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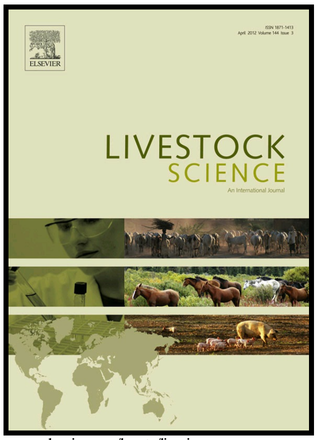

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Impacts of using a precision livestock system targeted approach in mountain sheep flocks

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Abstract

Although mountain sheep systems suffer from climatic and environmental handicaps that constrain productivity and economic viability, they have an important economic role, maintain habitats and species of high nature conservation value and support the provision of a range of ecosystem services of benefit to society. Using Precision Livestock Farming (PLF) in extensive mountain sheep systems could bring benefits for animal performance, economical performance and labour. This paper presents results from a 3 year experiment where PLF principles were implemented on an extensive mountain sheep farm and an assessment made of whether or not such an approach could benefit more marginal sheep systems. A 900 ewe flock (600 Scottish Blackface ewes, 300 Lleyn ewes) was divided equally into two separate systems, one where the flock was managed conventionally (CON) at group level, and the other where the individuals in the flock were subjected to a PLF management protocol where electronic weighing, recording and drafting equipment were used, linked to the electronic identification (EID) tags of the animals. Two main management strategies were compared and contrasted; one relating to winter feeding of the pregnant ewes, the other relating to anthelmintic treatment of lambs during the summer. Yearly labour profiles were created by measuring the time spent doing individual tasks associated with the two management systems. Net margins (£/ewe) were calculated for the two systems. Additionally, the yearly labour profiles were scaled-up using commercial data to quantify potential labour savings on more traditionally managed mountain farms if PLF principles were adopted. Analyses indicated that the two different management systems did not result in any significant difference in terms of ewe weights, mid-pregnancy scanning figures, ewe and lamb mortality rates, or lamb weight post-weaning. However, the proportion of lambs needing anthelmintic treatment was significantly reduced by 40% between the CON and the PLF, resulting in a reduction of 46% in the amount of anthelmintic used. Over a whole year, the total amount of labour required in the PLF management system was reduced by 36%. Across the 3 years, the net margin for the two systems showed an average difference of £3/ewe higher in the PLF. For a more traditional farm embracing a PLF approach, analyses suggested labour reduction of 19%, equating to £1.60/ewe savings. This study shows that it is beneficial for farmers to consider managing a mountain ewe flock at an individual rather than at flock or batch level using PLF technology.

Keywords:

Precision Livestock Farming, Targeted Selective Treatment, labour

1. Introduction

Extensively managed mountain livestock systems in North West Europe suffer from climatic and production handicaps (Morgan-Davies et al., 2012), that constrain productivity and economic viability in these areas. As a result, farming in these marginal areas of Europe has often been challenging (MacDonald et al., 2000). Such extensive mountain systems are also characterised by larger sheep flocks or cattle herds, grazing very large areas of poor quality grasslands (Bocquier et al., 2014), with low production levels, efficiency and labour supply (Cabaret et al., 2009), compared to their more intensive counterparts in the European lowlands. The farming population in these areas is also an ageing one, with succession problems and not enough attraction to retain the next generation of farm labour (Madelrieux and Dedieu, 2008).

However, these extensive mountain systems have an important economic and societal role in these areas (Ripoll-Bosch et al. 2012; O'Rourke et al., 2012; Ross et al. 2016), contributing to the rural economy and providing a source of local skilled labour, even if it is very seasonal (Waterhouse, 1996). Mountain systems are also increasingly recognised for their important role in maintaining habitats and species considered to be of high nature conservation value and for the provision of ecosystem services for wider society (Bernúes et al., 2014).

These systems are however often poor in terms of animal performance and welfare. They suffer from poor ewe survival over winter and high lamb mortality (Waterhouse, 1996; Dwyer, 2009), including what is commonly referred as ‘black loss’ – the unaccountable disappearance of lambs from farms (Morgan-Davies et al., 2008a). Management techniques that would help farmers to assess health and welfare of their animals more regularly, in a time-efficient manner, would be beneficial and would potentially help improve survival and sustainability of these types of flocks.

In Europe, mountain systems have not seen the same uptake of mechanisation and innovation as the more intensive areas of agriculture. Livestock farming in more intensive areas has indeed seen a rise in the use of innovations (Riddell and Walker, 2011) in such fields as genetics, breeding, feeding systems, milking devices and, more recently, what is called Precision Livestock Farming.

Precision Livestock Farming (PLF) can be defined as the management of livestock production using the principles and technology of process engineering (Wathes et al. 2008). It can also be described as farming using equipment, data or software which allows the use of information at an individual level for targeting decisions, inputs and treatments more precisely (Morgan-Davies et al., 2015a). It relies on being able to identify an animal individually, most often using a tag or a bolus. This principle has been enabled by Electronic Identification (EID), which was introduced in livestock farming in the early 1980s (Rossing, 1999).In 2004, the European Union rendered it mandatory to uniquely identify all sheep and goats via

EID technology (Council Regulation (EC) No 21/2004), further increasing scope for use of these technologies and management systems.

Although PLF historically has been more associated with intensive systems (Wathes et al., 2008; Jago et al., 2013), some authors (e.g. Bocquier et al., 2014; Australian Sheep Industry CRC, 2007) argue that these technologies could equally be beneficial if introduced in more extensive systems, whereby livestock management decisions are traditionally considered at the level of a group of animals rather than individually.

Some of the constraining factors in extensive conditions that could be improved by the use of these technologies encompass labour demand at handling (Bocquier et al., 2014; Morgan-Davies et al., 2015b), the management of reproduction (Bocquier et al., 2014), winter nutrition of pregnant animals, and the management of parasite burden and resistance (Umstatter et al., 2013).

