REVIEW OF SHEEP PARASITE CONTROL MEASURES WITH REFERENCE TO CLIMATE CHANGE

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1. INTRODUCTION

Climate predictions indicate that the world is becoming warmer, and more humid. As well as having implications for extreme weather, affecting the geographical distribution and maximum intensity of rainfall predicted changes in turn have a direct effect on microclimates, which are the distinctive climates of a small-scale area, and can vary considerably even in one locality. The weather variables in a microclimate, such as temperature, rainfall, wind or humidity, may be subtly different to the conditions prevailing over the area as a whole and it is the amalgam of many, slightly different microclimates that actually makes up the climate for a certain area. For many parasitic diseases whose developments outside the definitive host are sensitive to temperature and humidity, any changes in microclimate will theoretically have profound effects on parasite epidemiology. Predictions of far-reaching effects of climate have been made on, for example, a range of arthropod-borne diseases worldwide. However, evidence of systematic changes in the epidemiology of parasites of grazing livestock that can be ascribed to changes in temperature and rainfall patterns, has yet to be scientifically proven, despite increasing anecdotal evidence of such events occurring.

Control strategies currently employed in most sheep flocks, particularly for internal (endoparasite) parasite control, are still based on a ‘blue-print’ approach. These have the advantage of being easy to plan and record, are relatively cheap and historically, have been effective. However, some elements of these strategies are highly selective for the development of parasite resistance. As a consequence, guidelines, and revised worming strategies, have been produced under the auspices of SCOPS (Sustained Control of Parasites in Sheep), aimed at reducing the selection pressure particularly for anthelmintic resistance, in an attempt to change farmer practices and attitudes. Many existing parasite control strategies are based on research, which is more than 30 years old. In that time there have been significant changes in the size and structure of the sheep industry, the epidemiology of the parasites and the antiparasitic products available. For these reasons, there has been a ‘need for change’ in conventional parasite control strategies.

Against this background, there have been noticeable observed changes in the epidemiology of many common sheep parasites in recent years. It is not clear if these are due to the changes in production systems, through enforced legislative changes brought about by consumer, public and environmental concerns, or through observed changes in weather patterns increasing parasite prevalence and distribution. What is clear, however, it that both present and future parasite control strategies will need to take factors such as climate change, into account if they are to remain effective.

It is the intention of this review to focus on the important parasitic infections of British sheep and the potential impact of predicted and observed climatic changes on the parasite life cycles, their epidemiology, changes in prevalence and consequential effects on welfare and production. For this purpose, the parasites affecting sheep will be considered under two headings: endoparasites (internal parasites) and ectoparasites (external parasites).

Climate change also increases the risk of introduction and establishment of parasitic infections currently considered exotic to the UK, through international trade in livestock, particularly within the European Union (EU), but also within a widening global market and some of these risks will be identified and considered briefly within the review.

As well as considering climatic changes and the direct effects these may have on parasite incidence and control, the review will also consider any potential beneficial effects, for example, improved grass growth and nutrition. Additionally, climate change may necessitate fundamental changes in sheep husbandry and management that may impact on current control strategies. These issues will be discussed further in section 7 – Climatic Effects on Parasite Epidemiology and Control.

2. CLIMATE CHANGE

Global warming predictions suggest that mean global temperatures are likely to rise between 1.1 and 6.4°C (with a best estimate of 1.8 to 4°C) above 1990 levels by the end of this century. Current theories on global warming revolve around greenhouse gas emissions, which have accumulated in the atmosphere and intensified the greenhouse effect by absorbing more of the thermal radiation emitted by the land and ocean. Predictions based on these theories suggest that we will see ten-year periods, both globally and regionally, with little or no warming and other ten-year periods with very rapid warming.

(Source: Met Office *http://www.metoffice.gov.uk/climatechange*)

Since 1900 mean global temperatures have risen by nearly 0.8°C, much of it over the past 50 years, with the 17 warmest years on record all occurring in the last 20 years. Data for the UK shows a continued temperature warming of 0.1 °C per decade, such that during the 20th century, the annual mean central England temperature warmed by about 1°C. The 1990s were about 0.6°C warmer than the 1961-1990 average period, according to historical standards Central England Temperature (CET) records dating back to 1659 (Parker et al. 1992).

Prediction scenarios suggest that average annual temperatures across the UK may rise by between 2° and 3.5°C by the 2080s, with the degree of warming dependent on future levels of greenhouse gas emissions. It is predicted that in general there will be greater warming in the south and east than in the north and west of the UK and that higher summer temperatures will become more frequent, whilst very cold winters will become increasingly rare.

It is also predicted that not just temperatures will change, but also the amount and frequency of rainfall. Winters are expected to become wetter, while summers may become drier across all of the UK. Again the predictions are that the largest relative changes will be in SE England where summer rainfall may decline by up to 50 per cent by the 2080s. Heavy winter rainfall will become more frequent, but the amount of snow could decline by 90 per cent by the 2080s.

3. ENDOPARASITES OF SHEEP

The most important endoparasitic diseases seen in sheep are parasitic gastroenteritis (PGE) caused by a range of gastrointestinal nematodes; fasciolosis caused by the liver fluke, *Fasciola hepatica*, and coccidiosis caused by protozoan parasites of the genus *Eimeria*. Other internal parasitic infections seen in sheep include cryptosporidiosis, adult tapeworms and several metacestodes (intermediate tapeworm species), lungworms, and nasal bots (insect larvae of the family Oestridae).

3.1. HELMINTHS

3.1.1. PARASITIC GASTROENTERITIS

There are over 20 different species of gastrointestinal (GI) nematodes of sheep commonly found in British sheep (Table 3.1.).

Table 3.1. GI Nematodes of British Sheep

Species	Comments
Abomasum	
Haemonchus contortus	Barber's Pole worm' 1.5 -3.0 cm long and stout. Sporadic blood feeding nematode causing anaemia
Telodorsagia circumcincta *Ostertagia trifurcata* *Teladorsagia davtiani*	'Small brown stomach worm' 0.8-1.5 cm. "Ostertagian" parasites are considered 'morph' species. Common infection of sheep causing diarrhoea and weight loss.
Ostertagia leptospicularis *Skrjabinagia kolchida*	Ostertagian parasites of deer affecting domestic ruminants
Trichostrongylus axei	'Stomach hair worm' 0.3-0.6 cm. Common parasite of ruminants and equids
Small Intestine	
Bunostomum trigonocephalum	Potentially pathogenic hookworm – relatively uncommon in sheep
Capillaria longipes	'Hairworm'. Common infection of no clinical significance
Cooperia curticei	Common infection of sheep and significant cause of disease
Cooperia oncophora	Parasite of cattle also affecting sheep
Moniezia expansa	Common tapeworm of sheep
Nematodirus battus	Can cause disease, high mortality in young lambs
Nematodirus filicollis	Common infection and occasionally significant cause of disease in sheep
Nematodirus spathiger	Common and occasionally significant cause of disease in sheep
Strongyloides papillosus	'Threadworm'.May cause clinical disease in 2-6 week old lambs.
Trichostrongylus colubriformis *Trichostrongylus vitrinus*	'Black scour worm' 0.4 – 0.9 cm. Common infections of sheep and significant causes of disease.
Large Intestine	
Oesophagostomum venulosum	'Large bowel worm'. Common infection but low pathogenicity.
Trichuris ovis	Common but usually of no clinical significance.
Chabertia ovis	'Large mouthed bowel worm'. Usually moderate and insignificant infection.
Skrjabinema ovis	Very common 'pinworm' parasite of goats also affecting sheep

3.1.2 Liver Fluke

Liver fluke disease (fasciolosis) is caused by the trematode parasite *Fasciola hepatica*. Disease can result from the migration of large numbers of immature flukes through the liver, or from the presence of adult flukes in the bile ducts, or both. Liver fluke can infect all grazing animals (and man) but mainly affects sheep and cattle. It is most pathogenic in sheep. The incidence of liver fluke disease is greatly influenced by the weather, particularly rainfall, and as such the disease is more commonly seen in the wetter western areas of Britain.

3.1.3. Lungworms

Sheep are infected with a number of lungworm species, the most important being D*ictyocaulus filaria*. Several species of metastrongylid lungworms also occur in sheep and include *Protostrongylus rufescens*, found in the small bronchi, *Muellerius capillaris*, *Cystocaulus ocreatus* and *Neostrongylus linearis* all of which are present in the lung parenchyma forming small nodules.

3.1.4. Tapeworms

Tapeworms are mainly of importance as the intermediate larval stages in sheep. Adult tapeworms (*Moniezia* spp.) are common parasites of the intestines of sheep and are frequently diagnosed because of the presence of segments in the faeces. Their presence is usually of no consequence.

Intermediate stages of *Taenia* spp. may harm the host e.g. *Multiceps* (*Taenia) multiceps,* found in the brain (*Coenurus cerebralis*), causing 'sturdy' or 'gid' in sheep. Others such as *Echinococcus granulosus* (hydatid) found in the lungs and liver may be important in public health.

3.2. Protozoa

3.2.1 Coccidiosis

Eleven species of *Eimeria* have been identified in sheep, distinguished primarily on the morphology of the infective stage, the oocyst. Each stage of individual coccidial species has its preferences as to which cells it infects and which parts of the gut it infects. Those infecting the posterior part of the intestine tend to be more harmful. Although the majority of sheep, particularly those under one year old, carry coccidia only two species (*E. crandallis* and *E. ovinoidalis*) are known to be highly pathogenic.

Table 3.2. Species of Coccidia in Sheep

Species	Prediliction Site	Prepatent Periods (Days)
Eimeria ahsata	Small intestine	18 - 30
Eimeria bakuensis	Small intestine	18 - 29
Eimeria crandallis	Small and large intestine	15 - 20
Eimeria faurei	Small and large intestine	13 - 15
Eimeria granulosa	Unknown	?
Eimeria intricata	Small and large intestine	23 - 27
Eimeria marsica	Unknown	14 - 16
Eimeria ovinoidalis	Small and large intestine	12 - 15
Eimeria pallida	Unknown	?
Eimeria parva	Small and large intestine	12 - 14
Eimeria weybridgensis	Small intestine	23 - 33

3.2.2 Cryptosporidiosis

Recent molecular characterisations have shown that there is extensive host adaptation in *Cryptosporidium* and many animal species have host-adapted genotypes, which differ in both DNA sequences and infectivity. The main species found in sheep is *C. parvum*, although other species/genotypes have been reported.

3.2.3 Babesiosis

Two species of *Babesia* have been reported in sheep throughout Europe but have not been reported in UK sheep, despite the presence of reported *Babesia*-infected tick species (*Haemaphysalis punctata*) in Wales.

Further details on the life cycles, clinical signs and epidemiology of these helminth and protozoal diseases are provided in Appendix I.

4. ECTOPARASITES OF SHEEP

Many ectoparasites of sheep are commonly found in Britain, the most important of which are shown in Table 4.1. All ectoparasites are arthropods belonging to two major classes namely the Insecta (insects) and the Arachnida. Within the class Arachnida, members of the sub-class Acari (sometimes also called Acarina) containing the mites and ticks, are of veterinary importance.

Table 4.1. Important ectoparasites of sheep in the UK

Parasite Class	Parasite Species	Common Name	Comments
Acarina			
Mites	*Psoroptes ovis*	Sheep scab	Acute or chronic allergic dermatitis causing serious economic loss and welfare problems
	Sarcoptes scabei	Head scabies	Not reported in Britain for over 30 years
	Chorioptes bovis	Foot mange	Common infection on the feet
	Demodex ovis	Follicular mange	Rare commensal
Ticks	*Ixodes ricinus*	Castor Bean, Pasture, or Sheep Tick	A major cause of losses in specific areas of mainly rough grazing. Also a zoonotic risk. Vector of various diseases including Tick pyaemia, Louping ill
	Haemaphysalis punctata	Coastal Red tick	Restricted to parts of southern England and Wales. Vectors of *Babesia* and *Theileria* spp, in sheep
	Dermacentor retuculatus	Marsh Tick	
Insecta			
Lice	*Bovicola (Damalina) ovis* *Lingogathus ovillus* *Lignogathus pedallis*	Pediculosis	The incidence of chewing lice has increased significantly since the removal of compulsory dipping.
Keds	*Melophagus ovinus*	'Cockling' of skins	Prevalence again increased since the demise of compulsory diping. Economic significance to the tannery industry.
Blowflies	*Lucilia sericata*	Myiasis (strike)	Affects high % of sheep flocks and is a major welfare concern.
	Calliphora vicina *Protophormia terraenovae*		Secondary flies
Headflies	*Hydrotoea irritans*	Sheep headfly	Mainly affects horned breeds
Stable Flies	*Stomoxys calcitrans*		Common and widespread biting fly
Bot flies	*Oestrus ovis*	Oestrosis	Most prevalent in the warmer counties of England
Midges	*Culicoides spp.*		Vectors of bluetongue

4.1. MITES

4.1.1. Psoroptic Mange (Sheep Scab)

Sheep scab is an acute or chronic form of allergic dermatitis caused by the non-burrowing, astigmatid mite *Psoroptes ovis.* Sheep scab is endemic and widespread and of considerable ecomonic concern to the UK.

4.1.2. Chorioptic Mange

Foot and scrotal mange due to *Chorioptes bovis* has been recorded in low incidence in Australia and New Zealand. The parasite was recorded as infesting the pasterns of sheep in the UK in the late 1960s, and was thought to have been eradicated from sheep following 18 years of compulsory dipping against sheep scab (*Psoroptes ovis*). However, chorioptic mange was found again in 2000 and is now more commonly seen in mainland Britain.

4.1.3. Sarcoptic Mange

Sarcoptic or head mange in sheep, caused by *Sarcoptes scabiei* var *ovis* has been recorded in Europe, Africa, the Middle East, the Balkans, India and South and Central America but has never been recorded in the UK.

4.2. TICKS

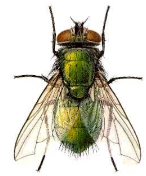
Several species of hard ticks are found in the UK. Only three species readily infest sheep – *Ixodes ricinus, Haemaphysalis punctata* and *Dermacentor reticulatus*, although other species that feed on mammals may occasionally attach to sheep.

