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Wishart, H; Morgan-Davies, C; Stott, AW; Wilson, R; Waterhouse, A

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1 **Liveweight loss associated with handling and weighing of grazing sheep**

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3 Harriet Wishart^{a,*}, Claire Morgan-Davies^a, Alistair Stott^b, Ron Wilson^c, Tony
4 Waterhouse^a

5 ^a*Scotland's Rural College (SRUC), Hill & Mountain Research Centre, Kirkton Farm,*
6 *Crianlarich, FK20 8RU, Scotland, UK.*

7 ^b*Scotland's Rural College (SRUC), Future Farming Systems, Kings Buildings, West*
8 *Mains Road, Edinburgh, EH9 3JG, Scotland, UK.*

9 ^c*University of Edinburgh, School of Geosciences, Kings Buildings, West Mains Road,*
10 *Edinburgh, EH9 3FE, Scotland, UK.*

11 *Corresponding author.

12 E-mail Addresses: Harriet.Wishart@sruc.ac.uk (H. Wishart), Claire.Morgan-
13 Davies@sruc.ac.uk (C. Morgan-Davies), Alistair.Stott@sruc.ac.uk (A. Stott),
14 Ron.Wilson@ed.ac.uk (R. Wilson), Tony.Waterhouse@sruc.ac.uk (T. Waterhouse).

15 **Abstract**

16 Sheep liveweight and liveweight change are important data both for research
17 and commercial farm management worldwide. However, they can contain errors
18 when procedures in collection are not standardised, including when weighing occurs
19 around other husbandry tasks resulting in varying time delays between removal from
20 grazing and weighing. This research had three stages with different objectives: 1) a
21 liveweight loss study, to quantify liveweight and liveweight change over three and six
22 hours of delay prior to weighing within a handling facility, and to develop a correction
23 equation for delayed liveweights; 2) a validating process, to examine the correction
24 ability of the equation by using it on a different set of delayed liveweights collected
25 under a range of situations; and 3) a management simulation, to explore what impact
26 delayed and corrected delayed liveweights could have when liveweight change was
27 used to assign ewes to feeding levels. Results from each stage showed that: 1)
28 ewes lost a significant amount of liveweight after three (1.8 ± 0.5 kg or 3.5 ± 0.8 %
29 liveweight) and six (2.9 ± 0.6 kg or 5.6 ± 1.0 % liveweight) hours delay during a
30 practical handling operation ($p < 0.001$). The following equation was developed to
31 correct delayed liveweights: $y = 100 (x / (100 + (-0.9301 t + 0.07106)))$ where y , x
32 and t are corrected liveweight (kg), delayed liveweight (kg) and time delayed in
33 decimal hours, respectively; 2) the correction equation provided a more accurate and
34 precise estimate of liveweight than a delayed liveweight alone; and 3) use of delayed
35 liveweights, to determine liveweight change over a two month period, resulted in
36 significantly more animals being assigned wrongly to higher feeding levels ($p < 0.001$),
37 than if the delayed liveweights had been corrected by time elapsed since gathering
38 from grazing fields. To conclude, a short-term delay prior to weighing associated with
39 a practical handling operation significantly reduces the numerical liveweight recorded

40 for each sheep. Using variably delayed liveweights in research and on commercial
41 farms will have significant consequences for research results and management
42 practices globally. Therefore collection of liveweights should occur without delay.
43 However, when this is not feasible delayed liveweights should be corrected and in
44 the absence of locally formulated correction equation, the one presented in this
45 paper could be used.

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47 Keywords: liveweight; weighing; accuracy; precision; data collection; sheep.

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1. Introduction

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Liveweights are indicative of an animal's current and changing physical state and measuring changes in liveweight is useful in assessing how an animal is responding to its current situation (Baker et al., 1947). As liveweight is affected by: growth, nutrition, health, stress, pregnancy and genetics (Brown et al., 2015; Coates and Penning, 2000), research exploring these areas in sheep can use liveweight as an important variable. Liveweights are one of the most frequently utilised measurements in livestock research worldwide due to: ease of collection and understanding; comparability within and between animals; changes in response to a range of stimuli; flexibility of quantitative data produced for statistical analyses; and the potential application of methods for monitoring and managing liveweights on commercial farms (Brown et al., 2015; Coates and Penning, 2000).

Liveweight recording and associated management decisions have been identified as key elements for improving productivity and efficiency on commercial sheep farms in Australia and the UK (Brown et al., 2015; Wishart et al., 2015; Young et al., 2011). New applications are being made possible through advances in commercially available weighing equipment. Radio Frequency Identification (RFID) chips within each animals ear tag and readers within the weigh crate allow liveweights to be easily collected and utilised on an individual animal basis (Morgan-Davies et al., 2015). Research and application in the field of Precision Livestock Farming (PLF), which uses technology to manage animals in a more precise individual manner (Banhazi et al., 2012), is expanding. Such weighing equipment has the potential to allow new management systems to be developed using sheep liveweight to aid decision making (Brown et al., 2014; Wishart et al., 2015).

Most research and commercial use of liveweight data involves making

74 comparisons between liveweights at different time points within and between animals
75 and groups. To be able to produce reliable, comparable liveweights the variation and
76 error associated with these data needs to be understood and controlled.

77 Liveweight is a measure of body mass which is composed largely of muscle,
78 fat, bone and organs. All of these have a relatively stable weight over a short period
79 of time, such as a day, but alter over longer periods in response to environmental
80 and biological conditions (Coates and Penning, 2000). Changes in weight of these
81 components are of most interest within research and industry. However, body water
82 and the fluids and digesta of the gastrointestinal tract (known as gut-fill) also make
83 up total body mass. Levels of these change over the day and result in fluctuations in
84 liveweights being observed. While this is an issue with weighing all animals, gut-fill
85 needs greater consideration with ruminants as the contents of the rumen can
86 account for 10-23% of total liveweight (Hughes, 1976).

87 The short-term liveweight fluctuations in ruminants are affected by: feed and
88 water consumption (Whiteman et al., 1954); time since last meal (Hughes, 1976);
89 quality and quantity of feed available (Hughes and Harker, 1950); age and size of the
90 animal (Lush et al., 1928); time of day relative to sunrise (Gregorini, 2012); ambient
91 temperature (Lush et al., 1928); and individual differences in grazing behaviour
92 (Hughes and Harker, 1950).