In particular, labour requirements on farm could be rationalised and farm performance improved by implementing such new technologies (Olaizola et al., 2008). The introduction of PLF on livestock farms could impact on labour organisation, as shown by Hostiou et al. (2016). Internationally, the quantification of workloads on livestock farms has been studied and various methods have already been proposed (Dedieu et al., 2000; Dedieu and Servière, 2012; Dieguez et al., 2010). Some studies also highlighted the variation of workload over the year (O'Donavan et al., 2008). However, labour data at farm-task level are often not measured (Sørensen et al. 2005). , or only quantified as a yearly figure (e.g. Nix, 2014), which does not reflect the seasonal variation in task workload.

The nutritional state of sheep can be assessed by body condition scoring (BCS) and live body weight (Behrendt et al, 2011). Body condition scoring provides a reliable measure of fat coverage and thus predicts overall body reserves and is not affected by sheep size or gut-fill at the time of assessment. However, it is subjective and time-consuming (Russel et al, 1969). Weight or weight change are more objective measures to identify if a ewe is maintaining, gaining or losing body mass (Brown et al, 2014), and can be easily collected using EID ear-tags and a compatible weigh-crate.

The growing concern about anthelmintic resistance on sheep farms, as previous worming strategies are increasingly failing and expensive (Garland and Leathwick, 2015), could also be relieved using technology. Targeted Selective Treatment (TST), or targeted worming, is a refugia-based approach to lamb worming, where only a proportion of the animals are treated with anthelmintics, based on their individual weight change (Kenyon et al., 2013). This approach relies on individual identification of animals, which is possible using electronic identification (EID) tags. It has been successfully implemented on lowland farms (Busin et al., 2014, McBean et al, 2016), and its introduction on a mountain farm could present some advantages.

In some areas of Europe, the introduction of mandatory EID in the sheep industry has been controversial (Moxey, 2011; Cappai et al., 2014) and farmers, especially in extensive systems, seem to perceive EID as an additional burden, without necessarily appreciating the benefits that this technology could bring to sheep management (Umstatter et al., 2013). One of the reasons is often a lack of quantification of all the potential benefits, including economic as well as the less quantifiable benefits, such as animal welfare (Morris et al., 2012) or farmer well-being (Hostiou and Fagon, 2012). Eory et al. (2015) also highlighted the lack of information regarding the financial benefits of PLF. The aim of this article is to investigate in more detail the potential, in economic, animal performance and farm labour terms, of introducing a more targeted or precision approach of sheep management into extensive mountain systems.

This paper presents results from a 3 year experiment where a targeted sheep management approach using EID based technology has been implemented and evaluated on an extensive mountain farm.

2. Methods

2.1. The research farm

Research was conducted on a mountain research farm in the western Highlands of Scotland, at SRUC's Hill and Mountain Research Centre, Kirkton and Auchtertyre. The farm carries a total of 1300 ewes (Scottish Blackface and Lleyn), and 22 cattle, on 2200 ha of ground. The 1300 ewe flock is composed of two sub-flocks, a commercial flock of 400 ewes and a research flock of 900 ewes, grazing in two separate areas of the farm. Most of the land is permanent grassland of poor quality (mountain grazing pasture), with only 230 ha of improved and semi-improved pastures. There are 2.5 full-time stockpersons employed on the farm.

The altitude ranges from 170 m to over 1000 m above sea-level, and the mean annual rainfall is 3000 mm, with the first three months of the year tending to be the wettest. Average temperatures peak in June and August at 15^{o}C, and are lowest in January at 1^{o}C.

2.2. Animals and Management Systems

In this long-term study, the 900 ewe research flock (approximately 600 Scottish Blackface and 300 Lleyn) was divided equally between two system groups, one managed conventionally (CON), and used as a comparison, and the other subjected to a new Precision Livestock Farming (PLF) management protocol, which encompassed a series of different targeted management approaches, making use of new technologies and handling systems.

The study ran over 3 full sheep production years (Nov. 2012- Nov. 2015) and involved an average of 902 individual ewes every year (435 and 467 in the CON and PLF systems respectively). The average numbers of ewes in each system were balanced for breed, age, live weight, litter size the previous year and sire and remained for their lifetime on the same treatment. Over the 3 years reported here, the average number of ewes per treatment per year was 574 Scottish Blackface ewes, 273 in the CON, 301 in the PLF; 328 Lleyn ewes, 162 in the CON, 167 in the PLF, for 2012-13, 2013-14, 2014-15 respectively. The animals were part of a performance recorded breeding scheme, which required single sire mating groups, tagging and recording at lambing, and weighing at set times across both systems.

The animals shared the same pastures. In the CON approach, the animals were identified, weighed and recorded manually, and managed at a group level. In the PLF targeted approach, the animals were managed using automatic identification, weighing and recording technology, with each animal identified individually using their electronic identification (EID) ear-tags. Although all of the animals on the farm were electronically identified using an EID RFID tag, in line with EU regulations (Council Regulation (EC) No 21/2004), only the PLF approach made specific use of the technology. In the CON approach, the EID tags were used as if they were standard non-EID management tags.

2.2.1. Handling systems

In the PLF system group, each animal was tagged with an EID ear tag (Richey's RD2000, Shearwell Data's SetTag or Allflex's button tags) containing a unique identification number, read by an Allflex® radio frequency identification portal reader (Allflex Australia, Queensland, Australia). This reader was contained within a weigh-crate incorporated into a Prattley 5-way Auto Draft (Prattley Industries, Temuka, NZ) with Tru-Test™ MP600 load bars.

When an animal entered the weigh crate, its weight was automatically recorded against its EID number on a TruTest™ XR3000 weigh head (Tru-Test Group, Auckland, NZ). This setup allowed PLF animals to be automatically sorted into their respective management groups, based on weight, weight change or any other information stored in relation to the animal's EID.

In the CON system group, each animal was also tagged with an EID ear tag, as required by the regulation. They were allocated manually to their different management groups, based on a shepherd's assessment of their condition. The equipment used for handling the CON ewes was a digital weigh crate (Pharmweigh©), with a race and a manual two-ways drafter.

All the animals were handled at various times during the production year (Figure 1 and Table 1).

2.2.2. Targeted managements:

2.2.2.1. Winter feeding

During the winter, ewes were grazed outside and received supplementary feeding in the form of mineral blocks, concentrate pellets and hay, as recommended by common husbandry practices (AFRC, 1993). The ewes were allocated to different feeding groups (standard or corrective). Two winter feeding periods were considered: early-pregnancy and mid-pregnancy (Figure 1), each lasting approximately two months.

