penalised B-spline was applied (Fine). The frequency of accepted liveweights, filtered to a final predicted liveweight was also then evaluated based on the number of individuals, as a percentage of the total mob, to accumulate 5, 8, 10 and 12 predicted liveweights. The ability of data collected using RFID-linked WOW to assist in management decision making could then be evaluated.

Statistical analysis was then carried out for the final filtered daily predicted liveweights using a mixed-effects linear regression model regarding date as a repeated factor over each animal and respective groups as fixed effects. Liveweight change (or growth rate) was calculated as the first derivative over the predicted liveweight curve, accounting for the time between two successive liveweight records for each lamb. A daily averaged liveweight and liveweight change value were then calculated for each lamb.

Temporal liveweight changes across both the mob and individuals were associated with both environmental and management factors. Environmental factors assessed included daily temperature range, rain events greater than 20mm within 24 hours, cloud cover at 9 am and hours of sunlight per day. Management elements recorded comprised of feed supplementation, mustering and/or yarding events, shearing, paddock changes and opening gates to addition pasture.

## Results

### *Repeatability and frequency of RFID-linked WOW data*

Over the 93-day trial period, the WOW system was operational for 61 days. During this time a total of 16 387 observations were recorded. From this total dataset, 2 622 (16%) erroneous entries were removed, with either no liveweight value or no EID number; resulting in a raw RFID-linked WOW success rate of 84% (Table 1). The remaining 13 765 RFID-linked WOW liveweights were then filtered by predetermined real mob parameters of 15 to 55 kg; a further4 096 (25%) were discarded, resulting in a coarse-filtered success rate of 59% (Table 1). To increase the accuracy of predicted liveweight further, the fitted B-spline smoothing and ± 1.5 times residual filter discarded 2 294 (14%) of the previously accepted values, to produce 7374 final predicted liveweights at a fine-filtered RFID-linked WOW success rate of 45%. The repeatability of raw RFID-linked data, coarse-filtered liveweight (equivalent to MBWOW) and fine-filtered final predicted liveweight analysed ($P$ <0.05) were 0.917, 0.965 and 0.995 respectively.

Time gaps in the observations of individuals varied widely between individuals; from 0 to 35 days, with an average time between successful final liveweights of 1.8 days (Table 1).

Therefore, the average number of successful and accepted liveweight observations per day across the mob was 0.75, which ranged from 0 to 8 (Table 1). A strong association was observed between the number of accepted liveweights and date ($P < 0.001$). Figure 1 illustrates the count of total observations captured per day over the 93-day trial, with dates of key environmental and management factors that impacted the collection of data. The impacts of such factors caused reduced observations due to either temporarily removing the mob from the paddock, reducing the time of operational hours per day, or in the case of extensive periods of cloud cover; preventing operation of the WOW system completely (Figure 1). The WOW system was not operational for a total of 31 days within the trial due to insufficient power supply.

Figure 2 provides an example of RFID-linked observations collected for a single Merino ewe lamb, once real mob parameters of 15-55 kg have been applied. After following the described filtering procedures a final predicted liveweight and liveweight change profile of the ewe lamb was calculated (Figure 2). Performing the same data analysis over the entire mob resulted in a decrease in observations coinciding with each finer level of filtration (Table 1). Figure 3 displays the daily distribution of total observations, accepted RFID-linked liveweights, final predicted liveweights and final per animal.day averaged liveweight. By applying the real mob parameters (15 < LW <55 kg) to all RFID-linked records, 41% of total observations were removed.

The number of observations in each respective filter category varied largely between days, with number of accepted liveweights and final predicted liveweights ranging from nil to 382 and 320 respectively (Figure 3). Although observation frequency varied largely between days, the success rate of each filter category remain generally constant; so that relative to total observations, the percentage of data records being either discarded or kept by filters stayed consistent (Figure 3; Figure 4). Figure 4 depicts the success rate (repeatability) of final predicted liveweights per day, as well as the total number of final averaged liveweights per animl.day as a percentage of total observations. Ranging from 0-78.3%, the daily success rate (repeatability) of fine-filtered final predicted liveweight was 43.6%; and further averaging these fine-filtered liveweights into a single daily value reduced the repeatability to 26.0% on average, with a range of 0-49.6% (Figure 4; Table1).

The frequency of accepted liveweight values filtered to a predicted liveweight (45% success rate) was assessed by the time (in days) necessary to accumulate 5, 8, 10 and 12 predicted liveweights. Figure 5 shows the cumulative number of animals through the WOW system after final implementation (day 0), as well as the cumulative number of animals, also as a percentage of total mob, to obtain the given number of final predicted liveweights. In the first 31 days, 100% of the mob accumulated 5 or more final predicted liveweights, 80% obtained 8 accepted records or more, 74% acquired 10 or more predicted liveweights, and 68% of the total mob recorded 12 or filtered liveweight values (Figure 5). In the first five days, 56 lambs had already amounted 5 or more accepted liveweight records; and by days 7, 14 and 21, the percentage of total mob with 5+ final records was 59, 82 and 92% (Figure 5).

*Liveweight and liveweight change*

A wide array of liveweights were observed across the mob, over the grazing period. Figure 6 displays the predicted daily liveweight history of each lamb. Once filtered and averaged into a daily value, predicted liveweights ranged from 22.4 to 50.0 kg with an average over the trial period of 36.76 kg (*s.d.* 4.97). Similarly, as seen in Figure 7, daily liveweight change had a large variation both between individuals and temporally; ranging from -1.50 to 0.95 kg with an overall average of 0.07 kg (*s.d.* 0.16). Figure 8 shows the average of final predicted liveweight and liveweight change per day across the mob, with daily error provided and dates of key management factors overlayed. Decreasing fluctuations, as well as diminishing standard errors, were observed in both traits over the first 25 as data was becoming more refined through improved filter accuracy (Figure8). Standard error of liveweight change also increased over extended periods of weight loss (Figure 8, 14-Apr-16 to 09-May-16) due to varied liveweight responses to environmental factors. Strong associations were observed between both liveweight and liveweight change, and date ($P < 0.001$).

It was possible to associate these temporal changes in liveweight with management and environmental factors. The dates and type of event recorded in Figure 8 allow conclusions to be drawn on the effect of these factors on lamb liveweight. As pasture was often limiting, supplementary feeding and paddock changes were seen to have to the largest effect on either liveweight or liveweight change (growth rate). While provided Barley hay, average liveweight change remain at a positive value; afterwards liveweight change decreased steadily until Lucerne hay was provided to the mob (Figure 8). Shearing caused a small decrease in liveweight as expected due to gut weight loss and fleece removal of some lambs. A combination of improved pasture quality and quantity as a result of a prior rainfall event, as well as the provision of a Barley grain ration caused a large increase in growth rate across the mob; however as pasture again became limiting, daily temperatures began decreasing and a severe weather/rain event occurred 20 days after shearing resulting in decreasing liveweights (Figure 8). Moving the mob to a new paddock increased the daily liveweight change above 0 kg/day so that average liveweight could continue to rise.