93 Robust methodology is required to reduce variation in liveweights between
94 animals and weigh points to ensure liveweight data collected are comparable. This
95 requirement becomes more essential as on-going improvements in weighing
96 equipment, software and data management is resulting in liveweight data having
97 greater use in research and management on farm. Methodologies to reduce variation
98 include: fasting prior to weighing (Coates and Penning, 2000); standardising

99 weighing procedure (Watson et al., 2013); taking an average of multiple liveweights
100 across a number of successive days (Koch et al., 1958); weighing at a specific time
101 relative to sunrise (Hughes and Harker, 1950); standardising feed before weighing
102 (Meyer et al., 1960); increasing the number of animals (Hughes, 1976); and
103 repetitions of the study (Lush et al., 1928). However, there is evidence that such
104 methodologies to reduce variation are not being considered or used in research. To
105 illustrate this we examined 35 recent peer-reviewed papers (from Small Ruminant
106 Research 2014, all issues of volume 120) and revealed that of the 11 papers
107 involving liveweights, only 2 clearly stated the method used to control liveweight
108 variation.

109 Reasons why variation reduction methodology is not being followed may be
110 that: broader methodology has not caught up with the improved weighing technology
111 now available; people collecting liveweights are simply not aware of the problem; or
112 such methodologies are not practical when liveweight collection (research or
113 commercial) is carried out in farm situations.

114 Consideration of the on-farm situation raises concern that not only is variation
115 in liveweight not being controlled but procedures in weighing could also be adding
116 systematic error to the data. On a research or commercial farm, weighing of sheep is
117 likely to occur alongside other husbandry or research procedures. On a large farm,
118 many animals may be gathered from fields of varying distances to be handled and
119 weighed on the same day. Inevitably, this results in delays, where groups of sheep
120 are removed from pasture and then wait varying lengths of time, without access to
121 food and water prior to weighing.

122 Delays in weighing leads to gut-fill weight loss, with previous literature
123 reporting losses of 0.5 to 2 kg after six hours and 1 to 4 kg after 12 hours (Hughes,

124 1976). Indeed fasting (removal of feed and water) is well documented as a suitable
125 method to reduce variation in liveweight, where feed and water are removed for fixed
126 long periods of time prior to weighing (e.g. Coates and Penning, 2000; Shrestha et
127 al., 1991; Wilson et al., 2015). Our review of the literature found that only research
128 carried out by Wilson et al. (2015) considered the impact of removal of feed and
129 water for less than six hours; however, this was with the focus of fasting to reduce
130 variation in gut-fill between animals or weigh points. Adjustment of liveweights has
131 previously been used as a method to reduce errors: by Scott (2011), via a moving
132 average of mean liveweights; and by Kane et al. (1987), using assumptions of feed
133 intake and quality. However, both these methods are unsuitable or challenging for
134 single weighings in a grazing sheep system. We found no published studies that
135 attempt to develop a correction equation for liveweights with a known short-term
136 period of delay prior to weighing as a result of a gathering and handling procedure of
137 six or less hours.

138 The aims of this paper are 1) to determine the extent of liveweight loss in
139 sheep, in a practical environment, as a result of delayed weighing over three and six
140 hours; 2) to explore whether this information can be used to produce a methodology
141 to reliably correct delayed liveweights across different situations; and 3) to
142 demonstrate the potential consequence of not correcting delayed liveweights.

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2. Materials and Methods

Data for this research were collected from Scotland’s Rural College (SRUC), Hill and Mountain Research Centre, Kirkton and Auchtertyre Farms in the West Highlands of Scotland. All work involving animals was carried out in accordance with EU Directive 2010/63/EU and was approved by SRUC’s Animal Welfare and Ethical Review Body.

This research was carried out in three stages:

- 1) A liveweight loss study: to quantify liveweight and liveweight loss over three and six hours delayed weighing within a handling facility and without access to feed or water. Then to use these findings to develop a correction equation for delayed liveweights.
- 2) A validating process: to examine the precision and accuracy of the correction equation by using it on different sets of delayed liveweight data collected under a range of situations.
- 3) A management simulation: to explore what impact delayed and corrected delayed liveweights could have when liveweight change is used to assign ewes to feeding levels.

2.1. Animals

All three stages of this research used the same base flock from which sheep and liveweight data were selected. The role of this flock was the long-term recording of 600 Scottish Blackface and 300 Lleyn ewes and their lambs (further details of the flock and research can be found in Morgan-Davies et al., 2015 and Umstätter et al., 2013).

169 **2.2. Weighing Facility**

170 The following weighing setup was used to collect all liveweights discussed in
171 this paper. A Prattley Auto Drafter (Prattley Industries, Temuka, New Zealand), with
172 Tru-Test™ MP600 load bars and XR3000 weigh head (Tru-Test Group, Auckland,
173 New Zealand) recorded all sheep liveweight data automatically. They were then
174 downloaded onto a computer for analysis.

175 The weigh head and weigh bars collected liveweights at a resolution of 0.1 kg
176 for weights between 0-50 kg; weights between 50-100 kg were recorded to 0.2 kg.
177 The weigh head was set to use the inbuilt system: Superdamp III (Sheep) (Tru-Test
178 Group, Auckland, New Zealand). This used a damping algorithm to allow accurate
179 liveweights to be collected from sheep in the weigh crate standing still or moving,
180 with the liveweight automatically recorded when within tolerance (TruTest XR3000,
181 Tru-Test Group, Auckland, New Zealand).

182 The liveweights were recorded in the weigh head against each ewe's unique
183 identification number stored on their low frequency RFID, or Electronic Identification
184 (EID), ear tag. This was read in the weigh crate via an Allflex® RFID portal reader
185 (Allflex Australia, Queensland, Australia). The EID tags used were either Ritchey™
186 RD2000 tags (Ritchey Ltd., County Durham, United Kingdom), Shearwell Data SET
187 Tags (Shearwell Data Ltd., Somerset, United Kingdom) or Allflex® Button tags
188 (Allflex UK Group Ltd, County Durham, United Kingdom). No difference in
189 performance was seen between different EID tags.

190

191 **2.3. Stage 1: Liveweight loss study**

192 **2.3.1. Animals**

193 For the liveweight loss study, 100 Scottish Blackface non-pregnant and non-

194 lactating ewes (25 from each of four age groups; 1.5, 2.5, 3.5 and 4.5 years of age)
 195 were randomly selected and separated from the larger flock grazing unimproved hill
 196 pasture. The 100 selected ewes were placed in a field of improved pasture overnight
 197 prior to the study on the following morning (6th November 2013).

