General introduction

Relative to most market sectors, Australian agriculture has experienced strong multi-factor productivity (MFP) growth from 1975 to 2004 (Australian Productivity Commission, 2005). MFP is a measure of growth of an industry's output, in dollar terms, relative to the combined contribution of key inputs, usually labour and capital. Although MFP growth within the agricultural sector has been strong (2.4% per year between 1977-78 to 2001-02), it has also been variable. Cropping industries (3.3% per year) have outperformed the mixed crop/livestock farms (2.5% per year) and, in particular, the sheep industry (0.9% per year), which has demonstrated the lowest MFP growth since the late 1970s (Australian Productivity Commission, 2005). Innovation is a key factor in retaining competitiveness in any industry, yet despite modest improvements in genetic material and livestock health products, insufficient innovation and adoption of technology and systems in the sheep industry has seen its MFP waning against that of competing land uses.

Low MFP growth within the Australian sheep industry has meant it has not kept abreast of its ever-decreasing terms of trade, evident in its low long-term profitability relative to other broad acre industries. However, shifting consumer preferences have provided some opportunity for producers to mitigate their declining terms of trade. Rising sheep meat prices relative to wool has seen those producers staying within the sheep industry able to diversify into multipurpose and specialist prime lamb flocks. Between 1988 and 2002, MFP gains of these sheep meat focussed production systems (1.6% per year) have been higher than all sheep production systems (0.9%) and high enough to offset declining terms of trade (0.7% per year) and retain competitive levels of profitability.

Flow-on effects for the Australian wool industry have been significant. The general shift away from sheep to competing land uses has resulted in an unprecedented population decline in the Australian sheep flock, currently sitting at a 106-year low of approximately 68 million sheep (Australian Bureau of Statistics, 2011). Similarly, production systems moving to multipurpose or specialist prime lamb flocks are joining higher proportions of ewes to terminal sires and increasing lamb turnoff rates, which is stifling the repopulation of the Australian flock.

The Australian sheep industry is currently in an era characterised by low labour availability and high labour prices (McEachern, 2008). Correspondingly, progressive sheep production systems are required to strive for high levels of labour efficiency to remain profitable in the face of declining terms of trade. Consequently, where labour resources were once deployed to perform a range of tasks, including livestock monitoring, an overall reduction total labour employed per farming business means that remaining labour resources are being increasingly restricted to core husbandry procedures. The time available for labour to monitor and interact with the livestock is diminishing, and hence the opportunities for livestock managers to make well-informed, timely decisions on their flock are becoming increasingly limited (Frost *et al.*, 1997).

The need for improved time efficiency provides an opportunity for the development of integrated monitoring technologies that collect, collate and process large volumes of data from different sources. This information, combined with existing knowledge and databases, may allow livestock managers to make more productivity-focussed decisions and even enable direct automation of systems. There are such technologies under development and in use in the more intensive animal productions systems, such as mount monitors to aid oestrus detection in the dairy industry (Rorie *et al.*, 2002) and strain gauge perches for estimating liveweight gains in the poultry industry (Turner *et al.*, 1984). The tighter control of animals in these systems enables more efficacious data collection and greater opportunity to respond to its ensuing recommendations, and the welfare and productivity of the animal are in the interest of and under the complete control of the livestock manager. Consequently these industries occupy this technological frontier as investment in the technology it is encouraged by higher, more certain returns.

There are some monitoring technologies available to producers in extensive livestock grazing systems. Radio frequency identification (RFID) technology is individually coded chips located in the ear tags of stock that can be 'read' by handheld of remote sensing equipment. Once the animal's RFID tag code is read it can be identified on a data base. In addition to providing traceability of livestock along the marketing chain this allows large amounts of relevant production data to be kept on each animal to aid animal selection and management decision making.

A monitoring technology that relies on RFID is Pedigree Matchmaker (PMM). PMM collects RFID data, namely animal code, date and time, remotely as ewes and their lambs pass by a strategically located RFID sensor. Resultant data is then processed in customised software to identify associations between ewes and lambs. The relative strength of these associations allows livestock managers to link lambs to their respective mothers and create pedigrees. The technology, although relatively new to the sheep industry, is useful to seed stock enterprises and is applied commercially in some instances.

Another monitoring technology that can be applied either with or without RFID is walk-over weighing (WOW). WOW functions by collecting liveweight data as sheep voluntarily cross a weighing platform as part of their normal daily routine. The liveweight data is then collected, processed and interpreted by livestock managers to aid nutritional management. This process can be performed on either a whole flock basis, or on an individual animal basis, the latter requiring RFID technology. The ability to track liveweight of sheep would provide a powerful management tool for sheep producers; however there is little robust information on the technologies ability to perform its purpose, nor demonstrative evidence of the concept working in a commercial context. It is with this in mind that WOW has been made the primary focus of the ensuing study.

Although the role of the stockman as the principal decision maker of sheep production systems is safe, their role as principal monitor of sheep is set to diminish and there will be increased pressure on the development and implementation of WOW technologies designed to monitor sheep and aid subsequent decision making. Although often a source of much speculation, the current lack of such monitoring systems in commercial sheep production systems today is not due to livestock manager's reluctance to adopt technology. It is indeed, to a greater degree, the failing of industry research and development organisations to innovate, develop and extend robust, cost effective systems that work with little time investment and have sufficient serviceability and on-going support. Consequently, investment into monitoring technologies is timely and warranted.

1 Literature Review

This literature review has been accepted for publication in *Animal Production Science* (excluding section 1.7).

Brown DJ, Savage DB, Hinch GN & Hatcher S (2013) Monitoring liveweight in sheep is a valuable management strategy: A review of available technologies. *Animal Production Science* (accepted).

1.7 Scope of thesis

The current study has been designed to investigate the factors affecting the potential of WOW for the Australian Sheep industry.

The initial phase of the research used three experiments on commercial farms to compare MBWOW data to static weighing data on a monthly basis to validate the technology's ability to generate flock average weights similar to conventional static weighing methods.