Further analysis of RFID-linked WOW data allowed temporal liveweight and liveweight change history to be compared between individuals, as well as between groups based on either breed, sex, varied treatments or any combination of these factors. A total of 156 lambs had additional information paired to their EID number. Figure 9 displays the daily average liveweight and liveweight change of lambs grouped by breed; either Merino or Crossbred (Merino x White Suffolk/Border Leicester) and sex. When analysed by mixed-effects regression, associations between predicted daily liveweight were established for factors; date ($P < 0.0001$), breed ($P < 0.0001$)(Figure 10) and sex ($P < 0.01$). Figure 10 further visualizes the temporal difference in average daily liveweight of lambs grouped by breed. When considering management and environmental factors such as those included in Figure 8, it was similarly possible to draw conclusions on the varied response in liveweight across breeds. The total association between shearing treatments within the Merino lambs was not statistically significant (P > 0.05).

**Discussion**

The primary objectives of this study were to report on the repeatability and frequency of remote RFID-linked WOW data, and evaluate its potential for use in commercial settings. New designs were used for both the weighing system and data processing. It is currently in accepted throughout literature within the field, although limited, that RFID-linked WOW data repeatability remains variable and low (<0.22), and data frequency is restricted by low frequency and success rate of accepted liveweight values (Brown *et al*. 2014a, 2014b; Lee *et al*. 2008). Contrary to this belief, the results of this investigation have provided evidence that repeatability, frequency and success rate of remote RFID-linked WOW data can be increased through alternative WOW system design and raw data analysis similar to that used within extensive beef operations (Gonzalez *et al*. 2014).

Efficiency of liveweight prediction was increased by firstly improving the rate of successful observations, through adopting a one-way bent-race weighing setup into the enclosure; and secondly through utilising more progressive data filtering techniques. Success rates of 84, 59 and 45 for raw, coarse and fine-filtered data groups respectively is a further improvement on similar methodologies; with reported success rates of approximately 43, 29 and 17% respectively (Brown *et al*. 2014a). The accepted hypothesis, that inconsistency of behaviour both between individuals and weighing events contributes the most to decreased repeatability of data, was observed during preliminary trials; giving rise to the endeavour to alleviate this restriction. The trialled WOW design improved the manipulation of lambs to traverse the weighing platform in a more uniform and repeatable manor; so that the occurrence of unrealistic weights, either from animals crossing to quickly over the platform or becoming congested on the platform, was reduced. This increase in efficiency of data collection was represented by the high repeatability values of 0.9174, 0.9653 and 0.9946 for raw, coarse and fine-filtered RFID-linked WOW data; compared to pooled values from similar trials of 0.1981, 0.4607 and 0.7580 respectively (Brown *et al*. 2014a). the effect of refining the exit design during the trial period is also clear in Figure 2 (03-Apr-16).

Current literature agrees that the necessary minimum requirement to generate an individual's liveweight estimate, while maintaining a 95% CI <2 kg (accepted distortion from digesta), is 12 fine-filtered records (Brown *et al*. 2014a, 2014b; Lee *et al*. 2008). This equates to approximately 190 raw data entries and >30 coarse-filtered data points. Obtaining this many records over 100% of a mob is not currently possible within a suitable timeframe of 5 days to allow informed management decisions. However, with the increased frequency and repeatability evident in this study, it is predicted a much lower number of raw and filtered liveweight values will be necessary; capable of being attained within a suitable timeframe. As seen in Figure 5, reducing the required number of fine-filtered liveweights rapidly increases the rate at which a mob reaches high enough percentages of accurate estimates to incorporate differential management across individuals. Increased observation rates evident after improving the exit (Figure 2, 03-Apr-16) suggest the system was not running at potential during the first 3-4 weeks when cumulative observations were being observed, which may further skewed results when added to the naivety of lambs having only 15 days prior conditioning to the WOW apparatus.

As this study is the first publication of RFID-linked WOW data being remotely collected to develop continuous individual liveweight and liveweight change histories in near-real time, it is apparent that further research into the application of this technology as a continuous monitoring system would benefit the progression of remote RFID-linked WOW monitoring, eliminating waiting periods for data accumulation before being able to make decisions. The benefit of the incorporated “rolling average” approach to the filtering process is it allow parameters of each individual sheep to adjust gradually over time, increasing the accuracy and repeatability of estimated liveweights and liveweight change trends.

Additional to the primary objectives of the study, the effectiveness of the analysed RFID-linked WOW data was evaluated on its ability to monitor temporal changes in individual daily liveweight as a result of both environmental and management factors, so as to assess the suitability of remote RFID-linked WOW for commercial extensive situations. Although hindered by the requirement to control all water sources within a grazing area, or otherwise provide an enticing enough attractant, RFID-linked WOW proved a successful monitoring tool, requiring low labour inputs. Provided high frequency and repeatability are maintained, further estimates can be calculated based on the most recent liveweight trends within a short time period (such as 5 days), allowing near-real time monitoring; and, with further development, eventually real-time individual-based liveweight monitoring.

The RFID-linked WOW system was successful at capturing temporal liveweight trends over the 93-day trial period and data was able to be transform into easy-to-understand mob, sub-group and individual profiles (such as Figure 2); however accuracy was temporarily and intermittently impacted by external factors such as weather. Due to unforeseeable circumstances including extensive periods of cloud cover and reduced daylight hours, the system was only operational a total of 61 days over the investigation (Figure 1). Rain events greater than 20 mm were observed to reduce total liveweight observations in ensuing days, and the battery powering the system failed to recharge if the total time of direct sunlight hours in three consecutive days was less than 18 hours.

Figure 8 was generated from the estimated liveweight (Figure 6) and liveweight change (Figure 7) profiles of all individuals; and depicts the simplified average liveweight and liveweight change of the mob over time. From this it would be possible to both statistically and subjectively associated liveweight changes with key management or environmental factors. In a more uniform mob, this would provide an accurate management tool for decision making. But as there is a wider than normal range of values within the trial mob, further differentiation is required to allow more prescriptive management of differing lambs. Figures 9, 10 and 11 provide ample testament to the usefulness of WOW technology, particularly when accompanied by RFID technology and EID stored datasets.

Of the 181 lambs within the investigation, 148 had additional information stored against their respective EID (RFID) numbers. Figures 9, 10 and 11 illustrate the ability of RFID-linked data to be further distinguished by any records paired to EID tags; in this case breed, sex and time of shearing. Statistical associations and levels of significance varied both across and between groups due mainly to wide variations of data entry frequencies (**n** ranging from 0 to 111 across days and groups), as a result of some small treatment groups (eg. short-wooled Merino wethers, **n** = 8). Despite this, clear managerial conclusions could be drawn from the data collected for the purpose of assisting decision making, such as the effect of fleece length (or lack of) on liveweight, during cold weather or severe weather events; or difference in performance of multiple animal classes managed under the same conditions. There is a large potential for RFID-linked WOW particularly in stud operations or commercial farms trying to rapidly improve specific genetic traits, as any producer could potentially monitor their own field trial to improve accuracy of decisions such as breeding selection or cull preference, especially when observed in combination with other stored lifetime EID information (Morris *et al*. 2012; Richards *et al*. 2010).

