Benefit-cost analysis of rabies control

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Overview

1. Starting point: Point of departure: MoH vs. MoA
2. Cross-sector economic analyses of zoonoses
3. From Benefit – Cost to Cost Effectiveness Analysis
4. Cost-effectiveness of rabies control in N’Djaména, Chad
5. Conceptual outlook
6. Next steps
Starting point

• Rabies control in developing countries is often poorly organized as a result of poor communication between the human and animal health sectors.

• Ministries operate with a narrow focus; for example, the Ministry of Health is unwilling to assume responsibility for an intervention outside of the public health sphere and the Ministry of Agriculture and Livestock prioritises cattle over dogs and wildlife. Neither is willing to allocate scarce resources to address a disease which is not their priority.

• Is rabies control profitable and cost-effective?
Cross-sector economic analyses of zoonoses

• Interventions in disease reservoirs
  • Livestock
  • Dogs
  • Wildlife

• Benefits
  • Public health
  • Private households
  • Agricultural sectors
  • Others...
Synoptic view of benefits and costs of livestock brucellosis mass vaccination in Mongolia (Roth et al. BWHO 2003)
From Benefit – Cost to Cost - effectiveness

- An economic analysis of rabies control provides a framework to examine the benefits and costs of interventions. Benefits in terms of saved resources and human and animal lives across all affected public and private sectors can then be compared to intervention costs, considering potential sharing across sectors.
  
  - Most important benefit: saved human lives
  - Benefit – Cost analysis is replaced with Cost-effectiveness analysis
  
  - Benefits / Intervention cost (Mongolia example)
  - Cost / DALYs averted (Disability adjusted live years) or
  - Cost / Life saved
  - Across sectors
Let us travel to N'Djaména, Chad
Housing: Mostly mud bricks, gated yards
**Dog rabies incidence (Kayali et al. 2003)**

<table>
<thead>
<tr>
<th>Incidence cumulative de la rage canine à N'Djaména (1-11 2003) corrigé pour la couverture vaccinale (carnets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 0 (2)</td>
</tr>
<tr>
<td>0.0001 to 0.00025 (1)</td>
</tr>
<tr>
<td>0.00025 to 0.0005 (3)</td>
</tr>
<tr>
<td>0.001 to 0.005 (1)</td>
</tr>
<tr>
<td>0.005 to 0.01 (1)</td>
</tr>
</tbody>
</table>

![Map of dog rabies incidence](image)

- **positive cases**
- **exposed persons**

<table>
<thead>
<tr>
<th>time in week</th>
<th>number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
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<tr>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
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<tr>
<td>6</td>
<td>19</td>
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<tr>
<td>7</td>
<td>22</td>
</tr>
<tr>
<td>8</td>
<td>25</td>
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<tr>
<td>9</td>
<td>28</td>
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<tr>
<td>10</td>
<td>31</td>
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<td>11</td>
<td>34</td>
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<td>12</td>
<td>37</td>
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<td>13</td>
<td>40</td>
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<td>14</td>
<td>43</td>
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<tr>
<td>15</td>
<td>46</td>
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<td>16</td>
<td>49</td>
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<td>17</td>
<td>52</td>
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<tr>
<td>18</td>
<td>55</td>
</tr>
<tr>
<td>19</td>
<td>58</td>
</tr>
<tr>
<td>20</td>
<td>61</td>
</tr>
</tbody>
</table>

**Legend:**
- Blue dots: positive cases
- Pink dots: exposed persons
Summary of preparatory results

- Vaccination coverage >70 %
- High community participation
- Proportion of stray dogs 5-10%
- Estimated dog population: 15-40'000 dogs
- Parenteral dog vaccination strategy can probably be recommended

- Is it profitable and cost-effective to vaccinate 25’000 dogs to prevent human rabies?
Simplified deterministic model of rabies transmission between dogs and humans (Zinsstag et al. PNAS 2010)

S = susceptible dogs
L = latent infected dogs
I = rabid dogs
R = vaccinated dogs
X = susceptible humans
Y = exposed humans
Z = rabid humans