The second phase of the research aimed to determine if the addition of RFID technology enabled differential management or monitoring of individual sheep liveweight. To do this, the repeatability and frequency of RFID-linked WOW data was assessed in four RFID-linked WOW datasets. This enabled the determination of the number of records required for confident individual and flock based liveweight estimates, and the concomitant suitability of RFID-linked WOW in commercial contexts was established. In response to knowledge gained from the first two phases of the research, the third phase was conducted to investigate issues associated with WOW data collection that resulted in insufficient data available for decision making. Insufficient WOW data collection was seen as a constraint to the commercial adoption of WOW, and investigating a remedy for the issue was appropriate in the context of the current study. An experiment was devised and conducted to determine if data collection frequency of young sheep post-weaning could be increased by exposing them to the WOW concept pre-weaning.

The fourth and final phase of the research draws on the findings from the current study and other studies to estimate the potential economic benefit of moving commercial average ewe liveweight profiles towards optimum profiles. The likely costs of implementing mob-based walk-over weighing, relative to condition scoring and static weighing, in commercial sheep production systems were also established.

2 Mob-based walk-over weights: similar to the average of individual static weights?

This experimental chapter has been published in *Animal Production Science*:

Brown DJ, Savage DB, Hinch GN & Semple SJ (2012) Mob-based walk-over weights: similar to the average of individual static weights? *Animal Production Science* **52**(7), 613-618. doi: http://dx.doi.org/10.1071/AN11306

3 Repeatability and frequency of in-paddock sheep walk-over weights: implications for individual animal management.

This experimental chapter has been published in *Animal Production Science:*

Brown DJ, Savage DB & Hinch GN (2013) Repeatability and frequency of in-paddock sheep walk-over weights: implications for individual animal management. *Animal Production Science*. doi: http://dx.doi.org/10.1071/AN12311

4 The use of walk-over weighing for preferential feeding in sheep production systems.

Sections 4.2 to 4.4 of this experimental chapter have been published in *Recent Advances in Animal Production*:

Brown DJ, Savage DB & Hinch GN (2013) The use of walk-over weighing for preferential feeding in sheep production systems. In 'Proceedings from the Recent Advances in Animal Nutrition 22nd Biennial Australian Conference'. (Eds. P Cronje), pp. 3-4. (Animal Science: University of New England, Armidale, New South Wales, Australia).

5 Repeatability and frequency of in-paddock sheep walk-over weights: implications for flock-based management.

This experimental chapter has been published in *Animal Production Science*:

Brown DJ, Savage DB & Hinch GN (2014) Repeatability and frequency of in-paddock sheep walk-over weights: implications for individual animal management. Animal Production Science **54**(2), 207-213. doi: http://dx.doi.org/10.1071/AN12311

6 Exposure of lambs to walk-over weighing equipment prior to weaning influences data collection frequency post-weaning

6.1 Abstract

Weaner mortality represents a major cost to the Australian sheep industry and walk-over weighing (WOW) systems offer potential to monitor weaner liveweights 'in-paddock' for better liveweight management and increased weaner survival rates. Past studies suggest that the frequency of WOW data is too low for individual animal management and the current study investigated whether the frequency of WOW data in weaner sheep can be increased by exposing them to WOW systems as lambs. A study comprising two experiments investigated a single exposure (Experiment 1) and six weeks of continuous exposure (Experiment 2) of 212 and 64 first cross lambs, respectively, to WOW equipment pre-weaning. The effect of the pre-weaning exposure on subsequent WOW data collection frequency post-weaning was compared to their naïve counterparts. Exposed weaners in Experiment 1 did not use the WOW for the seven days of data collection in the post-weaning phase. In contrast, the naïve flock used the WOW system, collecting a daily mean (± SE) of 0.8 ± 0.05 records per sheep and frequency of use increased throughout the data collection period from 0.0 and 1.4 mean records per sheep. Results from Experiment 2 showed that exposed weaners had higher (P < 0.05) mean daily WOW data collection frequency (2.5 ± 0.16 /weaner) than their naïve counterparts (1.4 ± 0.15 /weaner). However, this affect had diminished by the end of the data collection period, whereby the data collection frequency of the naïve weaners had increased to equal that of the exposed weaners. This result means that after only one week, there is no difference between

data collection of exposed and naïve sheep. In a commercial context, this is unlikely to be a difference that is of commercial importance.

6.2 Introduction

It has been observed that data collection frequency is generally low in the initial stages of sheep walk-over weighing (WOW) data collection, and begins to increase about two weeks after the implementation of the system (Brown *et al.*, 2013b). This pattern suggests that the sheep could be overcoming neophobia of the equipment and 'learning' to use the WOW system. This is analogous with a large body of work showing that pre-weaning exposure influences acceptance (reduces neophobia responses) later-in-life in sheep. For example, lambs exposed to grain feeding pre-weaning more readily accept grain than their naïve counterparts several years later (Green *et al.*, 1984; Savage *et al.*, 2008), especially when exposed with their dams (Lynch *et al.*, 1983). Similarly, sheep that have been trained to be familiar in yards in a particular fashion have out-performed their untrained counterparts when tested six weeks post-training (Hutson, 1980). These data demonstrate the potential for early-life training/exposure to influence behaviour in later-life. Thus, testing exposure of young lambs to the WOW system prior to weaning in order to increase data collection frequency post weaning seems warranted.

A particular system that may benefit from increased WOW data collection frequency is the nutritional management of weaner sheep for reduced mortality. Weaner mortality accounts for a considerable amount of reproductive wastage, with mortality rates as high as 39% reported in literature (Denney *et al.*, 1988). These losses are estimated to cost the Australian sheep industry AUD $75 million per annum, making it the fourth most costly endemic health issue (Sackett *et al.*, 2006). Weaner liveweight and growth rate have both been associated with post-weaning mortality, with those having low liveweights and low growth rates at a higher risk of mortality (Allden, 1968; Lloyd Davies, 1983; Hatcher *et al.*, 2008; Campbell *et al.*, 2009). This is because weaners with low liveweights do not have the energetic resources required to withstand the physiological stressors often imposed by weaning (Allden, 1970). It has been suggested that early nutritional intervention would improve weaner survival, and that preferential feeding of the lightest one-fifth of the flock could address nearly one-third of weaner mortalities (Campbell *et al.*, 2009). Furthermore, hazardous husbandry prodcedures for weaners sheep, such as shearing, would benefit from selectively increasing the liveweight of the lightest portion of the flock through less weaner deaths. Thus, research focussing on increasing WOW data frequency to enable individual weaner management for reduced mortality is warranted.

The hypothesis tested in the current study was that weaner sheep that have been exposed to a WOW system prior to weaning will be more accepting of the system after weaning than their naïve counterparts.