198

199 **2.3.2. Times and weighing**

200 Three weigh sessions were started at 9 am, 12 pm and 3 pm; each weigh
 201 session involved weighing the 100 ewes three times (Table 1). Each time, or round,
 202 involved weighing all ewes once before moving on to the next round immediately
 203 after the last ewe exited the weigh crate.

204

205 **Table 1** Actual times for weighing sheep at three weigh sessions, with varying
 206 lengths of delay prior to weighing. Each weigh session comprised of weighing 100
 207 ewes three times.

Weigh session	Approx. weigh time	Approx. hours delayed	Actual start time	Actual finish time of 3 rounds
1	9 am	0	08:59	09:43
2	12 pm	3	12:08	12:47
3	3 pm	6	15:04	15:45

208

209 A period of 30 minutes elapsed between sheep grazing being halted (by the
 210 stockperson and dog entering the field) and liveweight being collected from the first
 211 ewe entering the weigh crate for the first weigh session. Between weigh sessions,
 212 ewes were housed indoors with no access to feed or water. The first liveweights
 213 collected (9 am, round 1 liveweights), are referred to as the “without delay”
 214 liveweights. The term “without delay” liveweight will be used throughout this paper to
 215 describe any liveweight collected as soon as animals entered the handling facility;
 216 these may still contain some delay as a result of gathering from pasture. All other

217 liveweights will be referred to as “delayed” liveweights.

218 During the day, between weigh sessions, Body Condition Scores (BCSs;
219 scored on a 5 point scale with quarter intervals, according to Russel et al., 1969)
220 were collected. Three different experienced condition scorers assessed each ewe
221 three times; resulting in nine scores per ewe. An average (mode) score per ewe was
222 used in analysis.

223

224 **2.3.3. Liveweight and liveweight change**

225 The mean liveweight per ewe (from the three liveweights recorded per
226 session) was used to provide the best estimate of liveweight at each weigh session.
227 These were used to consider short-term liveweight change over three (9 am to 12
228 pm) and six (9 am to 3 pm) hours delay prior to weighing. These periods of delay are
229 comparable to the length of handling operations on a farm. Gathering extensive hill
230 grazing can take three hours (Stott et al., 2005), while six hours is a maximum length
231 of time gathering and handling is likely to occur in one day. The mean liveweights at
232 each weigh session were compared using a one-way ANOVA blocked for animal.

233 Mean “without delay” liveweight (calculated from all three liveweights collected
234 during the 9 am weigh session), BCS and age were all considered against the actual
235 and the proportion of liveweight change over three and six hours delay. Correlation
236 was used to explore mean “without delay” liveweight and one-way ANOVAs for BCS
237 and age. Liveweight change over the first three hours (9 am to 12 pm) and the
238 second three hours (12 pm to 3 pm) were compared via a paired t-test to determine
239 whether rate of change was the same throughout the six hours delay period.

240

241 **2.3.4. Delayed liveweight correction equation**

242 All nine liveweights over the three weigh sessions were then used in the
243 development of an equation to correct delayed liveweights. For this, liveweight loss
244 over the whole six hour period was treated as linear. Using all nine liveweights per
245 individual allowed for a greater number of data points in the analysis. The proportion
246 of liveweight loss was analysed via a Linear Mixed Model in GenStat 16th Edition
247 (Payne et al., 2013) to produce a regression equation (the correction equation). The
248 fixed model included decimal hours delayed and the random model included the
249 interaction between the individual sheep and decimal hours delayed. The proportion
250 of liveweight loss was calculated from the “without delay” liveweight for all
251 subsequent delayed liveweights (resulting in 800 data points). Decimal hours
252 delayed since the “without delay” liveweight were calculated for each delayed
253 liveweight as a result of time information automatically recorded by the weigh head.

254

255 **2.4. Stage 2: Validating process**

256 **2.4.1. Dataset**

257 The resulting correction equation from Stage 1 was tested on a different
258 dataset. This validation dataset contained 1581 pairs of liveweights, from 20 groups
259 of sheep. These were collected as part of a larger project being carried out on the
260 research farm, between and including January 2014 and June 2015. Each pair of
261 liveweights was collected from the same sheep over the same day and with a known
262 delay between the two liveweights. These data included sheep from outside the
263 narrow range of conditions of the original liveweight loss study, and encompassed
264 five different categories: breed, sex, stage of production, grazing location and hours
265 delayed prior to weighing (Table 2).

266 The first of each pair of liveweights was an actual “without delay” liveweight
267 (aWt1), collected as soon as the group of sheep entered the handling facility. The
268 second was an actual “delayed” liveweight (aWt2), collected later the same day after
269 varying lengths of delay within the handling facility, without access to feed and water.
270 While this is secondary data, all liveweights (aWt1 and aWt2) were collected
271 automatically with an individual time and date stamp; therefore the delay between
272 liveweights could be accurately calculated.

273 Whilst the sheep were first weighed immediately after entry into the handling
274 area, the groups used in the validation dataset came from grazing locations across
275 the large research farm. Three pasture types were identified and classified as: 1)
276 improved field, with good quality pasture, fertilised annually with the potential for
277 silage making, at an altitude of 180 m; 2) semi-improved park, with partially improved
278 semi-natural permanent grassland and wet heath, with an altitude of 180 to 230 m;
279 and 3) unimproved hill, which is a mosaic of semi-natural permanent grassland and
280 wet heath ranging in altitude from 230 to 680 m.

281 The grazing locations had widely different gathering times compared to the
282 liveweight loss study dataset. Therefore, two stockpersons and one technical staff,
283 all of whom had experience of time taken to gather sheep from each field/location,
284 were asked to estimate the normal gathering time. This was calculated from the
285 moment grazing was halted (by the stockperson and dog entering the field) to the
286 first of the group entering the weigh crate. These estimates were used to determine
287 the pre-gather time for each pair of liveweights. On average time elapsed was $1.21 \pm$
288 0.59 hours between pre-gather and aWt1. This length of delay prior to aWt1 was
289 also used in analysis (Table 2).