4.3. INSECTS

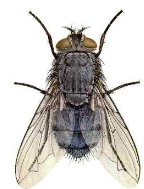
4.3.1. Myiasis (Blowfly Strike)

Blowfly strike is probably the commonest ectoparasitic disease that affects sheep in the UK. It is of economic significance through its damaging effects on fleece and hide. It is indiscriminate, even sheep in the best kept flocks can be affected. Blowflies are exceptionally mobile and do not recognise farm boundaries. Thus blowfly strike if not controlled is considered a major welfare problem.

UK sheep are parasitized by the larvae of three blowfly species. These species are not obligate parasites and large numbers are associated with the environmentally useful tasks of faecal and carcass decomposition.



Lucilia sericata (the "greenbottle") blowflies measure up to 10 mm in length and are characterized by a metallic greenish to bronze sheen. The sexes are very similar in appearance, but may be distinguished the distance between the eyes, which are almost touching anteriorly in males and separated in females.



Bluebottles, *Calliphora vicina* (*syn C. erythrocephala*) are stout flies and characterised by a metallic blue sheen on the body. The larvae are similar to those of *L. sericata* but differ in the arrangement of the posterior spiracles, which serves to differentiate the species.

The black blowfly, *Protophormia terraenovae* (the "black blowfly") is a black-coloured blowfly with an overlying metallic blue-green coloured sheen.

In other sheep-rearing areas of the world (Australia, New Zealand, South Africa etc) the obligate parasitic blowfly *Lucilia cuprina* is the major strike species.

4.3.2 Lice

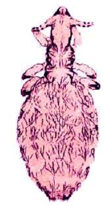
Mammalian lice can be divided into the blood-sucking lice (Anoplura), identified by their narrow head and the chewing ("biting") lice (Mallophaga). As their name suggests, chewing lice feed on skin debris and hair and can be identified by their wide heads (containing the musculature and mouthparts necessary for this method of feeding).

Three species of lice infest sheep the chewing louse *Bovicola ovis* (formerly *Damalinia ovis*) and the blood-sucking lice *Linognatus ovillus* (the face louse) and *L. pedalis* (the foot louse).

Chewing Lice (Mallophaga)

Bovicola (Damalinia) ovis, the Sheep chewing louse, is a small pale to reddish-brown insect, up to 3mm long, with a relatively large head that is as wide as the body and rounded anteriorly. *Bovicola* has a 3-segmented antenna and a single claw on each tarsus.

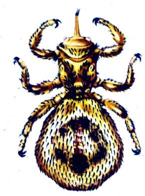
Sucking Lice (Anoplura)



Lignonathus ovillus, the long-nosed louse, is bluish-black, approximately 2.5mm with a long narrow head and slender body. The eggs are exceptional in being dark blue, and are less easy to see on hair.

The foot louse, *Linognathus pedalis* is bluish-grey, with a long pointed head and can reach up to 2 mm in length when fully engorged. Members of this family do not have eyes or ocular points.

4.3.4 Keds



The ked, (*Melophagus ovinus*), a wingless hippoboscid fly, is a blood-feeding ectoparasite of sheep in temperate countries. Adults are hairy, brown, wingless insect approximately 5.0–8.0 mm long with a short head and broad, dorsoventrally flattened, brownish thorax and abdomen. The abdomen is indistinctly segmented and is generally soft and leathery. They have piercing bloodsucking mouthparts and strong legs provided with claws that enable them to cling onto wool and hair. The 3.0–4.0 mm long brown pupae are easily visible on the fleece.

4.3.4 Headflies

The headfly, *Hydrotea irritans* is a muscid fly, similar in size to a house fly, with an olive green abdomen and orange-yellow wing bases. The thorax is black with grey patches. Adults measure 4-7 mm in length. Specific identification of non-biting muscid flies requires specialist advice.

4.3.5 Nasal Botflies

The nasal bot fly (*Oestrus ovis*) is a greyish-brown flies about 12 mm long, with small black spots on the abdomen and a covering of short brown hairs. The mouthparts are reduced to small knobs**.** Mature larvae in the nasal passages are about 30 mm long, yellowish-white and tapering anteriorly. Each segment has a dark transverse band dorsally. They have large, black, oral hooks, and the ventral surface bears rows of small spines.

Further details on the life cycles, clinical signs and epidemiology of these arthropod diseases are provided in Appendix I.

5. METHODS OF PARASITE CONTROL IN THE UK

5.1. Worm Control

Worm control in sheep relies heavily on the use of highly efficient anthelmintics products.

5.1.1. Wormer Groups

A wide range of worming products is available in the UK. Most anthelmintics are marketed for the control of PGE and are used for both treatment and prevention. Wormers have either a broad, or narrow spectrum of activity, and are classified into groups based on structure and mode of action (see Table 5.1 and Appendix III).

Table 5.1 Anthelmintic Groups

Chemical group	Nematodes	Trematodes	Cestodes	Ectoparasites
Broad-spectrum				
Benzimidazole (BZ)	+	±	±	-
Macrocyclic Lactones (ML) Avermectins/milbemycins	+	-	-	+
Imidazothiazoles (LM)	+	-	-	-
Narrow-spectrum				
Salicylanilides and substituted phenols	±	+	±	±

+ Highly effective; - Little or no activity; ± Variable activity

5.1.2 Treatment Strategies

Broad-spectrum wormers have until recently, been highly effective against adult and developing larval stages of the common gastrointestinal nematodes causing PGE and, in general, there was little to choose, in terms of efficacy, between any of the available worming products for treating sheep during the grazing season. That situation has now changed with the advent of anthelmintic resistance (AR). Knowledge of the resistance status on a farm, therefore, is becoming increasingly important when implementing worm control strategies.

In Great Britain, AR has been detected in a number of species of sheep nematodes. Based on surveys conducted in GB since 2000, a large proportion of lowland farms have BZ-resistance and a smaller, but a significant proportion has LV-resistance. The prevalence amongst hill farms may be lower than lowland farms. ML-resistance is now being reported in parts of GB, and further emphasises the importance of exercising some control over its development and spread between flocks, before it becomes widespread throughout the country. The emergence of ‘triple’ resistance’ on a small number farms is of concern and presents a challenge in terms of correct advice and management. However, as often only one species, mainly *T. circumcincta*, is involved acceptable control may still be achievable by appropriate monitoring and careful management.

Further details on treatment strategies for PGE is sheep are contained in Appendix III.

5.2. Liver Fluke Control

Fluke control programmes must take into account the farm history, topography, geographical location and the prevailing weather conditions. Farms on free-draining soils or in low rainfall areas are not prone to liver fluke but local conditions may vary sufficiently as to provide suitable snail habitats. Where fluke infection is present on a farm, the identification and exclusion of snail habitats from livestock offers some measure of control, although it can be difficult to identify all snail areas and is costly to isolate them from stock. Drainage eliminates the snail and offers a means of effective control but may be impracticable on many farms. Simply keeping stock off the wettest fields in the autumn and the winter, when the incidence of disease is at its highest, can reduce the risk from fluke.

5.3. Coccidiosis Control

Outbreaks of clinical coccidiosis can appear suddenly and may prove troublesome to resolve as they often occur on heavily stocked farms particularly where good husbandry and management are lacking. If deaths are occurring, early confirmation of the diagnosis is vital and should be based on the history, post mortem examination and examination of smears. Lambs should be medicated and moved to uncontaminated pasture as soon as possible.

5.4. Ectoparasite Control

Ectoparasiticides are essential for the control of sheep ectoparasites.

5.4.1. Ectoparasiticide Groups

Currently available chemicals for the control of ectoparasites on sheep are shown in the Table 5.3.

Table 5.3. Sheep Ectoparasiticide Groups and Chemicals

Chemical Group	Chemical	Formulation
Organophosphates (OP)	Diazinon	Dip
Synthetic Pyrethroids (SP)	Alphacypermethrin Deltamethrin	Pour-on Spot-on
Insect Growth Regulators (IGR)	Cyromazine Dicyclanil	Pour-on Pour-on
Macrocyclic Lactones (ML)	Doramectin Ivermectin Moxidectin	i/m injection s/c injection s/c injection

5.4.2. Sheep Scab Control

Scab control has relied heavily in the past on plunge dipping in an acaracide. However, with greater safety concerns over the use of dip-based products, and since the introduction of injectable endectocides (ML Products – see Appendix III) there has been a greater reliance on MLs and a move away from the use of dips.

5.4.3. Blowfly Prevention and Control

Dips used in scab control also provided protection against blowfly. Other management practices such as shearing, 'dagging' and controlling worms also provided some protection against blowfly 'strike'. Cure necessitated the removal of maggots by treatment with an insecticide. Prevention is best achieved by the application of an insect growth regulator (IGR) at prior to the anticipated start of the fly season (se Appendix III).

5.4.4. Lice and Ked Control

Lice and keds are commonest in winter when the fleece is long. Unfortunately, the management of these parasites in heavily pregnant, long-fleeced ewes is problematic. Shearing significantly reduces the lice and ked burdens by removing a large proportion of the parasites and exposing those remaining to the lethal effects of desiccation, but is usually impractical during winter months. Most farmers rely on the use of pyrethroid pour-ons for the treatment and control. Organophosphate plunge dips can provide effective control, but winter dipping and disposal of dip wash solution is difficult on many farms.

6. OTHER PARASITE CONTROL STRATEGIES WORLDWIDE

6.1 Worm Control

Australia

Worms reportedly cost the Australian sheep industry an estimated $369 million per annum and this is expected to rise to $700 million in 2010 as drench resistance rises and production losses accelerate.

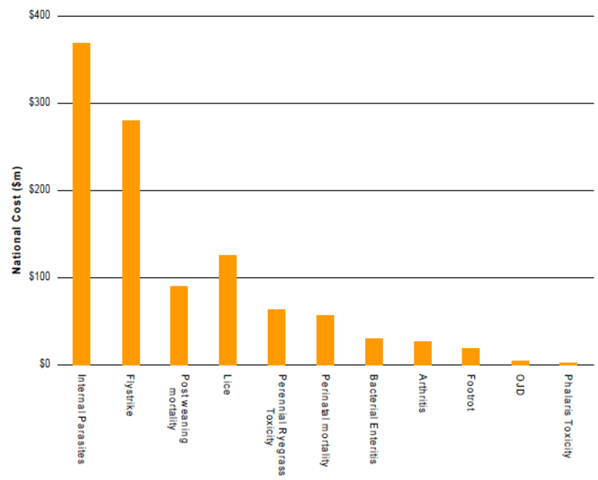


Figure 1. National cost ($million) of major sheep health issues in Australia. (Source: Holmes et al. 2006)

Wormer (‘drench’ resistant) worms are increasingly prevalent in many regions of Australia with control increasingly difficult to implement due to the presence of multiple resistant worm species.

The sheep farming regions of Australia now have epidemiologically-based guidelines for nematode control. These have been developed over a number of years in response to the need to reduce the number of anthelmintic treatments administered, local environmental conditions and dominating parasites. However, AR has continued to increase in frequency despite the widespread adoption of these strategies.

As a consequence an initiative called **WormBoss**, (with control recommendations very similar to SCOPS in the UK) was set up by Australian Sheep Industry Cooperative Research Centre (Sheep CRC) and Australian Wool Innovation Ltd (AWI) to help producers meet the increasing challenges from wormer resistance.

WORMBOSS

WormBoss recommends four general management practices:

- Monitor worm populations using worm egg counts to detect infestations early.
- Do regular drench resistance tests so you know which drenches are effective on your property.
- Maximise the use of non-chemical management strategies.
- If you are unsure of anything—seek professional advice.

The following information is taken from the WormBoss website (**WormBoss.com.au**). The principles and guidelines reflect current UK SCOPS recommendations and guidelines.

Drench resistance

In most sheep districts of Australia, knowing the drench resistance status of your property is essential if you are going to be able to effectively manage worms. If you do not have any drench resistance information, you should seek professional advice on how to have it done as soon as possible.

Theoretically, drench resistance occurs once a population of a species of worm can survive a dose of a drench that would have previously killed it. Worms killed by a drench are said to be susceptible to the treatment.

The currently accepted industry definition of drench resistance, as measured in a Faecal Egg Count Reduction Test (FECRT), is a reduction in worm egg count of less than 95 percent.

This definition is important to understand, because at this level of efficacy, drench resistance would most likely not be causing clinical worm problems, such as scouring, obvious weight loss or anaemia. However it could be associated with loss of production. By the time that obvious drench failure occurs then resistance is very well established within the worm population. This is one of the reasons why it is unlikely that resistance can be reversed, even if the drench group is not used for a long period of time. Preventing or reducing the onset of drench resistance is the best option.

Drench resistance is genetic (controlled by genes). Resistance to each group of drenches is controlled by different genes, meaning that resistance develops to each drench group separately. Being a genetic trait, drench resistance is also heritable (can be passed on from one generation of worms to the next).

Initially, resistant worms are rare in a population of worms. When a sheep is treated the resistant worms survive and, if they find a mate, can reproduce. The resultant offspring are resistant and if they survive as larvae on the pasture and infect another sheep they will make up a greater proportion of the worm population than their parents did. Over time, and with continued treatment, the overall resistance level to the treatment within the worm population increases.

The rate of development of drench resistance can be influenced by many factors such as:

- The chemical group and persistency of the product involved
- The frequency of treatments
- The worm species involved
- Environmental factors such as climate.

As demonstrated in Table 6.1, AR in sheep nematodes is more widespread and problematic that the situation in the UK (see 5.1.2). ML resistance in particular, is more prevalent on Australian farms with higher levels of multiple resistant strains. Haemonchosis is a particular problem in Queensland and New South Wales and a number of programmes involving the use of closantel (“WormKill”, “DrenchPlan”) were instigated before widespread resistance appeared in northern New South Wales in the 1990s.