Potential also exists for the complementation of RFID-linked WOW technology with other 'precision sheep management' systems; in particular auto-drafting. Successful in-paddock differentiated nutritional management would result in a large increase in productivity and profitability, realised through increased resource utilisation, improved health and welfare of animals, increased lamb survival and ewe fertility, as well as increased marketing management through more precise gridding of saleable individuals (Geenty *et al*. 2007; Young *et al*. 2011). The continued improvement of RFID-linked WOW and further synergies with other technology will increase allow implementation of this technology into commercial situations in the future.

**Conclusions**

The repeatability, frequency and success rate of remote RFID-linked WOW data were notably improved from previous literature using similar methodologies. RFID-linked WOW system performance was further improved through the incorporation of a one-way "Z" bent race consisting of two 90° angles either side of a weighing platform, accompanied by a more sophisticated data processing, methodology, appropriated from RFID-linked-WOW data analysis in cattle. The repeatability of data based on the three filter levels; raw, coarse and fine, was calculated at 0.9174, 0.9653 and 0.9946 respectively. This was a vast improvement compared to the previous accepted normal repeatability of < 0.22. Comparison between this study and previous standards for the success rates of accepted liveweights from total observed data for raw, coarse and fine-filtered groups were 84% vs. 46%, 59% vs. 23% and 45% vs. 17% respectively. It is also concluded that time taken to collect minimum required liveweight observations to produce an accurate estimate was shortened, due to increased repeatability lowering the required number of records, as well as higher success rates increases accepted records per observation.

RFID-linked WOW data was evaluated as an effective monitoring tool to generate near-real time liveweight and liveweight change profiles of individuals, sub-group and mobs; capable of displaying effects of management, animal and environmental factors on liveweight and liveweight change. The data analysis methods applied would allow producers to make more informed decisions at multiple levels within the flock based on temporal changes observed due to associated animal, management or environmental factors, provided they have technical proficiency. Finally, is concluded that RFID-linked WOW data can be increased in accuracy, repeatability and usefulness within commercial situations. However further progression is still required to develop a more robust and user-friendly complete system before industry implementation can be achieved.

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## Tables and figures

Table 1. Descriptive statistics of data lamb liveweight data collected using RFID-linked WOW

| | Filter level (repeatability) | n | % of total | Minimum | Mean | Maximum | s.d |
|---|---|---|---|---|---|---|---|
| All observations | | 16 387 | 100 | 0 | 22.46 | 77.4 | 18.99 |
| RFID-linked weights | Raw (0.9174) | 13 765 | 84 | 15 | 39.24 | 77.4 | 16.81 |
| RFID-linked (15kg < LW < 55kg) | Coarse (0.9653) | 9 668 | 59 | 15 | 36.42 | 55 | 6.32 |
| Successful LW | Fine (0.9946) | 7 374 | 45 | 15 | 36.07 | 55 | 5.82 |
| Final daily LW | - (0.9984) | 3 932 | 24 | 22.4 | 35.76 | 54.9 | 4.97 |
| Final daily LWC | | 3 678 | - | -0.99 | 0.07 | 0.91 | 0.16 |
| Days between obs. | | 7 376 | - | 0 | 1.8 | 35 | 3.52 |
| Total observations/lamb | | 7 443 | 45 | 12 | 40 | 83 | 14.65 |
| Observations/lamb.day | | 7 443 | 45 | 0 | 0.75 | 8 | 0.92 |

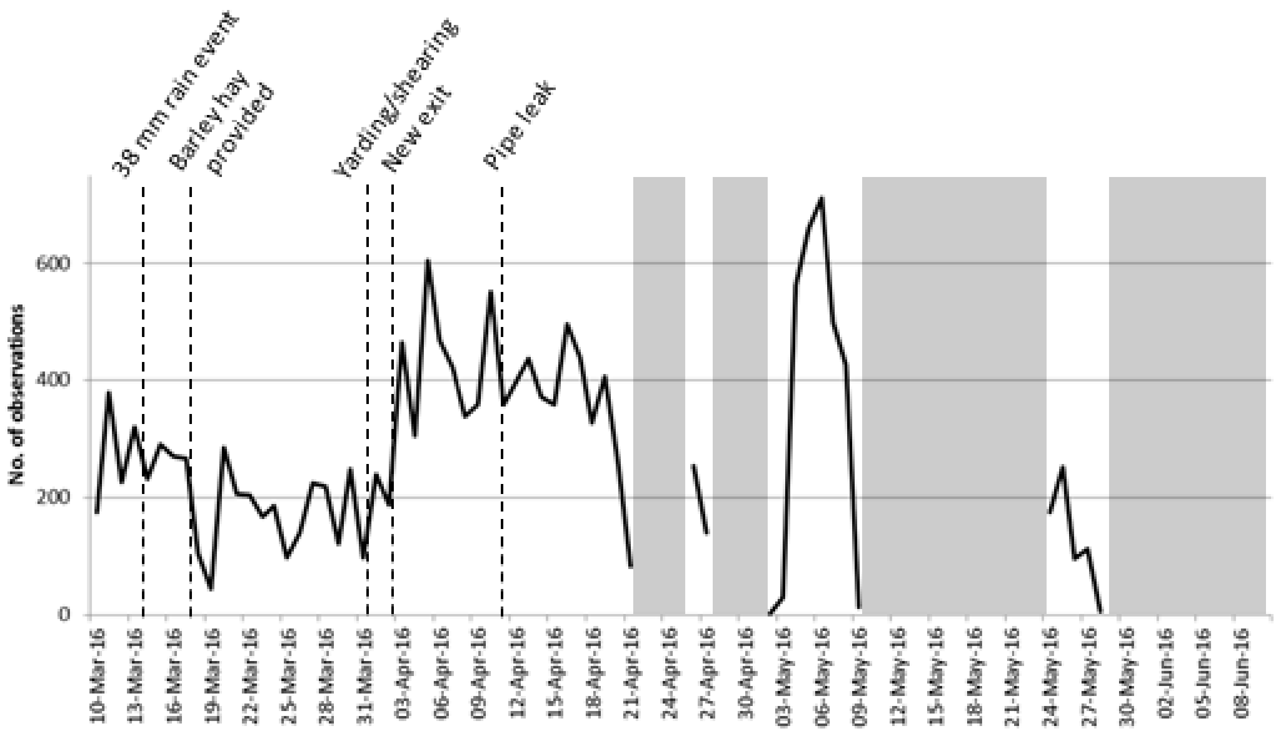


Figure 1. Count of total observations captured using RFID-linked WOW with key environmental and management factors (dashed vertical lines) overlayed, as well as non-operational periods (grey shading).