The feeding levels in the standard and corrective groups aimed to provide enough supplementary feed to respectively maintain or improve ewe current body reserves. The supplementary feed was provided at a level appropriate to meet the aim of the relevant feeding group.

Ewes in the CON management were allocated to their feeding groups based on ewe condition assessment, done manually by a shepherd by palpating the loin, whilst the ewes in the PLF management group were allocated to their feeding group based on their percentage weight change (and number of lambs expected) since last weighed, as measured by the automated EID reader and weigh crate, with the five-way automated drafter (Table 1).

2.2.2.2. Targeted worming

In this study, lambs in the PLF system were subjected to a targeted worming approach or Targeted Selective Treatment (TST) (Figure 1). At 8 weeks of age, all lambs were wormed and weighed. Thereafter, lambs were weighed monthly– in July, August and September - and wormed only if they did not reach their individual target weight, which was calculated using the "Happy Factor" algorithm developed by Greer et al. (2009), based on pasture availability. Lambs were automatically sorted into those that did not require dosing, or did require dosing. In the latter case, lambs were further subdivided into groups with different weight ranges and wormer doses were based on animal weight (always to the level recommended for the heaviest animal, within a 10 kg weight range). The treatment stopped once the lambs were removed from pasture for finishing indoors (October).

Lambs in the CON system were wormed using a whole flock approach, based on the findings from pooled faecal samples. If the faecal egg count (FEC) was >500 eggs/g, all lambs in that grazing group were wormed (dose based on the heaviest animals in that group); if the count was lower, all lambs were not wormed.

2.3. Measurements

2.3.1. Animal performance

Ewe and lamb performance data were recorded at each of the handling events in the production year (Figure 1). Key flock (litter size at mid-pregnancy ultrasound scanning, barren rate, weaning rate, kg lamb weaned/ewe scanned) and welfare indicators (ewe and lamb mortality) were also collected and calculated for both the CON and PLF groups. Data were collected over three years of production (2012-13, 2013-14, 2014-15), and assessed year by year, as well as on average.

2.3.2. Labour

Yearly labour profiles were created by measuring the time spent doing each individual task under the two different management systems. At each major handling task (Figure 1), two observers directly recorded each sub-task (Table 1) using a stop-watch and hand-held devices for continuous recording (The Observer XT, version 9.0, Noldus Information Technology)). Depending on the tasks, the number of workers involved varied, from 2 persons (e.g. weighing sheep in the EID crate) up to 4 persons (e.g. gathering the sheep on the mountain pastures). To allow a comparison, the number of seconds needed for the task was apportioned to the number of persons needed for that particular task (in seconds per sheep). The individual tasks being measured were seasonal and followed the sheep production year (Figure 1) and encompassed (Table 1) mating (November), early-pregnancy (January), mid-pregnancy (February/March), 8 weeks after lambing (June), shearing (July), weaning (August), post-weaning (September), ewe stock draw and lamb selection for sales (October). The daily tasks (e.g. monitoring the animals or moving animals from one pasture to another) were not taken into account, as both CON and

PLF animals were run together as one flock. For this particular study, labour recording during lambing was deliberately not included. Both systems were managed identically at lambing, due to the requirements of the performance recording protocol, so it was assumed that there would be no differences due to lambing labour. The labour requirements for both systems were calculated in minutes/animal over the whole year for each year of production (2012-13, 2013-14, 2014-15). The total labour requirements (in working days of 8 hours) for the full flock were also calculated for each year of production, based on the flock number data on these particular years.

Additionally, a comparison of labour required to do the tasks involved in more typical extensive 'traditional' low-input sheep management systems, with (Trad-PLF) or without PLF technology (Trad-CON) was carried out. These two additional yearly labour profiles were created using questionnaire answers from 17 extensive sheep farmers who attended a farm open day in 2014. These farmers had farms and sheep farming systems typical of the area where the research farm is located, with similar number of animals to the research farm (between 500 and 1200 ewes). However, they tended to handle their sheep less often, and thus were more representative of the extensive sheep farmers in these areas. The farmers were asked to select which pre-defined tasks they carried out on their farms. The tasks concerned the same sheep production year tasks as described in Table 1, namely: mating, early-pregnancy, mid-pregnancy, 8 weeks after lambing, shearing, weaning, post-weaning, ewe stock draw and lamb sales. The resulting labour profiles (Trad-CON and Trad-PLF) were quantified by task by multiplying the proportion of farmers that selected those different tasks (Table 2), with the actual labour measurements (minute/animal) from both the PLF and CON systems (Table 1). That allowed a scaling of tasks, to create these two profiles (Trad-CON and Trad-PLF), as if a 'typical extensive' farm was implementing a PLF and a CON approach. This was to investigate whether applying a PLF approach to a farm that handles animals less often than a research farm could still be beneficial, specifically in terms of labour.

The assumptions for modelling labour demand on such a 'typical extensive farm' were a flock of 1200 ewes, with a mid-pregnancy ultrasonographic scanning rate of 100%, weaning 1000 lambs, and a ewe replacement rate of 25%. Most of the lambs (86% - based on Table 2) were sold to the market in August/September, with the remaining being sent to the abattoir. The modelled results were then converted into working days (of 8 hours) over a whole year of production.

2.3.3. Economic performance

Inputs (feed quantity, anthelmintic and medicine quantity, fertilisers, market costs, etc.) and outputs (number of animals sold, wool produced) were collected on the SRUC research farm for the financial years 2012-2013; 2013-2014; 2014-2015. Fixed costs (rent, building costs, insurance, etc.) were also collected for the same periods; however, they were divided equally across both systems as the animals were run together, except at handling times. The labour costs were calculated using the labour measurements collected for the two different management systems.

An annual gross margin (£/ewe) and a net margin (£/ewe) were subsequently calculated for the two systems. Subsidy and support payments were not included in the calculations of the net margin (SAC, 2010). In this study, we were interested in the economic comparison between two management systems on the same farm, so, although the fixed costs (including rate of labour costs) were farm-specific, the resulting comparison is still relevant to any mountain farm. A return on investment for the weighing/-EID equipment was also subsequently calculated based on flock size and costs of equipment.