290

291 **Table 2** Description of validation dataset containing pairs of actual liveweights (aWt1, liveweight collected without delay and aWt2,
 292 delayed liveweight) collected from the same individual sheep on the same day with varying length of delay in weighing between the two,
 293 for different categories (SD in brackets).

Categories	<i>n</i>	Mean aWt1 (kg)	Mean aWt2 (kg)	Mean Difference aWt2-aWt1 (kg)	Time range between aWt1-aWt2 (hours)
All	1581	40.94 (10.56)	40.06 (10.35)	-0.88 (0.72)	0.3 - 4.9
Stage of production					
Non-pregnant & non-lactating ewe	455	51.06 (5.91)	50.07 (5.93)	-0.99 (0.59)	2.3 - 4.9
Pregnant ewe	164	50.79 (6.25)	49.25 (6.20)	-1.55 (0.78)	2.2 - 3.65
Lactating ewe ^a	88	47.72 (5.67)	47.04 (5.73)	-0.68 (0.43)	0.85 - 2.62
Suckling lamb ^b	69	26.56 (3.89)	26.09 (3.69)	-0.48 (0.52)	1.28 - 4.72
Weaned lamb ^c	805	33.70 (5.81)	32.97 (5.62)	-0.73 (0.73)	0.3 - 4.72
Sex					
Female	1014	44.12 (11.38)	43.31 (11.04)	-0.81 (0.76)	0.3 - 4.9
Male (lambs only)	567	35.24 (5.36)	34.25 (5.28)	-0.99 (0.65)	0.38 - 4.72
Grazing location					
Improved field ^d	823	39.34 (8.35)	38.33 (8.29)	-1.01 (0.66)	0.38 - 4.72
Semi-improved park ^e	390	33.59 (9.23)	33.29 (9.09)	-0.3 (0.55)	0.3 - 4.57
Unimproved hill ^f	368	52.30 (6.40)	51.12 (6.43)	-1.18 (0.71)	2.2 - 4.9
Breed					
Scottish Blackface	623	39.21 (9.27)	38.32 (9.22)	-0.88 (0.67)	0.37 - 4.72
Lleyn	857	43.57 (10.70)	42.67 (10.40)	-0.9 (0.77)	0.3 - 4.9
Crossbred ^g (lambs only)	101	29.27 (5.57)	28.62 (5.24)	-0.65 (0.57)	1.28 - 4.72
Hours delayed prior to aWt1 ^h					
0 to 1	658	41.31 (8.25)	40.28 (8.22)	-1.03 (0.62)	0.6 - 4.72
1 to 2	690	37.11 (10.65)	36.47 (10.4)	-0.64 (0.74)	0.3 - 4.9
2 to 3	233	51.22 (8.95)	50.08 (8.80)	-1.14 (0.75)	1.92 - 4.67

294 NB: ^aewes which had been with their lamb immediately before aWt1 but without contact with lamb between aWt1 and aWt2; ^blambs remained with

295 their ewe between aWt1 and aWt2 and aged three to five months old; ^clambs aged four to six months old; ^dgood quality pasture, fertilised annually

296 with the potential for silage making; ^epartially improved semi-natural permanent grassland and wet heath; ^fa mosaic of semi-natural permanent
297 grassland and wet heath; ^gcrossbred lambs with dam of Scottish Blackface or Lleyn and opposite breed sire; and ^hestimated hours elapsed prior to
298 aWt1 (from halting grazing to entering the weigh crate).

299 **2.4.2. Comparing corrected and uncorrected liveweights**

300 The correction equation was used on aWt2 to generate a corrected version of aWt1
301 (cWt1) using the known length of delay between aWt1 and aWt2. In practice, to account
302 for the varying lengths of delay prior to aWt1, the correction equation could be used to
303 correct aWt2 to a pre-gather liveweight. However this pre-gather liveweight is not known
304 so correction to the “without delay” liveweight (aWt1) allows the correction ability of the
305 equation to be tested. This is possible as the equation treats liveweight loss as linear over
306 this short-term period.

307 To explore whether cWt1 or aWt2 was a more accurate and precise estimate of
308 aWt1, paired two-way t-tests were used to compare each with aWt1. The distribution of
309 differences between these pairings of liveweights was also examined.

310

311 **2.4.3. Category differences in correcting**

312 To explore whether the correction equation had the same precision across a range
313 of categories, a Linear Mixed Model in GenStat 16th Edition (Payne et al., 2013) was used
314 on the difference between cWt1 and aWt1. The five different categories (listed in Table 2)
315 were explored. Stage of production and grazing location were the only categories identified
316 as being statistically significant and were included in the final fixed and random models.
317 Predicted means were then generated to compare the different levels within each of these
318 two categories.

319

320 **2.5. Stage 3: Management simulation**

321 **2.5.1. Dataset**

322 A dataset was compiled to simulate the impact of assigning ewes to feeding levels
323 based on liveweight change, comparing when actual delayed liveweights or corrected
324 liveweights were used. This management example involves assigning feeding levels to

325 pregnant ewes based on liveweight change over a period of two months. It was chosen as
326 it is advised that pregnant ewes should be provided with supplementary feeding (e.g.
327 Fthenakis et al., 2012). Assigning individual ewes' feeding levels based on liveweight
328 change over the first two months of pregnancy, is one method that has been shown to be
329 effective at allocating ewes to different supplementary feeding levels (Wishart et al., 2015).

330 Actual "without delay" liveweights from 395 ewes (Lleyn ewes, $n = 239$, were 1.5 to
331 7.5 years of age and Scottish Blackface ewes, $n = 156$, were 1.5 years of age) were
332 collected from the research flock at pre-mating as soon as animals entered the handling
333 facility (PreWt, November 2014). "Delayed" liveweights were also collected from the same
334 animals two months later at post-mating after varying periods of time within the handling
335 facility without access to feed and water (PostWt, January 2015). The correction equation
336 was used on both sets of liveweights (PreWt and PostWt) to produce corrected pre-gather
337 sets of liveweights (cPreWt and cPostWt, respectively). Time of pre-gather was calculated
338 from the automatically recorded time stamp and the estimated time to gather each field
339 (same method as previously explained in Stage 2). Overall the average delay prior to
340 weighing for PreWt was 2.6 ± 1.3 hours and for PostWt was 4.9 ± 1.3 hours.