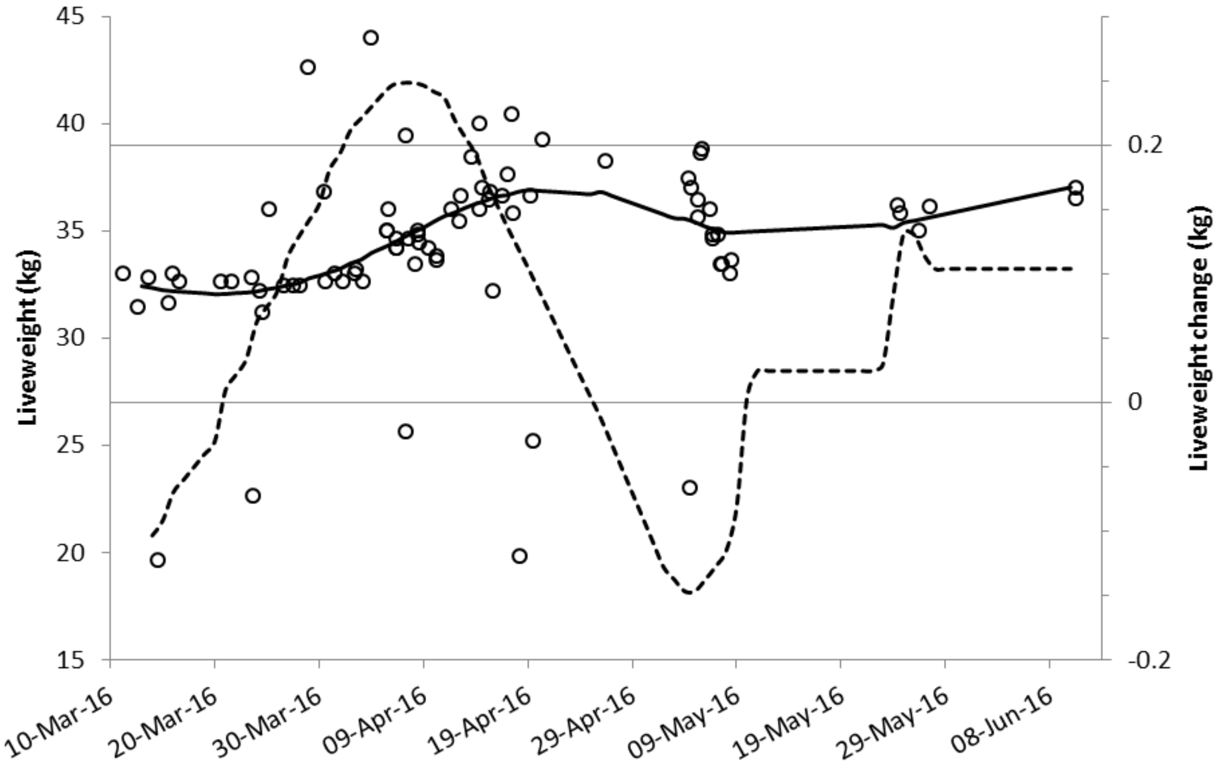


Figure 2. Example raw observed liveweight values (circles), modelled liveweight profile (solid line) and liveweight change (dashed line) of an individual lamb.

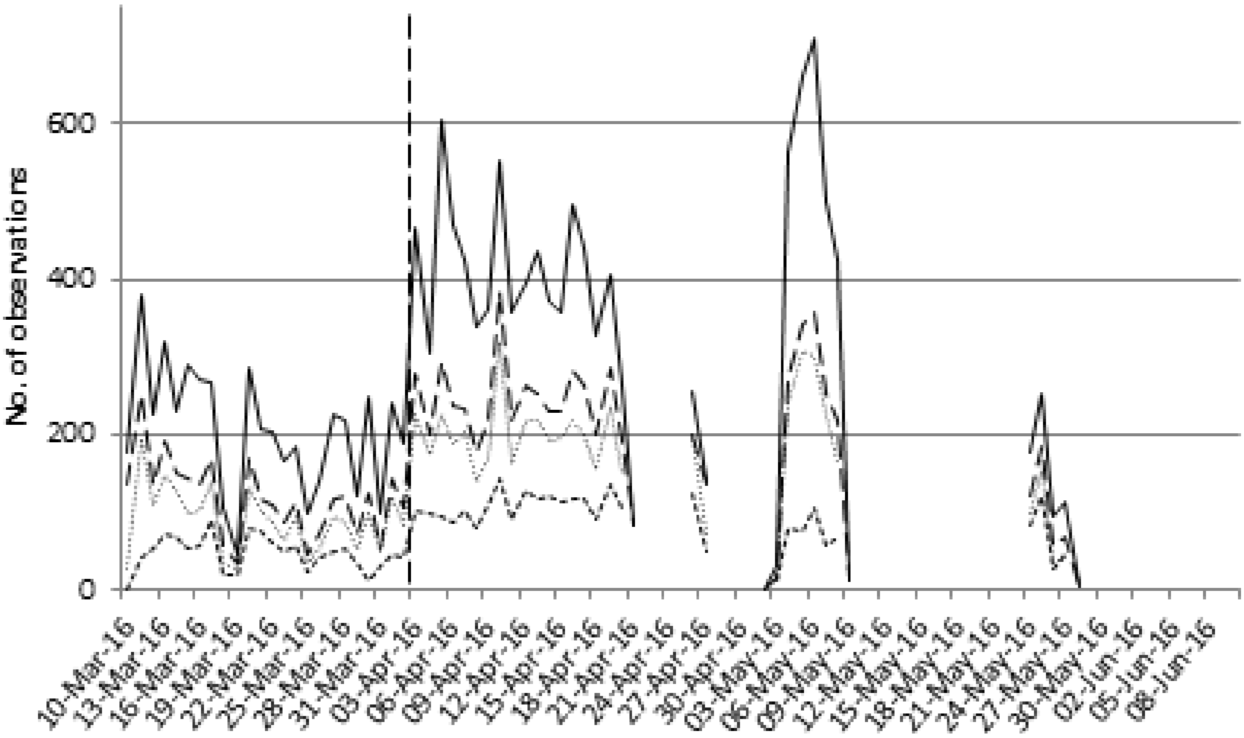


Figure 3. Count of total observations (solid line) and filtered data by groups; Coarse (long dashed line continuous line), Fine (dotted line) and Final daily averaged liveweight (Short dashed continuous line); with date of additional new exit indicated (vertical dashed line).