Dogs

\[
\frac{dS_d}{dt} = b_d N_d + v_{id} R_d + \left( \frac{1}{i_d} (1 - r_d) E_d \right) - m_d S_d - \beta_d S_d I_d - \gamma N_d S_d - v_{ed} v_{cd} S_d
\]

\[
\frac{dE_d}{dt} = \beta_d S_d I_d - m_d E_d - \gamma N_d E_d - \left( \frac{1}{i_d} (1 - r_d) E_d \right) - v_{ed} v_{cd} E_d - \left( \frac{1}{i_d} r_d E_d \right)
\]

\[
\frac{dI_d}{dt} = \left( \frac{1}{i_d} r_d E_d \right) - m_d I_d - \gamma N_d I_d - m_{rd} I_d
\]

\[
\frac{dR_d}{dt} = (v_{ed} v_{cd} (S_d + E_d)) - m_d R_d - \gamma N_d R_d - v_{id} R_d
\]

\[
\gamma = \left( \frac{(b_d - m_d)}{KN_d} \right)
\]

\[
N_d = S_d + E_d + I_d + R_d
\]
Humans

\[
\frac{dS_h}{dt} = (b_h (S_h + E_h + R_h)) + v_{ih} R_h + \left( E_h \left( \frac{P2(1 - P6)}{i_{head}} + \frac{P3(1 - P7)}{i_{arm}} + \frac{P4(1 - P8)}{i_{trunc}} + \frac{P5(1 - P9)}{i_{leg}} \right) \right) - m_h S_h - v_{eh} v_{ch} S_h - \beta_{dh} S_h I_d
\]

\[
\frac{dE_h}{dt} = \beta_{dh} S_h I_d - m_h E_h - P10 v_{eh} E_h - \left( E_h \left( \frac{P2(1 - P6)}{i_{head}} + \frac{P3(1 - P7)}{i_{arm}} + \frac{P4(1 - P8)}{i_{trunc}} + \frac{P5(1 - P9)}{i_{leg}} \right) \right) - \left( E_h \left( \frac{P2(1 - P6)}{i_{head}} + \frac{P3(1 - P7)}{i_{arm}} + \frac{P4(1 - P8)}{i_{trunc}} + \frac{P5(1 - P9)}{i_{leg}} \right) \right)
\]

\[
\frac{dI_h}{dt} = \left( E_h \left( \frac{P2(1 - P6)}{i_{head}} + \frac{P3(1 - P7)}{i_{arm}} + \frac{P4(1 - P8)}{i_{trunc}} + \frac{P5(1 - P9)}{i_{leg}} \right) \right) - m_h I_h - m_{rh} I_h
\]

\[
\frac{dR_h}{dt} = P10 v_{eh} E_h + v_{eh} v_{ch} S_h - m_h R_h - v_{ih} R_h
\]
Endemic stable dog-human rabies transmission in N’Djamenarabid dogs per km2
exposed persons per km2

compass south

0 0.005 0.01 0.015 0.02
0 0.005 0.01 0.015 0.02

compass north

time in weeks

time in weeks
Effect of different control strategies on the transmission of rabies

![Graph showing the effect of different control strategies on the transmission of rabies. The x-axis represents time in weeks, ranging from 0 to 320. The y-axis represents rabid dogs per km², ranging from 0 to 0.0012. The graph compares different strategies: no intervention, vaccination campaign with 70% coverage, vaccination campaign with 50% coverage, shooting campaign twice with 10% coverage, and shooting campaign twice with 5% coverage. Each strategy is indicated by a different line color and marker style on the graph.]
## Cost structure

### Public Cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Vaccine subsidies</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Vaccine subsidies</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Unit Outpatient cost</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Outpatient cost</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Total Public cost</strong></td>
<td><strong>0.00</strong></td>
<td><strong>0.00</strong></td>
</tr>
</tbody>
</table>