341

342 **2.5.2. Assigning ewes to feeding levels**

343 Ewes were assigned to feeding levels based on liveweight change between
344 November and January (the period covering mating): low level feeding (LOW) for ewes
345 that had put on liveweight; medium level feeding (MED) for ewes that had lost up to 5%
346 liveweight; and high level feeding (HIGH) for ewes that had lost over 5% liveweight
347 (method adapted from Umstätter et al., 2013).

348 Two simulations were run with the data, to assign ewes to feeding levels, one using
349 the actual collected "without delay" (PreWt) and "delayed" (PostWt) liveweights to
350 determine liveweight change and the second using corrected versions of these liveweights

351 (cPreWt and cPostWt). Counts of ewes assigned to each feeding level, based on these
352 two alternative simulations, were compared via a chi-squared test.

353

3. Results

3.1. Stage 1: Liveweight loss study

3.1.1. Times and weighing

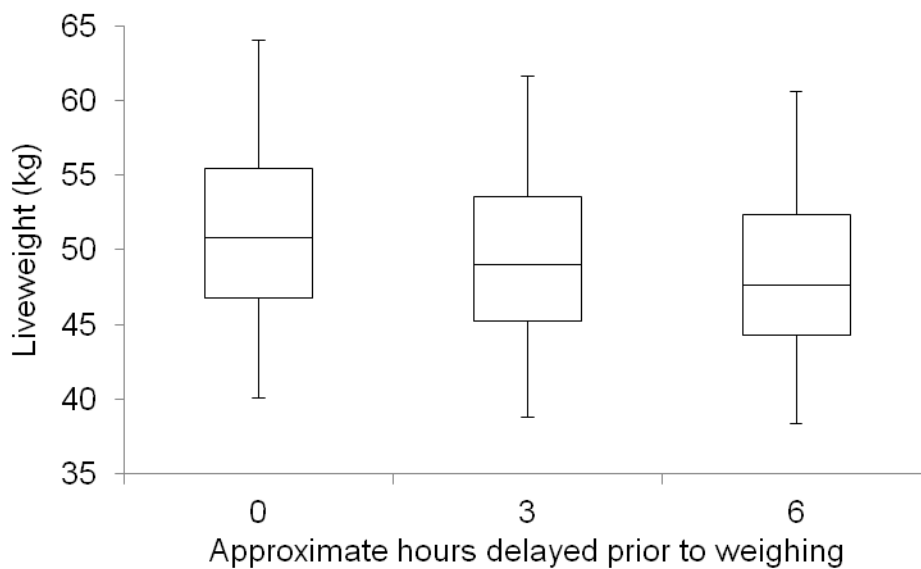
356 Each weigh session (where all 100 ewes were weighed three times) lasted $41.3 \pm$
357 2.5 minutes. The weighing rate, over all nine rounds was 7.5 ± 0.5 seconds per ewe.

358

3.1.2. Liveweight and liveweight change

360 The analysis showed that ewes lost liveweight ($p < 0.001$) over both three and six
361 hours delayed prior to weighing (Fig. 1). They lost 1.8 ± 0.5 kg or 3.5 ± 0.8 % liveweight
362 and 2.9 ± 0.6 kg or 5.6 ± 1.0 % liveweight at three and six hour delays, respectively.

363



364

365 **Fig. 1** Liveweights at the three weigh sessions where 100 ewes were weighed three times
366 per session with a time delay between sessions. Box and whisker plot shows median,
367 upper quartile, lower quartile (box) and range of liveweights (whiskers).

368

369 The mean “without delay” liveweight was found to be correlated ($p < 0.001$) with
370 actual liveweight change over three and six hour delays ($r = -0.48$ and -0.63 , respectively),
371 with heavier ewes losing more liveweight. However, there was a non-significant poor

372 correlation between the mean “without delay” liveweight and proportion of liveweight
373 change over both delay intervals ($r = -0.05$ and -0.18 for three and six hour delays,
374 respectively). BCS did not impact on actual or proportion of liveweight change. However,
375 age impacted at both three and six hour delay intervals for actual ($p < 0.001$) and proportion
376 ($p < 0.05$) of liveweight change. The youngest ewes (aged 1.5 years old) lost less than all
377 other age groups; they were also lighter than all other ages.

378 Over the first three hours (9 am to 12 pm) ewes lost more liveweight compared to
379 the second three hours (12 pm to 3 pm) delayed ($p < 0.001$, 1.8 kg compared to 1.1 kg
380 liveweight lost, respectively).

381

382 **3.1.3. Delayed liveweight correction equation**

383 The equation developed during Stage 1, to correct delayed liveweights when length
384 of delay is known ($p < 0.001$), was:

$$y = 100 \left(\frac{x}{(100 + (-0.9301 t + 0.07106))} \right)$$

385 Where:

386 y = corrected liveweight (kg)

387 x = actual delayed liveweight (kg)

388 t = time difference in decimal hours delayed

389

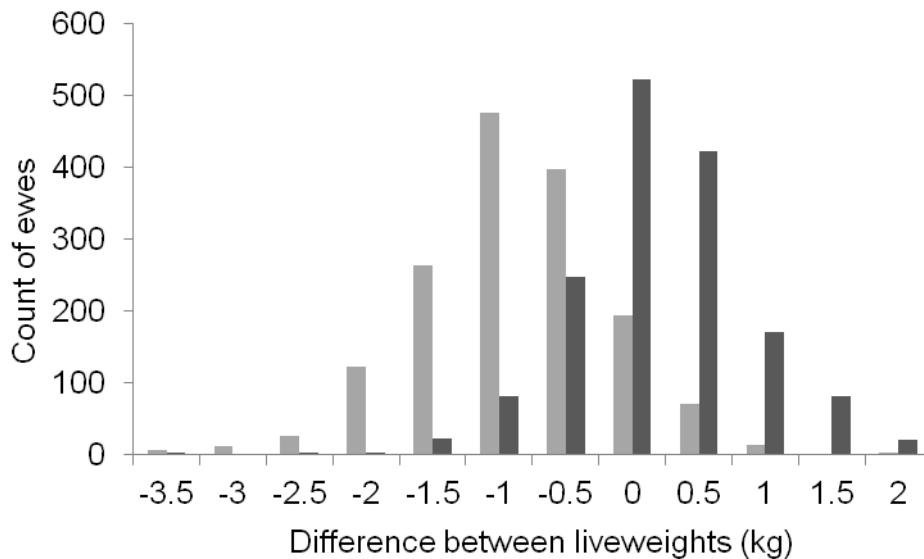
390 **3.2. Stage 2: Validating process**

391 **3.2.1. Comparing corrected and uncorrected liveweights**

392 In comparing liveweights, aWt2 and cWt1 were both different to aWt1 ($p < 0.001$).
393 However, cWt1 was a more precise estimate of aWt1 compared to aWt2, demonstrated by
394 72% of aWt1 liveweights being closer to cWt1 than to aWt2. Figure 2 illustrates how
395 correction reduces the error that would occur if the delayed liveweight (aWt2) were used
396 as the only liveweight for these sheep. Simplifying this data, the counts of sheep with a

397 cWt1 that was: close to (-0.24 to 0.25 kg); higher than (>0.25 kg); or lower than (<-0.24 kg)
 398 aWt1, were very different (with a chi-square statistic of 1172.6, $p<0.001$) to the equivalent
 399 groupings of aWt2 to aWt1.