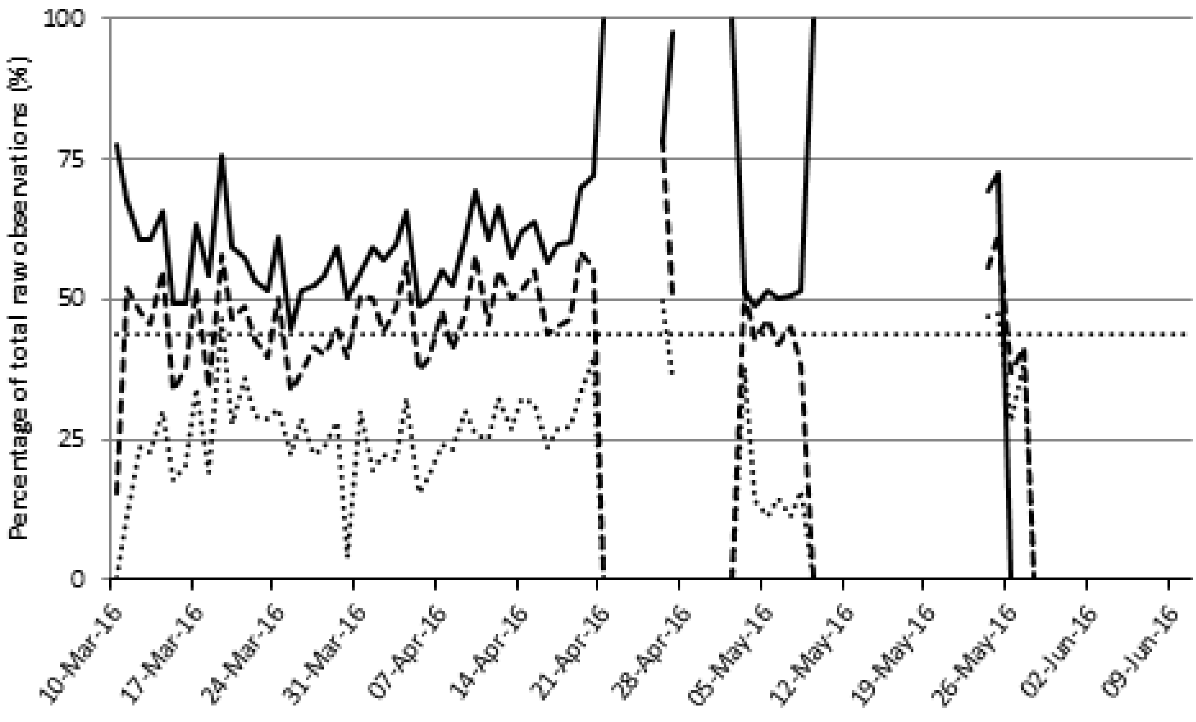


Figure 4. Percentage of total observations in filtered groups; Raw (solid line), Coarse (dashed line), Fine (dotted line). Total average of coarse filtered data is also indicated (horizontal dotted line).

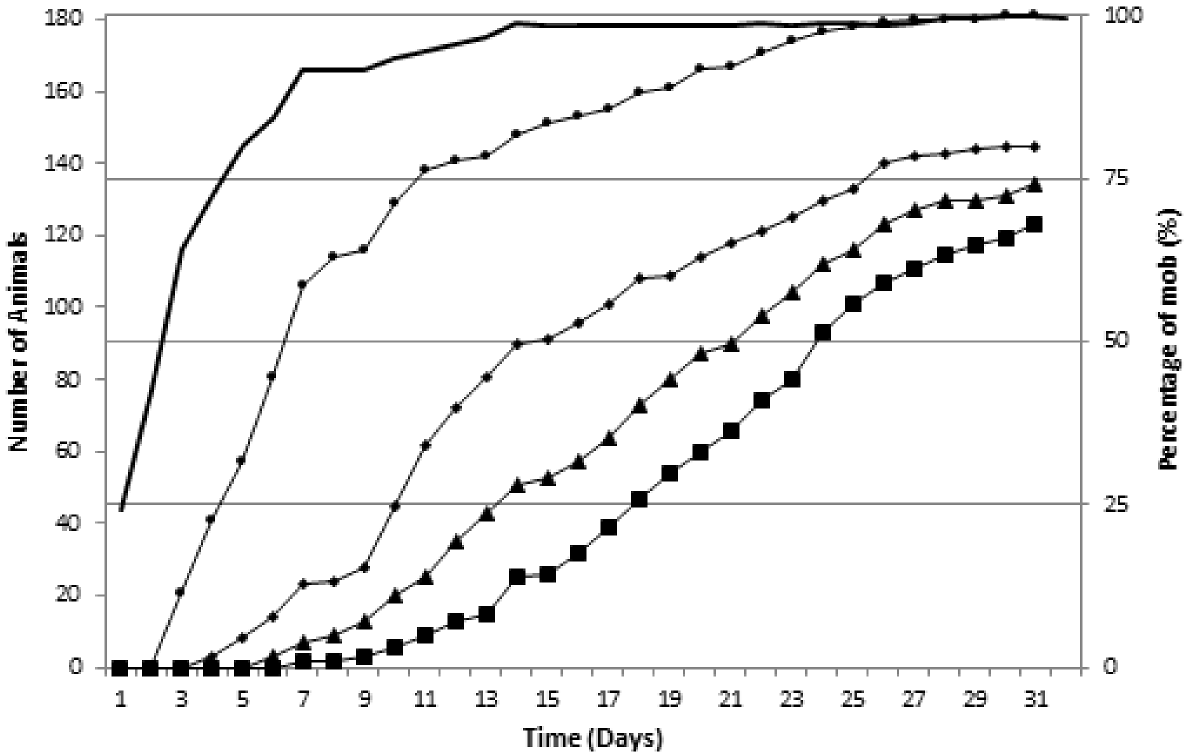


Figure 5. Cumulative total of animals recording first accepted data point (solid line); and percentage of total mob (n=181) accumulating 5(circles), 8 (diamonds), 10 (triangles) and 12 (squares) fine-filtered records over the first 31 days of RFID-linked WOW implementation.