Table 6.1. Overview of drench resistance in Australia

Drench or drench group	Prevalence of resistance*
Benzimidazole (BZ) or ‘White’ drenches	Approximately 90% of properties.
Levamisole (LEV) or ‘Clear’ drenches	Approximately 80% of properties.
Combination (BZ + LEV) drenches	Approximately 60% of properties.
Macrocyclic lactone (ML, ‘mectin’) drenches: Avermectins (ivermectin, abamectin) Milbemycins (moxidectin)	Becoming more common. About 60% of sheep farms in WA have ML-resistant *Ostertagia*. ML-resistance in *Haemonchus* in northern NSW and southern QLD is becoming more common (possibly 30–60% of farms). ML-resistant *Ostertagia* occurs on up to 30% of farms in southern NSW and other non-seasonal to winter rainfall areas of south-eastern Australia.
Naphthalophos (Rametin®, Combat®)	One recorded case in QLD.
Closantel	Resistance in *Haemonchus* is common in northern NSW and south east QLD. Some isolates are also ML-resistant. Small number of resistant strains of liver fluke in Australia.
Triclabendazole (Fasinex®, Flukare®, Flukex®)	Small number of resistant strains of liver fluke in Australia.

* Drench efficacy < 95 percent. Prevalence of ML-resistance: these estimates refer to avermectins (ivermectin, abamectin) resistance. The prevalence of resistance to moxidectin, which is more potent, is currently somewhat lower. (Source: Love, 2005)

Combination drenches (containing actives from two or more effective broad spectrum drench groups) were introduced into Australia and New Zealand in the early 1990s and are now used routinely where it is generally accepted that in order to delay the development of resistance it is better to use a combination drench, rather than using these drenches on their own. This is in direct distinction to the UK and the EU, where such combinations are neither available, nor currently considered appropriate by licensing authorities. Initially combinations contained a benzimidazole (generally oxfendazole or ricobendazole) and levamisole, but now there are formulated triple combinations (with the addition of ivermectin or abamectin) and even a four-way combination with the further addition of the salicylanilide anthelmintic, closantel.

New Zealand

In New Zealand, a five-drench preventive treatment program has been the mainstay of nematode control on New Zealand sheep farms for a number of years. As has occurred in Australia, this practice has apparently led to the selection for AR and combination drenches have been the mainstay of worm control on many farms. Last year saw the launch of the first new mode of action anthelmintic (monepantel) for over 20 years, and its use and integration into current NZ worm control schemes is being very closely monitored and observed. Its launch in the UK is imminent.

South Africa

As in parts of Australia, haemonchosis is a particular problem in the Transvaal areas of South Africa, with increasing reports of multiple resistance to this parasite.

FAMACHA

Acute haemonchosis, resulting from the ingestion of many infective larvae over a short period of time, produces anaemia leaving animals weak and which may collapse if driven. Pallor of the mucous membranes is striking but examination of the oral mucosa or skin and differentiation from a normal appearance can be difficult. A system has been developed in South Africa whereby the anaemia is assessed by inspection of the conjunctivae using the *FAMACHA* © assessment system to determine the need for worming.

6.2. Ectoparasite Control

In the UK, the three most important ectoparasitic infections are sheep scab, blowfly strike and lice. All three diseases are of major importance in most of the sheep rearing countries of the world with the exception of Australia, New Zealand, Canada and the USA, where sheep scab is not present. In most countries, the treatment and control strategies are similar to those practiced in GB. Sheep scab was eradicated In Australia and New Zealand, by the late 19th century by compulsory slaughter of infected sheep. In Australia, where wool production is the main output of their sheep industry, lice infections are more problematic, and have serious costs to the wool industry at more than $120 million annually, through reduced fleece weight and downgrading of wool quality.

The control of populations of arthropod pest species using non-return traps and targets (screens), usually accomplished by semiochemical baits, has been considered widely for parasites such as ticks or flies. The aim is to attract and kill targeted pests in appropriate numbers during the stages in which they are off the host. In Australia, a non-return insecticide-free trap for catching *Lucilia cuprina* has been developed and is now commercially available (see |LuciTrap). This approach has also been used as a component of the eradication of the screwworm fly, *Cochliomyia hominivorax*, from North America and for control of the horn fly, *Haematobia irritans*. Given the large numbers of adult females that must be attracted and killed to achieve effective population management, this is often not possible with the visual and olfactory baits available.

LICEBOSS

LiceBoss is a decision support system, developed by Australian Wool Innovation, designed to help woolgrowers control lice more effectively, minimise pesticide residues and reduce the cost of lice control.

The LiceBoss website http://www.wool.com/Liceboss consists of two main sections:

- 'Tools' section - that allows the user to enter data and find answers applicable to their property and management circumstances; and
- 'LiceInfo' section - that contains up to date reference material on all facets of sheep lice control.

Reports of resistance to synthetic pyrethroid (SP) compounds are reportedly widespread and resistance to insect growth regulators (IGRs) has also been identified. As with other antiparasitics, there are few if any new products on the horizon, and importance is placed on the adoption of strategies to minimise the development and spread of resistance and maintaining effectiveness of currently available chemicals.

When most breakdowns are closely investigated they are found to be due to poor application techniques with most resistance cases resulting from the misuse of backline products.

Some general principals given on the website to prevent or delay the development of resistance include:

- Make certain that backline products are applied strictly according to label directions and that sheep are treated at dose rates calculated for the heaviest sheep in the mob.
- Ensure that EVERY sheep is treated evenly along the middle of the backline from head to rump.
- If a long wool treatment is used, ensure that a chemical from a different chemical group is used at next shearing.
- As a general principal it is a good idea to rotate products from different chemical groups at consecutive treatments.
- Don’t mix treated and untreated sheep, particularly if there is a chance that the untreated sheep may be carrying lice. Don’t forget lambs.
- If a chemical breakdown is suspected, use the treatments module in LiceBoss to see if a management reason (e.g. stray sheep, incomplete muster, wrong dose rate, and incorrect application) could be the cause. If no reason can be found, discuss with an adviser or chemical company representative and be sure to treat all sheep with a product from a different chemical group at the next shearing.
- If treatment for fly strike and lice is required in the same year, use chemicals from different chemical groups.

LICESENSE

Australian Wool Innovation have also developed LiceSense, which is a woolgrowers’ guide to managing sheep lice in response to spreading lice infestations available as a downloadable

PDF from the AWI website or as a hardcopy. AWI also offer training days and a helpline for producers.

LUCITRAP

The Australian sheep blowfly is one of the most important parasites affecting the sheep and wool industry in Australia, costing the industry $280 million per year through losses in wool quantity and quality, sheep deaths and expenditure on pesticides and labour. A number of Integrated Pest Management (IPM) practices are promoted in Australia to minimise the impact of blowflies and the use of pesticides in its control. The LuciTrap system is a key non-chemical component of an IPM program for blowfly control. The LucipTrap consists of a specifically designed trap with a patented blend of chemicals to attract and capture the Australian sheep blowfly (*Lucilia cuprina*). The trap consists of a translucent bucket made from tough ultraviolet-stabilised plastic and a removable lid with a flat surface, entrance cones that allow the sheep blowfly to enter but not leave the trap, and holes for fixing the trap to a tree, fence post or star picket. The lid is fixed to the bucket with a twist and lock design. The traps are located strategically on the farm in areas where sheep blowflies are most likely to be found and are introduced in early spring when fly populations are low, in order to reduce the build up of future blowfly populations. Reductions in strike incidence of up to 46% have been reported.

7. CLIMATIC EFFECTS ON PARASITE EPIDEMIOLOGY AND CONTROL

Parasitic Gastroenteritis

The effects of rainfall and temperature on the population dynamics of *T. circumcincta* and *Trichostrongylus* spp are well described and any effects of climatic changes are therefore, theoretically predictable. Accumulation of infective L_3 accelerates at higher temperatures, brought about by shorter generation intervals, leads to higher parasite abundance and increased risk of disease from midsummer onwards. Increases in temperature may also lead to an extension of transmission into the late autumn and winter and conversely appearances of more cold-tolerant species earlier in the season. There may be a decrease in spring disease attributed to decreased larval survival over the winter and spring due to milder temperatures, the consequential effects of which are decreased exposure to infection early in the year, delays in acquisition of immunity and subsequent higher burdens building up later in the year. A computer model capable of simulating a wide range of sheep management practices relevant to the UK weather patterns and the subsequent effect of different anthelmintic control programs on parasite infection levels and resistance development on individual farms have been developed at the Food and Environment Research Agency (Fera) for this purpose and is being developed as an advisory tool for use in the field.

Predicted climatic changes have a number of potential and consequential effects on sheep husbandry and grazing management. Hot dry summers in southern counties, or high rainfall and risk of flooding in northern Britain, both impact on grass production. Drought conditions may increase the need for supplementary feeding or the development of drought resistant grazing. Bioactive forages, such as chicory, birdsfoot trefoil, sulla, and sainfoin have been shown to reduce the negative effects of parasitism in sheep. Chicory is the most promising bioactive forage and can be incorporated into normal grass leys or sown in conjunction with clover and/or grasses. Drought resistance is also an important property of chicory, which contributes to nutritional requirements in the latter part of the season. Importantly this also coincides with the time we normally see the highest pasture larval challenges to lambs. However, much still needs to be learned about using bioactive forages in practical production systems.

Haemonchosis caused by *Haemonchus contortus*, is generally sporadic in its appearance and often entirely unpredictable, but has been increasingly reported over the last decade with a much wider distribution to more northerly latitudes. It occurs, although is less commonly diagnosed in Wales and Scotland, but is recorded more now in central England as well as in southern England. Whilst disease is mainly in late summer, there are increasing numbers of cases in other months with a shift in peak disease towards autumn. Higher autumn temperatures may well affect parasite behaviour resulting in less larval inhibition than would normally occur with falling temperatures, and with a greater propensity to cause disease shortly after ingestion of infective larvae.

Recent evidence for *N. battus* suggests that larval hatching is occurring at times other than the traditional spring hatch traditional seen in late spring in areas such as Northern England and Scotland. Synchronised mass hatching usually occurs when temperatures >10^{o}C follow a period of frost. Disease however, is now reported at other times of the year, including the autumn, and in parts of south of England particularly, where early lambing is practised, in late winter/early spring (January-March). In these situations early or late frosts in spring or autumn may be the trigger factor although periods of drought followed by heavy rainfall may also trigger a hatch. If such conditions occur then early or late lambing flocks may experience disease at these times of the year, when the presence of susceptible or non-immune lambs coincides with hatching of eggs and the ingestion of large numbers of infective larvae.

Lungworms

Lungworm infection with *D. filaria* is predominantly a problem in areas that have a mild climate, a high rainfall and abundant permanent grass. Infections occur mainly in late summer and autumn as development to the L_3 occurs during the period from spring to autumn. A warmer climate with higher rainfall, would provide ideal conditions for larval survival for all lungworm species, and would also benefit the molluscan intermediate hosts of the metastrongylid species.

Tapeworms

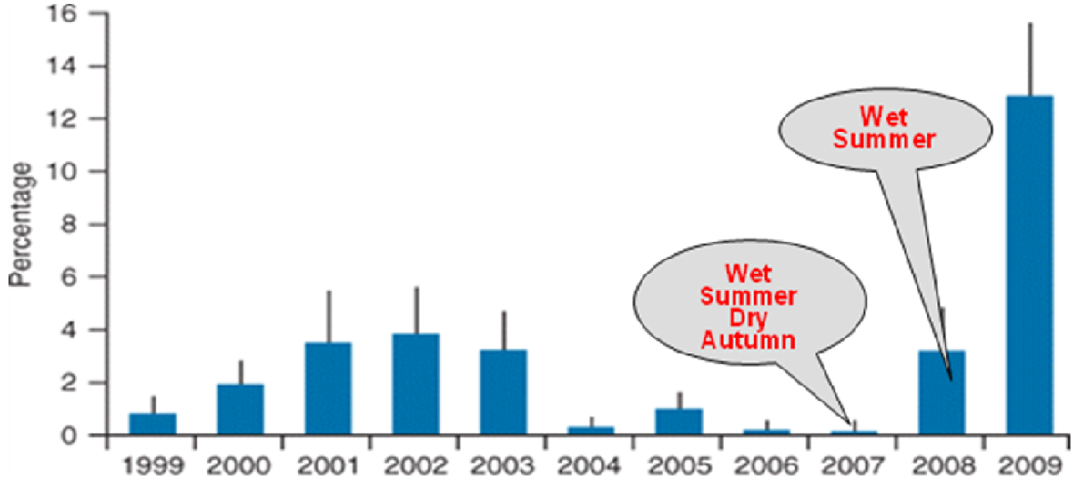
Climate and changes to land management could have significant effects on tapeworm population densities by increasing populations and survivability of oribatid pasture mites (the intermediate hosts of *Moniezia*).

Fluke

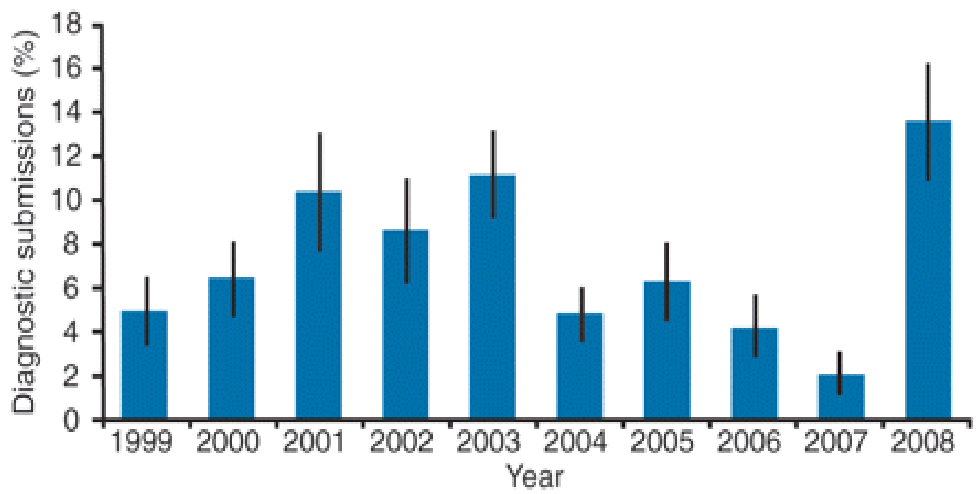
The last decade has seen higher than average rainfall and temperatures leading to increasing reports of liver fluke disease in various parts of the UK. This is certainly the case for the more traditional fluke areas in western Britain, but it also now appears to be more widely distributed and has been more commonly reported in eastern regions of the country. Milder winters have resulted in the 'winter infection of snails' scenario with the effect that acute fluke disease has been reported as early as June, (as opposed to September/October) in some parts of the country.