6.3 Materials and Methods

All procedures reported in this paper were conducted according to the guidelines of the Australian code of practice for the care and use of animals for scientific purposes and received approval from the University of New England's Animal Ethics Committee (AEC12/083).

Two experiments were designed to investigate the effect of pre-weaning exposure of lambs to WOW systems on their subsequent use of WOW equipment. Experiment 1 examined the effect of a single exposure while Experiment 2 examined the effect of continuous exposure, to WOW systems as suckling lambs. Lambs used were from Merino dams joined to Poll Dorset sires, producing cross-bred progeny born in October 2012 (spring) and weaned in January 2013 (summer). Lambs were sourced from within the National Sheep Resource Flock, held at research farms owned by the University of New England, Armidale, Australia (30°51'S, 151°66'E).

For both experiments the lambs, still with their dams, were randomly allocated to two treatment groups; a 'naïve' group (control with no pre-weaning exposure to WOW equipment) and an 'exposed' group (treatment with the lambs exposed pre-weaning to WOW equipment).

In Experiment 1, lambs (n = 212) were exposed to a WOW system on one occasion, after lamb marking and before weaning (December, 2012). The ewes and lambs selected for exposure to WOW equipment were already running as a separate flock in one of the small paddocks, or 'lambing plots', used on the university's research farm for lambing National Sheep Resource Flock ewes. The ewes and their lambs of the treatment and control flocks had been separated from the same larger management groups only for the purpose of lambing and hence this method of selection was deemed adequately random. At 0900h the flock was mustered though a gateway into a purpose-built holding yard (50m x 10m) in the corner of their current paddock. Once the flock was captive in the holding yard, the entrance gate was replaced with a WOW platform (Brown *et al.*, 2012). The ewes and lambs were then left to negotiate their way out of the holding yard via the WOW platform free of human intervention. The flock was under casual observation. By 0900h the following morning, all ewes had exited the holding yard via the WOW platform, while three lambs remained, which were gently ushered out of the yard to re-join the flock in the paddock. The naïve lambs (n = 200) were kept in another lambing plot on the research farm with their dams but were not exposed to WOW equipment in the pre-weaning period.

In Experiment 2, lambs (n = 64) had constant exposure to a WOW system from birth for approximately six weeks. The lambs were free to follow their mothers as they accessed supplementary feed and water via a WOW platform but were not forced to use the WOW equipment at any stage. Observation suggested that the lambs had begun to use the WOW system voluntarily before access was removed.

The four groups of ewes and lambs in the two experiments (2 x exposed and 2 x naïve) were managed as separate flocks until weaning. At weaning, the lambs were combined with other groups of recently weaned lambs to form larger management groups (approximately 700 lambs). All lambs were individually identified with radio frequency identification tags (RFID).

6.3.1 Data collection post-weaning

The post-weaning measurements were undertaken within two months of weaning. The weaners were offered unrestricted access to self-feeders that contained a grain-based supplement, for at least five days before a three-wired electric fence enclosure (80 m × 40 m for Experiment 1 and 15 m × 15 m for Experiment 2) was erected around them. Thereafter, access to the feeders remained via large (4m) openings (two openings situated on opposite sides of the rectangular enclosure for Experiment 1 and one opening for Experiment 2), designed to replicate a gateway. The weaners were given further time (12 days for Experiment 1 and two days for Experiment 2) to become accustomed to the electric fence enclosure before data collection commenced. Observation suggested the frequency of access to the troughs was not inhibited by the introduction of the enclosure.

For Experiment 1, the exposed weaners were separated from the naïve weaners one day before data collection and then placed back into the experimental paddock. The experimental paddock consisted primarily of native grasses in the late flowering stage characteristic of pastures in late summer/early autumn in the New England Tablelands. Although objective pasture tests were not performed, it is estimated that the food on offer was high (3000 kg of dry matter per hectare) and the digestibility low (< 60% digestability). The naïve group were placed in an adjoining paddock but out of sight of the WOW system. This ensured that social facilitation between conspecifics (Tribe, 1950; Thorhallsdottir *et al.*, 1990) was removed from the experimental design. The feeders were then closed off from the rest of the paddock and access given only via the two WOW platforms. A RFID reader panel and control box was used in conjunction with the WOW system to collect RFID-linked WOW data. Data, stored in Tru-Test™ indicators, were downloaded at completion of one week of data collection.

While the exposed weaners were in the experimental paddock collecting data the naïve flock had continual access to automatic grain feeders in the adjacent paddock. On completion of data collection on the exposed weaners the naïve weaners were placed in the experimental paddock. Data collection on these animals continued for one week as per the treatment group.

For Experiment 2, data collection on the naïve and exposed groups occurred simultaneously, as the smaller animal numbers facilitated data measurement in two smaller paddocks, concurrently. These paddocks were slashed before the experiment to ensure equal pasture availability in both. The WOW systems were introduced in the same manner as in Experiment 1, and data collection also continued for seven days. Data collection for both flocks was interrupted on days five and six of data collection due to the RFID panel readers becoming dislodged. Data were downloaded from the Tru-Test™ indicators and analysed as outlined below.

6.3.2 Data handling and analysis

All sheep that traversed the WOW platforms contributed to the RFID-linked WOW data files. Data were fine filtered according to the method outlined by Brown *et al.* (2013b) to remove records outside of a 25% range of a recent RFID-linked WOW flock average reference weight. This ensured all 'half' and 'double' liveweight records were removed. The remaining 'fine filtered RFID-linked WOW data' (henceforth referred to as 'data') have been shown to create individual liveweight estimates with the smallest 95% confidence intervals (Brown *et al.*, 2013b), and these data were used to examine the data collection frequency for the flock. As data collection for both flocks in Experiment 2 was interrupted on days five and six of data collection, these data were excluded from the analysis.

For Experiment 1 the exposed flock did not access the feeding area and therefore no comparative analysis of experimental groups was possible. For Experiment 2, non-normality of the data meant that a Mann-Whitney (Wilcoxon) test was used to compare differences in the median number of records per sheep between the naïve and exposed flocks on each day of the experiment. These analyses were performed using Statgraphics Centurion XVI (Statgraphics, 2009).

