HACCP application to worm control in sheep production: playing the GAME

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Introduction

Gastrointestinal nematode (GIN) infection and associated parasitic gastroenteritis (PGE) is arguably one of the biggest challenges for British sheep production, costing an estimated £84 million per annum to the industry (Nieuwhof and Bishop, 2005). In sheep affected by PGE, gastrointestinal tract damage, protein or blood loss and a costly immune response results in observable drops in daily live weight gain, scouring, and in the case of *Haemonchus contortus,* anaemia and increased mortality (Coop et al., 1982, Coop and Kynazakis, 1999, Sargison 2009, Mavrot et al. 2015) (Figure 1 and 2). Although infected lambs may still achieve 110 g/day growth (Kenyon et al., 2009) this is below their potential resulting in delays to finishing time (Miller et al., 2012), delayed onset of puberty in breeding ewe lambs and, in some cases, permanent stunting. Furthermore, PGE can result in a 10.4% reduction in carcass value (Miller et al., 2012). Ineffective treatment of PGE has been demonstrated to result in 60-100% drops in growth relative to effective treated animals (Sutherland et al., 2010).

Historically, anthelmintics have played a central role to management of PGE (Miller et al. 2012). However, effective control now requires a more thoughtful approach in the face of multiple challenges. First and foremost, dependency on anthelmintic products and misuse has led to the development of anthelmintic resistance (AR). It is hoped that headline figures showing extremely high prevalence of AR (Box 1) will drive home the message that this is not simply something that happens to 'other farmers'; that AR is widespread; and, despite the fact that it may not be causing visible reductions in productivity on most farms, sustainable use of anthelmintics is required to preserve their efficacy and prevent deterioration to the point where performance and welfare are compromised.

BOX 1: Anthelmintic resistance (AR) in sheep in the UK

Ten percent of farmers surveyed felt there was evidence of failure of anthelmintic efficacy in their flocks, but this is likely to be a gross underestimate (Morgan et al., 2009). Resistance is currently defined as a post-treatment faecal egg count (FEC) reduction of less than 95% (see Coles et al., 1992 for protocol) but clinically obvious failure, i.e. poor resolution of clinical signs post treatment, will only become apparent when treatment efficacy is less than 85% (Abbott et al., 2012), by which point anthelmintic performance is severely compromised, with little chance of preserving useful efficacy of that drug class. The true prevalence of AR in the UK is unknown, but some regional surveys are available (see table below).

	Percentage of farms with evidence of AR

Anthelmintic	Wales Autumn/Winter 2014 (Thomas et al., 2015)	Wales Spring/Summer 2015 (Thomas et al., 2015)	Devon 2013 (Glover et al., 2017)
1-BZ (benzimidazoles)	89% (n=25)	100% (n=30)	96% (n=24)
2-LV (levamisole)	68% (n=19)	73% (n=22)	60% (n=15)
3-Macrocylic Lactone (ML) IVM (ivermectin)	25% (n=7)	70% (n=21)	67% (n=18)
3-ML MOX (moxidectin)	18% (n=5)	30% (n=9)	N/A
Multiple drug resistance	68% (n=19)	90% (n=27)	84% (n=21)

Worryingly, multiple drug resistance was detected on the majority of farms surveyed in Devon (Glover et al., 2017) and Wales (Thomas et al., 2015). Overall, 19% of Welsh flocks surveyed had evidence of triple resistance and moxidectin resistance i.e. 1-BZ, 2-LV and 3-ML (ivermectin and moxidectin) resistance (Thomas et al., 2015). Ivermectin and moxidectin do overlap in mechanism of action but resistance mechanisms are not entirely homogenous between the two, hence why resistance for each is considered separately (Prichard et al., 2013). There have been documented cases of monepantel resistance in New Zealand (Scott et al., 2013) and the Netherlands (van den Brom et al., 2015) and the first case of monepantel resistance was diagnosed in the UK in 2018 (Hamer et al., 2018). [END OF BOX 1]

Second, there are broader environmental implications of PGE and AR beyond the farm gate, which are becoming increasingly important to both producers and consumers as environmental awareness increases. Sheep production is responsible for an estimated 52% of all agricultural emissions in Scotland and PGE was identified as one of the 'top 3' diseases with a significant impact on greenhouse gas emissions in the livestock sector, based on its impact on growth and feed conversion rates (Bartley et al., 2016). In addition, the impact of anthelmintics on dung fauna and knock-on effects at higher trophic levels is well-documented (Floate et al., 2005). Repeated, ineffective treatments, either due to user error or exacerbated by AR, have the potential to contribute to increased environmental impacts associated with PGE control.