2.4. Statistical Analysis

The results were analysed using parametric and non-parametric tests in the Genstat statistical package (VSN International Ltd, 2013). The animal (ewe and lamb) performance differences between the two management systems were investigated by means of Linear Mixed Models (LMM), with 'year' as a random effect. For the ewe performance (ewe weights at mating, early pregnancy, mid-pregnancy, pre-lambing, 8 weeks post-lambing and weaning), the ewe breed, ewe age, number of lambs expected/born/reared and previous weights were considered in the models as fixed effects. For the lamb weight at lambing, weaning and post-weaning, the lamb breed, lamb sex, lamb parity (single or multiple), and system were fitted in the LMM. The ewe mid-pregnancy scanning and weaning results between the two management systems were analysed using a Generalised Linear Mixed Model (GLMM), with a binomial distribution and a logit link function. The fixed effects considered in the models included ewe breed, ewe age and previous weights (mating and early pregnancy), as well as management system; year was fitted as a random effect.

The ewe and lamb mortality rates and the percentage of lambs given anthelmintic in each system were compared using non-parametric tests (χ^2 test). The kg lamb/ewe mated and the kg lamb/ewe scanned pregnant were calculated for both management systems and analysed using an F test.

3. Results

3.1. Ewe performance

The unadjusted animal (ewe and lamb) performance data across both systems for the 3 study years are presented in Table 3.

<Table 3. Ewe and lamb performance data (weights in kg with standard deviation (SD), barren, scanning and mortality rates in %, kg lamb/ewe in kg) for the 3 study years, for both PLF and CON management systems. >

When considering the management system alone as a fixed effect in the model, the LMM showed that, over the 3 years, the system did have a significant effect on mating weights (P=0.018), early pregnancy weights (P=0.004) and 8 weeks post lambing weights of the ewes (P=0.043), with the PLF ewes being heavier than the CON ewes (Table 3). However, when breed, age, scanned lamb numbers and previous weights were also included in the models, the management system did not have a significant effect on any of the ewe weights (mating, early pregnancy, mid-pregnancy, pre-lambing, 8 weeks post-lambing and weaning). Breed, age, scanned lamb numbers and previous weights were significant (P<0.001), except for breed on early pregnancy weights (P=0.140), mid-pregnancy weights (P=0.083) and pre-lambing weights (P=0.106).

The GLMM analysis of the mid-pregnancy scanning results over the 3 years did not show a significant effect of the management systems (P=0.884) even when breed (P<0.001), age (P=0.413) and previous (early pregnancy) weights (P<0.001) were included in the model. The GLMM analysis of the barren rate (ewe pregnant or not) over the 3 years were not significantly affected by the management system (P=0.945), ewe age (P=0.726) and the mating weight (P=0.130). However, the breed (P<0.001; Lleyn ewes having a lower barren rate than the Blackface ewes) and the early pregnancy weights (P<0.001) did have a significant effect when included in the GLMM.

The ewe and lamb mortality rates over the 3 years were not significantly affected by the management system (χ^2, P=0.306 and P=0.88 respectively). Likewise, the kg lamb/ewe mated and the kg lamb/ewe scanned pregnant were not different (F test, P=0.58 and P=0.82 respectively) across both systems.

Overall, the PLF management system did not have an impact on ewe performance or animal mortality (welfare indicator).

3. 2. Lamb performance and targeted worming:

For the lamb performance at lambing, weaning and post-weaning, the system alone did not have a significant effect over the 3 years. At lambing, when breed, sex, and parity were accounted for in the Linear Mixed Model, these variables had a significant effect (Lleyn being heavier than Scottish Blackface, P<0.001; male being heavier than female lambs, P<0.001); single being heavier than twin and triplet, P<0.001), but the system did not (P=0.679).

At weaning, when breed, sex, parity, were included in the Linear Mixed Model alongside the system, sex (P<0.001) and parity (P<0.001) were significant on weaning weights. The breed did not have an effect (P=0.939), neither did the system (P=0.08, with predicted means: PLF = 27.33 kg, CON= 27.65 kg). However, at post-weaning, the sex (P<0.001), parity (P<0.001) and the breed (P=0.039; predicted means: Scottish Blackface = 30.07 kg, Lleyn = 30.48 kg) had significant effect on post-weaning weights, but not the system (P=0.114; predicted means: PLF = 30.12 kg, CON= 30.43 kg).

Despite the PLF system lambs' final weight at post-weaning (Table 3) being slightly lower than their CON counterparts, the difference observed was not significantly affected by the management system.

However, on average over the three years, the proportion of lambs receiving worming treatment (Figure 2) was significantly reduced by 40% (χ^2 test, P<0.001) between the CON and the PLF approach. In terms of amount of anthelmintic used, this resulted in a three year average difference of 46% (15 litres) between the two systems.

3. 3. Labour profiles

Over the 3 years, the total amount of seasonal labour required for one ewe and one lamb in the CON system averaged 35 minutes, compared to 23 minutes in the PLF system (Figure 3), which equated to a labour reduction of 36%. There were however differences between the months, with some periods showing a larger difference than others (e.g. June, July, August, September, average difference of 1.5 minutes, compared to November- March, average difference of 0.5 minutes).

Using the number of animals in each management system, their respective scanning percentage, and taking into account the lamb mortality (applied at weaning time), the calculated total number of 8 hours working days of labour required in each management system year by year and on average over the 3 years are shown in Table 4.

Over the 3 years, the total amount of labour required per year varied from 40 to 43 working days for the CON system versus 23 to 26 working days for the PLF system, an averaged difference of 17 days per year.

Looking specifically at the targeted management for the winter feeding period (January-March, Figure 1) and the lamb worming period (June – September, Figure 1), the savings between the two systems were, respectively, 1 and 4 working days per year (Table 4). Combining both targeted management approaches, the total savings would equate to 5 working days per year.

For a more traditional farm, with different tasks being carried out routinely (as defined by the farmer questionnaire results, see Table 2), the impacts of implementing a PLF approach are also shown in Figure 3. Over a whole year, the total amount of labour required for one ewe and one lamb in a traditional farm with a conventional approach (Trad-CON) averaged 21 minutes, compared to 16 minutes if a traditional farm took a PLF approach (Trad-PLF). This would equate to a labour reduction of 19%.