6.4 Results

6.4.1 Experiment 1

The exposed flock from Experiment 1 did not use the WOW for the seven days of data collection. In contrast, the naïve flock generated 529 records (fine filtered RFID-linked WOW data), and frequency of use increased throughout the data collection period. The mean number of daily data collected per sheep (± SE) by the naïve flock was 0.8 ± 0.05, ranging between 0.0 and 1.4, with the maximum daily data per sheep reached by Day 6 of data collection (Figure 6.1).

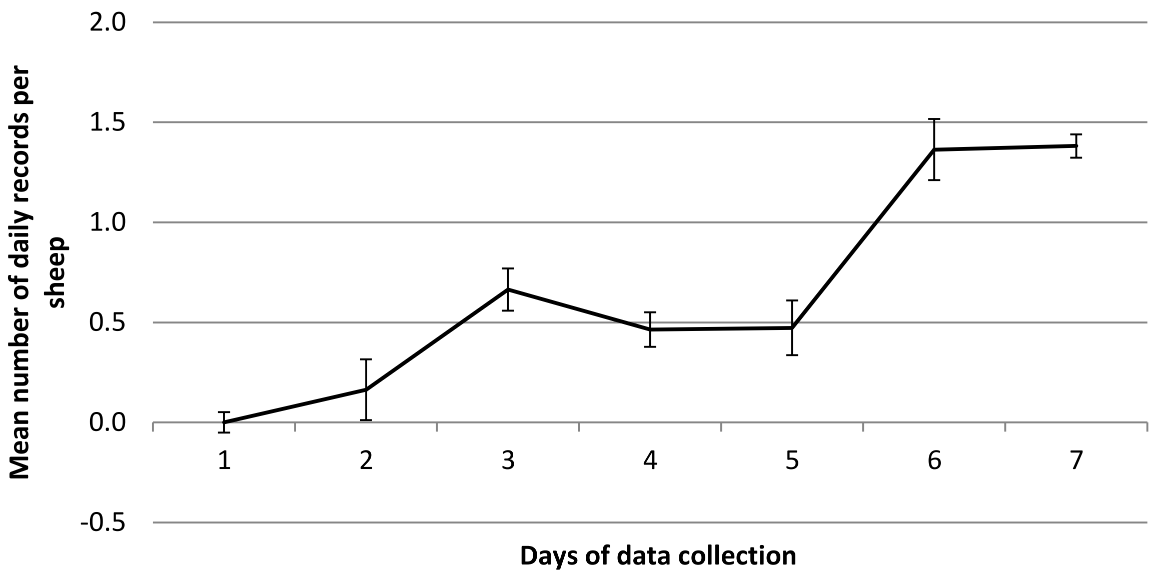

Figure 6.1 The mean ± se number of records (per weaner) for the naïve weaners on each day of Experiment 1. Exposed weaners did not use the WOW system during data collection and are not represented in the figure.

The proportion of the naïve flock that generated data on each day of data collection ranged from 0% to 38%, and the maximum proportion of the flock generating data occurred on Day 6 of data collection (Figure 6.2).

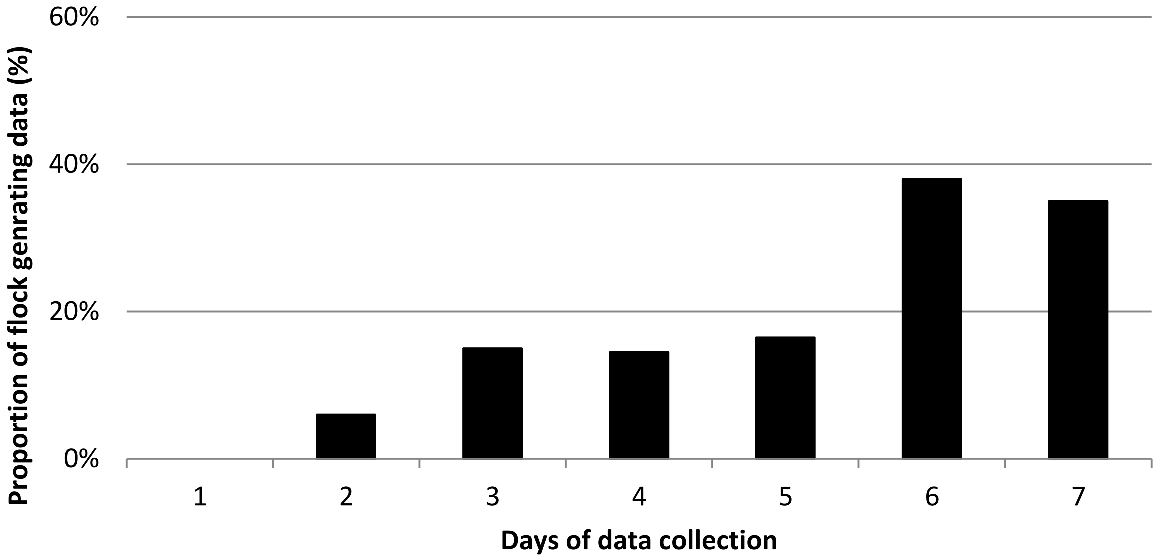

Figure 6.2 The proportion (%) of the naive weaners recording data on each day of Experiment 1. Exposed weaners did not use the WOW system during data collection and are not presented in the figure.

The cumulative proportion of the naïve flock to generate >11 records over the course of the experiment is a useful indicator of how many weaners will have confident liveweight estimates on each day after the commencement of data collection. By the end of data collection 8% of the naïve flock had accumulated >11 records (Figure 6.3).