The following graphs (Source: Veterinary Record) show Veterinary Investigation Diagnosis Analysis (VIDA) incidents of acute and chronic fasciolosis, as a percentage of diagnostic submissions to the Veterinary Laboratories Agency, for the spring (January-March) of each year 1999-2009. The incidence of both acute and chronic fluke in 2009 was a particularly bad, reflecting the higher than average rainfall of 2008. Additionally, slaughterhouse liver condemnations indicate that fasciolosis is widespread and increasing in frequency. The National Animal Disease Information Service (NADIS) http://www.nadis.org.uk provides a regional fluke forecast based on rainfall data and at the start of 2010 is predicting that liver fluke disease remains a serious threat over large areas of the country. Use of such information and forecasts allows producers to decide of additional treatments are required.

Acute Fluke



Chronic Fluke



Coccidiosis

Stress plays a part in the lambs' susceptibility to coccidial disease and is more common in twin lambs. Cold, wet weather causes stress to lambs and can precipitate disease, whilst warm, moist conditions provide optimal conditions for oocyst development and survival and subsequent higher levels of challenge to later born lambs.

Cryptosporidosis

In lambs, chilling due to adverse weather conditions in the neonatal period, inter-current infections or nutritional or mineral deficiencies may exacerbate or increase the likelihood of disease. Disease outbreaks in people have been associated with waterborne transmission after periods of high rainfall when contamination of potable water supplies has occurred.

Babesiosis

The sheep tick, *Ixodes ricinus*, a vector of *B. ovis*, is common and increasing in prevalence throughout GB. Small populations of *H. punctata* and *D. reticulatus* exist in parts of England and Wales and can be vectors of *B. motasi*. Whilst climate change may have no direct effect on the *Babesia* parasites themselves, introduction and spread of indigenous and exotic tick vectors may increase disease risk through changes in climate that are more conducive to the tick life cycle (see 4.2).

Mites, Lice and Keds

Scab, lice and ked infestations are commonest in winter when the fleece is long. Prolonged rainfall makes the fleece continually damp thereby increasing relative humidity providing optimal conditions for the parasites survivability and spread. Conversely, such conditions may necessitate in-wintering of sheep on some farms, and where winter shearing is deemed practical and necessary, may actually lead to improved ectoparasite control.

Flies

Warmer and more prolonged summers can increase the incidence and distribution of a whole range of flies. Recent milder autumns and springs have meant that in the SE of England, for example, blowfly strike has been reported over an extended fly season any time between March and December as flies remain active. Nasal Bot flies have been confined mainly to the south of England. However, more northern areas of Britain could become foci of infestation, through the movement of infested sheep from the endemic south with warm summers allowing the establishment of temporary or more permanent fly populations.

A model for predicting blowfly strike (**Strikewise** http://www.strikewise.com/) can be used to determine appropriate timing of preventative treatments with IGRs and possible need for extended treatment periods. The model uses recordings of daily temperatures and rainfall, along with a detailed understanding of fly and sheep biology to forecast the patterns of fly and strike.

Ticks

Tick infestations are of growing concern because their epidemiology and geographical distribution are changing as a consequence of changing farming practices, land usage, and as a possible consequence of climatic changes. There are increasing human reports of tick bites and disease transmission, particularly Lyme disease. Grouse moors are also experiencing outbreaks of tick-transmitted louping ill with anecdotal reports suggesting that ticks are becoming less seasonally active and now attaching and feeding almost year round as a consequence of wetter milder seasons.

Table 7.1 Predicted Effects of Climate Changes (Rainfall and Temperature) on Parasites

	Rainfall		Temperature	
Parasites	**Increase**	**Decrease**	**Increase**	**Decrease**
PGE Nematodes	**Summer**: increased release of larvae and disease risk; very wet summers may decrease or delay risk due to flooding; higher risk from haemonchosis; **autumn/winter/ spring**: heavy rainfall -decreased risk due to flooding/poaching and need for housing	**Summer**: decreased risk due to low numbers of larvae; drought conditions decrease risk due to need for supplementary feeding or drought resistant crops; **autumn/winter/ spring**: increased risk due to longer season	**Summer**: More rapid larval development; increased generation intervals and increased disease risk; higher risk from haemonchosis; hot and dry summers reduced risk; **autumn**: longer season; **winter**: decreased larval survival of cold tolerant species; **Spring**: decreased exposure and disease	**Summer**: slower larval development; decreased disease risk; **autumn**: shorter season; **winter**: increased larval survival; **spring**: increased exposure and disease risk
Lungworms	**All seasons**: increased larval survival and release; greater survival of molluscan hosts (with some lungworm species)	**Summer**: decreased risk due to low numbers of larvae and lower transmission levels; reduced survival of molluscan hosts	**Summer**: increase parasite levels; decreased survival of larvae and intermediate hosts in hot dry summers; **autumn/winter/ spring**: longer season; increased mollusc activity	**Summer**: slower larval development; decreased disease risk in summer; **autumn/spring**: shorter season
Tapeworms	**Summer**: heavy rainfall and flooding reduce risk	**Summer**: hot and dry summers reduce risk	**Summer**: increased risk due to increased numbers of oribatid mite numbers; hot dry summer reduced risk	**Summer**: reduced mite activity and transmission
Fluke	**All seasons**: increased risk of transmission; creation of snail habitats and greater snail survivability and multiplication; greater risk in subsequent year	**All seasons**: decreased risk of transmission; loss of snail habitats and reduced snail survivability and multiplication; reduced risk in subsequent year	**Summer**: more rapid development; increased parasite levels; hot dry summers reduced risk; **autumn/winter/ spring**: longer season; increased mollusc activity and survival; greater risk in spring	**Summer**: slower development; decreased parasite levels; **autumn/spring**: shorter season; decreased mollusc activity and survival; **winter**: cold winters decrease survivability of snail populations; less risk in spring

Table 7.1 Predicted Effects of Climate Changes (Rainfall and Temperature) on Parasites (continued)

	Rainfall		Temperature	
Parasites	**Increase**	**Decrease**	**Increase**	**Decrease**
Coccidiosis	**Spring**: increased oocyst development at pasture; delayed turnout may increase risk in housed lambs; wet weather may precipitate stress and disease	**Spring**: decreased oocyst development at pasture; early turnout may decrease risk	**Spring**: increased oocyst development at pasture; early turnout may decrease risk in housed lambs but increase risk at pasture	**Spring**: cold weather may precipitate stress and disease in twin lambs
Cryptosporidiosis	**Spring**: wet weather may precipitate stress and disease			**Spring**: cold weather may precipitate stress and disease
Babesiosis	Tick-transmitted-infections. See comments for ticks			
Mites, Lice, Keds	**Winter**: increases risk of disease and spread; prolonged heavy rainfall may require in-wintering and shearing thus reducing risk		**Spring/summer /autumn:** decrease in survivability especially in shorn sheep	
Flies	**Spring/summer / autumn:** increased 'scour' and odours and risk of strike	**Spring/summer / autumn:** reduced risk of 'scour' and dry fleece less attractant	**Spring/summer / autumn:** increased risk due to extended fly season; spread to non-endemic regions for some species	**Spring/autumn:** reduced fly season and risk
Ticks	**Spring/summer/ autumn:** increase in microclimate humidity and bio-habitats and increase and spread of ticks; establishment of invasive tick species	**Spring/summer/ autumn:** decrease in microclimate humidity; reduced tick activity and survival through desiccation	**Spring/summer/ autumn:** increase in tick activity; hot dry conditions reduce activity and survival of some tick species; establishment of invasive tick species	**Spring/summer/ autumn:** seasonal tick activity; reduced risk of establishment of invasive tick species

8. CONCLUSIONS AND RECOMMENDATIONS

Predicted climate changes will theoretically at least, have profound effects on parasite epidemiology, distribution and prevalence for many parasitic diseases, particularly for those whose free-living stages are sensitive to temperature and humidity. This no doubt, will challenge the ability for continued control, unless strategies adapt accordingly.

There have been noticeable observed changes in the epidemiology of a number of common sheep parasites in recent years although at this stage it is not clear if these have been brought about solely through observed changes in weather patterns. Against this background, many of the existing parasite control strategies remain unchanged and based on a 'blue-print' approach that is heavily reliant on available antiparasitics. In that time there have been significant changes in the size and structure of the sheep industry, and the antiparasitic products available. For these reasons, there has been a 'need for change' in conventional parasite control strategies. Additionally, some elements of these strategies are highly selective for the development of parasite resistance, leading to the development of SCOPS guidelines for worm control aimed at reducing the selection pressure for AR, in an attempt to change farmer practices and attitudes. This message needs to be carried forward for other parasitic diseases of sheep and continue the process of modification and adaptation of newer parasite control strategies.

The increased risk of introduction and potential for establishment of parasitic infections currently considered exotic to the UK, is something that needs to be addressed at the national level, requiring increased surveillance and appropriate instigation of effective intervention control measures. Once introduced, eradication and control may prove extremely difficult especially where suitable habitats exist for long term survival of reservoir populations either as free-living stages, or in susceptible wildlife hosts.

Predicted climatic changes have a number of potential and consequential effects on sheep husbandry and grazing management. Drought conditions may increase the need for supplementary feeding or the development of drought resistant grazing and in this respect research into bioactive, drought-resistant forages, such as chicory, which can be incorporated into practical production systems, warrants further research.

The use and development of computer simulation models capable of simulating a wide range of sheep management practices relevant to sheep parasitic diseases and predicted UK weather patterns should be encouraged. Such systems are in development for worm control practices and blowfly strike and should be pursued for use with other predictable parasitic diseases such as liver fluke. In this respect, greater use of forecasting system should be used to target treatments at appropriate times and encourage more responsible use to help limit the development of resistance.

Within some of the other large sheep-producing countries of the world, particularly Australia and New Zealand where resistance parasite populations have become more common and widespread, national and regional networks of advisors have been established. National advisors have developed guidelines and parasite control principles for common parasite infections, particularly worm control and resistance management, lice and blowfly control. These are made available to producers and regional advisors through publications, interactive websites, meetings and on-farm demonstrations, funded through various levy bodies. Whilst such initiatives have been implemented to some extent in Britain, through groups such as SCOPS, lack of support from core government departments like Defra, threatens the continuation and ability to promote sustainable sheep parasite control. This has been exemplified by a continued failure to initiate a national sheep scab control policy or at least make recommendations for a way forward. It is therefore important that levy bodies such as the English Beef and Lamb Executive (EBLEX) and Hybu Cig Cymru - Meat Promotion Wales (HCC) continue to support promotional activities for sustainable parasite control strategies and consider new initiatives such as interactive websites for producers and advisers.

In this respect, EBLEX produce advisory leaflets on parasite control: **8: Target Worm Control for Better Returns** and **10: Controlling external parasites for Better Returns** and HCC also produce booklets (www.hccmpw.org.uk). Some updating of these texts to take into account possible effects of climate change on parasite epidemiology, seasonality, available treatments and control strategies are recommended.

9. FURTHER READING AND PUBLICATIONS

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Appendix I

ENDOPARASITES

HELMINTHS

Parasitic Gastroenteritis

Life Cycles

The life cycles of the gastrointestinal nematodes are all very similar, with one or two minor exceptions, and the following description applies particularly to ***Teladorsagia, Trichostrongylus*** and ***Haemonchus*****.**

Adult female worms in the sheep lay eggs, which pass out in the faeces and hatch; releasing first-stage larva (L_1). The L_1 develop and moult to second stage larvae (L_2). The L_1 and L_2 are active and feed on bacteria in the faeces. At the second moult to the third stage larvae (L_3), the cuticle of the L_2 remains as a sheath, protecting the L_3 but also preventing them from feeding. The L_3 is the infective stage. L_3 migrate on to the herbage where they are ingested by sheep. In the walls of the stomach or intestines they develop into fourth stage larvae (L_4), before emerging as adult worms. The prepatent period (time from infection to appearance of egg in faeces) is about 16–21 days. The development and release of L_3 onto the herbage is greatly influenced by climatic conditions, particularly temperature and rainfall.

Important variations on the basic life cycle

Nematodirus battus

For all *Nematodirus* spp, development to the L_3 takes place within the egg. With *N. battus*, hatching and release of the L_3 occurs as a result of climatic stimulus, usually a period of chill followed by a mean day/night temperature of more than 10^{o}C. The prepatent period can be as short as 14 days.

Strongyloides papillosus

The L_3 has no protective sheath. L_3 can infect the host by ingestion or by skin penetration. Transmission may also occur to lambs via the milk of the ewe. The prepatent period is about 9 days.

Bunostomum trigonocephalum

Infection of the host occurs by ingestion or through the skin. Following skin penetration the larvae pass to the lungs and then to the small intestine. The prepatent period is about 56 days.

Trichuris ovis

Infection of the host occurs through ingestion of the L_1 in the egg. After ingestion the plugs at the ends of the egg are digested and the L_1 released. All four moults occur within the sheep. The prepatent period is 1 to 3 months.

Disease

Disease caused by gastrointestinal nematodes may be acute in onset, with outbreaks of clinical disease in 10% of a flock or more, with occasional deaths. The devastating effects of such outbreaks on a flock are obvious. Gastrointestinal parasites also cause sub-clinical disease, with reduced growth rate, reduced milk production and reduced body condition. Although far less dramatic, the insidious losses to sub-clinical infections involve large numbers of sheep for prolonged periods and result in a much higher cost to the industry than clinical disease.

The main pathogenic species are *Teladorsagia circumcincta*, *Haemonchus contortus*, *Nematodirus battus* and *Trichostrongylus* spp. *T. circumcincta* and *Trichostrongylus* spp are the primary contributors with heavy infections, cause inappetance, diarrhoea, dehydration, and weight loss. Severe infections of *N. battus* cause sudden onset diarrhoea and dehydration and sudden death in affected lambs. *Haemonchus contortus* is a blood-feeding parasite causing anaemia and sudden death in ages of sheep.