Assuming this modelled traditional farm was a typical mountain farm with 1200 ewes and 1000 lambs, the total number of 8 hours working days of labour required without PLF (Trad-CON) equated to 48 days, versus 39 days with PLF (Trad-PLF). This meant a difference of 9 working days over a whole year (Table 4).

3.4. Economic data

Based on the number of animals in each system across the 3 years, the net margin (gross margin minus fixed costs) for the two systems over the 3 study years (Table 5) varied from -£33/ewe to -£20/ewe in the CON system, and from -£29 to -£18 in the PLF system, depending on the year. On average, there was a difference of £3/ewe, to the benefit of the PLF system.

The initial cost of an EID Prattley 5-way Auto Draft weigh crate was £10,000 (approximately), which, given the average number of PLF ewes (470), meant an additional cost of £21 per ewe. However, since the use of the technology brought an average annual saving of £3/ewe, this meant that the equipment would be paid off after 7 years. This estimation did not take into account depreciation costs. After that initial period of 7 years, this PLF approach could potentially provide an extra £1,260 per year (470 x £3/ewe).

If the PLF management approach was deployed to the whole flock (average of 902 ewes over 3 years), then the cost of the EID weigh crate could be paid off after 4 years (£10,000/ (902 animals x £3/ewe)), and the financial benefits would be increased to £2,700 per year (902 x £3/ewe) after the fourth year.

From these results, an approximation of savings was estimated for a situation more typical of traditional farms. The savings of £3/ewe were largely due to the 36% reduction in labour (Figure 2). Based on that figure, and using the modelled traditional farm results showing a 19% reduction in labour by using a PLF approach (Figure 2), the savings per ewe could be approximated at £1.60 (£3 x 0.19/0.36) per year. For an assumed flock of 1200 ewes, this could mean that the equipment worth £10,000 would be paid off in 5 years, bringing a surplus of £1,920 per year thereafter.

4. Discussion

This long-term study showed that the implementation a PLF management approach on a mountain sheep farm can be useful, despite the fact that these types of farms handle livestock less frequently than their more intensive lowland farms counterparts (Hargreaves and Hutson, 1997), and operate in harsh environment where the technology may have limitations (Ruiz-Garcia and Lunadei, 2011). Performance of the animals was not affected by the introduction of the technology to aid in decision-making. Although the benefits of implementing the PLF approach translated into an increase in ewe performance, with PLF ewes displaying slightly heavier weights than their CON counterparts, statistically, once the effects of breed, age and expected litter size were accounted for, this difference was not significant. However, in the context of ewe pregnancy, Wishart et al. (2015) argued that, a weight-based PLF approach could bring further benefits, such as managing body reserves more efficiently to reduce business risks, despite no difference in performance. Moreover, although the targeted winter feeding did not impact on the animal weights after the winter, that approach nevertheless provided an average labour difference of one working day (8 hours) between the 2 systems. Alvarez and Nuthall (2006) also argued that although farmers use technology to ease their workload and improve their management, it often does not inherently have any impact upon biological efficiency.

Likewise, this study showed that introducing a targeted approach to lamb worming, with large reductions in drug usage and some reductions in labour, did not prevent the young animals achieving similar post-weaning weights as their CON counterparts. The reduction in drug usage in such a worming approach has been demonstrated in lowland conditions (Kenyon et al., 2013; Busin et al., 2014). This study, however, further demonstrates its potential in a mountain environment, with less handling events and different grazing conditions. Benefits to this targeted approach also go beyond the effects on performance alone. The additional benefits in terms of slowing down any wormer-resistance build-up (with the significant reduction in the proportion of lambs being wormed) in these livestock systems are important, especially since gastrointestinal nematode anthelmintic treatments can have a high failure rate (Keane et al., 2014). Further, if resistance is allowed to build up on any farm, this can lead to performance loss and ultimately have negative financial impacts (Sutherland et al., 2014). Reducing resistance to anthelmintic treatments also has beneficial impacts on animal welfare (McBean et al., 2016), and on the wider soil fauna (e.g. invertebrates).

A targeted management approach within a flock can also provide better control over the flock, since each animal is identified individually, and can, if necessary, be targeted with any treatment or feeding regime (Banhazi et al., 2012). This has the potential to increase efficiency (and ultimately reduce carbon footprint) of the whole flock, by targeting treatments and differential management towards animals that need it most. For instance, Bowen et al. (2009) in Australia demonstrated the benefits of using a remote drafting system for supplementing ewes. Wishart et al. (2016) has also shown the benefits of using ewe individual lifelong performance to predict their future outputs. Bocquier et al. (2014) highlighted the potential benefits of such a targeted approach to extensive livestock systems in France, and Morris et al. (2012) showcased the cost-effectiveness, welfare benefits and labour efficiency that these technological tools can bring to extensive systems in Australia.

This study has shown that the main benefit of such a PLF approach was the labour savings and cost-effectiveness of using the technology, which leads to financial gain for the whole system. Although the net margin is negative in all cases, mostly due to non-accounting of subsidies on the farm that contribute, in these types of mountain farms, to a substantial amount of the farm income (Morgan-Davies et al., 2008b), it is the difference between the two managements that is interesting. The £3/ewe annual difference is mainly due to labour costs. This reinforces the thoughts of Aubron et al. (2016) who stated the crucial role of labour to any trajectory changes of French sheep marginal production systems. Similarly, Conradie and Piesse (2015) in South Africa, argued that labour self-efficiency on extensive sheep farms is a key factor to optimal intensity. Likewise in Greece, where Theodoridis et al. (2012) suggested that, in their sample of sheep farms, efficient farms used less labour. Jouven et al. (2010) in Mediterranean rangeland systems also argued that a framework of precision livestock system could minimise human intervention and labour at farm scale.

The CON and PLF approach profiles in this study were designed to directly compare and benchmark the effect of using technology on an extensive research farm, with a relatively high input management input, in terms of labour as well as performance indicators. However, the modelled traditional profiles allowed further comparisons of labour input, as they represented more of the inherent variation in husbandry practices within the extensive farmers' population (Morgan-Davies et al., 2012). Although introducing technology on relatively lower input management sheep did not bring savings of the same magnitude, it demonstrated how the use of technology can still bring potential benefits in terms of labour efficiency.