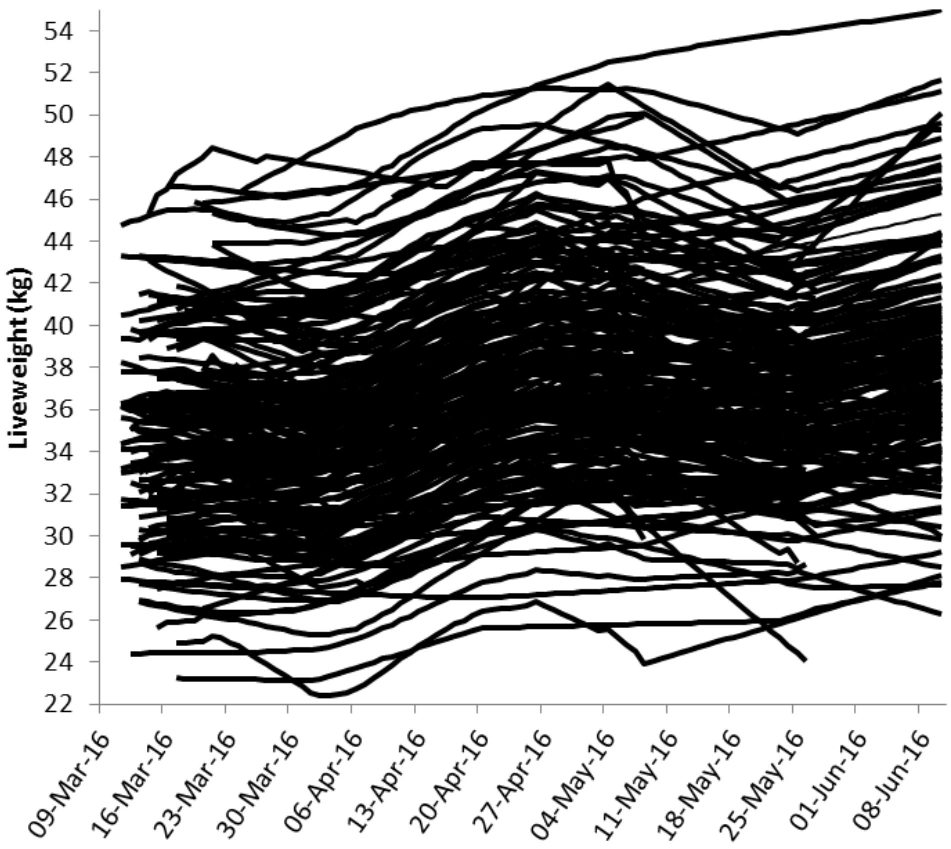


Figure 6. Predicted daily LW profiles of 181 grazing lambs monitored using RFID-linked WOW.

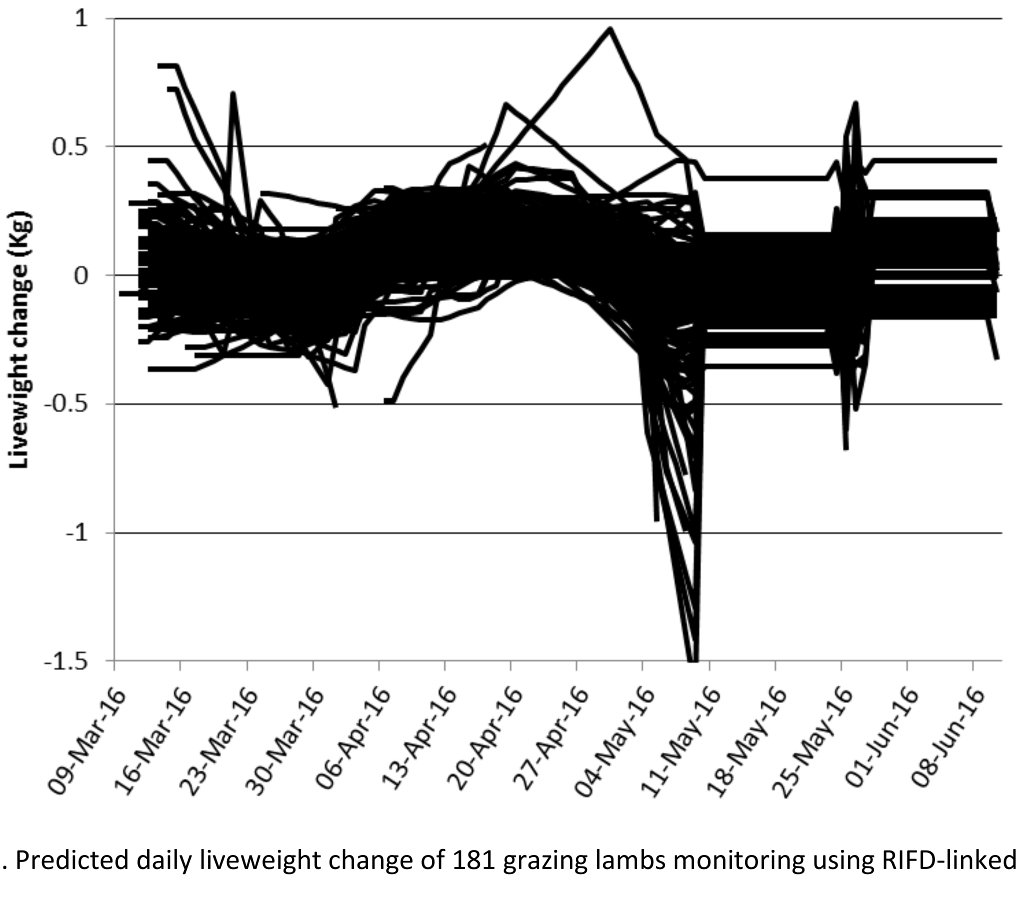


Figure 7. Predicted daily liveweight change of 181 grazing lambs monitoring using RIFD-linked WOW.