400



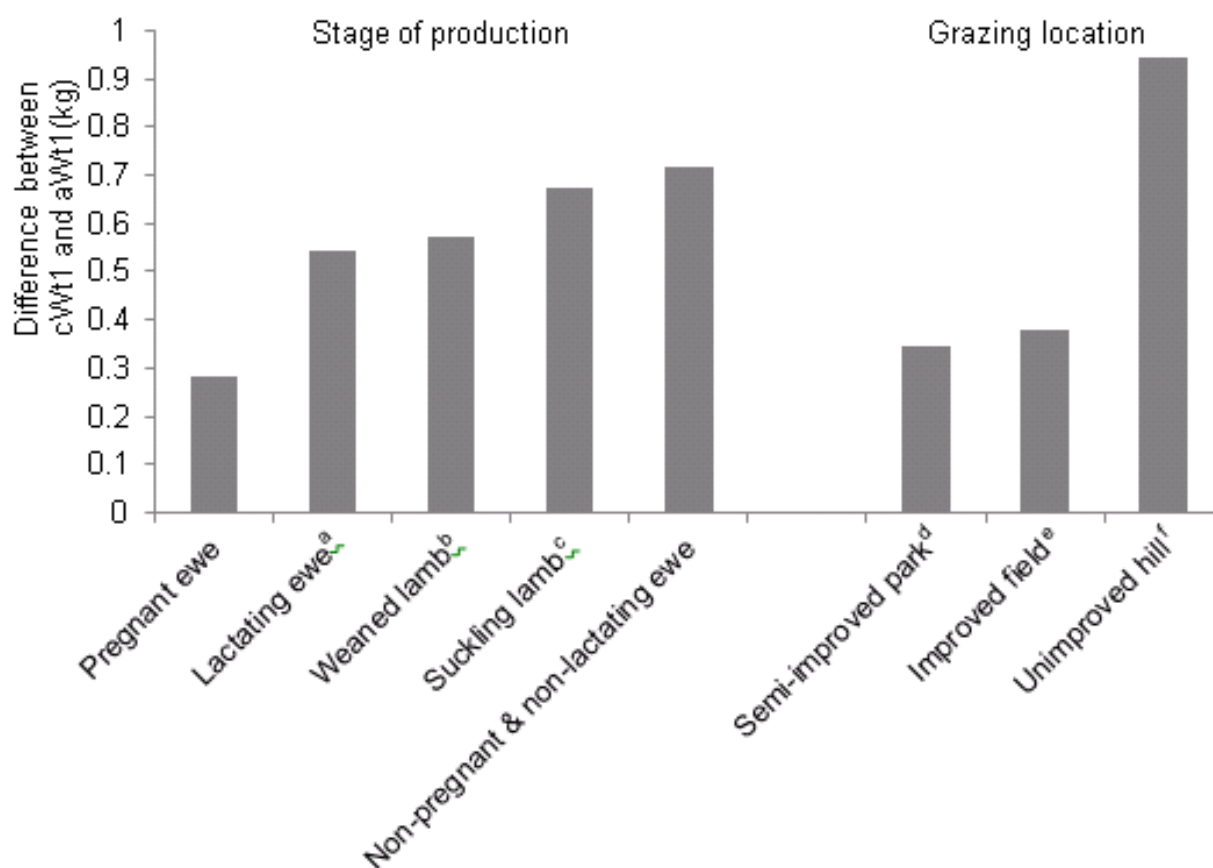
401

402 **Fig. 2** Distribution of difference between two sets of liveweights: 1) grey bars, actual
 403 delayed liveweight (aWt2) minus actual “without delay” liveweight (aWt1); and 2) black
 404 bars, corrected from aWt2 to the time of aWt1 (cWt1) minus aWt1. X axis labelling is the
 405 mid-point of the group difference (i.e. 0 kg means difference fell between -0.24 and +0.25
 406 kg).

407

408 **3.2.2. Category differences in correcting**

409 Considering the ability of the correction equation to predict for different categories
 410 (listed in Table 2) of sheep revealed that out of the five originally explored (stage of
 411 production, sex, grazing location, breed and hours delayed prior to aWt1), only stage of
 412 production and grazing location had an impact ($p<0.001$) accounting for 24.6 % of
 413 variance. Of these categories, pregnant ewes, semi-improved park, and improved field had
 414 the best correction ability with the difference between predicted means cWt1 and aWt1
 415 being within 0.4 kg (Fig. 3).



417

418 **Fig. 3** Difference (in absolute value) between a “without delay” liveweight collected as
 419 soon as the group entered handling facility (aWt1) and a delayed liveweight corrected to
 420 the time of aWt1 (cWt1), displayed as predicted means, for different categories. NB: ^aewes
 421 which had been with their lamb immediately before aWt1 but were delayed without contact
 422 with lamb; ^blambs aged four to six months old; ^clambs remained with their ewe during
 423 delay and aged three to five months old; ^dpartially improved semi-natural permanent
 424 grassland and wet heath; ^egood quality pasture, fertilised annually with the potential for
 425 silage making; and ^fa mosaic of semi-natural permanent grassland and wet heath.