Additionally, these labour savings can also be identified as a form of opportunity labour savings, where the farmer can devote the extra time gained through the use of PLF to any off-farm work (farming or non-farming). In these remote areas, such opportunity is valuable and can increase financial farm outputs (Lien et al., 2010). The financial benefit becomes also a social one; labour can be scarce in such marginal areas and this is becoming a wider social issue (Sutherland et al., 2014; Jouven et al., 2010). Having the opportunity to reduce labour on a mountain sheep farm while still maintaining livestock productivity means that other forms of occupation (sometimes more lucrative) could be found, such as tourism diversification or off-farm contractual work (Meert et al., 2005; Maye et al. 2009). A better labour efficiency can also ease pressure on farming life, potentially making it more attractive to the younger generations who have different life aspirations (Blanc et al., 2008).

However, the benefits highlighted in this study can only become widely applicable if the farmers themselves are keen to embrace these forms of technology. Bocquier et al. (2014) already mentioned constraints and barriers (such as diversity of the information required in extensive systems, as well as cost of the technology) that farmers face to implement such an approach. The cost of upwards of £10,000 for a state of the art handling system may appear excessive to mountain farmers, who do not always have large financial outlays for farm machinery, unlike lowland livestock or crop farmers. So, in parallel to this presented study, farmer surveys at sheep shows and events have been carried out in 2013 and 2015 to better understand barriers to uptake of the technology. Although the majority (97%) of respondents thought that the technology could help farm management, only a quarter of them had EID readers that they actively used on their farms. The main barriers for further implementation and use were the (perceived) cost of the technology, the lack of specific training on how to use the equipment, and the diversity of systems and type of readers available on the market (Morgan-Davies and Lambe, 2015; Morgan-Davies et al., 2015a). Although the lack of financial help for farmers to equip their farm with technology to exploit EID for management purposes were identified as barriers to enable increased uptake, active demonstration and face to face training were thought to be part of the solution. This knowledge transfer demand and the potential role that advisory services should play to enhance any uptake has already been identified by Cabaret et al. (2009). Likewise, Reichardt et al. (2009) in Germany stated that to promote awareness of precision farming, information and training materials must be adapted to the relevant educational levels of the farmers targeted. Bocquier et al. (2014) equally stressed the need for advisory services and professional knowledge transfer towards the farmers.

Introducing a precision livestock farming approach to sheep management in mountain areas can bring a range of potential benefits, as highlighted in this study. However, to ensure that this approach prevails and to promote it, an integrated process that couples farmer training, efficient knowledge transfer and financial incentive would also be valuable.

5. Conclusions

This study indicates that it is feasible and beneficial to consider and manage a mountain ewe flock at individual rather than flock or batch level using technology. Segregating large flocks for winter nutrition, reducing the amount of anthelmintic products used on lambs without compromising lamb final weights, reducing labour at handling and providing increasing economic returns were all advantages that such an approach can provide.

A precision livestock farming approach, which incorporates the use of technology such as in this study, can therefore bring benefits in terms of labour efficiency, anthelmintic control, animal welfare and economic resilience, even when the variation in farmers' practices (high input management or low input management) are taken into account. Provided the initial costs of the associated technology can be met and uptake by the farming community further fostered, precision livestock can make mountain farming systems more labour efficient and resilient. The benefits of using such technology do not simply relate to the UK and Europe; they can relate to other areas of the globe where either EID is now mandatory (such as Victoria Australia from 2016).

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Figure 1. Sheep production year handling events for both CON and PLF management systems (hashed boxes show the targeted management events in the PLF)

Figure 2. Proportion of lamb dosed at shearing, weaning, post-weaning (3 year average across both systems).

Figure 2

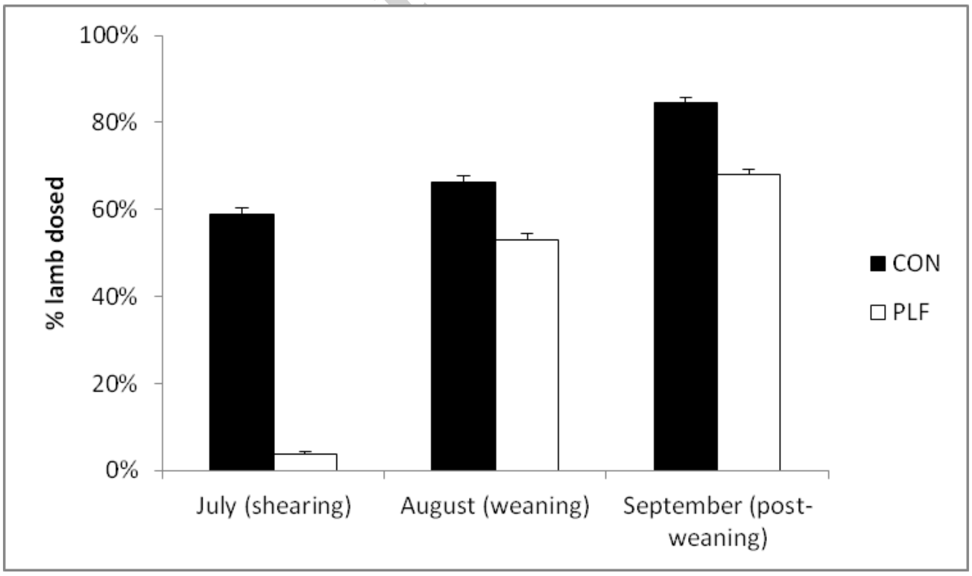

Figure 3. Yearly labour profiles for both study systems (PLF and CON) and for a modelled traditional farm without (Trad-CON) or with PLF (Trad-PLF) – in minute/animal.

