Optimizing Breeding Programs

COST-BENEFIT
Cost - Benefit of breeding programs

Cost of breeding programs for genetic improvement

Fixed costs (logistics, scientists etc. etc.)

Cost related to breeding strategy

• cost of phenotyping
• cost of genotyping
• cost of reproduction

Benefits

Benefit of more genetic gain
Market share
Benefits of genetic gain

• Assuming the benefit is expressed by the breeding objective (economic values of trait improvement)

• Variation in breeding objective is variation in genetic merit for profit

\[ \sigma_H \]

Difference between best and worst is about 6 \( \sigma_H \)
Benefits of genetic gain

- Benefit is transmitted is multiplied over many animals

Diagram:
- Nucleus: 50,000 cows
- Multipliers: 1 million cows
- Commercial producers: 20 million cows
Benefits of genetic gain

- Benefit is cumulative

\[
\text{yr1} \quad \text{yr2} \quad \text{yr3} \quad \text{yr4} \quad \text{yr5} \quad \text{yr6}
\]

\[
= \frac{dG}{yr}
\]
Benefits of genetic gain

Benefit is
- Cumulative
- Multiplied over many

But:
- Are they achieved?
- Who gets the benefit?
  - Breeders, Producer? Retail? Consumer?

Benefits can be expected to be large
Economic value of genetic improvement

– Value difference between two bulls
– Value of selecting better bulls

  – Bulls sold to Commercial
  – Bulls used in Stud

– Value of genetic improvement – whole herd
## Two Commercial Bulls

<table>
<thead>
<tr>
<th>Bull</th>
<th>EBV YWT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bull 1: Kevin</td>
<td>+10 kg</td>
</tr>
<tr>
<td>Bull 2: Tony</td>
<td>+15 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nr Progeny:</td>
<td>100</td>
</tr>
<tr>
<td>Value of 1 kg YWT</td>
<td>$4</td>
</tr>
<tr>
<td>Difference in progeny</td>
<td>2.5 kg</td>
</tr>
</tbody>
</table>

**Difference in value:**

\[
\text{Difference in value} = 5 \times \text{Value of 1 kg YWT} \times \text{Nr of Progeny} \times 0.5
\]

\[
= 5 \times 4 \times 100 \times 0.5 = 1000
\]

\[= \$1000.\]
Two Commercial Bulls

$Index

Bull 1: Kevin  +190
Bull 2: Tony   +180

Nr Progeny:  100

Difference in progeny  $5

Difference in value:  

as commercial bulls  $10 * 100 * 0.5

Selection  Nr of  Expression

Difference  Progeny  per progeny

= $500.-
Selecting Better Bulls

Average of 100 rams sold:  With Genomics +182
No Genomics +180

Nr Progeny: 100 per bull

Difference in progeny $1.0

Difference in value: $2 * 100 * 0.5
as commercial bulls

Selection Nr of Expression
Difference Progeny per progeny

= $100.- * 100 rams = $10,000.
So principles are

**Value of a superior bull**

\[ \text{Value of a superior bull} = \text{Selection Difference} \times \text{Nr.Progeny} \times \text{expressions per progeny} \]

We look at all expressions in **commercial** progeny

To evaluate benefit we need to predict

- the extra Selection Difference we can get
  
  *this will depend a lot on extra accuracy*

- the number of expressions
How about selection of stud bulls?

Value of a superior bull

= Selection Difference * Nr. Progeny * expression per progeny

Progeny in commercial, so for a stud bulls these are actually grand progeny, great grand progeny, etc
(allele) frequency of one unit of superiority as expressed in commercial herd

The fate of superiority from commercial bull vs a stud bull

Noting that a commercial bull also transmits the superiority from a stud bull
## GENEFLOW

### Donors of genes

<table>
<thead>
<tr>
<th></th>
<th>Sires of Nucleus</th>
<th>Dams of Nucleus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P matrix</strong></td>
<td>1  2  3  4  5</td>
<td>1  2  3  4  5  6  7  8  9  10</td>
</tr>
<tr>
<td><strong>1</strong></td>
<td>0  0.5  0  0  0</td>
<td>0  0.166667  0.166667  0.166667</td>
</tr>
<tr>
<td><strong>2</strong></td>
<td>0  0  0  0  0</td>
<td>0  0  0  0  0  0  0  0  0  0  0</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td>0  0  0  0  0</td>
<td>0  0  0  0  0  0  0  0  0  0  0</td>
</tr>
<tr>
<td><strong>4</strong></td>
<td>0  0  0  0  0</td>
<td>0  0  0  0  0  0  0  0  0  0  0</td>
</tr>
<tr>
<td><strong>5</strong></td>
<td>0  0  0  0  0</td>
<td>0  0  0  0  0  0  0  0  0  0  0</td>
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</tbody>
</table>