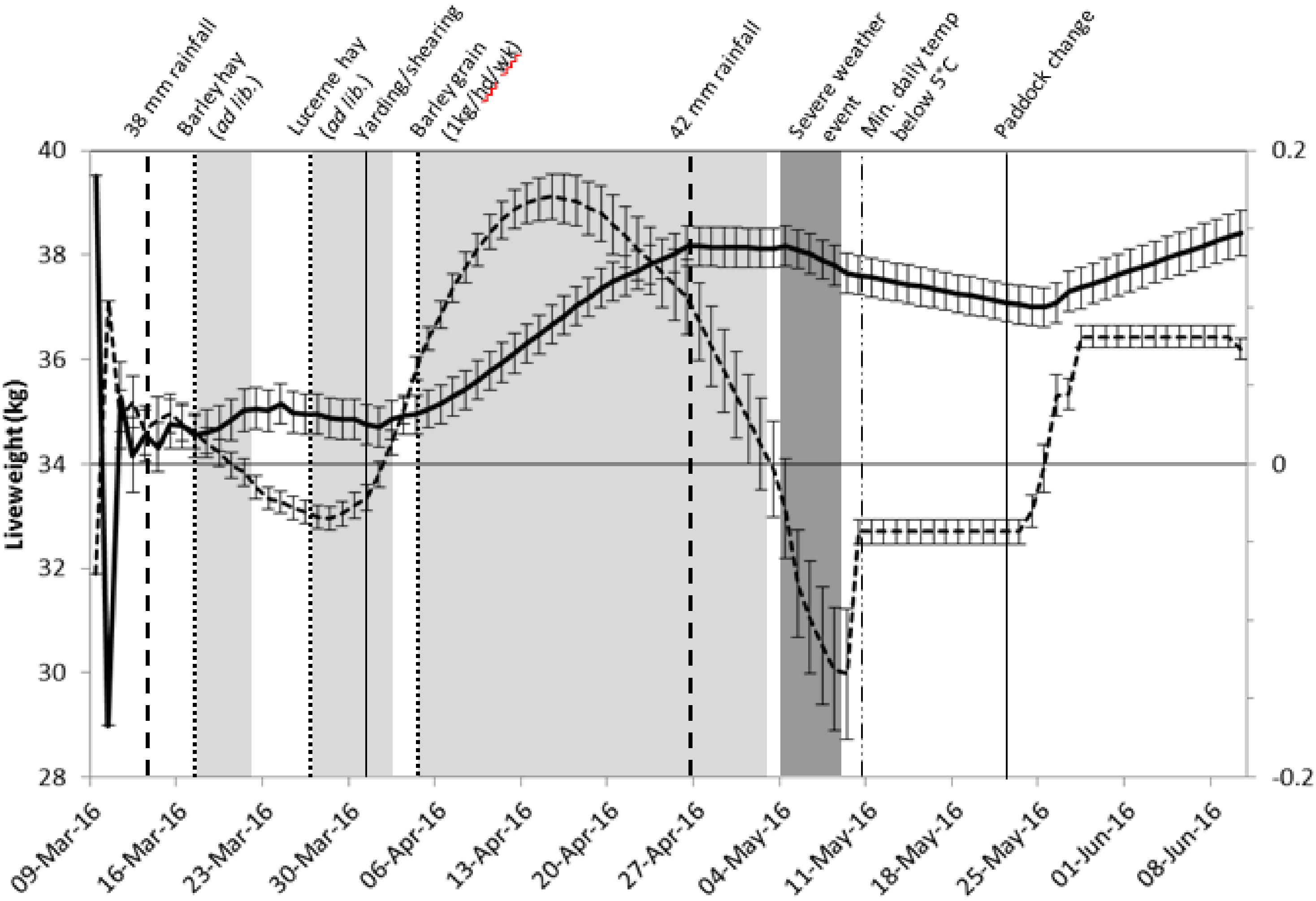


Figure 8. Mob average predicted daily liveweight (solid continuous line) and liveweight change (dashed continuous line) with standard error bars. Management events are indicated with solid vertical lines, weather events with vertical dashed lines and dark shading, and supplementary feed events with vertical dotted lines are light grey shading.

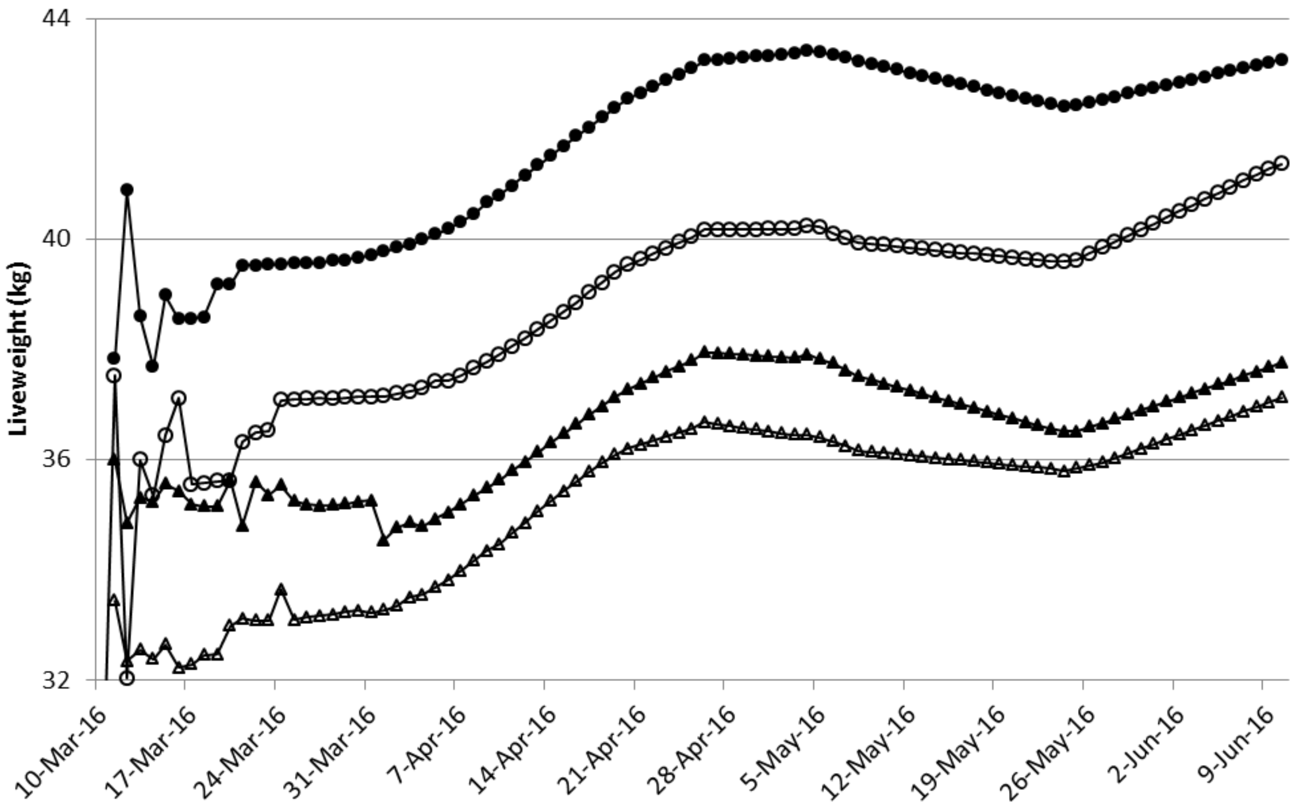


Figure 9. Average predicted daily liveweight of grazing lambs grouped by breed and sex; Merino ewes (empty triangles, n=66), Merino wethers (solid triangles, n=45), crossbred ewes (empty circles, n=21), crossbred wethers (solid circles, n=15).