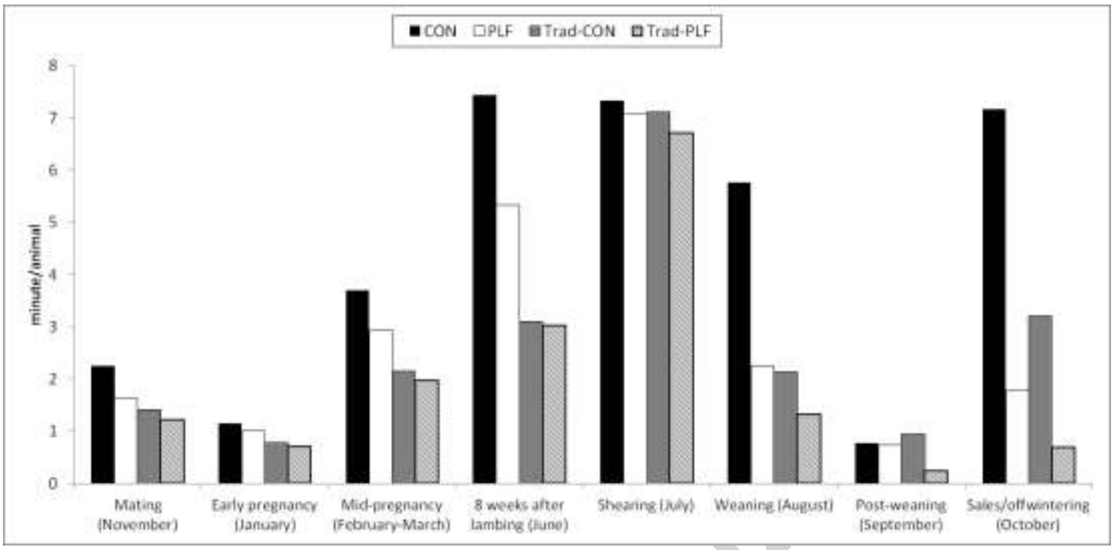

Table 1. List of tasks carried out at each handling event, in the CON and PLF management systems, and grazing locations.

Handling events	**CON**	PLF
Mating (Nov) *On improved and semi-improved pastures*	Gather Manually read ID tag, weigh and condition score Manually sort into mating groups Worm ewes	Gather Automatically read EID tag, weigh and sort into mating groups Worm ewes
Early pregnancy/post-mating (Jan) *On mountain and semi-improved pastures*	Gather Manually sort into feeding groups	Gather Automatically read EID tag, weigh and sort into feeding groups
Mid-pregnancy (Feb-March) *On mountain, semi-improved and*	Gather Ultrasound scanning Manually read ID tag, weigh and condition score	Gather Ultrasound scanning Automatically read EID and sort into pregnancy groups

improved pastures	Manually sort into feeding and pregnancy groups Worm/vaccinate ewes	Automatically read EID, weigh and sort into feeding groups Worm/vaccinate ewes
8 weeks after lambing (June) *On semi-improved and improved pastures*	Gather Worm, ear-notch, castrate, vaccinate lambs Manually read ID tag and weigh lambs Manually read ID tag and weigh ewes Mother -up	Gather Worm, ear-notch, castrate, vaccinate lambs Automatically read ID tag and weigh lambs Automatically read ID tag and weigh ewes Mother -up
Shearing (July) *On semi-improved, improved and mountain pastures*	Gather Faecal Egg Count (FEC) lambs Manually sort into lamb worming groups Worm lambs based on FEC Shear ewes	Gather Automatically read EID, weigh, sort lambs in to worming groups Worm lambs based on weight assessment Shear ewes
Weaning (August) *On improved, semi-improved and mountain pastures*	Gather Manually read ID and weigh lambs Manually sort into lamb worming groups Worm lambs + FEC lambs Manually read ID, weigh and condition score ewes Vaccinate ewes	Gather Automatically read EID, weigh and sort lambs into worming groups Worm lambs Automatically read EID and weigh ewes Vaccinate ewes
Post-weaning (Sept) *On improved pastures*	FEC lambs Manually sort lambs into worming groups Worm lambs	Automatically read EID, weigh and sort lambs into worming groups Worm lambs
Sales (lambs) (every 2 weeks from Oct to March) *In shed*	Manually read ID and weigh lambs Manually record lamb ID for sale	Automatically read and record EID and weigh lambs Automatically sort lambs into sale groups and record lamb ID for sale
Sales (ewes) (Sept/Oct) *On semi-improved and improved pastures*	Manually read and record ID and weigh ewes	Automatically read and record EID and weigh ewes

Table 2. Proportion of farmers (%) who carry out the farm tasks at each handling event in the sheep production year.

Handling events	Tasks	Percentage of farmers who carry out the task on their own farm
Pre-mating (Nov)	Gather ewes	94.1%
	Weigh the ewes	5.9%
	Condition score the ewes	52.9%
	Sort ewes in mating groups	78.6%
	Worm ewes	71.4%
Early pregnancy (Jan)	Gather ewes	76.5%
	Condition score the ewes	23.5%
	Weigh the ewes	0.0%
	Sort ewes in feeding groups	29.4%
Mid-pregnancy (Feb-March)	Gather ewes	100.0%
	Ultra-sound scanning the ewes	82.4%
	Weigh the ewes	0.0%
	Condition score the ewes	64.7%
	Sort ewes in feeding/pregnancy groups	76.5%
	Worm ewes	94.1%
	Vaccinate ewes	88.2%
Marking (June)	Gather the animals	88.2%
	Weigh the ewes	0.0%
	Condition score the ewes	17.6%
	Vaccinate ewes	5.9%
	Worm ewes	35.3%
	Treat ewes for ectoparasites	35.3%
	Weigh lamb	5.9%
	Tag lamb	23.5%
	Ear-notch lamb	58.8%
	Vaccinate lamb	29.4%
	Worm lamb	41.2%
	Treat lamb for ectoparasites	58.8%
	Castrate lamb	82.4%
	Tail lamb	58.8%
	Mother up	88.2%
Shearing (July)	Gather the animals	100.0%
	Weigh lamb	5.9%
	Worm lamb	76.5%
	FEC lamb	17.6%
	Treat lamb for ectoparasites	47.1%
	Worm ewes	35.3%
	Weigh ewes	5.9%
	Treat ewes for ectoparasites	35.3%
	Shear ewes	100.0%
Weaning (August)	Gather the animals	100.0%

	Weigh lamb	23.5%
	FEC lamb	17.6%
	Worm lamb	82.4%
	Vaccinate lamb	52.9%
	Weigh ewe	5.9%
	FEC ewe	5.9%
	Condition score ewes	23.5%
	Sort ewes/lambs	70.6%
Post-weaning (Sept)	Weigh lamb	29.4%
	FEC lamb	5.9%
	Worm lambs	41.2%
Sales (lambs)	Weigh lambs	47.1%
(every 2 weeks	Read/record lamb ID	52.9%
from Oct to March)	Send lambs to market	76.5%
	Send lambs to abattoir	11.8%
Sales (ewes)	Weigh ewe	5.9%
(2x main)	Condition score the ewe	52.9%
	Read/record ewe ID	29.4%
	Treat ewes for ectoparasites	58.8%

Table 3. Ewe and lamb performance data (weights in kg with standard deviation (SD), barren, scanning and mortality rates in %, kg lamb/ewe in kg) for the 3 study years, for both PLF and CON management systems.