Epidemiology

Two terms are used to describe the conditions of pastures containing the free-living nematode stages. Pastures are ***'contaminated'*** if there are eggs and larvae present, but pastures are only ***'infective'*** if there are L_3 present and climatic conditions are suitable for them to move up onto the herbage, where they can be ingested. Both rainfall and temperature influence the infectivity of pastures.

Periparturient Rise in Ewes

Ewes around lambing time undergo a periparturient rise in faecal egg counts, which is greatest in those ewes lambing in the spring ("spring rise"). These worm burdens are derived either from over-wintered infective larvae on the pasture, or from hypobiotic larvae overwintering in the ewes. Eggs deposited in the spring in turn develop to produce the mid-summer rise in pasture larvae. Both rainfall and temperature influence the infectivity of pastures. The rate of development to the infective stage (L_3) is dependent on temperature. Rain tends to increase the infectivity of pastures by assisting in the movement of L_3 out of faecal pellets or pats and by providing the film of moisture necessary for L_3 to migrate onto herbage.

Development of L_3 from eggs deposited in early spring may take 10–12 weeks but eggs deposited later in the season develop faster. Summer-deposited eggs can give rise to L_3 in just 1–2 weeks. Consequently, eggs passed onto pasture in spring and early summer tend to reach the infective stage at about the same time, resulting in high levels of pasture infectivity from mid-summer onwards. Rainfall records have been used to predict the peak of availability of nematode larvae on pasture, and temperature records have been used to predict the risk of nematodirosis in lambs.

Three species of *Nematodirus* affect sheep of which the most important is *Nematodirus battus. N. battus* has a much slower life cycle than other gastrointestinal nematodes, with infection passed from a lamb crop in one year to the lambs born in the following year. The long survival of *Nematodirus* eggs permits this relatively long generation interval. As a result of the specific climatic requirements for egg hatching of *N. battus*, large numbers of infective larvae can appear on pasture almost synchronously. This usually occurs in spring between April and June each year. When mass hatching coincides with the presence of lambs of 6-12 weeks of age on pasture, severe outbreaks of nematodirosis can occur.

Larval Overwintering

L_3 are most active during warm weather and, if they are not ingested, consume their energy stores and suffer high mortality rates. In autumn and winter, L_3 can survive longer and some will over-winter on pasture. Some worm species are better at winter survival than others. *Haemonchus* larvae do not survive well in freezing temperatures but *Nematodirus* eggs can survive prolonged cold temperatures. Milder winters may promote development of eggs on pasture, and favour survival of less cold-tolerant species.

Over-wintering L_3 provide a source of infection to grazing sheep in late winter and early spring but do not survive long on pasture after ambient temperatures rise. Pasture infectivity tends to decline rapidly to low levels in late April or early May.

Hypobiosis

The abomasal nematodes *Teladorsagia* spp, *H contortus* and *T axei* are capable of interrupting their development at the L_4 stage and persisting for long periods in a state of dormancy or hypobiosis. They then resume their development and become normal, egg-laying adults. This interruption of development occurs principally to larvae ingested in the late autumn and winter. It can be considered as an evolutionary adaptation which delays egg production (and death) until the following spring when eggs deposited on pasture have a higher chance of continuing the worm's life-cycle. In the case of ewes, most of the *Teladorsagia* population in the host between November and February exists as hypobiotic larvae. Between April and September, there are very few, if any, hypobiotic larvae and most parasites exist as adult or actively developing forms.

The small intestinal parasites are also capable of hypobiosis but this does not appear to be an important feature of their epidemiology.

Liver Fluke

Life Cycle

Compared to other helminths the life cycle is complex, involving an intermediate host, the mud snail *Galba truncatula* and several free-living stages. The snail prefers muddy, slightly acidic conditions and particularly areas associated with poor drainage, such that the incidence of liver fluke is far greater in the wetter areas of the country and in years when there is high summer rainfall. The snail is also a prolific breeder, with just one snail capable of producing 100,000 offspring in three-four months. Under optimal conditions favouring both the fluke stages and the snail, there is the potential for large numbers of parasites to build up causing a serious threat to livestock.

The adult fluke is found in the bile ducts of the liver of the final herbivore host. Adult flukes are hermaphrodites (containing both male and female organs) and produce eggs, which pass out in the bile to the intestines and then into the environment via the faeces. The eggs hatch only in damp conditions and if the temperature exceeds 10ºC, producing a motile larva (miracidium) after about three-four weeks. The mobile miracidia have to find a suitable intermediate snail host within a few hours or they die. Miracidia that find a snail enter it and undergo development over a four to eight week period progressing through two stages (sporocysts and rediae), before developing into further mobile stages (cercariae). These swim on the wet pastures before settling on herbage where they encyst to form metacercariae (the highly resilient infective stage of the liver fluke). One miracidium can therefore develop into hundreds of cercariae. Under unfavourable conditions, cercariae can remain dormant within snails buried in mud for up to a year, usually emerging from the snail when the temperature and moisture levels are suitable. Metacercariae can remain infective to herbivores for up to ten months. Following ingestion with herbage, the young flukes hatch within 48 hours of ingestion and migrate to the liver, through which they tunnel, causing considerable tissue damage. About eight weeks after penetrating the liver the flukes enter the bile ducts where they become fully mature at about 10-12 weeks post-infection and start to lay eggs.

Disease

Heavy infections can result in sudden death but more generally there is loss of condition, anaemia (pale mucous membranes in the eyes and gums) and a tender, possibly fluid-filled abdomen. Bottle-jaw may also be seen in chronic infections. Liver fluke disease in sheep occurs in three main clinical forms – acute, sub acute and chronic fasciolosis. Which form occurs depends on the numbers of infective metacercariae ingested and the period of time over which they are ingested. Fluke infection also predisposes sheep to “Black Disease” (*Clostridium novyi* infection).

Epidemiology

The hatching of fluke eggs and the multiplication of snails depend on adequate moisture and temperatures greater than 10ºC. Such conditions normally occur from May-October in the UK. Levels of infection and incidence of disease due to liver fluke are very much dependent on rainfall during this period, in particular during May-July when many fluke eggs hatch and snails multiply, and September/October when cercariae develop and are released on wet pastures before encysting onto herbage.

Although snails can carry infection at most times of the year, infection potentially reaches peak levels twice a year depending on climatic conditions. The epidemiology of liver fluke is therefore often viewed as the result of two distinct cycles of snail infection and pasture contamination.

- *Summer infection of snails*

  In wet summers, snail populations multiply rapidly and snails are invaded by hatching miracidia from May-July. If wet weather continues, the snails shed massive numbers of cercariae onto pasture during July-October. Conversely, if the climate in May-July is dry or cold, fewer snails appear, fewer fluke eggs hatch and levels of contamination in the autumn are much lower. Clinical fasciolosis resulting from summer infection of snails arises usually from ingestion of large numbers of metacercariae over a short period of time in June-October.

- *Winter infection of snails*

  Less commonly, snails can become infected in late summer or early autumn and development within infected snails is delayed as the snails become dormant and hibernate. The cercariae are then not shed onto the pasture until the following spring. This can produce an initial and significant infection in herds or flocks in the spring.

Since the fluke life cycle and the severity of liver fluke disease depend on climate, in particular rainfall, systems for predicting the incidence of disease have been devised. These "forecasts" are based on meteorological data throughout the summer months, supported by abattoir and surveillance data. When higher than average rainfall occurs in the spring/summer and again in late summer/early autumn, increased risk from fluke may be anticipated that year with a carry-over of infection to the following spring. Thereafter, the potential for increased risk of disease in subsequent years depends on the prevailing climatic conditions.

Lungworms

Life Cycles

Larvae of *D. filaria* pass out into the faeces and develop to L_3 similar to GI nematode larvae. After ingestion, the L_3 penetrate the intestinal mucosa and pass to the mesenteric lymph nodes where they moult. The L_4 then travel via the lymph and blood to the lungs, and break out of the capillaries into the alveoli about one week after infection. The final moult occurs in the bronchioles, a few days later, and the young adults then move up the bronchi and mature.

The life cycles of the various metastrongylid lungworms are similar and indirect, requiring a molluscan intermediate host. Sheep are infected by ingesting a slug or snail containing an infective L_3. Following ingestion of an infected mollusc with herbage, the larvae are freed and travel to the lungs via the lymph and blood vessels, and enter the mesenteric lymph nodes and lungs.

Disease

Disease due to lungworm in sheep is usually less severe than those seen with cattle. Infections with *D. filaria* may cause dyspnoea and coughing in grazing animals usually in the autumn. Mild infections usually of metastronglid lungworms are inapparent. Heavy infections may cause bronchopneumonia and emphysema.

Epidemiology

In temperate areas, the epidemiology of *D. filaria* is similar to that of the cattle lungworm, *D. viviparus* with development to the L_3 occurring during the period from spring to autumn. In warmer climates, where conditions are often unsuitable for larval survival, outbreaks of disease in young susceptible animals are most likely to occur after a period of prolonged rain.

The distribution and prevalence of other species of metastrongylid lungworms are partly attributable to the presence of molluscan, intermediate hosts, and the ability of larvae to overwinter in the molluscs. Factors which play a part in ensuring the endemicity of these worms are, first, the ability of the L_1 to survive for months in faecal pellets and secondly, the persistence of the L_3 in the intermediate host for the lifetime of the mollusc, each of which depend on climatic conditions, especially high rainfall.

Tapeworms

Life Cycles

With *Moniezia*, eggs are passed in the faeces and on pasture where the onchospheres are ingested by pasture mites and develop into cysticercoids in 1-4 months. Infection of the final host is by ingestion of infected mites during grazing. The prepatent period is approximately 6 weeks.

The larval tapeworms found in sheep (metacestodes stages of *Multiceps multiceps* and *Echinococcus granulosus*) are acquired by ingestion of eggs passed out in the faeces of the final canid hosts (dogs and foxes). The life cycle is completed when a dog or fox feeds on infected sheep viscera.

Disease

While a great variety of clinical signs including unthriftiness, diarrhoea, respiratory signs and even convulsions have been attributed to *Moniezia*, infections are generally symptomless.

Hydatid infections in sheep are generally not associated with clinical signs. Clinical signs of *Coenurus cerebralis* depend on the location and size of the cyst or cysts and include circling behaviour, visual defects, and peculiarities in gait, stumbling, non-coordinated movements or paraplegia. As the infection progresses animals may become anorexic and lose weight and death may result. With the syndrome 'gid' the animal holds its head to one side and turns in a circle to the affected side.

Epidemiology

Tapeworm infections are relatively common in grazing sheep and factors such as decreased use of BZ anthelmintics (which are effective against *Moniezia*), and increased ML anthelmintics (which are not effective) used as a consequence of advice on resistance management, may result in apparent increases in reports.

Reports of hydatidosis have increased in parts of Wales probably as a result of less worming of farm dogs, and failure to prevent scavenging of sheep carcases, because of the changing economics of carcase disposal.

PROTOZOA

Coccidiosis

Life Cycle

Following ingestion of the sporulated oocysts, there are usually two merogony (asexual) stages, producing initially "giant" first-generation meronts, in some species, followed by smaller second-generation meronts. During gametogony (sexual phase), fusion of macrogametocytes and microgametocytes leads to zygote formation and the excretion of unsporulated oocysts in the faeces. Sporulation outside the body may be completed in 1-4 days under ideal conditions, but can take several weeks in cold weather. The life cycle takes between 2-4 weeks depending on the species of *Eimeria.*

Disease

Generally the first signs of coccidiosis in a flock are failure of young lambs to thrive, with some showing a 'tucked-up' and open fleeced appearance and, possibly, faecal staining around the hindquarters due to diarrhoea. Affected lambs eventually lose their appetite and become weak and unthrifty. As the disease progresses some lambs show profuse watery diarrhoea, often containing streaks of blood. If left untreated, these animals may continue to scour and eventually die of dehydration.

Epidemiology

Coccidia are normally present in animals of all ages and usually cause no clinical signs as immunity is quickly acquired and maintained by continuous exposure to re-infection. However, intensification may alter the delicate balance between immunity and disease with serious consequences for young animals. Coccidiosis is one of the more important diseases of lambs particularly in their first few months of life. Whilst coccidial infection is common, the presence of infection does not necessarily lead to the development of clinical signs of disease and in many situations low levels of challenge can actually be beneficial by stimulating protective immune responses in the host. Development of disease is dependent on a number of factors in particular on husbandry and management.

Adult animals are highly resistant to the disease, but not totally resistant to infection. As a result, small numbers of parasites manage to complete their life cycle and usually cause no detectable harm. In the wild or under more natural, extensive systems of management, susceptible animals are exposed to only low numbers of oocysts and acquire a protective immunity. Extensive grazing, as occurs under natural conditions in the wild, limits the level of exposure to infective oocysts. Under modern production systems, however, lambs are born into a potentially heavily contaminated environment, and where the numbers of sporulated oocysts are high, disease often occurs. Three management factors are associated with the development of high levels of infection and the development of disease; (1) pens are not cleaned on a regular basis; (2) overcrowding in the pens; (3) pens are used to house different age groups.

Adult ewes, although possibly the original source of infective oocysts in the environment, are not usually responsible for the heavy levels of contamination encountered. The source is often the lambs themselves, which following an initial infection in the first few days of life may produce millions of oocysts within their own environment. Growing animals may then face potentially lethal doses of infective oocysts, 3 weeks later when their natural resistance is at its lowest. Later born lambs introduced into the same environment are immediately exposed to heavy oocyst challenge. Under unhygienic, overcrowded conditions, the lambs will be exposed to and ingest a large proportion of this infection and will develop severe disease and may even die from the infection. If conditions are less crowded and more hygienic, the infective dose ingested will be lower, they may show moderate, slight or no clinical signs and develop immunity to re-infection, but they in turn will have multiplied the infection a million fold. Stress factors, such a poor milk supply, weaning, cold weather and transport, will reduce any acquired resistance and exacerbate the condition.

Colostrum provides passive immunity to coccidiosis during the first few weeks of life. Thereafter, susceptibility to coccidial infections has been found to progressively increase. Subsequently animals acquire resistance to coccidia as a result of active immunity. While animals of all ages are susceptible to infection, younger animals are generally more susceptible to disease. The majority of lambs will probably become infected during the first few months of life and may or may not show signs of disease. Those that reach adulthood are highly resistant to the pathogenic effects of the parasites but may continue to harbour small numbers throughout their lives.