HACCP: Risk-based PGE management planning

Overall, these challenges highlight the necessity for growth rate performance as a key driver of environmentally efficient production, and equally the necessity for solutions to be practical and accessible by commercial sheep producers. Risk assessment and management

planning (RAMP) approaches to disease management are commonly used to retrospectively identify disease challenge and risks, and implement corrective action (McAloon et al., 2015). However, RAMP is largely based on recollection by farmers of risk to their production process, is often confined to a single temporal point of assessment, i.e. annual review, depends on good record-keeping of mortality and growth rates, and is typically applied after disease becomes an issue. The conditions are therefore often not in place for effective application of RAMP to sustainably manage AR. HACCP (Hazard Analysis and Critical Control Points) is an alternative risk-based and process-driven approach which involves proactive monitoring with defined end points (Box 2).

HACCP Principles and application guidelines (adapted from FDA 1997)

1. Conduct a hazard analysis
   a. Define the production process e.g. lamb production from tupping to leaving the farm
   b. Define which hazard we are trying to avoid and mitigate e.g. drops in daily liveweight gain (DLWG) due to PGE.
2. Determine the critical control points (CCPs) i.e. opportunities to influence/protect DLWG through minimising exposure to GIN infection. CCPs are steps at which control can be applied. This is essential to prevent or eliminate a hazard or reduce it to an acceptable level. CCP decision trees should be developed in order to restore deviations from predetermined ranges to within normal 'safe' parameters.

3. Establish a framework for:
   a. Critical limits i.e. what is acceptable for DLWG?
   b. Monitoring procedures i.e. how are we going to establish that infection is present?
   c. Record keeping and documentation procedures
4. Establish corrective actions i.e. how are we going to mitigate infection if present? Corrective actions should take into account the existing flock management calendar and any flexibility within this to ensure actions are practical.

Establish verification procedures, i.e. how are we going to evaluate what we have done is working? These should be activities, other than monitoring, that determine the validity of the HACCP plan and ensure that the system is operating according to the plan.

HACCP in practice

HACCP was developed for use in food safety but has been adapted for primary production such as bovine Johne's disease (McAloon et al., 2015), bovine mastitis control (Noordhuizen and Frankena, 1999), bovine lameness control (Bell et al., 2009), trematode management in aquaculture (Clausen et al., 2015), tapeworm control in sheep (Gascoigne and Crilly, 2014) and ovine abortion (Crilly and Gascoigne, 2016). Here we apply the HACCP model to the process of fat lamb production with the end goal of minimising losses in daily live weight gain (DLWG) through improved control of PGE (Box 2; Figure 3). The hazard in this case is 'exposure to worms'.

Developing a PGE management plan or discussing improved PGE management with a client using the HACCP model is a stepwise process (see above and Box 2) which aids in understanding the production process, points where the risk of exposure to infection can be manipulated (critical control points; CCPs), and sustainable corrective actions at these CCPs using the GAME strategy described below, which focus place anthelmintic use as the final

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option for control (Box 2). SCOPS guidelines (Abbott et al.,2012) and good farming practices should be the cornerstone of corrective actions and CCPs. When prevention cannot be achieved, corrective measures will need to be introduced and this may necessitate revising flock health plans. The GAME approach is based on an adaptation of the founding SCOPS four principles of PGE management i.e. making sure that any treatment is fully effective, reducing reliance on anthelmintics using management and monitoring, quarantine and minimizing selection for resistance when treating, and best practice when administering treatment (Figure 4). Data and record keeping on farm is a prerequisite i.e. through medicine book recording for meat withdrawal purposes and sheep movements. However, vets should think outside the box for performance data i.e. look at finishing profile of lambs - what is the average days to finish? This may help estimate overall daily live weight gains retrospectively and assess overall efficacy of the HACCP process.

Box 2: **HACCP & GAME quick reference**
Step 1: **HA** - Hazard identification
Step 2: **CCP** - Critical Control point identification
Step 3: Framework for critical limits, monitoring and record keeping
Step 5: Corrective actions
      G - General health & Genetics
      A - Avoidance
      M - Monitoring
      E - Effective & Efficacious treatment
Step 6: Verification
[END OF BOX 2]

Corrective actions: GAME

Having identified practical CCPs, there are four key areas which could be addressed to minimise the impact of disease. These four areas, if sequentially considered, place administering oral anthelmintics as the *final* option for management, after making maximum use of the alternatives.