### Private Cost

#### Out of pocket

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Transport Cost</td>
<td>5.01</td>
<td>2,433.33</td>
</tr>
<tr>
<td>Transport</td>
<td>115,689.72</td>
<td>124,303.46</td>
</tr>
<tr>
<td>Unit Lab fee (dog examination)</td>
<td>11.73</td>
<td>5,700.00</td>
</tr>
<tr>
<td>Lab fee</td>
<td>270,999.21</td>
<td>291,176.59</td>
</tr>
<tr>
<td>Human unit vaccine cost*</td>
<td>90.03</td>
<td>43,750.00</td>
</tr>
<tr>
<td>Human vaccine cost</td>
<td>2,080,037.81</td>
<td>2,234,908.01</td>
</tr>
<tr>
<td>Unit drug cost</td>
<td>19.04</td>
<td>9,250.00</td>
</tr>
<tr>
<td>Drug cost</td>
<td>439,779.42</td>
<td>472,523.41</td>
</tr>
<tr>
<td>Unit outpatient cost</td>
<td>4.12</td>
<td>2,000.00</td>
</tr>
<tr>
<td>Outpatient cost</td>
<td>95,087.44</td>
<td>102,167.22</td>
</tr>
<tr>
<td><strong>Total out of pocket cost</strong></td>
<td><strong>3,001,593.61</strong></td>
<td><strong>3,225,078.69</strong></td>
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</table>

### Loss of income

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Cost</th>
<th>Total Cost</th>
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</thead>
<tbody>
<tr>
<td>Loss of income per case</td>
<td>10.29</td>
<td>5,000.00</td>
</tr>
<tr>
<td><strong>Loss of income</strong></td>
<td><strong>237,718.61</strong></td>
<td><strong>255,418.06</strong></td>
</tr>
</tbody>
</table>
DALY estimation

DALY = YLL and YLD $\rightarrow$ limited to YLL

Age structured, no gender difference

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Population</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposed Persons (modelled Y when no vacc)</td>
<td>48</td>
<td>51</td>
</tr>
<tr>
<td>Exposed Persons by age groups</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;5</td>
<td>9.03</td>
<td>9.71</td>
</tr>
<tr>
<td>5 to 15</td>
<td>17.12</td>
<td>18.39</td>
</tr>
<tr>
<td>&gt; 15 (Median)</td>
<td>21.39</td>
<td>22.99</td>
</tr>
</tbody>
</table>

Cost-effectiveness = Cost per DALY averted (discounted)
Comparative cost of rabies control in N‘Djaména
(Zinsstag et al. PNAS 2009, 106(35) 14996–15001)

Dog and human vaccination

Human vaccination alone
Comparative cumulative cost-effectiveness of PET alone vs. PET and dog mass vaccination
Towards individual based stochastic rabies transmission models (with Smieszek T. ETHZ)

Green: susceptible, blue: latent (exposed), red: rabid dogs
A generalized rabies comparative cost frameworks
Conceptual outlook

- Expand concept of benefits
  - value the lives of companion animals
  - wildlife conservation, both of which are part of ecosystem “integrity”.

→ ecosystem-health approach to rabies control.

→ Strong cultural and religious determination of human-animal relationship.

→ Indirectly influence on rabies transmission
Food dog traders in Central Mali
Health in Social-Ecological Systems (HSES) (Zinsstag et al. PVM 2010)

Health Outcomes:
- Physical
- Emotional
- Spiritual (humans)

Health and Wellbeing

Social – Cultural - Economic - Political – Determinants and outcomes of health
- Governance, Infrastructure, Education,
- Agro-economics
- Public and animal health systems,
- Burden of disease, Health economics
- Livelihood, Resilience, Access, …
- Equity effectiveness of interventions, ….

Ecological Determinants and Outcomes of health
- “Sustainability”
- Resilience
- Adaptive management

Systems biology of Humans - Domesticated animals - Wildlife
Hosts and their various levels of scales

Ecosystems and their health related components:
Vectors, Pathogens

Vegetation and Natural resources
Food, feed and Water

Urban – Rural: Industrial and agricultural production and pollution, …

Physical: Erosion, Climate change, …

Population
Body
Tissue
Single cell
Molecule

Social – Ecological System of Humans and Animals (SES)
Next steps: Validate simulation model and economic analysis with a mass vaccination campaign in N'Djaména, Chad (2012/2013)

→ Extension to Bamako, Noukchott, Addis Ababa, ....
→ Concerted approach for West- and Central