Occasionally, acute coccidiosis occurs in adult animals with impaired cellular immunity or in those which have been subjected to stress, such as dietary changes, prolonged travel, extremes of temperature and weather conditions, changes in environment or severe concurrent infection. An animal's nutritional status, mineral and vitamin deficiencies can also influence resistance to infection. Suckling animals, in addition to benefiting from colostral intake, may forage less and hence pick up fewer oocysts from pasture. Well-nourished animals may simply be able to fight off infection more readily.

Cryptosporidiosis

Life Cycle

The life cycle of *Cryptosporidium* is very similar to the coccidia although sporulation takes place within the host so that oocysts are immediately infective when passed in the faeces.

Disease

Clinically the disease is characterised by anorexia and diarrhoea, often intermittent, which may result in poor growth rates.

Epidemiology

In young lambs infection appears to be age related with seasonal peaks reported to coincide with birth peaks in spring. The primary route of infection is mainly by the direct animal-to-animal faecal-oral route. In lambs, chilling due to adverse weather conditions in the neonatal period, inter-current infections or nutritional or mineral deficiencies could exacerbate or increase the likelihood of disease. Infection in these cases is likely to occur through grooming, nuzzling, coprophagy or by faecal soiling through contact with infected animals. Infection may also occur indirectly through consumption of contaminated foods, pastures or water.

Babesiosis

Life Cycle

The merozoites of *Babesia* occur in the erythrocytes of infected sheep where they multiply asexually by binary fission. Transmission occurs following a bite from an infected tick.

Disease

Clinically affected animals develop a haemolytic anaemia leading to haemoglobinuria, fever, and jaundice.

Epidemiology

Babesiosis is not considered endemic in the UK but occurs throughout Europe where infection is transmitted by ticks of the genus *Ixodes*, *Haemaphysalis*, *Dermacentor* and *Rhipicephalus*. The presence of disease in sheep reflects the distribution and prevalence of competent tick vector species.

Appendix II

ECTOPARASITES

MITES

<u>Psoroptic Mange (Sheep scab)</u>

Life Cycle

The scab mite can remain viable off the host for 15-17 days and still be capable of infesting sheep. The life cycle takes 14 days in ideal conditions and consists of the egg, hexapod larvae, octopod protonymphs and tritonymphs and adult males or females.

Adult males attach to female tritonymphs, and occasionally protonymphs, and remain attached until the females moult for the final time, at which point insemination occurs. Moulting between instars, lasts 12 - 36 hours. Once fertilised, the adult female will not mate again but will live for an average of 40 days, laying 1 or 2 eggs daily. The median life expectancy for an adult female *P. ovis* is about 16 days, during which it will have laid about 40-50 eggs. Populations of *P. ovis* on a host may therefore grow quickly doubling every 6 days or so.

Disease

Infestations can be debilitating with high morbidity and fatalities can occur through loss of condition, malnutrition, secondary infections and hypothermia. The disease is also of considerable economic significance because of poor animal growth, fatalities and the downgrading of wool and leather.

Epidemiology

Sheep scab is a winter disease, with most cases occurring between September and April, although a significant number of cases do occur in the summer months, particularly on animals still full-fleeced and on "ridges" of longer fleece on poorly shorn sheep. Sheep scab mites will actively migrate to the "cryptic sites" (axilla, groin, intraorbital fossa, pinna and ear canal). The presence of the mites in the ears cause chronic irritation often associated with head shaking and scratching.

Common grazing or poor on-farm biosecurity, such as the maintenance of farm boundaries, bought-in sheep, all add to the risk of disease spread. Shearing is an important factor in scab control and the poor economics of wool production, coupled with increased use of contract shearers, dippers and more worryingly the introduction of spray or shower systems from abroad have probably all contributed to the worsening situation with sheep scab. The effect of legislative changes and that of increased and varied choices of products for the control of sheep scab have already been alluded to. Legislative and socio-economic changes have impacted on scab control and contributed to a worsening situation such that the disease has become widespread and endemic.

Chorioptic Mange

Life Cycle

The life cycle is typical: egg, 6-legged larva, followed by 8-legged protonymph, tritonymph and adult. All developmental stages occur on the host. The complete egg to adult life cycle takes about 3 weeks. Eggs are deposited at a rate of one per day and are attached to the host skin. Adult females produce 15-20 eggs and live for 2-3 weeks. Mites may survive for up to 3 weeks off the host, allowing transmission from housing and bedding as well as by direct contact.

Disease

Chorioptes mites infest the less woolly areas, particularly the lower parts of the hind legs and scrotum, and can decrease fertility by causing inflammation of the scrotal skin. *C. bovis* does not pierce the skin, but feeds on skin debris leading to a yellow-brown lesion with haemorrhaging fissures resulting from allergic reactions to the mites or mite by-products. Intense itching causes foot stamping and biting.

Epidemiology

Mite populations are highest in the winter and may regress over summer especially after shearing.

Life Cycle

The entire life cycle takes place on the host. Mating probably takes place at the skin surface, following which the female creates a permanent winding burrow, parallel to the skin surface.

Each tunnel contains only one female, her eggs and faeces. Maturation of the eggs takes 3 or 4 days, following which the female starts to oviposit 1–3 eggs/day, over a reproductive life of about 2 months. The eggs, which are oval and about half the length of the adult, are laid singly at the ends of outpockets, which branch off along the length of these tunnels. Three to four days after oviposition, the six-legged larva hatches from the egg, moulting after 2-3 days to a protonymph, tritonymph and then adult. The total egg to adult life cycle takes between 17 and 21 days, but may be as short as 14 days. During this period, the mortality rate is high, with just 10% of mites that hatch completing their development. During an infection mite numbers increase rapidly, then decline, leaving a relatively stable mite population.

Sarcoptic Mange

Disease

Scabies mites on sheep are found on the sparsely haired parts of the body, such as the face and ears. Mites burrow into the epidermis and feed on tissue fluids, which causes irritation and consequent scratching, leading to inflammation and exudation, which forms crusts.

Epidemiology

Sheep are infected by contact with other infected sheep, mainly by the transfer of larvae, which are commonly present more superficially on the skin surface. Infestation may also occur by indirect transfer, since the mites have been shown to be capable of surviving off the host for short periods. The length of time that *S. scabiei* can survive off the host depends on environmental conditions but may be between 2 and 3 weeks. Consequently, animals' bedding and grooming tools may become contaminated and are possible sources of infestation.

Ticks

Life Cycles

The life cycles of ixodid ticks involve four instars: egg, six-legged larva, eight-legged nymph and eight-legged adult. During the passage through these stages ixodid ticks take a number of large blood meals, interspersed by lengthy free-living periods. They are relatively long-lived and each female may produce several thousand eggs.

Ticks have developed a variety of complex life cycles and feeding strategies, which reflect the nature of the habitat, which the various species of tick inhabit and the probability of contact with an appropriate host. For most, a three-host life cycle has been adopted. Larvae, nymphs and adults all feed on different hosts. Blood feeding typically takes between 4 and 6 days after which they drop to the ground and either moult to the next life-cycle stage or lay eggs. Ticks must then re-locate a suitable host to feed and moult again or lay eggs.

Disease

Heavy tick infestations can cause irritation and anaemia. The major importance of ticks is in the transmission of diseases to livestock and humans. *I. ricinus* ticks are important vectors of Lyme disease (*Borrelia burgdorferi*), human granulocytic ehrlichiosis (*Anaplasma phagocytophilum*) and Q-fever (*Coxiella burnetti*) in humans; tickborne fever (*A. phagocytophilum*), louping ill, tick pyaemia in sheep; as well as babesiosis in cattle (*Babesia divergens*) and louping ill in gamebirds (grouse etc.) in the UK. The ticks are also capable of transmitting a range of viruses, protozoal and rickettsial diseases currently considered exotic to the UK.

D. reticulatus is a vector for the transmission of a wide range of pathogens. In sheep, it is a vector for *Babesia ovis*, *Theileria ovis*, and also transmits babesiosis in cattle, horses and dogs. *H. punctata* transmits *Babesia motasi* and benign theileriosis (*Theileria ovis*) to sheep.

Epidemiology

In temperate habitats, feeding and generation cycles of hard ticks are closely synchronized with periods of suitable temperature and humidity conditions. Ticks, particularly in the immature stages, are very susceptible to desiccation, particularly when ticks are active. To minimize drying out they start questing when saturated with water and return to the humid ground level when dehydrated. Water may also be imbibed by drinking.

The distribution of ticks is closely linked with the availability of a micro-environment with a high relative humidity, such as occurs in the mat which forms under the surface of rough grazing. Where suitable grass cover does exist it has been generally accepted, since temperatures are suitable for development throughout a large part of the year, that the distribution of ticks is mainly governed by rainfall, with a mean annual rainfall of more than 60 cm required for survival.

However, recent studies have shown that the factors underlying the maintenance of the necessary microclimate with a high relative humidity are rather more complex, and depend on the transpiration of plant leaves. As long as this continues, adequate humidity is maintained in the microclimate despite the dryness of the ambient temperature. However, when the rate of evaporation increases beyond a certain level, the stomata on the leaves close, transpiration ceases and the low humidity created in the microclimate rapidly becomes lethal to the ticks.

In the field, the stability of the microclimate is dependent on factors such as the quantity of herbage or plant debris and the grass species. The various genera of ticks have different thresholds of temperature and humidity within which they are active and feed, and these thresholds govern their distribution. Generally, ticks are most active during the summer provided there is sufficient rainfall, but in some species the larval and nymphal stages are also active in milder weather. This affects the duration and timing of control programmes.

Myiasis (Blowfly strike)

Life Cycles

The life cycle for the three blowfly species is essentially similar. Female blowflies are anautogenous and must obtain a protein meal before maturing their eggs. The gravid female blowfly is attracted by the odour of decomposing matter and lays clusters of yellowish-cream eggs on dead animals. The larvae pass through three stages before leaving the feeding site and pupating in the round. Adults emerge some weeks later, the precise time depending on temperature.   When protein is freely available the gravid female blowfly lays clusters of 225-250 yellowish-cream eggs on wounds, soiled fleece or dead animals, attracted by the odour of the decomposing matter.

In temperate areas under summer conditions, the eggs hatch into larvae in about 12 hours. The larvae then feed, grow rapidly and moult twice to become fully mature maggots in 3 days. The larvae usually feed superficially on the epidermis and lymphatic exudates, or on necrotic tissue. They will only begin to feed on healthy tissue in crowded conditions. The mouth-hooks are used to macerate the tissues, and digestion occurs extra-orally by means of amylase in the saliva and proteolytic enzymes in the larval excreta. Mature larvae drop to the ground and pupate. The pupal stage is completed in 3–7 days in summer. Adult flies can live for about 7 days. The time required to complete the life cycle from egg to adult is highly dependant on the ambient temperature but is usually between 4-6 weeks, and in temperate seasonal habitats up to four generations may develop per year. In these areas, the final generation overwinters in the soil as larvae, to emerge in the following spring. In warmer climates the number of generations per annum is greater and up to nine or ten have been recorded in southern Africa and Australia.

Disease

Blowflies attack in waves, classified as primary, secondary or tertiary fly waves. Primary flies (*Lucilia* and *Phormia*) oviposit on damaged or soiled areas of fleece. The larvae crawl to the skin which they eventually lacerate and digest.

Secondary flies (*Lucilia* spp, *Phormia* spp or *Calliphora* spp) are attracted by the smell of the primary lesion. Similarly, the third wave of flies is attracted by the increasing lesion and secondary bacterial infection. If unchecked, extensive infestations of secondary, tertiary or further waves of flies occur and sheep can die a quick agonizing death.

Signs of blowfly strike include agitation and dejection. In breech strike, infested sheep stamp their hind legs, shake their tails vigorously or gnaw and rub at the breech. As lesions develop a distinctive odour is noticeable and the wool becomes matted and discoloured. If the infestation remains untreated the affected area increases and wool is shed from the centre, accompanied by signs of constant discomfort.

Epidemiology

Blowflies have low population densities, with under 1 500 flies per square mile and only gravid females are attracted to sheep. Blowfly myiasis in the UK can be classified as body strike or breech strike. In body strike, flies are attracted to sheep by the odours of excessive “sweating” and/or decaying organic matter in the fleece. In breech or tail strike, flies are attracted to fleece contaminated with urine and/or faeces and are particularly associated with scouring. Other forms of strike include foot strike, head strike occurring in horned breeds with accumulation of dirt and grease at the horn base or through wounds from fighting or de-horning, and pizzle strike, occurring in the wool around the opening of the prepuce.

In a survey of sheep farmers in England and Wales, 80% reported at least one case of blowfly strike in their flocks, with an estimated half a million sheep struck annually. An average of 1.6% of sheep was reported to be struck within flocks. The prevalence of blowfly strike is weather-dependent, with most cases of body strike occurring during periods of high humidity or warm periods after heavy rain. If preventative measures are not used to prevent strike then it has been estimated that between 3.7% and 5% of lambs could be struck between June and August.

Lice

Life Cycles

Bovicola ovis prefers areas close to the skin such as the back, neck and shoulder, but is highly mobile and severe infestations will spread over the whole body. During a life span of about a month the female lays 2-3 operculate eggs per day, which are glued to the hair. A nymph (similar to the adult but smaller) hatches from the egg, moults twice at 5-9 day intervals, until eventually moulting to become an adult. The whole cycle from egg to adult takes 2–3 weeks.

Adult *Lignonathus* female lice lay a single egg per day. Eggs hatch in 10-15 days, giving rise to nymphs that require about 2 weeks to pass through three nymphal stages. The egg-to-adult life cycle requires about 20-40 days.

Disease

Infestations of lice constitute a chronic dermatitis, characterized by constant irritation, itching, rubbing, tagging and biting of the fleece. Infestations can cause considerable, but unmeasurable losses from unthriftiness, retarded growth and damaged wool and leather.