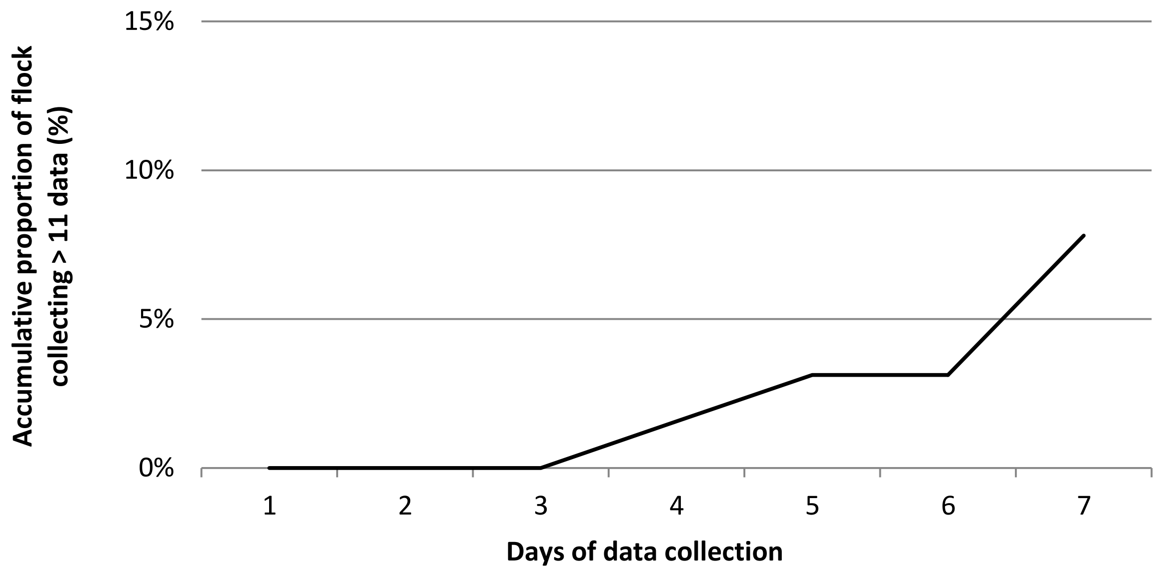

Figure 6.3 The accumulative proportion (%) of the naïve weaners recording >11 records on each day of Experiment 1. Exposed weaners did not use the WOW system during data collection and are not presented in the figure.

6.4.2 Experiment 2

During the data collection period, the naïve flock generated 616 records and the exposed flock 1125 records. The mean number of daily records per sheep (± SE) collected by the naïve flock (1.4 ± 0.15) was less ($P < 0.05$) than that collected for the exposed flock (2.5 ± 0.16).

The mean number of daily records per sheep, by day, for the naïve and exposed flocks is presented in Figure 6.4. The exposed flock had more ($P < 0.05$) daily records per sheep on the first three days of data collection and the naïve flock did not reach its maximum mean number of daily records per sheep until the Day 7. In contrast, the exposed flock reached its maximum on Day 2 of data collection. There was no difference in the mean number of daily records per sheep between the flocks after Day 3 of data collection.

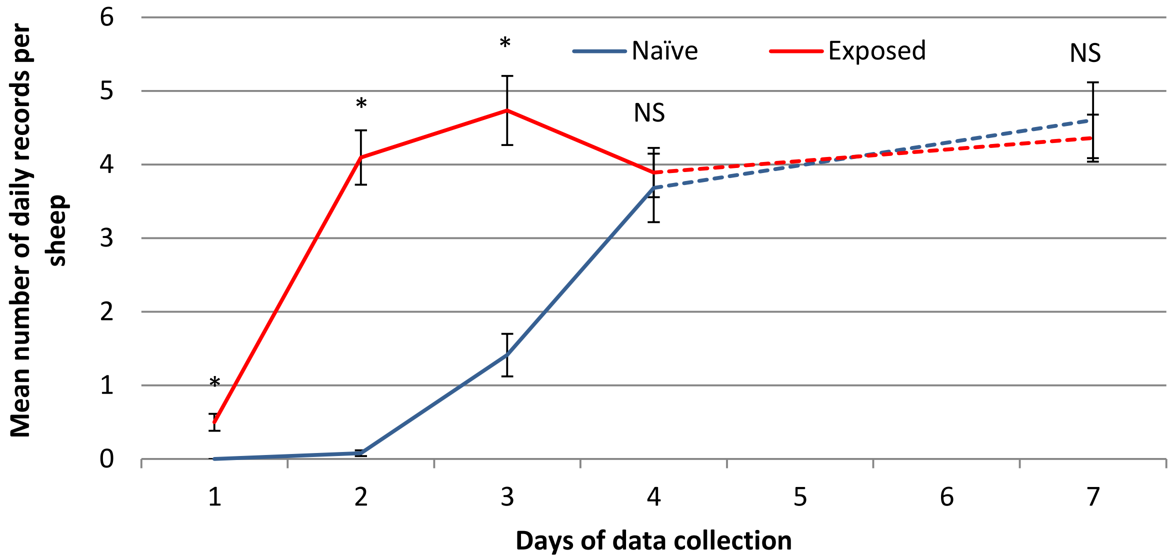

Figure 6.4 The mean ± se number of records for weaner sheep that are either naïve to WOW (control) or exposed to WOW as lambs (treatment) on each day of Experiment 2. Differences significant (*) at *P* = 0.05. Days 5 and 6 removed from analysis due to insufficient data.

The proportion of the flock generating data on each day of data collection is shown in Figure 6.5. The exposed flock collected data on each day, and generated records for a majority (91%) of the flock on Day 2 of data collection. In contrast the naïve flock did not collect data on the first day, and the highest proportion to generate data was 75%, and this did not occur until Day 7 of data collection.

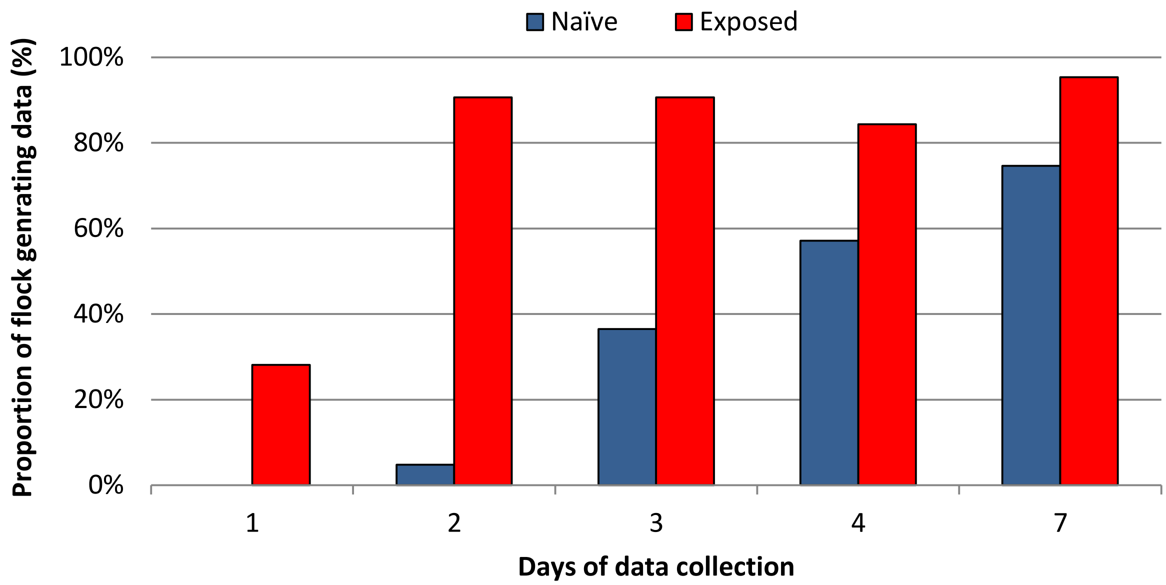

Figure 6.5 The proportion (%) of the flock generating records for weaner sheep that were either naïve to WOW (control) or exposed to WOW as lambs (treatment) on each day of Experiment 2. Days 5 and 6 removed from analysis due to insufficient data.

