Modeling Management Strategies for the Control of Bighorn Sheep Respiratory Disease

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The problem
Biological understanding of problem

• *Mycoplasma ovipneumoniae* (Movi) is necessary to cause epidemic and chronic pneumonia
  – Domestic sheep & goats
  – Invades BHS, triggers all-age die-off, some adults become chronic carriers, this facilitates perennial lamb failure

• Unknown how other pathogens contribute to severity of morbidity and mortality

• Unknown how often Movi goes extinct
Where simulation models can help...

- Can we generate predictions given our current biological understanding?
  - Disease dynamics—are simulations realistic?
  - Which parameters are most influential?
  - Management tools and outcomes
Pathogen invasion
Pathogen invasion
Pathogen invasion

Pathogen persistence
Can we reduce the persistence of Movi through management?
Disease model

\[ \lambda \]

\[ \text{birth} \]  

\[ \text{3 weeks 16 weeks} \]

\[ \text{15\%} \]  

\[ \text{lifelong} \]

\[ \text{85\%} \]  

\[ \text{lifelong} \]
Disease model

\[ \text{Sur} = 0.77 - 0.8; 0.5 \]

\[ \text{Sur} = 0.87 - 0.9; 0.5 \]

\[ \text{Sur} = 0.5; 0.1 \]
Disease model

\[
\begin{align*}
S & \xrightarrow{\lambda} E \xrightarrow{3 \text{ weeks}} I \xrightarrow{15\%} C \\
& \enspace \xrightarrow{16 \text{ weeks}} I \xrightarrow{85\%} R \\
& \quad \xrightarrow{\text{lifelong}} C \\
& \quad \xrightarrow{\text{lifelong}} R
\end{align*}
\]

\[
\text{March survey} \quad \text{October survey}
\]

\[\lambda \quad \text{Weekly time step within annual cycle}\]

\[
\text{Rut}
\]

\[
\begin{align*}
\text{Sur} &= 0.77 - 0.8; \, 0.5 \\
\text{Sur} &= 0.87 - 0.9; \, 0.5 \\
\text{Sur} &= 0.5; \, 0.1
\end{align*}
\]
Assumptions about transmission

• Density dependent transmission
  – Contact rate increases with density

• Frequency dependent transmission
  – Contact rate is independent of density
Basic dynamics
Basic dynamics

Density Dependent; High survival

Population size

0 100 300

Year

0 20 40 60 80 100
Basic dynamics
Basic dynamics

- Density Dependent; High survival
- Frequency Dependent; High survival
- Density Dependent; Low survival
- Frequency Dependent; Low survival
Management Tools

• Augmentation
• Test and cull
• Density reduction (non-selective cull)
• Depopulation and reintroduction

*Focused on transmission, not resiliency
Augmentation

- Scenario 1: Add 30 ewes that are immune to the recipient herd’s strain of Movi

- Scenario 2: Add 30 susceptible ewes to the recipient herd
Augmentation
Augmentation

- Does not improve recovery
- What if strain typing doesn’t identify epitope variation?
Test and Cull

• Scenario 1: Capture and test 95% of the herd and remove any individual testing positive (infectious or carriers) for Movi

• Scenario 2: Repeat above for a total of two consecutive years
Test and Cull

No Management

Population Size

0 200 400
0 20 40 60 80 100

Test (95%) and Cull

Population Size

0 200 400
0 20 40 60 80 100

One Year
Two Years
Test and Cull

- Assumes you can’t detect “exposed” individuals
- Success is improved by repeating test and cull for 2 years
Density Reduction

Translocation out

Translocation into

Pneumonia outbreak
Density Reduction

No Management

Population Size

Year

Density Reduction

Population Size

Year

25%

50%
Density Reduction

- Stochastic removal of exposed, infected, and carrier individuals
- If transmission is density dependent, may slow rate of new infections
Depopulation and Reintroduction

Tendoy Mountains
Bighorn sheep herd in Montana's Tendoy Mountains targeted

Jul 12, 2015

• Ideally, depopulation = 100% removal

• What if we are only able to remove 95% of the herd?
Depopulation and Reintroduction

No Management

Depopulation (95%) and Reintroduction
Depopulation and Reintroduction

- Ability to find sufficient numbers of “clean” sheep?
- How long does it take to completely depopulate?
Density Dependent Transmission

No Management

Augmentation (30 Ewes)

Test (95%) and Cull

Density Reduction

Depopulation (95%) and Reintroduction
Probability of Movi extinction

*Assuming high host survival*
Probability of Movi extinction

*Assuming low host survival; note shorter time scale
Conclusions

• Augmentation not predicted to help

• Density reduction offers small improvement
  – Added risk of inbreeding depression, Allee affects

• Test and cull and depopulation predicted to offer best probability of recovery
  – Must test or depopulate large portion of herd

• Shinny app
Caveats

• Model results are preliminary—still need full sensitivity analysis

• Different measures of “success” and acceptability
  – Speed/probability of population recovery
  – Management costs
  – Values

• Timescales
  – Action vs waiting?
  – Waiting is complicated if spillover risk continues
Management must address entire picture to make progress

- Prevention is still best practice