G – General health & genetics
Poor general health and nutrition of the flock will undermine immune status, increasing susceptibility to disease. Trace element status, nutritional status and endemic diseases will contribute towards increased worm egg shedding (Sargison et al., 2007, Coop and Holmes, 1996, Wallace, 1996). Dietary supplementation with metabolisable protein pre-lambing has been shown to dampen peri-parturient worm egg shedding in ewes (Houdijk et al., 2000) and Vipond (2010) found that providing 100 g Digestible undegradable protein (DUP) per lamb in late pregnancy can significantly reduce worm egg shedding in the peri-parturient period and enhance ongoing lactational performance i.e. enhancing lamb daily live weight gain. The use of bioactive forages has been explored by various authors with mixed results (Hoste et al., 2006, Suttle, 2010).

Genetically resilient and/or resistant sheep (Bisset et al., 2001; Jackson et al., 2009) may also enhance the ability of sheep to perform under worm challenge. Resistant sheep control worm egg production by mounting an immune response, whereas resilient sheep might have a degree of tolerance to PGE, growing in the face of high burdens but continuing to shed eggs (Jackson et al., 2009). Such sheep could potentially be identified and selected for breeding under conditions of high infection pressure either for resilience using DLWG EBVs (estimated breeding values) and breeding policies with positive growth despite high infection pressure, or for resistance using FEC EBVs to identify those shedding fewer worm eggs or IgA EBVs (Shaw et al., 2012). Over time, selecting for resistance could reduce the susceptibility of the flock to PGE while reducing pasture contamination and ongoing exposure to infection, thus reducing need to use anthelmintic whilst maintaining growth.

The role of vaccination of sheep against GIN is developing with a commercially available vaccine for *Haemonchus contortus* available in Australia and South Africa (Barbervax®, Wormvax Australia Pty Ltd) and trial work published supporting the efficacy of subunit vaccines in reduced ewe shedding of *Teladorsagia cirumcincta* eggs at the time of lambing (Nisbet et al., 2016). However, it is unlikely that these vaccines will achieve a greater than 90% reduction in egg counts and as a consequence, whole flock strategies are still necessary (Matthews et al., 2016).

A – Avoidance
Understanding the epidemiology of infection and development of immunity is essential for avoidance-based strategies on farm, which rely on grazing high risk animals on the lowest risk grazing and forward planning to enable ongoing avoidance of such pastures. Strongyle eggs can survive on pasture for more than 12 months (Rose, 1961) and pre-existing burden should be considered when assigning risk to pastures. Knowing where previous high risk shedding classes of stock have been enables risk to be assigned to pastures (Figure 5).

Recording "where" and "when" strongyle burdens are greatest on farm by monitoring movements enables avoidance of infection (Box 3). Grazing vulnerable lambs on high risk pasture will undermine productivity and growth, necessitating high drench usage in order for

production to continue (Figure 2; Coop et al., 1982). FECs and weather-based disease alerts can also feed into pasture-mapping and risk monitoring (Box 3). For example, pastures assessed as high risk based on contamination by growing lambs shedding *Nematodirus* eggs (identified in FECs) the previous year can be avoided when *Nematodirus* risk is predicted to be highest and lambs are most vulnerable to infection (Figure 6).

Avoidance strategies also extend to buying in anthelmintic resistant GINs with new stock. Morgan et al., (2012) found that 35% of flocks surveyed were buying in sheep but only 17% quarantined as a standard procedure. Treatment with a new derivative and a sheep scab control is 'gold standard' quarantine practice (SCOPS, 2016). It is imperative that all advisors are regimented and consistent in delivery of this advice. Total new derivative usage in 2015/2016 accounted for 1% of total drench usage (SCOPS, 2017) a fraction of the likely number of sheep moving premises? in the same period.

M – *Monitoring*

Having planned a strategy based on having high risk lambs on the lowest risk category of grazing available (Figure 5; Box 3), ongoing monitoring and review of avoidance strategies is essential to evaluate efficacy, ongoing performance and to establish if treatment is necessary.