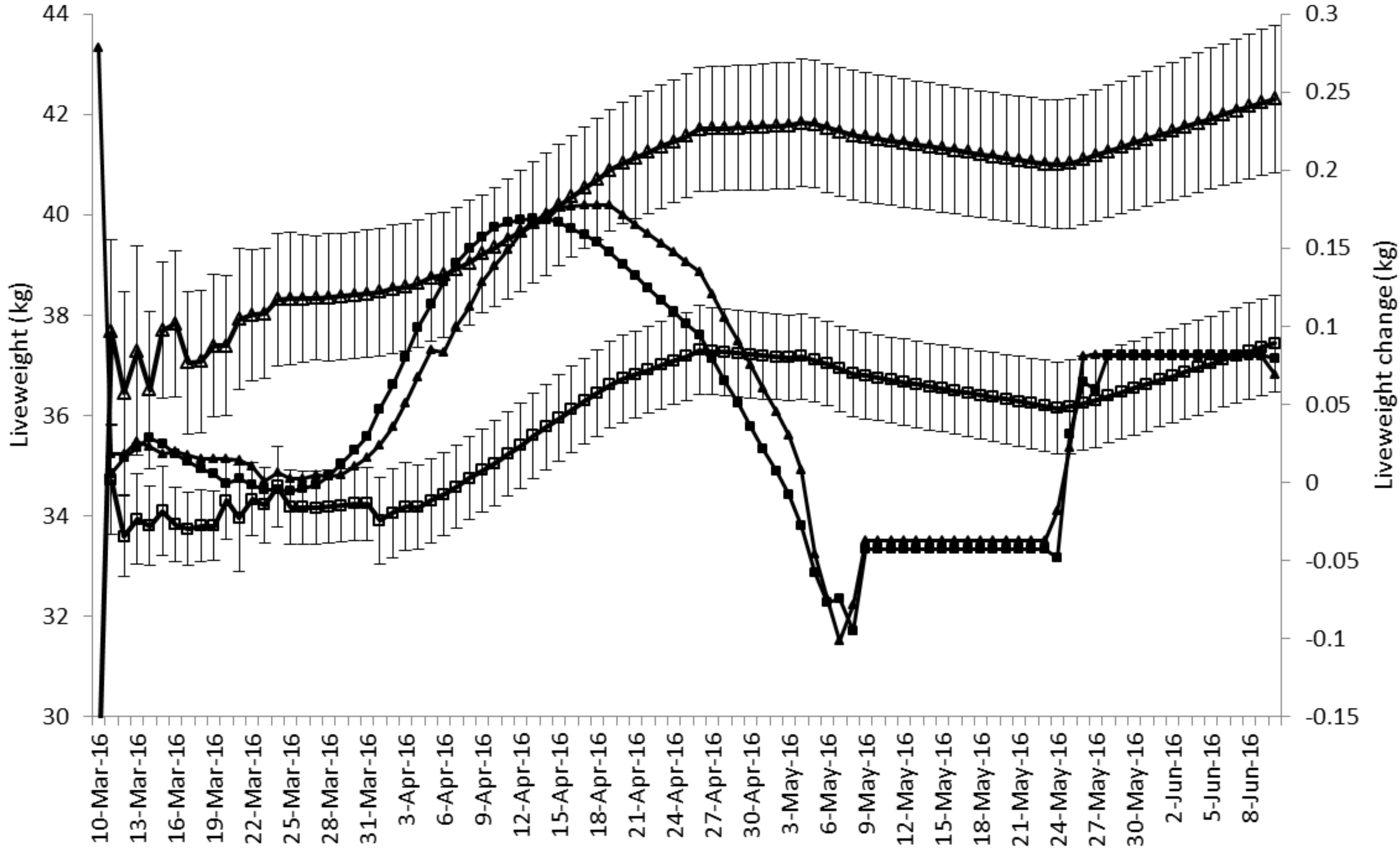


Figure 10. Daily average predicted liveweight (weighted shapes, s.e. bars shown) and liveweight change (small shapes) of grazing lambs grouped by breed; Merino (squares, n=111), crossbred (triangles, n=36).

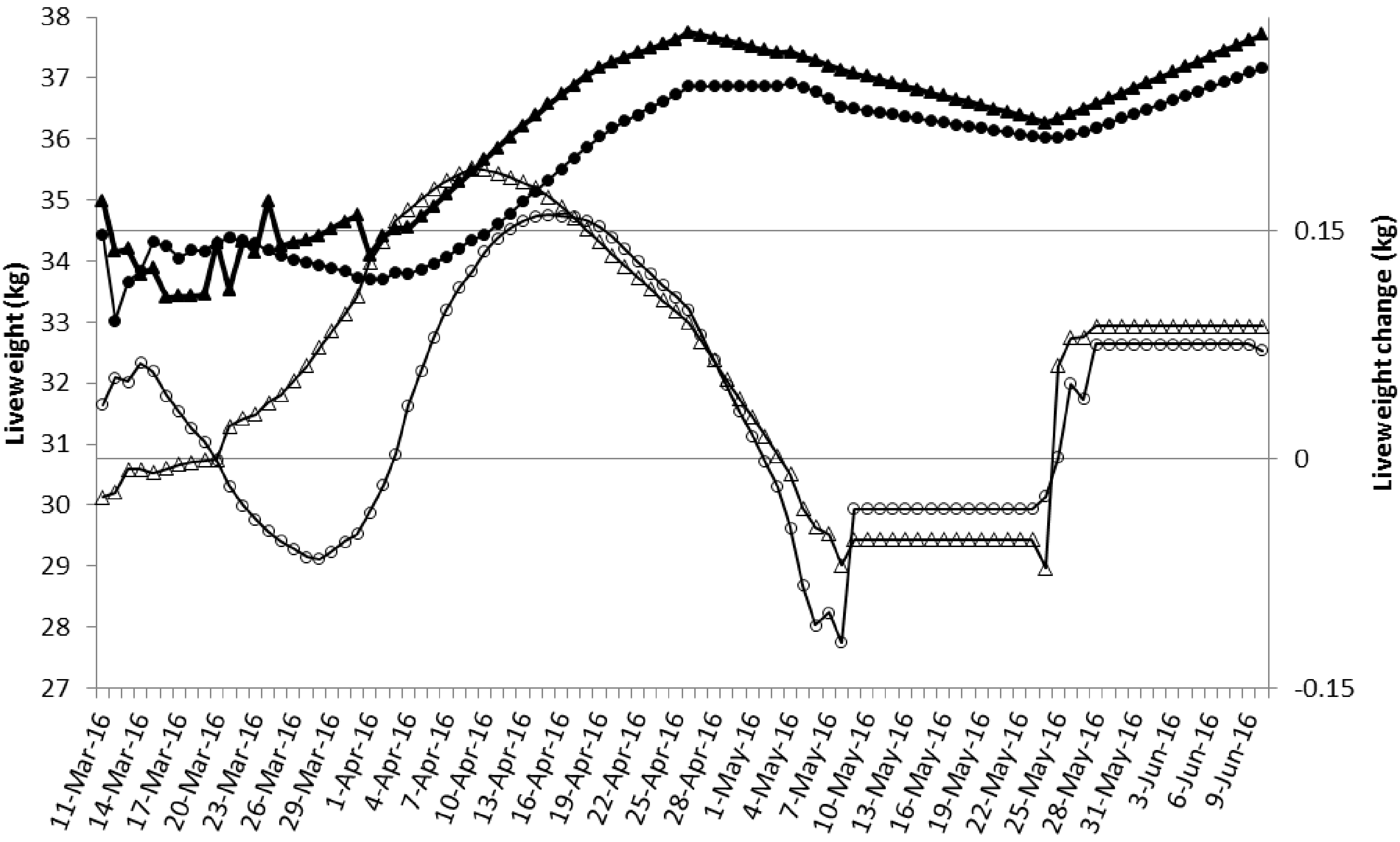


Figure 11. Daily average predicted liveweight (solid shapes) and liveweight change (empty shapes) of Merino lambs grouped by Shearing time; unshorn (triangles, n=61), shorn March 3 (circles, n=14).

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