	2012-2013		**2013-2014**		**2014-2015**	
	CON	**PLF**	**CON**	**PLF**	**CON**	**PLF**
Mating weight (kg ± SD)	51.9 ± 9.9	53.3 ± 8.2	46.9 ± 6.0	46.9 ± 6.7	51.8 ± 6.1	52.4 ± 6.4
Early pregnancy weight (kg ± SD)	48.7 ± 5.8	50.1 ± 5.7	48.1 ± 5.8	48.3 ± 6.0	52.3 ± 6.3	52.7 ± 6.4
Mid-pregnancy weight (kg ± SD)	45.4 ± 11.0	46.3 ± 11.7	47.7 ± 5.9	48.1 ± 6.5	50.7 ± 5.9	51.2 ± 6.1
Number lamb/ewe scanned at mid-pregnancy	1.33	1.35	1.14	1.16	1.33	1.31
Barren rate at mid pregnancy	0.11	0.12	0.18	0.16	0.11	0.12
Pre-lambing weight (kg ± SD)	51.1 ± 6.5	51.6 ± 7.3	51.2 ± 7.1	51.1 ± 7.8	53.3 ± 8.2	54.2 ± 8.5
Ewe 8 weeks post lambing weight (kg ± SD)	46.4 ± 13.5	48.4 ± 11.0	52.2 ± 7.7	51.9 ± 8.0	51.8 ± 6.6	52.2 ± 6.7
Ewe Weaning weight (kg ± SD)	52.6 ± 6.1	52.7 ± 7.0	55.1 ± 7.1	55.2 ± 7.3	53.7 ± 6.8	53.8 ± 7.0
Ewe mortality (%)	6.0	5.2	9.6	6.6	5.2	5.9
Lamb birth weight (kg ± SD)	3.4 ±0.9	3.4 ± 0.9	3.7 ± 0.9	3.6 ± 0.9	3.8 ± 0.8	3.8 ± 0.8

Lamb weaning weight (kg ± SD)	27.2 ± 4.6	27.3 ± 4.6	28.6 ± 4.3	27.3 ± 4.6	28.8 ± 4.6	28.3 ± 4.3
Lamb post-weaning weight (kg ± SD)	29.6 ± 5.0	30.0 ± 5.1	32.3 ± 4.9	31.6 ± 5.2	30.5 ± 5.2	29.9 ± 4.8
Lamb mortality (%) from birth to weaning$	19.7	22.9	14.1	15.8	19.1	16.2
Number of lamb weaned/ewe scanned at mid-pregnancy	0.98	0.86	0.93	0.93	0.98	1.1
kg lamb weaned/ewe mated	23.9	23.7	25.6	23.0	26.1	26.4
kg lamb weaned/ewe scanned pregnant	25.6	25.6	31.2	29.4	29.4	30.0

$includes lamb born dead or aborted

Table 4. Amount of labour (in 8 hours days) required in each management system for every year and on average over the 3 years: in total, at winter feeding and for lamb worming, for all animals, and the amount of labour (in 8 hours days) required in the modelled traditional farm with or without PLF over one year (shown as an average)

	2013	2014	2015	*average*
CON total	42	40	43	***42***
PLF total	26	23	26	***25***
CON winter feeding	4	4	4	***4***
PLF Targeted winter feeding	3	3	3	***3***
CON worming	13	12	14	***13***
PLF Targeted worming	10	8	10	***9***
Trad-CON total*				***48***
Trad-PLF total*				***39***

** modelled for 1200 ewes and 1000 lambs over one year*

Table 5. Net margins (£/head) for the two management systems for the 3 study years.

	2012-2013		2013-2014		2014-2015		AVERAGE	
	CON (£/head)	**PLF (£/head)**	**CON (£/head)**	**PLF (£/head)**	**CON (£/head)**	**PLF (£/head)**	**CON (£/head)**	**PLF (£/head)**
lamb income	£68	£69	£63	£63	£56	£55	£62	£62
ewe income	£35	£31	£43	£42	£46	£44	£41	£39
wool income	£2	£2	£2	£2	£2	£2	£2	£2
total output	***£105***	***£102***	***£109***	***£107***	***£104***	***£102***	***£106***	***£104***
winter feed	£16	£15	£11	£11	£15	£16	£14	£14
finishing feed	£27	£27	£23	£26	£20	£20	£23	£24
off-wintering	£14	£14	£15	£15	£17	£17	£15	£15
health costs	£11	£11	£8	£7	£9	£8	£9	£9
total variable costs	***£68***	***£67***	***£56***	***£59***	***£61***	***£61***	***£62***	***£62***
gross margin ***(output minus variable costs)***	**£37**	**£35**	**£52**	**£48**	**£43**	**£40**	**£44**	**£41**
labour[1]	£15	£10	£16	£10	£16	£11	£16	£10
other fixed costs[2]	£55	£55	£56	£56	£56	£56	£56	£56
total fixed costs	***£70***	***£65***	***£73***	***£66***	***£72***	***£67***	£72	£66
NET MARGIN ***(gross margin minus fixed costs)***	**-£33**	**-£29**	**-£20**	**-£18**	**-£29**	**-£26**	**-£27**	**-£24**

[1] based on contract shepherding, not permanent labour

[2] includes: fuel, rent, buildings costs (electricity, maintenance), fencing maintenance, vehicle repairs, machinery costs, haulage, dead stock.

Highlights

- Precision livestock system targeted approach can be implemented on a mountain sheep farm
- Targeted worming reduces the amount of anthelmintic required without compromising lamb growth
- Precision Livestock Farming did not improve animal (ewe and lamb) performance
- Precision livestock system targeted approach can reduce required on-farm labour by 36%.
- Net margin savings between a conventional and a PLF targeted approach can be up to £3/ewe