The cumulative proportion of the flock to generate >11 records relative to time is displayed in Figure 6.6. By the end of the data collection period (Day 7) the exposed flock had 70% of the flock generate >11 records compared to 44% for the naïve flock.

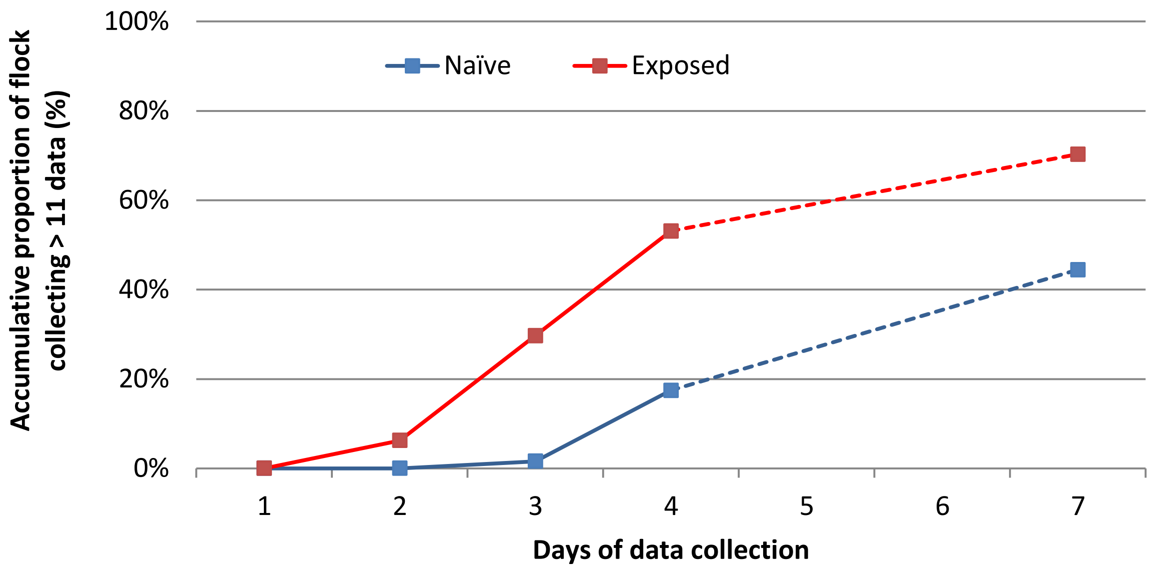

Figure 6.6 The accumulative proportion (%) of the flock generating >11 records for weaner sheep that are either naïve to WOW (control) or exposed to WOW as lambs (treatment) on each day of Experiment 2. Days 5 and 6 removed from analysis due to a breakdown in data collection.

6.5 Discussion

The hypothesis tested in this current study was that weaner sheep that have been exposed to a WOW system prior to weaning will be more accepting of the system after weaning than their naïve counterparts. The results indicate that single exposure of weaners to the WOW system pre-weaning was unsuccessful at increasing acceptance of the WOW systems. Alternatively, continual exposure of weaners pre-weaning was successful, as demonstrated by their increased frequency of data collection.

In Experiment 1 the exposed flock did not accept the WOW system whereas the naïve flock demonstrated a small (relative to the size of the flock) number of animals accepting the WOW system. The most plausible explanation for the results of Experiment 1 is that the single exposure to WOW afforded to the exposed flock as lambs was insufficient to reduce their neophobia of the equipment post weaning. The exposed flock of Experiment 1 were only exposed to WOW on a single occasion, whereas the exposed flock of Experiment 2 received constant exposure to a WOW system from birth to ~6 weeks of age, and this is reflected in their willingness to traverse the platform on the Day 2 of data collection.

However, this does not help explain why the naïve animals in Experiment 1 accepted the WOW system. Consequently, an alternative reason why the exposed animals in Experiment 1 did not accept the WOW system may be associated with the inclement (heavy rain and wind) weather conditions during data collection. Weather data were not collected specifically for this study, however it is possible that it plays large role in WOW data collection and closer observation of it is recommended for future studies. Precipitation and humidity has been shown to reduce the propensity of ruminants to access supplements (Champion *et al.*, 1994; Wilson *et al.*, 2005), and thus the treatment differences in Experiment 1 could simply reflect differences in weather conditions. This is an important observation as it emphasises that environmental conditions can interfere with the reliability WOW data collection. The number of naïve weaners in Experiment 1 accepting the system increased during the data collection period, suggesting that despite being naïve to the WOW system they were overcoming their neophobia of the equipment and capable of 'learning' to use it.

In Experiment 2 weaners continuously exposed to WOW systems as lambs were more accepting of the WOW system. This was demonstrated by a greater ($P < 0.05$) number of daily data records (fine filtered RFID-linked WOW data) per weaner, a greater proportion of the flock generating data (not analysed) and a greater accumulative proportion of the flock generating >11 data (not analysed) than their naïve counterparts. This effect is synonymous with studies investigating the effect of pre-weaning exposure of lambs to supplementary feed on subsequent acceptance of a supplement post-weaning (Lynch *et al.*, 1983; Green *et al.*, 1984; Savage *et al.*, 2008),

The convergence of acceptance of the WOW system by the naïve and exposed weaners in Experiment 2 within the experiment period has important implications for the commercial application of WOW. It demonstrates that despite exposure of lambs to WOW systems pre-weaning increasing their acceptance of it post-weaning, this effect diminishes within seven days. This means exposed weaners would only have seven days when their data collection would be more than that of their naïve counterparts. In a practical context this does not present an important benefit, especially when considering the resources used to ensure that the lambs are continuously exposed to WOW pre-weaning, and may do little to help the application of WOW on an individual basis.