426

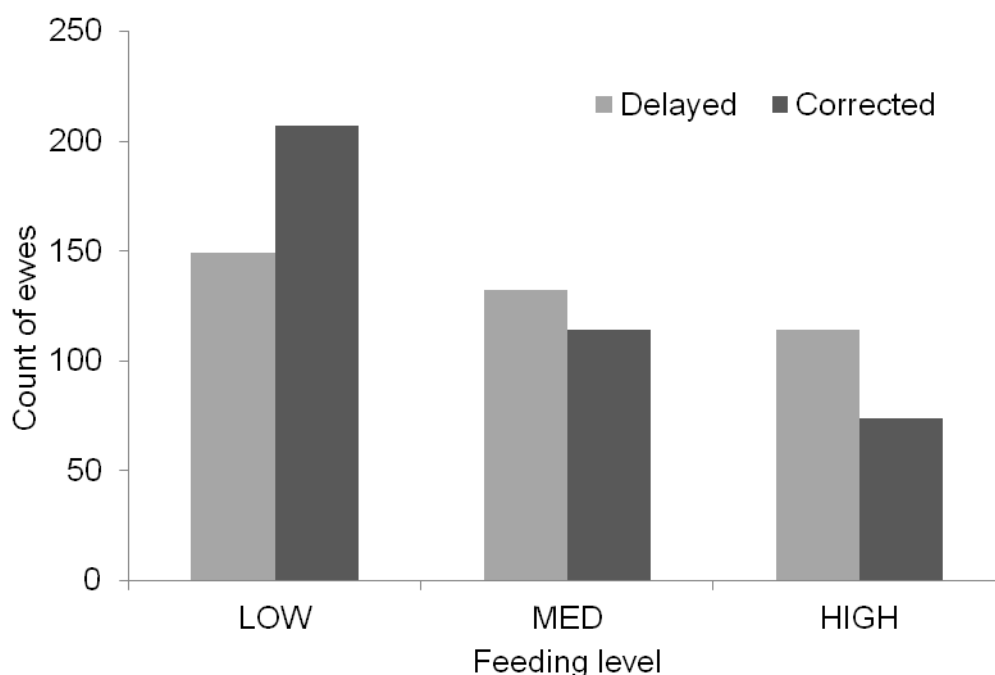
427 3.3. Stage 3: Management simulation

428 Comparing each actual delayed liveweight (PreWt and PostWt) to their respective
 429 corrected liveweight at pre-gather (cPreWt and cPostWt) showed a mean liveweight loss

430 of 1.2 ± 0.7 kg and 2.4 ± 0.8 kg for PreWt and PostWt, respectively.

431 When corrected liveweights (cPreWt and cPostWt), rather than actual delayed
432 liveweights (PreWt and PostWt), were used to determine liveweight change over the
433 mating period, a different distribution of ewes to three feeding levels was seen (Fig. 4),
434 with a substantial proportion (24.3%) of ewes being assigned to different management
435 feeding levels ($p < 0.001$).

436



437

438 **Fig. 4** Number of ewes per feeding level based on the same decision rules but different
439 liveweight calculations used to determine liveweight change between November and
440 January. Three feeding levels available: LOW, ewes gained weight; MED, lost up to 5%
441 liveweight; and HIGH, lost over 5% liveweight. Two different pairing of liveweights were
442 used; Delayed, where collection of liveweights was delayed; and Corrected, where
443 delayed liveweights were corrected to a pre-gather time point.

444

4. Discussion

445

4.1. Stage 1: Liveweight loss study

446

447 The first stage of this research found that ewes lost a significant amount of
448 liveweight after a delay of three and six hours within a handling facility. The magnitude of
449 liveweight loss found is likely to impact on research findings and management decisions
450 on-farm, unless it can be accounted for.

451 Although previous literature reported losses of 0.5 to 2 kg and 1 to 4 kg after six and
452 12 hours, respectively (as reviewed by Hughes, 1976), our study found greater losses.
453 These losses were closer in agreement to findings by Wilson et al. (2015). The ewes in our
454 study moved from poor quality unimproved hill pasture to improved field grazing the night
455 before the liveweight loss study commenced. This allowed for near-by, easy access of the
456 animals to commence work the following morning and is a typical management practice for
457 any extensive sheep system. Change in pasture quality has been suggested to alter
458 liveweight loss (Hughes and Harker, 1950). Therefore, while this change may result in
459 higher liveweight loss compared to Hughes (1976), it is representative of a real-life
460 situation.

461 It is interesting to note that ewes lost liveweight at a slightly higher rate over the first
462 three hours compared to the second three hours, which is in agreement with previous
463 research of liveweight loss (reviewed by Hughes, 1976). This could be explained by daily
464 biological rhythms where the previous day's digesta is passed from the animal in the early
465 morning (Whiteman et al., 1954) but could also simply be a result of diminishing returns.
466 Both linear and non-linear correction equations were explored, as liveweight loss was not
467 linear over the six hour period. However, a linear equation was ultimately used as it was
468 both simpler to carry out and the alternatives provided no additional precision to the
469 correction of delayed liveweights.

470 There was negative correlation between mean "without delay" liveweight and

471 liveweight change, therefore heavier ewes lost more liveweight than lighter ewes.
472 However, this was not to the same degree when liveweight loss was considered as a
473 proportion of liveweight. The difference is explainable as larger animals would have a
474 larger holding potential for water and digesta and therefore have a greater potential for
475 loss. Nevertheless this appears to be at a similar rate of loss proportional to body size,
476 which is why the correction equation uses proportion of liveweight.

477 This study demonstrated that liveweight can be collected at a rate of 480 ewes per
478 hour with modern weighing facilities using EID technology, making it an attractive option
479 for collection of liveweights both for research and on farm. This increases the potential of
480 managing sheep according to liveweight and liveweight change.

481

482 **4.2. Stage 2: Validating process**

483 Weighing without any delay would clearly provide liveweights with the least error.
484 However, when this is not possible the validating process demonstrated that the correction
485 equation could be used to provide corrected liveweights (cWt1) that were a more accurate
486 and precise estimation of an actual liveweight (aWt1) than a delayed actual liveweight
487 (aWt2).

488 Given the wide range of factors, as well as period of delay, that can impact on gut-
489 fill and short-term liveweight variation (as described in Coates and Penning, 2000;
490 Hughes, 1976), it is encouraging that the correction equation worked well across the
491 different categories of sheep. This is evidenced as breed, sex and hours delayed prior to
492 aWt1 did not have a significant impact on the precision of correction, adding strength to
493 the application potential of the equation.