The clinical signs of chewing lice can be confused with that of sheep scab (*Psoroptes ovis*) and thus possible resistance may occur in both ectoparasites if they are not professionally identified and the correct treatment applied. Sheep can also present with mixed infestations of sheep scab and chewing lice.

With infestation of *Linognathus* spp. anaemia is common where high populations of lice exist. Anaemia may predispose animals to respiratory or other diseases. Heavy infestations of *L. pedalis* cause foot stamping and biting and can produce lameness.

Epidemiology

The mouthparts of mallophagan lice are adapted for chewing the outer layers of the hair shafts, dermal scales, and blood scabs. *Bovicola ovis* is capable of rapid population expansion and may be aided by their ability to change from sexual to asexual reproduction by parthenogenesis. *Bovicola ovis* is very active, roaming in the wool over the entire body. It is susceptible to high temperatures, but it also intolerant of high humidity.

Lignonathus spp populations peak in spring, and lambs may be particularly susceptible to infestation. Transmission occurs when sheep are brought together as in sale yards, and especially when sheep are housed for the winter since the heavy fleece provides a habitat that is readily colonized by lice. Adult lice positioned near to the tip of the wool fibre are passed on to the new host as it brushes past an infected sheep and itt takes a single infested sheep just four months to infest the entire flock.

<u>Keds</u>

Life Cycle

Keds are permanent ectoparasites and live for several months feeding on the blood of sheep and sometimes goats. The female is viviparous, retaining the larva within a modified oviduct until it is fully grown, depositing it as an immobile pre-pupa, that pupates once attached to the wool. The egg hatches inside the body of the female and the larva is retained and nourished within the female during its three larval stages, until it is fully developed. The mature larvae produced by the females adhere to the wool and pupate immediately. The pupae are fully formed within 12 hours of larviposition and are resistant to treatment. Adult keds emerge in approximately three weeks in summer, but this period may be extended considerably during winter. A female produces between 10 and 20 larvae in its lifetime. Thus, a cycle from newly emerged adult female to emergence of an adult of the next generation is 5 weeks. Pupae develop over a relatively narrow range of temperature (25^{o}C-34^{o}C) with optimal development at 30^{o}C. Puparia are glued to the fleece and carried away from the skin as the fleece grows. Temperature at skin level will be close to 37^{o}C but considerably cooler nearer the fleece tip. Puparia are therefore deposited in areas where a suitable temperature will be found during the 3 weeks of pupal development. In hoggs, over 50 per cent of the pupae are found in the neck region, while 60 per cent of adult *M. ovinus* are found on the forelegs and flanks. On lambs, puparia are concentrated on the hind legs, neck and belly, although substantial numbers of adults are found on the flanks and forelegs.

Disease

Adult keds are blood feeding and large numbers can gradually exsanguinate the host and cause variable degrees of anaemia. Excreta can stain the wool and downgrade the fleece. Large numbers can cause restlessness, the sheep biting, kicking and rubbing the affected areas, mechanically damaging the fleece. Keds are also responsible for an allergic dermatitis in sheep characterised by small nodules in the skin, reduced weight gain, and darkened patches at the affected site. They are spread by contact and long-wooled breeds appear to be particularly susceptible.

Epidemiology

Keds are permanent ectoparasites. The spread of sheep keds is largely through contact, and the movement of keds from ewes to lambs is an important route of infestation. Within a flock, transfer occurs when sheep keds move to the tips of the fleece in response to increasing air temperature. Air temperature must usually be 21°C or above before many keds are observed on the surface of the fleece. Consequently, transfer between animals is more likely, and occurs more rapidly, in summer than in winter. Sheep with dense, long or clotted fleeces are more likely to spread the infection because the keds come to the surface of such fleeces. Heavy infestations of keds are most commonly seen in autumn and winter. Poorly fed animals or those that are not sufficiently protected against cold weather are most liable to suffer from ked infestations.

Headflies

Life Cycle

Eggs are laid in decaying vegetation or faeces in late July and September, which then hatch within 7 days and develop into mature larvae by the autumn. Each female produces one or two batches of about 30 eggs in its lifetime. Third-stage larvae may be predatory on other larvae. These larvae then go into diapause (a temporary cessation of development) until the following spring when pupation and development is completed, with emergence of a new generation of adults in early summer. Thus there is only one generation of headfly each year.

Disease

Headflies are attracted to sheep and cattle and feed on tears, saliva, sweat and wounds, such as those incurred by fighting rams. They are facultative blood-feeders and will ingest blood at the edges of wounds if available. Horned breeds of sheep, such as the Swaledale and Scottish Blackface, are most susceptible to attack. Swarms of these flies around the head lead to intense irritation and annoyance and result in self-inflicted wounds, which then attract more flies. Clusters of flies feeding at the base of the horns lead to extension of these wounds, and the condition may be confused with blowfly myiasis. Secondary bacterial infection of wounds is common, which may encourage blowfly strike. The economic losses due to headfly infection are difficult to assess, but are thought to be substantial.

Epidemiology

Adult flies prefer still conditions and are found near woodlands and plantations, with peak numbers occurring in mid-summer.

Nasal Botflies

Life Cycle

Female flies are viviparous and infect the sheep by squirting a jet of liquid containing larvae at the nostrils during flight, which delivers up to 25 larvae at a time. The newly deposited L_1 are about 1.0 mm long, and migrate through the nasal passages to the frontal sinuses feeding on the mucus that is secreted in response to the stimulation of larval movement.

Larvae attach themselves to the mucous membrane using oral hooks, which cause irritation. The first moult occurs in the nasal passages, and the L_2 crawl into the frontal sinuses where the final moult to L_3 takes place. In the sinuses, the larvae complete their growth and then migrate back to the nostrils, from where they are sneezed to the ground. Larvae pupate in the ground and pupation lasts for between 3-9 weeks.

The larvae remain in the nasal passages for a variable period, ranging from 2 weeks in summer to 9 months during colder seasons. Where flies are active throughout the year, two or three generations are possible, but in cool or cold weather the small L_1 and L_2 become dormant and remain in recesses of the nasal passages over winter. They move to the frontal sinuses only in the warmer spring weather, and then complete their development into the L_3, which emerge from the nostrils and pupate on the ground to give a further generation of adults. The females survive only two weeks, but during this time each can deposit up to 500 larvae in the nasal passages of sheep.

Disease

In the UK, signs of oestrosis are most prominent in May, appearing in flocks as early as March but still recorded in November. Signs include nasal discharge (rhinitis), sometimes haemorrhagic, sneezing, wheezing breath, snorting, head shaking, unthriftiness, rubbing noses against the ground, head tossing, nervous excitability, "gadding" and sometimes blindness, pneumonia and death.

Larvae (particularly L_1) can also be recovered from animals not demonstrating any clinical signs. Clinical oestrosis can be confused with scrapie, psoroptic otoacariasis or even sheep scab.

Epidemiology

Oestrosis is more frequent in older ewes with over half reported to show signs in late summer. The prevalence of *O. ovis* varies from year to year. Higher incidences of infestation may follow years with unusually hot summers and thus a greater number of active adult flies challenging sheep. Larvae in the nasal sinuses are sneezed out and pupate in the soil. The pupal period can last 17-70 days and is extremely temperature-dependent. Exposure to temperatures <16^{o}C and > 32^{o}C are lethal and the optimum temperature has been recorded as 27^{o}C. In the UK, there appears to be only one wave of adult flies, consisting of two overlapping generations. The first generation originates from an overwintering population of larvae emerging in May and June which then deposits L_1 larvae in June or July. These larvae form the basis of the second generation, depositing L_1 larvae in August, September or October. Larvae deposited by the second generation remain quiescent as L_1 larvae in the nasal turbinates until the following spring, when they continue their development.

An abattoir survey for the whole of Great Britain revealed a national incidence of 0.75% with *O. ovis* was most prevalent in the warmer counties south of latitude 52° which may represent the northernmost range of the species. Localized surveys covering south Wales and southwest England recorded prevalences of 0.5% and 0.75% respectively but a survey in Surrey and West Sussex revealed a prevalence of 16.6%.

Appendix III

Worm Control

Wormer Groups

Benzimidazoles (1-BZ) ('white' drenches)

All are effective against nematodes and are ovicidal although individual generic products may vary in efficacy against some nematode species, particularly *N. battus*. Most are efficacious against tapeworms. After administration, the BZ passes into the rumen, which acts as a reservoir, allowing gradual release into the bloodstream. BZs act by inhibiting tubulin activity in intestinal cells of nematodes or tegumental cells of cestodes, preventing uptake of glucose. The longer the time it stays in the animal the more effective it is.

Benzimidazole anthelmintics (BZ) are effective against BZ-sensitive nematodes and are ovicidal. Most are efficacious against tapeworms. The BZs possess high activity against the adult and immature larvae of *N battus*. Some BZ anthelmintics at increased dose rates (containing albendazole) are also active against liver fluke. Triclabendazole is narrow spectrum (liver fluke only) and differs from all the other BZ in many respects but is classed with them because of its chemical structure.

Imidazothiazoles (2-LM) ('yellow' drenches)

This group includes the imidazothiazoles (levamisole) and tetrahydropyrimidines (morantel, pyrantel). Only levamisole is currently available on the UK market for use in sheep. These drugs are rapidly absorbed and excreted and most of the dose is lost from the system within 24 hours. Therefore, it is not essential to maintain high concentrations in the sheep for protracted periods. LMs act on the nerve ganglion of the parasite, causing paralysis. Levamisole is effective against gastrointestinal nematodes and *Nematodirus*, but has no activity against tapeworms or fluke.

Macrocyclic Lactones (3-ML) ('Clear' drenches)

Macrocyclic lactones (MLs) are fermentation products of soil micro-organisms (*Streptomyces* spp.) and have been chemically modified to produce the avermectins (ivermectin and doramectin) and the milbemycins (moxidectin). MLs are referred to as "endectocides" being effective against both nematodes (endo-) and external (ecto-) parasites. These compounds are highly lipophilic and following administration are stored in fat tissue from where they are slowly released. They act on glutamate gated Cl- channels and γ-aminobutyric acid (GABA) neurotransmission sites in nematodes, blocking interneuronal stimulation of inhibitory motor neurones, leading to a flaccid paralysis. ML compounds are available for sheep either as injectable formulations (ivermectin, moxidectin, doramectin), or oral drenches (ivermectin, moxidectin). All injectable MLs (and oral moxidectin) have persistent activity against some, but not all, worm species and can be used at extended treatment intervals in strategic dosing strategies, although unlike in cattle, the treatment intervals have not been clearly defined.

Only one product has a licensed claim for persistent activity in sheep; moxidectin will prevent re-infection with ML-susceptible *Teladorsagia* spp and *Haemonchus* for 5 weeks. The period of protection from re-infection with *Trichostrongylus* is much shorter. The MLs have variable activity against *N battus* although doramectin at increased dose rate is active against L4 larvae of this species. Moxidectin (oral or injectable) has no persistent activity against *N battus*.

Worm Control Strategies

Adult Sheep at Tupping

At this time most ewes in good body condition will be carrying low worm burdens as they will have a strong acquired immunity. Treatment at this period can significantly select for anthelmintic resistance. It is therefore recommended that only mature ewes with a low body condition score or immature ewes are dosed around tupping. It is important to use an anthelmintic, which is effective against arrested larval stages.

Adult Sheep at Lambing

The most important source of infection for the lamb crop is undoubtedly the increase in nematode eggs in ewe faeces during the periparturient rise and prophylaxis will only be efficient if this is kept to a minimum. Effective anthelmintic therapy of ewes during the fourth month of pregnancy should eliminate most of the worm burdens present at this time including arrested larval stages and in the case of ewes on extensive grazing, where nutritional status is frequently low, this treatment often results in improved general body condition. Treatment around lambing or turnout, and again 4-5 weeks later will significantly reduce the ewe contribution to pasture contamination but it may also increase the selection for drug resistance. To reduce the selection pressure it has been suggested that ewes are dosed early in the lactation period to allow them to become re-infected before a high level of immunity is re-established. In addition, leaving a proportion of the ewes untreated (Targeted Selective Treatments -TSTs) will allow the pasture to be contaminated with unselected parasites. Both of these approaches could however increase the risk of disease in the lamb crop later in the season. Where ewes are in-wintered or housed for a period before lambing, dose them on entry to the shed. Following turnout onto contaminated pasture they may require further treatment in about 4-5 weeks.

Lambs

In general, lambs should be treated at weaning, and where possible moved to ‘safe’ pastures, i.e. those not grazed by sheep since the previous year. Recommendations now are to delay the “move” after the “dose”. This is to allow the treated flock to become ‘lightly’ re-infected before allowing them access to the low contamination pasture to reduce selection pressure for AR The number of days for which dosed sheep should be allowed to graze contaminated pasture before being given access to the ‘clean’ grazing will depend on variations in pasture infectivity and climatic factors. If the pastures are of high infectivity and the sheep reasonably susceptible to parasites (less than one year old, for example) then 4–7 days of grazing may be a satisfactory compromise between making best use of the ‘clean’ pasture resource and reducing the selection pressure for AR.

Where such grazing is not available, prophylactic treatments should be repeated until autumn or marketing. The number of treatments will vary depending on the stocking rate, one treatment in September sufficing for lambs under extensive grazing and two between weaning and marketing for those under more intensive conditions. In order to reduce unnecessary dosing of lambs it is recommended that faecal egg counts are monitored to predict the need for treatment.

The prophylactic programmes outlined above are relatively costly in terms of drugs and labour but are currently the only practicable options available where the enterprise is heavily dependent on one animal species.

Alternate grazing of sheep and cattle

On farms where sheep and cattle are both present in significant numbers, effective control is theoretically possible by alternating the grazing of pasture on an annual basis with each host, due to the relative insusceptibility of cattle to sheep nematodes and *vice versa.* In practice, control is best achieved by exchanging, in the spring, pastures grazed by sheep and beef cattle over the previous year, preferably combined with anthelmintic treatment at the time of exchange. On these mostly intensive farms, rotation of crops and grass is often a feature, and therefore new leys and hay and silage aftermaths are available as safe pastures each year and can be reserved for susceptible stock. In such a situation, control should be based on a combination of grazing management and anthelmintic prophylaxis.

