Balancing cost and income in red deer management – a case study from Norway

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Recent large increases in deer population sizes both in Europe and North America

Ecological key stone species

- Vegetation and general ecosystem impact

Increased potential hunting benefits

Costs related to traffic incidents, damage to forestry, agriculture field damage
Norwegian red deer stock:
Two main reasons:

1. Selective harvesting
   - Harvest more bulls (stags), calves and yearlings, less females

2. Forestry practice
   - From selective logging to clear cutting
Motivation:

- Biological project to maximize meat production
- Economic considerations?
  - Stage structured harvesting
  - Overall red deer stock
Stage structured harvesting in general

- Calf harvesting:
  - Resistance among hunters

- Trophy hunting:
  - Trophy bulls very rare
Overall stock size in general:

- Grazing damage costs
- Traffic damage costs
  - material costs as well as road accident deaths
Map, study area: Flora and Gloppen
Landowner perspective:

- Case 1: Landowners maximising hunting value only: $V+B$

- Case 2: Landowners maximizing hunting value taking grazing damage costs into account: $V+B-D$
Ecological model

- five-stage model:
  - calves ($X_c$)
  - female yearling ($X_{yf}$)
  - male yearlings ($X_{ym}$)
  - adult females ($X_f$)
  - adult males ($X_m$)
Hunting

- Choosing harvest fractions (controls):
  1) $h_c$: Harvest rate calves
  2) $h_{yf}$: Harvest rate female yearlings
  3) $h_{ym}$: Harvest rate male yearlings
  4) $h_f$: Harvest rate females
  5) $h_m$: Harvest rate males
Ecological model

1) \[ X_{c,t} = r_{yf}(X_{yf,t})X_{yf,t} + r_{f}(X_{f,t})X_{f,t} \]

2) \[ X_{yf,t+1} = \psi s_c (1-h_{c,t})X_{c,t} \]

3) \[ X_{ym,t+1} = (1-\psi)s_c (1-h_{c,t})X_{c,t} \]

4) \[ X_{f,t+1} = s_{yf}(1-h_{yf,t})X_{yf,t} + s_{f}(1-h_{f,t})X_{f,t} \]

5) \[ X_{m,t+1} = s_{ym}(1-h_{ym,t})X_{ym,t} + s_{m}(1-h_{m,t})X_{m,t} \]
Code of conduct restriction:

- Calves dependent on mother first winter:

\[ h_c X_c \geq h_f X_f \]
Avoid extremely sex skewed sex ratio

- $h_{ym,t} \leq \bar{h}_{ym}$ and $h_{m,t} \leq \bar{h}_m$

- Or

$$\frac{X_{m,t}}{X_{f,t}} \geq \bar{x}$$
\[ L = \sum_{t=0}^{\infty} \rho^t \left\{ \left[ p_c h_{c,t} [r_{yf}(X_{yf,t})X_{yf,t} + r_f(X_{f,t})X_{f,t}] + [p_y h_{yf,t} + p_{ym} h_{ym,t}(1-\psi)/\psi)]X_{yf,t} + p_f h_{f,t} X_{f,t} + p_m h_{m,t} X_{m,t} \right] \\
+ \frac{z}{\theta}(h_{c,t} + h_{yf,t} + h_{ym,t} + h_{f,t} + h_{m,t}) - \rho \eta_{t+1} \left[ X_{yf,t+1} - \psi s_c (1-h_{c,t}) [r_{yf}(X_{yf,t})X_{yf,t} + r_f(X_{f,t})X_{f,t}] \right] \\
- \rho \lambda_{t+1} \left[ X_{f,t+1} - s_{yf} (1-h_{yf,t}) X_{yf,t} - s_f (1-h_{f,t}) X_{f,t} \right] - \rho \mu_{t+1} \left[ X_{m,t+1} - s_{ym} (1-h_{ym,t})(1-\psi)/\psi] X_{yf,t} - s_m (1-h_{m,t}) X_{m,t} \right] \\
- \rho \omega_{t+1} \left[ h_{f,t} X_{f,t} - h_{c,t} [r_{yf}(X_{yf,t})X_{yf,t} + r_f(X_{f,t})X_{f,t}] \right] - \rho \xi_{t+1} (h_{m,t} - \bar{h}_m) \right\} \]
Kuhn-Tucker conditions

\[
\frac{\partial L}{\partial h_{i,t}} \leq 0 ; \quad 0 \leq h_{i,t} < 1 \quad (i = c, yf, ym, f, m)
\]
What can be shown analytically?

- Not much...
- Possible to say something about the harvest pattern when the recreational value is zero (or negligible)
- Especially if we ignore the code of conduct harvest restrictions as well....
- Without female-calf restriction: No calf harvest
- With the restriction, it is always binding
- All adult males should be harvested
## Baseline results, biological

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h_c$</td>
<td>0.11</td>
<td>0.12</td>
</tr>
<tr>
<td>$h_{yf}$</td>
<td>0.33</td>
<td>0.37</td>
</tr>
<tr>
<td>$h_{ym}$</td>
<td>0.55</td>
<td>0.55</td>
</tr>
<tr>
<td>$h_f$</td>
<td>0.08</td>
<td>0.11</td>
</tr>
<tr>
<td>$h_m$</td>
<td>0.55</td>
<td>0.55</td>
</tr>
<tr>
<td>$H$</td>
<td>752</td>
<td>682</td>
</tr>
<tr>
<td>$X_c$</td>
<td>1 176</td>
<td>1 021</td>
</tr>
<tr>
<td>$X_{yf}$</td>
<td>392</td>
<td>336</td>
</tr>
<tr>
<td>$X_{ym}$</td>
<td>392</td>
<td>336</td>
</tr>
<tr>
<td>$X_f$</td>
<td>1 720</td>
<td>1 137</td>
</tr>
<tr>
<td>$X_m$</td>
<td>264</td>
<td>227</td>
</tr>
<tr>
<td>$X$</td>
<td>3 944</td>
<td>3 057</td>
</tr>
</tbody>
</table>
# Baseline results, economic

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meat value (V)</strong></td>
<td>3,016</td>
<td>2,700</td>
</tr>
<tr>
<td><strong>Recreational value (B)</strong></td>
<td>809</td>
<td>850</td>
</tr>
<tr>
<td><strong>Hunting value (V+B)</strong></td>
<td>3,825</td>
<td>3,550</td>
</tr>
<tr>
<td><strong>Grazing cost (D)</strong></td>
<td>2,099</td>
<td>1,594</td>
</tr>
<tr>
<td><strong>Overall net benefit (R=V+B-D)</strong></td>
<td>1,726</td>
<td>1,956</td>
</tr>
<tr>
<td><strong>R/H</strong></td>
<td>2.295</td>
<td>2.868</td>
</tr>
<tr>
<td><strong>R/X</strong></td>
<td>0.438</td>
<td>0.640</td>
</tr>
</tbody>
</table>
Optimal uniform harvest rate

- Case 1: \((h=0.18)\), net benefit=\(\text{NOK 693}\) (from \(1,726\))

- Case 2: \((h=0.19)\), net benefit=\(\text{NOK 752}\) (from \(1,956\)) in Case 2.
Sensitivity analysis

- Economic results sensitive to the male harvest constraint
- Harvest pattern generally very stable to different parameter changes, except…
- High recreational value: More calf than female harvest (restriction does not bind!)
Concluding remarks

- Stage structured harvest pays off
- Recreational value crucial
- Grazing damage important
- Current red deer stock is too high
- Current harvest pattern is wrong