Furthermore, general acceptance of the WOW system by naïve sheep in a more extensive grazing system may not be as rapid as seen in the current study. In this context exposure of sheep pre-weaning may elicit greater differences between them and their naïve counterparts, and the marginal increase in data available for liveweight management decisions may be warranted. It seems reasonable to suggest that WOW would benefit from extending the current study to an extensive grazing context.

A general observation from Experiment 2, combined with those of other studies (Bowen *et al.*, 2009; Brown *et al.*, 2012; Brown *et al.*, 2013b), was that the inclusion of water as an incentive failed to ensure daily data collection for the entire flock. This is a surprising outcome considering that the data collection period was unseasonably warm and dry, with low dew levels, for that time of year in the New England region. Although both experimental paddocks consisted of mature pasture that had been slashed before the experiment, it is not known how much water the flock was receiving from their grazing. Nonetheless we suggest that the use of water as an incentive will not ensure daily data collection on an entire flock. This is a relevant outcome to be noted by extension officers and industry consultants and a more thorough investigation into scenarios that may improve its efficacy is warranted before it is recommended to producers.

6.6 Conclusion

Continual exposure of weaners to a WOW system pre-weaning will increase their acceptance of it post-weaning, while a single exposure will not. However, the effect of continual exposure is short lived as the data collection frequency of their naïve counterparts will increase and equal that of their exposed counterparts within a seven-day period. This implies that there will only be a short period of time where the data collection frequency of the exposed flock will be greater than that of the naïve flock, and the additional resources used to ensure continual exposure of lambs pre-weaning may not be justified by the marginal increase in WOW data.

7 Mob-based walk-over weighing: a low-cost alternative to condition scoring for managing ewe liveweight for higher profitability

This experimental chapter has been submitted to *Animal Production Science*:

Brown DJ & Young JM (2013) Mob-based walk-over weighing: a low-cost alternative to condition scoring and static weighing for managing ewe liveweight for higher profitability. *Animal Production Science* (submitted).

8 General discussion

The object of this thesis was to develop an understanding of the factors affecting the potential of walk-over weighing (WOW) for commercial application. While each experimental chapter discusses its results within the scope of its hypothesis, this general discussion integrates the key findings of the thesis in the context of the Australian sheep industry.

Mob-based walk-over weighing (MBWOW) data can generate flock average liveweight estimates that are comparable with static weighing when appropriate data processing techniques, identified and developed by the current study, are employed. Regular feedback on flock average liveweight provides the livestock manager opportunity to make timely and informed nutritional management decisions. It also allows an estimation of how many sheep are in different liveweight categories, as sheep liveweights are normally distributed (Brown *et al.*, 2013a). This will be beneficial for predicting if there are enough sheep in a flock above a minimum sale liveweight to warrant booking into an abattoir, or if there are enough sheep below a certain liveweight threshold to warrant drafting off the lighter animals ('tail') for supplementary feeding. This flock-based approach has immediate industry application as most commercial flocks do not use RFID ear tags and the flock, as opposed to the individual sheep within it, is still the most common management unit.

The current study has exposed the counterproductive nature of improving WOW liveweight estimate reliability through data filtering and grouping. Data filtering increases WOW data repeatability by removing illogical data from the dataset, while grouping draws data together over consecutive days to increase the number of records available for analysis. However, this results in less liveweight estimates, and consequently there are fewer opportunities for timely nutritional management decisions. This trade-off between accuracy and timeliness does not preclude WOW data filtering as viable method to increase the repeatability of WOW liveweight estimates, but it does give merit to finding better alternatives.

A conceivable barrier for the successful uptake of WOW is its underdeveloped process of data management post-collection. Livestock managers are required to collect the data from the paddock then manually process it for meaningful interpretation. This requires the allocation of time and, when considered against competing priorities, may not be perceived as warranted. It is suggested that this may limit adoption of the WOW concept in the sheep industry.

A possible solution to this problem is the development of the WOW technology to discriminate between logical and illogical data in real time. This would mean that all incoming signals from the load cell are interrogated, and only those that are logically compatible with the flock under observation are recorded as data. This technology is currently available from some commercial weigh equipment providers, such as Rotem™, yet it is not compatable with WOW. Furthermore, the technology may be further developed to compile logical data until there is enough for a reliable liveweight estimate of the flock, before it starts compiling data for the next estimate. This will reduce the time taken for livestock managers to interpret the data and make faster, more confident nutritional management decisions.

At its current stage of development, WOW offers little opportunity for individual animal management. This is because a large (> 11) number of records are required for reliable individual liveweight estimates, and it is unlikely that an entire flock will achieve this number of records at any one time. This number of records is required due to the variation of individual WOW liveweights, and an explanation of how this affects flock and individual liveweight estimates is presented in Appendix 10.2. The requirement of repeated records on individual animals is a common theme in past research into WOW with sheep (Richards *et al.*, 2006) and dairy cattle (Filby *et al.*, 1979). The practical implication for livestock managers is that an entire flock needs be handled for the management of only a few individual sheep. Consequently, it is unlikely that liveweight data on individual sheep would translate into cost effective management decisions. Currently, there are no known methods available to generate the number of records required for useful individual liveweights. Thus a lack of relevant individual animal data provided by WOW systems at any given time represents a major constraint to the commercial adoption of WOW for individual animal management.

It is pertinent that while the current study has identified the limitations of WOW to aid individual management, it does not negate its future applications given sufficient development of the technology. For instance, there is a substantial amount of literature demonstrating the relative production and economic merits of targeted sheep nutrition (Rowe, 2004; Rowe & Masters, 2005; Jordan *et al.*, 2006; Rowe *et al.*, 2007; Hatcher *et al.*, 2008), suggesting that continued investment by the research sector into this aspect of WOW is warranted.

It is evident that for WOW to play a future role in, and capture the benefits of, individual animal management, the improvement of either WOW data repeatability or frequency is necessary. There is merit in the proposal to increase WOW repeatability through adapting technology from the broiler industry to WOW systems. This is because collecting static liveweights from sheep should reduce the level of error involved in obtaining liveweights from sheep in motion, and increase WOW repeatability. With regard to increasing the frequency of WOW data, the current study has shown that the prolonged exposure of sheep to WOW equipment as lambs will effectively increase their propensity to traverse the WOW platform as weaners. However, this effect is relatively short lived, with the data collection frequency of the naïve weaners increasing and equalling that of their exposed counterparts within a week. This suggests that, unless lambs are exposed to WOW as a matter of course during ewe liveweight observation, the marginal increase in data collection may not warrant purposeful exposure of weaners to WOW as lambs.