Prophylaxis by alternative grazing and anthelmintics

Good control is possible with only one annual anthelmintic treatment of ewes when they leave the lambing field. This will terminate the periparturient rise in faecal egg counts prior to moving the ewes and lambs to a safe pasture. At weaning, the lambs should be moved to another safe pasture (delaying the move after the dose as described earlier).

A second system has been devised for farms where arable crops, sheep and cattle are major components and involves a three-year rotation of cattle, sheep and crops. With this system the aftermath grazing available after cropping may be used for weaned calves and weaned lambs.

It has been suggested that anthelmintic prophylaxis can be disposed of completely under this system but clinical PGE has sometimes occurred when treatment has been omitted. As anthelmintics may not remove all the worms present and some cattle nematodes can infect sheep and *vice versa*; and a few infective larvae on the pasture can survive for beyond two years it is advisable to give at least one annual spring treatment to all stock prior to moving to new pastures.

Control by grazing management alone

Systems using strip or creep grazing, which limit the return of sheep to pastures until the contamination has declined to a low level, have been used with some success but are costly in terms of labour and fencing and require a degree of forethought and planning

Anthelmintic Resistance

The routine use of highly effective anthelmintics, and where possible, grazing management, has controlled worms very successfully in the majority of sheep flocks. Recently, however, the prevalence of anthelmintic resistance (AR) in the UK has risen sharply and an increasing number of flocks are finding that one or more of the chemical groups are no longer effective against some worm species.

Resistance is a heritable ability of the parasite to tolerate a normally effective dose of an anthelmintic although ‘resistant’ individuals can often be removed by exposure to higher dose rates of anthelmintic up to the maximum tolerated dose. Anthelmintics will continue to give clinical responses in parasitised sheep, consequently, sheep farmers may not be aware that AR is present although significant production losses from poor worm control may have occurred, and additionally, resistance can be expected to become more severe quite rapidly if the anthelmintic remains in use.

In the UK, AR has been confirmed in a number of species of sheep nematodes. Resistance to BZ anthelmintics is now widespread, levamisole (LM) resistance appears to be increasing with reports of ML resistance and “triple” resistant (resistance to all 3 broad spectrum groups) *T. circumcincta* populations on some farms.

The genes, or alleles, which allow parasites to become resistant to anthelmintics are believed to pre-exist in unselected worm populations. Consequently, for all anthelmintics that have been introduced to date, it appears that the development of AR is an inevitable consequence of their use but its development can be delayed and because of improved understanding of these factors, new guidelines for anthelmintic use have been devised. More details on anthelmintic resistance and measures to avoid its development are provided in “Sustainable worm control strategies for sheep – SCOPS technical manual for Veterinary Surgeons and Advisors” available at *www.nationalsheep.org.uk*.

The new SCOPS guidelines for anthelmintic use and worm control in sheep

1. Work out a control strategy with your veterinarian or advisor.	The need for specialist consultation is greater now than before. Decisions about judicious use of anthelmintics in worm control programs are complex, and will require on-going consultations
2. Use effective quarantine strategies to prevent the importation of resistant worms in introduced sheep and goats	Introduction of resistant alleles is considered a major cause of AR in UK flocks.
3. Test for AR on your farm	It is fundamental that sheep farmers know which products are effective in their flocks.
4. Administer anthelmintics effectively	Administer the right dose in the right way, and exploit opportunities to enhance drug efficacy, if appropriate
5. Use anthelmintics only when necessary	Understand the trade-off between tolerating some level of parasitism and minimising selection for AR. FEC monitoring has an important role.
6. Select the appropriate anthelmintic for the task	Consider narrow spectrum treatments whenever possible. Use rotations in appropriate ways.
7. Adopt strategies to preserve susceptible worms on the farm	Aim to reduce the heavy selection for AR when treating immune sheep or when dosing onto low contamination pastures.
8. Reduce dependence on anthelmintics	Alternative control measures include grazing management, risk assessment and using rams that have been selected for resistance to nematodes.

Fluke Control

Fluke control programmes rely heavily on flukicidal treatments. The choice of product and frequency of use will depend on the level of fluke challenge, the time of year, and the management and husbandry systems on the farm. It is important to use the appropriate drug for each situation. Most flukicidal drugs on the market are effective in treating chronic fasciolosis, because they kill adult fluke, but few are effective in treating acute fluke infections in sheep caused by the immature flukes migrating through the liver. Triclabendazole (TCB) is generally the drug of choice but as resistance to flukicides can occur with repeated and frequent use, alternatives should be used wherever possible, in order to reduce the potential for the development of TCB-resistance.

Fluke burdens can be monitored in sheep flocks by *post-mortem* examinations when the opportunity arises, or with faecal egg counts. Flocks should be monitored before a flukicide is used unless there is a history of fluke infection on the farm. Continued monitoring can help determine the need for repeated treatments. For treatment in late summer and autumn, a flukicide that is active against immature fluke is recommended. Treatment may need to be repeated in winter (January). If treatment is required in spring (April-June), it may be appropriate to use a flukicide with adult activity only. In a high-risk year, additional doses may be required for sheep in November and June. The treatment interval will depend on the activity of the flukicidal drug against immature stages and persistence in activity. The use of combination fluke and worm products should generally be discouraged as it can lead to off-target selection for resistance to broad-spectrum anthelmintics in nematodes, or flukicide resistance in *F hepatica*.

Flukicide Resistance

The widespread use of TCB, due to its activity against immature fluke, has unfortunately led to the development of resistance in several countries and reports of suspected resistance in the UK. Resistance usually manifests first as a failure to kill the youngest immature flukes, with subsequent re-appearance of fluke eggs in the faeces earlier than would be expected if the drug retained full efficacy. As resistance develops, eventually adult fluke are able to survive treatment as well. The possibility of other reasons for flukicide failure should always be considered, particularly if animals are in poor condition or may be suffering from liver damage. Where resistance is suspected to a particular product, then an alternative flukicide should be considered, taking into account the variations in activity against immature fluke between products. More details on flukicide resistance and measures to avoid its development are provided in "Sustainable worm control strategies for sheep – SCOPS technical manual for Veterinary Surgeons and Advisors" available at *www.nationalsheep.org.uk*.

Coccidiosis Control

Only a few licensed products are available for the treatment of coccidiosis. Diclazuril (or toltrazuril) can be used to treat “at risk” lambs at 3-4 weeks of age. In cases of heavy challenge or mixed age groups of lambs, repeat treatment 2-3 weeks later. Timing of treatment is crucial as it is important to prevent severe infections but at the same time allow protective immunity to develop through adequate parasite exposure. Alternatively, decoquinate may be used as a creep feed additive for the treatment of clinical disease.

Normally all lambs in a flock should be treated as even those showing no symptoms are likely to be infected. Severely affected lambs that are diarrhoeic and dehydrated may additionally require fluid therapy using either oral rehydration solutions. Concurrent helminth infections, particularly with *N. battus*, may require appropriate anthelmintic treatment.

Where non-specific symptoms of weight loss or ill-thrift are present, it is important to investigate all potential causes and seek laboratory confirmation. If coccidiosis is considered significant, much can be done through advice on management and instigation of the preventive measures outlined earlier. Batch rearing of lambs in groups of similar ages helps to limit the build up and spread of oocysts to younger crops of lambs, and allows targeting of treatment of susceptible age groups through treatment of lambs with targeted treatment with diclazuril or toltrazuril, or creep feeding of lambs over the danger periods.

Ectoparasite Control

Ectoparasiticide Groups

Organophosphate (OP) Compounds

Diazinon was approved for scab control in the UK in 1981, although it had been licensed for blowfly and lice control since the early 1970’s. Propetamphos (also an OP) was approved for scab, lice and blowfly control in the UK in 1982, but was removed from the market for economic reasons. OP dip formulations have been incriminated in human toxicity and as a consequence their future availability as sheep dips always remains in the balance.

Synthetic Pyrethroid (SP) Compounds

The first synthetic pyrethroid (SP), flumethrin, was licensed in 1987 in the UK for scab and lice control and later dip and pour-on formulations containing high-cis cypermethrin (HCC) were licensed for the British market for ectoparasite control. Alpha-cypermethrin pour-on products are effective against blowfly strike, lice, ticks and headfly. Spot-on formulations of deltamethrin are effective against headfly, ticks, lice, keds and established blowfly strike. These are the only SPs currently available in the UK The VMD rescinded the marketing authorisation for the remaining SP dip, cypermethrin on in 2006 because of environmental concerns. There are now no licensed SP containing dip products in the UK.

Macrocyclic Lactones (MLs)

Macrocyclic lactones (MLs) are fermentation products of soil micro-organisms (*Streptomyces* spp.) and have been chemically modified to produce the avermectins (ivermectin and doramectin) and the milbemycins (moxidectin). MLs are referred to as "endectocides" being effective against both nematodes (endo-) and external (ecto-) parasites. These compounds are highly lipophilic and following administration are stored in fat tissue from where they are slowly released. Their mode of action in arthropods is not completely understood but LLs probably acts on neuro-receptor sites similar to those found in nematodes. The MLs are active against sucking lice (*Linognathus* spp), nasal bot flies (*Oestrus*) and mange mites (*Psoroptes*, *Sarcoptes*, *Chorioptes*). There is little or no activity against chewing lice (*Bovicola ovis*), ticks or keds.

Insect Growth Regulators (IGRs)

Insect growth regulators (IGRs) represent a relatively new category of insect control agents. They constitute a group of chemical compounds that do not kill the target parasite directly, but interfere with growth and development. IGRs act mainly on immature stages of the parasite and as such are not usually suitable for the rapid control of established adult populations of parasites. Where parasites show a clear seasonal pattern, IGRs can be applied prior to any anticipated challenge as a preventative measure. Based on their mode of action they can be divided into chitin synthesis inhibitors (benzoylphenyl ureas), chitin inhibitors (triazine/pyrimidine derivatives) and juvenile hormone analogues. IGRs are widely used for flea control in domestic pets and for blowfly control in sheep but have limited use in other host species.

Currently available IGRs include the triazine derivative (cyromazine) and pyrimidinamine (dicylanil), which are licensed in the UK for blowfly control in sheep.

Sheep Scab Treatments

Plunging sheep in baths of ectoparasiticide has been the most effective method of sheep ectoparasite control throughout the World. To achieve complete saturation sheep must be kept moving as the swimming action displaces the air in the fleece and aids dipwash penetration. Immersion times are important: thirty seconds is adequate for the control of lice, blowfly or ticks but at least 60 seconds (with the head immersed twice) is required to eradicate sheep scab. Even if the head is immersed correctly dipwash does not penetrate the ear canal completely and mites in the ears can survive dipping and their exposure to sub-lethal concentrations of acaricide could select for resistance.

Sheep dip formulations have been divided into stripping dips (eg formulations containing the OP, diazinon) and non-stripping dips (eg most SP formulations – now no longer available). All sheep actively absorb suspended or emulsified active ingredient from the dip wash into the wool grease (stripping), resulting in greater amounts of active ingredient remaining in the wool and decreasing amounts in the dip wash. If active ingredient is not replaced dip wash concentrations will eventually become depleted (too low to be effective). Large amounts of water are also retained by the fleece, the volume dependent on the size of the sheep and the length of fleece. Adequate concentrations of active ingredient and volume of dip wash must therefore be maintained at all times (replenishment). Traditionally concentrate and water are replenished after a certain number of sheep, or after a specified drop in volume. For stripping formulations replenishment is the regular addition of concentrate (at a level greater than the initial charge) and water to compensate for depletion. For the non-stripping dips the wash was topped-up with wash (concentrate and water) at the same concentration and there was no need to wait for a specific drop in volume or a specified number of sheep.

Care should be taken when dipping wet sheep, as they can add extra water to the dip wash. Ectoparasiticides have a strong affinity to fleece lipid, wet sheep will therefore remove little water from the dip wash but will remove relatively the same amount of active ingredient as dry sheep. Thus dip wash volume will be slow to fall, despite depletion of the active ingredient. Replenishment by a drop in volume does not take into account wet sheep, thus a head count method is advisable. Heavy rain during or directly after dipping can wash active ingredient out of the fleece, as can subsequent washing or bloom dipping. Continuous heavy rain falling on the draining pens and water contained in the fleece can also dilute the dip wash.

Sheep dipping is an exact science and attention must be paid to detail. If dipping is not carried out correctly, ectoparasites can be exposed to sublethal concentrations, which increase the risk of resistance developing. The problems with plunge dipping are multi-factorial. To the operator it is time consuming, labour intensive and OP formulations have been incriminated in human toxicity. Residues in the fleece and the disposal of large volumes of used dip wash (particularly with the SPs) pose considerable problems for the environment.

The main advantages of ML products over plunge dipping for scab control are that they are quicker and safer to use, cause less stress to the sheep (including pregnant ewes), do not require any special handling facilities and fixed equipment (ie. Dip baths) and there is not the same environmental concerns over the disposal of spent products. Their main disadvantages are their relatively narrow range of efficacy against ectoparasites and their relatively long meat withdrawal periods. They are not licensed for the control of lice, ticks and blowfly. MLs can kill *P. ovis* but sheep can suffer irritation for some time after treatment, due to the retention of allergens that would be washed out by plunge dipping. Many farmers have now removed their dipping facilities, relying solely on the use of MLs. In Britain there appears to be an increasing problem with chewing lice (*Bovicola ovis*), mainly brought about by the use of endectocides for scab control.

Blowfly Prevention

At recommended dose rates, the IGR, cyromazine (Vetrazin^{TM}), shows only limited activity against established strikes and must, therefore, be used preventatively before anticipated challenge. Blowflies usually lay eggs on damp fleece of treated sheep. Although larvae are able to hatch out, the young larvae immediately come into contact with cyromazine, which prevents the moult to second instars. The use of a ‘pour-on’ preparation of cyromazine has the advantage that efficacy is not dependent upon factors such as weather, fleece length, and whether the fleece is wet or dry. In addition, the persistence of the drug is such that control can be maintained for up to 13 weeks after a single pour-on application, or longer if applied by dip or shower. Dicyclanil (Click^{TM}) is also highly active against blowfly larvae and is available as a pour-on formulation for blowfly control in sheep providing up to 16 weeks’ protection.