Modelling Jaagsiekte Control Measures in Scottish Sheep Flocks
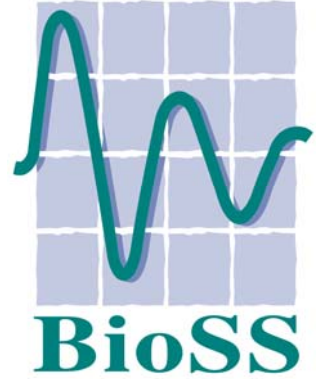
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Jaagsiekte

Jaagsiekte, also known as Ovine Pulmonary Adenocarcinoma (OPA), is a contagious lung cancer of sheep.

- The disease is caused by the Jaagsiekte Sheep Retrovirus (JSRV).
- Although considered a particular problem in Scotland, it is also found in many other countries around the world.
- Clinical symptoms often include production of copious lung fluid (see photo, right).
- Transmission is believed to occur mainly via the respiratory route but indirect transmission via the environment cannot be ruled out.

Modelling of Jaagsiekte infection

- Progression of infection is modelled using an SEIR compartmental model:
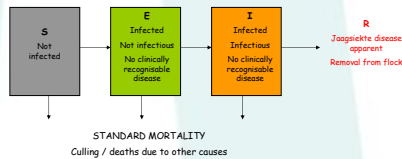
- Horizontal transmission and environmental transmission are modelled by calculating a cumulative hazard value for each sheep, initially set to zero. At each timestep (of one week), the hazard is incremented by a term

$$\beta_{direct}(I+R)+\beta_{indirect}\int_{t_{n-1}}^{t_n}f(c(t))dt.$$

Here the two β parameters quantify the *direct* transmission rate between sheep and the *indirect* transmission rate via the environment. The function $c(t)$ models environmental contamination, while $f(c(t))$ represents the force of infection corresponding to $c(t)$. Transmission occurs when the cumulative hazard passes the random threshold specified for a specific animal.

- Vertical transmission between the ewe and lamb is modelled via p, the probability that a lamb is infected given an infectious dam.
- In our survey we tested sheep for Jaagsiekte infection on 125 Scottish farms.

Modelling Scottish sheep management

There are a wide variety of different sheep management systems operating in Scotland. However, there are two important ways in which flocks can differ in terms of their risk for Jaagsiekte transmission. First, is the flock open or closed? Second, is the flock extensive or intensive? These considerations, informed by analysis of questionnaire data from the farm survey, led to the modelling of five flock types: Extensive Closed (archetypical hill), Intensive Closed, Extensive Open, Intensive Open (archetypical lowland) and Pedigree flocks (similar to Intensive Closed but with a reduced flock size).

Control measures for Jaagsiekte

0	Baseline	Cull clinically affected animals – this happens on all farms.
1	Basic Cull	Baseline plus culling of offspring from clinically affected animals.
2	Intermediate Cull	Basic Cull plus culling of mother of clinically affected animals.
3	Wide Cull	Intermediate Cull plus culling of siblings of clinically affected animals.
4	Conditional Basic Cull	Conditional versions of control measures 1-3. Non-clinical animals are only culled if they test positive for JSRV.
5	Conditional Intermediate Cull	
6	Conditional Wide Cull	
7	Vaccination	Use of a hypothetical vaccine with plausible properties.

Model parameterisation

There is a substantial amount of uncertainty and variability in some of the parameters in both the sheep management model and the infection transmission model. Such parameters were considered variable between different batches of simulation runs, with properties guided by previous studies and published literature (see table below). Different choices of the parameters were randomly grouped together to produce 1000 different scenarios. This is a standard procedure in Latin Hypercube Sampling based quantitative risk assessment (Vose, 2000; Iman & Conover, 1980). The scenario outcomes were then allocated weights calculated relative to the test results collected in our survey. This procedure was repeated for each flock type. The table below and the results that follow are for the Extensive Closed (EC) flock type, without environmental transmission.

| Latin Hypercube parameter	Distribution	Derived from
Direct transmission rate (per week per susceptible)	Gamma (shape=5.83, scale=0.0000605).	Analysis of past longitudinal study data collected by the Moredun Research Institute.
Proportion of incubation period in which a sheep is infectious.	Uniform on [0,1].	No data relating to this parameter.
Probability of vertical transmission.	Three parameter gamma (shape=2.981, scale=0.1095, threshold=0.1399).	Analysis of past longitudinal study data collected by the Moredun Research Institute.
Ewe mortality rate (per week).	Gamma (shape=9.54, scale=0.0000191).	Beaton, 2006.
Flock size.	Three parameter gamma (shape=1.532, scale=294.7, threshold=52.15).	Analysis of sheep management questionnaire data.
Diagnostic test sensitivity and specificity.	Gamma distributions.	Analysis of diagnostic test assay data from this project (Lewis *et al*).

Results
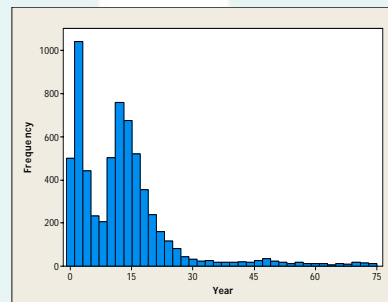
Histogram of Number of Years to Extinction of Infection for Farm Type EC. In the absence of any control measures, the EC simulation runs demonstrate two main modes of behaviour

- short period epidemics (0-15 years)
- long term epidemics (5-75+ years).

Comparing control measures to the baseline control: change in total number of clinical cases after 15 years of simulated infection on an EC farm. The graph shows the 95 percentile range and weighted median for each control measure. There are very different outcomes for different scenarios, reflecting a high level of uncertainty and variability in the model parameters. Widening the scope of the cull increases the efficacy, while conditional culling reduces it. Vaccination is the most effective control measure for many scenarios – a vaccine is currently under development.
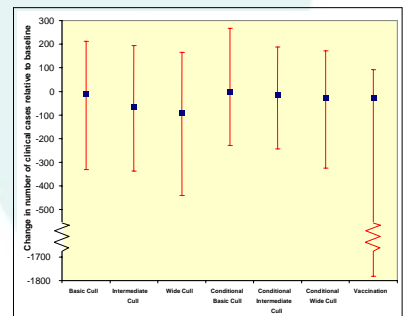
References

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Iman, R., Conover, W., 1980, Small Sample Sensitivity Analysis Techniques for Computer Models, with an Application to Risk Assessment, *Commun. Statist.-Theor. Meth.* **A9**(17), 1749-1874.

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