Monitoring daily live weight gain (Figure 7) in lambs although not very specific for parasitic disease, is by far the most sensitive. If performed regularly it will identify early drops in performance before significant damage to the gut lining has occurred and before irreparable stunting. The disadvantages to such a method is the potential high labour inputs especially if labour saving technology is not utilised for weighing and data recording (Figure 7). Large flocks, however, can often justify the cost of investment based on PGE-associated losses in performance, and labour saving solutions such equipment offers. Such monitoring will identify drops in group performance as well as individuals and generate opportunities for targeted selective treatment protocols (Stear et al., 2009, Kenyon et al., 2009, Busin et al., 2014,) further reducing overall drench usage. A review of key phases of growth is described by Gascoigne and Lovatt (2015).

When used alongside other diagnostic tools such as FECs (Figure 8) we will improve the specificity of DLWG monitoring which may highlight other challenges for performance such as nutritional deficits, underlying trace element deficiencies etc. FECs give an indication of burden and can be used regularly to monitor worm egg shedding throughout the growing season to target treatments, evaluate anthelmintic efficacy and record pasture contamination. They are easy to perform and can be offered by technical solutions such as FecPak® (Technion Group, Aberystwyth, Wales) or by veterinary practices. However, sample collection and handling techniques are critically important to generate robust, repeatable results (Abbott et al., 2012, Morgan et al., 2005, Crilly and Sargison, 2015) and correct interpretation requires engagement with a veterinarian or qualified adviser. FECs will vary across groups and pastures, and care should be taken when applying single FEC counts across an age category or a whole farming enterprise. Finally, there will be delay between infection, gut inflammation and egg production and pre-patent disease cost will be missed by FECs e.g. nematodirosis.

Finally, monitoring can incorporate clinical signs e.g. dag scoring (Figure 1), evidence of ill thrift, and visible drops in body score in lambs. We suggest that this is undesirable with high levels of subjectivity, and substantial drops in daily live weight gain before this is

recognisable. Relying solely on such indicators is likely to be highly inefficient with both economic and environmental costs accumulated in the interim with increased days to finishing and in instances of severe disease burdens, mortality (Sargison, 2009). Evidence of clinical disease indicates failure of the checks and balances already in place.

E – Effective and Efficacious treatment

Once a group is identified with evidence of PGE, despite avoidance, monitoring and attention to general health, targeted treatment of affected groups of animals is warranted. Treatments should adhere to the SCOPS principles (Abbott et al., 2012, www.scops.org.uk) and farmers should be made aware of the 5 R's for effective treatment (Figure 4). Drench usage can be reduced further by using targeted selective treatments i.e. treating those individuals with evidence of disease such as drops in DLWG, without having a negative effect on performance (Kenynon et al., 2010, Learmount et al., 2015, Busin et al., 2014). This is a significant change in rhetoric for many farmers and vets and may be impractical for some flocks to achieve without accurate record keeping.

Given the high prevalence of AR (Box 1), the AR status of a farm should be checked at intervals to ensure that only efficacious anthelmintic classes are used. This can be assessed using pre- and post-treatment FECs and checking for >95% reduction or by checking post-drench samples for presence of <50 eggs per gram. However, the limitation of the latter method is inability to assess percentage reduction and reliance on a high pre-treatment FEC. Nevertheless, routine post-drench checks should be encouraged, even if the pre-treatment FEC is unknown. Readers also need to be aware that resistance profiles may vary between strongyle species on farm and therefore within season due to the seasonal succession of nematode species within the hosts (e.g. Thomas et al., 2015, Box 1) and even between areas on a farm. Speciation and repetition will enable practitioners to decipher if variation occurs between different times of year and equally if drenches retain efficacy depending on species. This understanding should be built up over time, by integrating drench checks into routine flock health monitoring.

Equally, the new derivatives Monepantel (Zolvix®- Elanco Animal Health) and Deraquantel/Abamectin Dual Active (Startect®- Zoetis Animal Health)) have a role to play as mid-late season knock-out/break-dose drenches. Every time any anthelmintic is utilised on an animal, its gut strongyle population is skewed so that only resistant worms survive to contaminate pasture. Over the season and as multiple drenches are utilised, there will be a selection pressure for and accumulation of the resistant population. Mid-late season treatment of remaining lambs on farm, aims to remove these worms, preventing continued pasture contamination by these resistant strains. At that time of year, there is likely to be a substantial on-pasture *refugia* hence reducing the risk of development of new derivative resistance due to dilution of any resistant strains developed. In a scenario where a low drench dependency management system has been developed and a targeted minority of lambs have been treated, break-dosing/mid-late season knock-out drenching may not be necessary, but where sequential treatments have been used, modelling has demonstrated that this targeted treatment can slow resistance (Leathwick and Hosking, 2009). Combination anthelmintics may also slow the development of resistance if the pre-existing levels of resistance are low and there are sufficient parasites in refugia (Bartram et al., 2012, Leathwick et al., 2012).