494 The two categories that significantly impacted on precision of the equation were
495 stage of production and grazing location. For these, corrected liveweights had a high level
496 of precision for pregnant ewes and sheep previously grazing improved fields and semi-

497 improved parks compared to all other stages of production and sheep from unimproved hill
498 grazing. Pregnancy did not hamper the ability of the correction equation. Indeed, these
499 ewes were all in mid-pregnancy, at around 90 days gestation, at which point the conceptus
500 weight has very little impact on ewe liveweight (Henderson, 2002).

501 It is understandable that delayed liveweights of ewes from unimproved hill grazing
502 corrected with a lower level of precision compared to improved fields and semi-improved
503 parks given that sheep on hill grazing vary greatly in their time to gather (Morgan-Davies et
504 al., 2006; Stott et al., 2005), adding to the variation on liveweight. However as hours
505 delayed prior to aWt1 did not have a significant impact in the correction ability, it is
506 considered that the grazing type was the most important factor. As previously mentioned,
507 quality and quantity of pasture impact on liveweight variation (Hughes and Harker, 1950;
508 Hughes, 1976) which may be contributing to the differences seen between sheep from
509 different grazing types. Future research in the field of liveweight variation would benefit
510 from collecting pasture data such as quality and quantity available. Also, having two
511 categories (stage of production and grazing location) impacting on the correction ability of
512 the equation suggests that alternative correction equations could be developed for
513 different situations.

514 To be able to quantify the precision of the correction equation, as previously
515 explained, the delayed liveweight (aWt2) was corrected back to the time of the actual
516 “without delay” liveweight (aWt1) and not the time of pre-gather. This allowed for a
517 comparison of cWt1 and aWt2 to a known liveweight (aWt1). Due to the distribution of
518 ewes being gathered from fields of varying distances from the handling facility, different
519 delays would already be impacting on the aWt1. The majority of aWt1 were collected
520 within two hours of grazing being disturbed (85% of 1581 liveweight pairs). It is likely that
521 as time elapsed, since gathering increased, the correction precision would change. In
522 reality, to be able to produce comparable liveweights, the delay period caused by

523 gathering should also be included in the hours delayed prior to weighing (as it was in the
524 Stage 3: Management simulation). Therefore the correction equation should be used to
525 correct delayed liveweights to a pre-gather time point.

526 There were a small number of individual sheep within the validation dataset whose
527 liveweights actually increased from aWt1 to aWt2, contradicting what would be expected.
528 As no food or water would have been provided during this time, the increase is likely to be
529 an impact of random error of weighing. The weigh equipment described in this research
530 used a damping algorithm that allowed collection of the liveweight of a moving sheep.
531 While this allows for some inaccuracy it is more accurate than using more traditional
532 scales where the location of the needle needs to be read by eye (Hirsch, 1985). This may
533 also explain the overestimation of the correction equation when comparing cWt1 to aWt1.

534 Overall, however, the comparison between corrected delayed and “without delay”
535 liveweights highlights the reliability of the equation to correct delayed liveweights to a
536 specific time point. There are no known published attempts of developing a correction
537 equation for liveweights subjected to this short-term period of delay prior to weighing.
538 Therefore, the success of this correction equation is important and could be useful to all
539 practitioners collecting and utilising liveweights where delay is unavoidable.

540

541 **4.3. Stage 3: Management simulation**

542 The final stage showed that when delayed liveweights were used, ewes appeared
543 to lose more liveweight, which considerably altered the identity and number of ewes in
544 each feeding level compared to if these liveweights had been corrected to a pre-gather
545 liveweight. It should be noted that the pre-defined liveweight change boundaries for each
546 feeding level constrains the example. Any alterations to these boundaries would impact on
547 the number of ewes that would move from one feeding level to another. However it does
548 serve to demonstrate that greater delay in weighing at PostWt (January) suggests a

549 greater loss in liveweight, causing a higher proportion of ewes to be assigned to higher
550 feeding levels. This in turn would increase the amount of feed provided, resulting in a
551 significant cost to the farm that would not be required if more accurate (i.e. corrected)
552 liveweights had been used. A higher level of feed could also lead to over-supplementation
553 with the risk of dystocia and lamb death.

554 The larger correction or error on January liveweights (PostWt), which were collected
555 after delay compared to liveweights in November (PreWt) collected without delay,
556 highlights the advantage of collecting without delay. Depending on the time delay
557 associated with gathering, collecting liveweights without delay may be sufficient in
558 reducing error, and a correction equation might not be required.

559 Within each handling, we know from the equipment time stamps that there is further
560 variation in the delay between the first and last ewe weighed. Therefore if correction
561 equations cannot be used, weighing as quickly as possible from the first to the last sheep,
562 to reduce delay during the weighing session, is essential.

563

564 **4.4. Wider implications of improved liveweight reliability**

565 While feeding management has been explored by this research, there are other
566 farm practices which could also benefit from correcting delayed liveweights: firstly,
567 achieving a target carcass weight at the abattoir, by more accurately selecting finishing
568 lambs to sell based on liveweight; secondly, producing more accurate Estimated Breeding
569 Values (EBVs) when they are generated from liveweights; and thirdly, providing a more
570 appropriate level of anthelmintic based on liveweight bands, as widely recommended as
571 best practice (for example, Henderson, 2002).

572 Current advice for reducing liveweight variation in research includes increasing
573 animal numbers (Hughes, 1976) and weighing multiple times (Koch et al., 1958). However,
574 correcting delayed liveweights may allow fewer animals and weighings required to reduce

575 error and thereby follow the principles of the 3Rs (Replacement, Reduction and
576 Refinement; Russell and Burch, 1959).

577 Finally, variation in liveweight may become less of a concern with the development
578 of weighing technology that can collect liveweights in real-time, without extra handling or
579 gut-fill issues, for instance walk-over weighing (Brown et al., 2014).

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5. Conclusions

We have shown that sheep lose a significant amount of liveweight over a short-term delay prior to weighing, as a result of practical handling operations. When this delay is uncontrollable, one method to improve reliability and comparability is by correcting delayed liveweights (via correction equations such as the one presented in this paper). Alternatively, since the value of correction increases as the length of delay increases, collecting liveweights immediately (without delay) may be sufficient in producing reliable liveweights. Such approaches will reduce error in liveweights which, if used, can lead to incorrect conclusions in research and negative consequences for management practices of grazing sheep systems globally. Finally, research papers should provide sufficient details of weighing procedures, particularly with respect to time delays between removal from feed and grazing, to actual weighing.

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