Before the current study there was little understanding of the economic impact of sub-optimal ewe liveweight profiles in the Australian sheep industry, or of the factors affecting WOW's potential as a liveweight management aid. The outcomes of the current study, combined with past economic modelling, has enabled an economic analysis of WOW that has highlighted some of the potential benefits of ewe liveweight management in commercial flocks, and the likely costs of monitoring ewe liveweight for improved management.

The outcomes of the economic analysis suggest that average, commercial liveweight profiles are economically sub-optimal. A possible cause for this is that the optimal liveweight profiles used in the current study (Young *et al.*, 2011) were generated by a resource allocation optimization model that, in particular, matches the stocking rate to pasture availability (Young, 1995). Sub-optimal liveweight profiles do not reflect the most desirable combination of stocking rate and level of supplementary feeding possible for whole farm profit maximisation. The success of matching stocking rate to pasture availability in a commercial context with the same efficacy afforded to an optimization model is unlikely due to limited labour and capital resources combined with fluctuating seasons, hence commercial ewe liveweight profiles will be economically sub-optimal by comparison. Alternatively, it is feasible that commercial, average ewe liveweight profiles are economically sub-optimal because there are insufficient means available to monitor ewe liveweight. In view of this, the economic analysis established the likely cost of monitoring ewe liveweight with MBWOW, compared to condition scoring and static weighing.

What sheep businesses should invest in mob-based walk-over weighing?

The demonstrated magnitude of disparity between commercial and optimal liveweight profiles is large. Even if a small portion of the benefit in reducing this disparity is attributed to liveweight monitoring, investment into relevant technology is warranted by commercial sheep businesses.

An examination of the cost analysis assumptions helps determine whether businesses should invest in either MBWOW as opposed to condition scoring or static weighing in order to capture some of the benefit of managing ewe liveweight profiles. A prerequisite for the successful investment in MBWOW is a long investment horizon (~10-20 years). Furthermore, sheep systems must either employ at least monthly nutritional assessments or have larger flocks (three flocks of > 1000 ewes) to benefit from cheaper nutritional monitoring through MBWOW rather than static weighing or condition scoring. Those sheep businesses that do not fit one or more of the latter two criteria will not justify investment into MBWOW, and are better served monitoring their flocks with existing methods such as condition scoring.

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10 Appendices

10.1 Walk-over weighing: Required hardware and approximate costs

Both MBWOW and RFID-linked WOW have a base set of hardware required for collecting and storing either mob-based or RFID-linked records (Table 10.1). All valuations provided are approximate and inclusive of GST.

Table 10.1 The basic hardware required for mob-based walk-over weighing and RFID-linked WOW, including its approximate value.

Hardware item	Approximate value ($)	
	MBWOW	RFID-linked WOW
Trutest™ walk-over weighing enable indicator	$3,308 [A]	$3,308 [A]
Trutest™ load cells	$2,141 [A]	$2,141 [A]
Pratley's™ portable weighing platform	$1000 [A]	$1000 [A]
Deep-cycle 12V battery	$180 [A]	$360
20W solar panel	$330 [A]	Na
80W solar panel	Na	$550 [B]
Allflex RFID reader panel & control box	Na	$2,586 [B]
Allflex RFID ear tags	Na	$2625 [BC]
Total value	**$6,959**	**$12,570**

[A] Values relevant July 2010

[B] Values relevant May 2012

[C] Allflex RFID ear tags = $1.75 each; assumed capacity of one WOW unit to serve ~1500 sheep

The brand of weighing indicator chosen in the current study is Trutest™. It is possible that there are other similar brands available that are compatible with WOW, although they are not reported in the literature.

Both MBWOW and RFID-linked WOW may require addition hardware (Table 10.2), depending on the method of data collection and the number of sheep in the flock/s. Sheep need a barrier between them and some form of incentive so that can be forced to traverse

WOW platform. If there is no existing barrier, then this will need to be built from mesh or portable panels. Steel posts are required to 'sure-up' both makeshift and permanent structures. Otherwise, depending on the infrastructure of the farm, fenced off water points, or enclosures, could be utilized. Feed troughs or bins will be required to hold attractant. These may vary from simple drums fashioned to hold attractant, to elaborate self-feeding systems. Attractant will also vary considerably from a salt and molasses combination to a basic substitute feeds such as oats or lupins.

Table 10.2 Additional hardware required for either MBWOW or RFID-link WOW, depending on number of sheep and method of collection

Additional hardware - WOW	Approximate value ($)[B]
Portable panels ($/panel)	$185
Mesh ($/sheet)	$80
Steel posts ($/post)	$5
Feed troughs ($/dish)	$40
Attractant ($/ewe)[A]	$0.30

[A] Attractant; salt and molasses combination
[B] Approximate values of additional WOW hardware required source from local product providers in Wagga Wagga, 2650, NSW, in 2011.

10.2 Why mob-based walk-over weighing liveweight estimates have smaller margins of error than individual animal liveweight estimates

Despite a fine filtered MBWOW sample having a higher standard deviation that a fine filtered individual's RFID-linked WOW sample due to that additional variation of each animals' liveweight around the flock mean, it is expected to have a lower standard error due to the vast increase in available WOW liveweight data. A hypothetical example demonstrating the difference in standard errors between flock average and individual liveweight estimates due to differences in expected sample size shows that, with sample sizes assumed at n = 100 and n = 5 for a MBWOW liveweight sample and an individual liveweight sample respectively, MBWOW samples are expected to have lower standard errors (Table 10.3).

Table 10.3 A hypothetical example demonstrating the difference in standard errors between flock average and individual liveweight estimates due to differences in expected sample size.

	Flock average liveweight estimate	Individual animal liveweight estimate
Sample size	100	5
Population SD	7	0
SD of WOW (fine filtered)	3.3	3.3
Expected SD of WOW sample	$\sqrt{(7^2 + 3.3^2)} = 7.74$	3.3
Standard error of WOW sample	$7.74/\sqrt{100} = 0.77$	$3.3/\sqrt{5} = 1.48$