Box 3: Pasture avoidance for parasite management

Understanding where high levels of infection are found on the farm permits grazing rotations to be designed to avoid parasite burdens. Risk assessments should be performed periodically throughout the production year. Highest risk animals, i.e. fast growing lambs, should be placed on lowest risk pastures available.

Pastures can be referred to as high risk (red), medium risk (amber) or low risk (green) pastures and practical application could be assigning risks to ordnance surveys maps of the farm at flock planning meetings (Figure 5 and 9) .

INSERT FIGURE 9*

The pasture risk assessment approach can be extended by incorporating FECs to assess the magnitude of contamination, and therefore risk, on each pasture. These risk assessments also evaluate the scale of the on-pasture refugia population which should highlight and emphasise the importance and risks associated with dose and move (Abbott et al., 2012) and be used to adjust treatment schedules where appropriate. For example, leaving a proportion of the flock untreated is especially important if they are to be moved to low risk pasture to ensure a population of worms in refugia within the sheep are available to mitigate the lack of significant on-pasture refugia. Furthermore, mathematical models predicting GIN population dynamics and risk of infection, such as the *Nematodirus* forecast (Figure 6; Gethings et al., 2015, www.scops.org.uk) and *Haemonchus contortus/Teladorsagia circumcincta* models (Rose et al., 2015) can be integrated with the pasture-mapping exercise and regularly reviewed in conjunctions with FECs and grazing history to inform pasture-level risk assessments.
[END OF BOX 3]

Summary and conclusion

Parasitic gastroenteritis and anthelmintic resistant PGE are a significant threat to the productivity of commercial sheep flocks in the UK. This risk is rapidly escalating and veterinary surgeons have a central role in its management.

This necessity for engagement is emphasised by other bodies in the sector such as the National Sheep Association and the Farm Animal Welfare Council (FAWC). Given the broader implications of anthelmintic resistance, FAWC'S 2016 report stresses the importance of knowledge sharing and improving performance will create a "margin for care" and permit reinvestment (FAWC, 2016).

As flock planning advisors we need to be clear about the aims of management plans on farm i.e. our aim is efficient and rapid growth on lambs on farm, and PGE is a significant threat to that. We have described a framework for flock-wide discussion of PGE and key strategies which should be utilised at each critical control point highlighting that chemical control should be utilised only after a series of avoidance strategies have been put in place, monitored and found to be necessary.

The veterinary surgeon's ability to understand and deal with this integral limiter of performance by using a flock-wide approach including nutrition, infectious disease, trace element status, best practice and evidence-based medicine places us as veterinary surgeons in a unique position to facilitate management of PGE. The challenge for many practitioners is the initial development of a proactive working relationship, but the evidence for necessity is compelling, the real-life farm case study evidence mounting and the threat of uncontrolled AR rapidly becoming a reality.

Images
Figure 1: Ewe with signs of scouring
Scouring and increased dag score can indicate PGE. Evidence of advanced stages of PGE, i.e. slowed growth and drops in weight, significant scouring, increased dag score, is undesirable as a monitoring tool because affected individuals are likely to have significant damage to their gastrointestinal tract and delayed finishing times, incurring a large cost to the flock and may constitute a welfare issue.

Figure 2: This needs a title and looks like a print screen from a previous published article. Needs to be acknowledged

Figure reproduced with permission from Coop, R.L., Sykes, A.R. & Angus, K.W. (1982) The effect of three levels of intake of *Ostertagia circumcincta* larvae on growth rate, food intake and body composition of growing lambs. *The Journal of Agricultural Science* **98**, 247-255.

Significant costs of PGE are associated with drops in DLWG performance and increased time to finishing. Infection with worms results in drops in appetite and a costly gut inflammatory response. Even if we deliver regular, routine and effective treatments there will still be a cost of exposure to worms, hence the need for avoidance strategies. The cost of exposure was demonstrated by Coop et al., 1982 where increasing exposure to infective larvae resulted in slowed growth rates that could not be mitigated by anthelmintic treatment. Lambs in 5 groups were exposed to zero (ad libitum control group, ALC), 1000 (group 1), 3000 (group 2), 5000 (group 3) and 5000 (group 4) infective larvae of *Teladorsagia circumcincta*. Lambs in group 4 received an effective anthelmintic treatment every 21 days. Although the performance of group 4 was better than group 3, the lambs did not achieve the DLWG performance of the clean group (ALC), despite anthelmintic treatment, and their performance was similar to that of group 2. This highlights the necessity of avoidance of exposure to high levels of infection, and not just regular anthelmintic treatment *in situ*.

Figure 3: HACCP application to a flock health calendar.
Notice key points for intervention in the production cycle. The hazard, Gastrointestinal nematode(GIN) infection, resulting in reduced weight gain, was identified and the production system, with key management events, was defined on the calendar. A system for record keeping and monitoring was put in place. Critical control points (CCPs), shown highlighted in green, were identified. These are points at which the hazard (infection) can be eliminated, prevented, or reduced to acceptable levels. For example, purchasing stock presents a hazard (buying in worm species not present on farm, or buying in Anthelmintic resistant GINs), which can be mitigated by correct quarantine procedures. For each CCP, corrective actions are identified using the GAME strategy. Finally, options to verify control throughout the year and at the end of the year were identified and put in place, shown in orange.

Figure 4: The principle of 5 'R's outlining best practice for anthelmintic treatments (adapted from the COWS 5 R's; cattleparasites.org.uk).

Choosing the right product includes using a product that is effective (established through regular testing for AR) and suitable for the parasite burden of the flock. Treating the right animal can include, for example, avoiding unnecessary treatment of ewes, and by extension, targeted selective treatment of lambs based on DLWG and/or FECs. Treating at the right time includes monitoring to identify the optimal timing for treatment. Administering the right dose rate includes dosing to the correct weight of the individual (or heaviest in the group) and calibrating equipment. Administering treatment in the right way includes the correct drenching technique or injection site. (Drench gun image courtesy of Alice Geddes).

Figure 5: Guidelines for classifying pasture according to risk of gastro-intestinal nematode infection, adapted from AHDB (2016). This may need rewording – I think this is the Nematodirus forecast system – so does the map illustrate Nematodirus risk or all nematodes risk?

Some farmers use the SCOPS *Nematodirus* forecast to predict infection high risk windows and treat lambs or avoid high risk pastures as necessary.

Figure 6: Lambs being weighed using an automated weigh crate attached to an auto-drafter.

Lambs not meeting pre-determined DLWG targets can be drafted for further investigation and/or treatment. This technology can be used to facilitate Targeted Selective Treatment protocols (Stafford et al., 2009, Kenyon et al., 2009) but may not be cost-effective on smaller units. It may be used to reduce necessity for whole group treatment in large flocks and facilitate effective treatments, i.e. with accurate weights for lambs.

Figure 7: Examples of worm eggs (*Nematodirus battus*, trichostrongyle, *Strongyloides papillosus* and *Moniezia expansa*) found in routine faecal egg counts.

Regular screening is essential for early identification of parasitic gastroenteritis caused by trichostrongylid nematodes (e.g. *Haemonchus contortus, Teladorsagia circumcincta, Trichostrongylus colubriformis)* as a likely cause of poor performance. However, in some cases, prepatent infections can cause disease, especially in cases of nematodirosis and on heavily contaminated pastures. Prepatent infection will not be picked up by fecal egg counts.

Figure 8: Example of an exercise in pasture-mapping conducted as part of Flock Health Clubs (www.flockhealth.co.uk).

Pasture plots/fields are clearly labelled by name (or arbitrarily as Field A, B, C etc. in this example) on a map of the premises. Each field is also labelled with grazing history, which is used to assign risk levels. An explanation of the risk level assigned is given. Further details on low, medium and high risk pasture is provided by ADHB (2016). Pasture-mapping can be extended to include fecal egg count history to identify fields which received higher levels of contamination than others due to high egg counts at the time of grazing (Box 4). In addition, weather-based predictions of infection risk based on parasite life-cycle (such as the SCOPS *Nematodirus* forecast; Figure 5) can further enhance the risk assessment.

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