### Recipients of genes

<table>
<thead>
<tr>
<th></th>
<th>Sires of Nucleus</th>
<th>Dams of Nucleus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P matrix</strong></td>
<td>1  2  3  4  5</td>
<td>1  2  3  4  5  6  7  8  9  10</td>
</tr>
<tr>
<td><strong>1</strong></td>
<td>0  0.5  0  0  0</td>
<td>0  0.166667  0.166667  0.166667</td>
</tr>
<tr>
<td><strong>2</strong></td>
<td>0  0  0  0  0</td>
<td>0  0  0  0  0  0  0  0  0  0  0</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td>0  0  0  0  0</td>
<td>0  0  0  0  0  0  0  0  0  0  0</td>
</tr>
<tr>
<td><strong>4</strong></td>
<td>0  0  0  0  0</td>
<td>0  0  0  0  0  0  0  0  0  0  0</td>
</tr>
<tr>
<td><strong>5</strong></td>
<td>0  0  0  0  0</td>
<td>0  0  0  0  0  0  0  0  0  0  0</td>
</tr>
</tbody>
</table>

*Predict more precisely when benefits occur*
<table>
<thead>
<tr>
<th>Recipients of genes</th>
<th>Sn</th>
<th>Dn</th>
<th>Sc</th>
<th>Cm</th>
<th>Cf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sn</td>
<td>Sn&lt;Sn</td>
<td>Sn&lt;Dn</td>
<td>Sn&lt;Sc</td>
<td>Sn&lt;Cm</td>
<td>Sn&lt;Cf</td>
</tr>
<tr>
<td>Dn</td>
<td>Dn&lt;Sn</td>
<td>Dn&lt;Dn</td>
<td>Sf&lt;Sc</td>
<td>Dn&lt;Cm</td>
<td>Dn&lt;Cf</td>
</tr>
<tr>
<td>Sc</td>
<td>Sc&lt;Sn</td>
<td>Sc&lt;Dn</td>
<td>Sc&lt;Sc</td>
<td>Sc&lt;Cm</td>
<td>Sc&lt;Cf</td>
</tr>
<tr>
<td>Cm</td>
<td>Cm&lt;Sn</td>
<td>Cm&lt;Dn</td>
<td>Cm&lt;Sc</td>
<td>Cm&lt;Cm</td>
<td>Cm&lt;Cf</td>
</tr>
<tr>
<td>Cf</td>
<td>Cf&lt;Sn</td>
<td>Cf&lt;Dn</td>
<td>Cf&lt;Sc</td>
<td>Cf&lt;Cm</td>
<td>Cf&lt;Cf</td>
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</table>
**GENEFLOW**

**Donors of genes**

<table>
<thead>
<tr>
<th>Sn</th>
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<th>Sc</th>
<th>Cm</th>
<th>Cf</th>
</tr>
</thead>
<tbody>
<tr>
<td>P = matrix describing transmission of genes</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Recipients of genes</th>
<th>Sires of Nucleus</th>
<th>Dams of Nucleus</th>
<th>Stud born males to sire commercial</th>
<th>Commercial born males</th>
<th>Commercial born females</th>
</tr>
</thead>
<tbody>
<tr>
<td>P matrix</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.5 0 0 0 0 1 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>0 0 0 0 0 1 0 0 0 0</td>
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</tr>
<tr>
<td>3</td>
<td>0 0 0 0 0 0 0 0 0 0</td>
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<td>0 0 0 0 0 0 0 0 0 0</td>
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<td>0 0 0 0 0 0 0 0 0 0</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Sn**

**Dn**

**Sc**

**Cm**

**Cf**

**Commercial born males** to sire commercial

**Commercial born males**

**Commercial born females**

**Sn**

**Dn**

**Sc**

**Cm**

**Cf**

**Recipients of genes**

<table>
<thead>
<tr>
<th>Sires of Nucleus</th>
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<tbody>
<tr>
<td>P matrix 10</td>
<td>0.5 0 0 0 0 0 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sn**

**Dn**

**Sc**

**Cm**

**Cf**

**Commercial born females**

**P = matrix describing transmission of genes**
GENEFLOW

- $R$ = a matrix defining gene transmission of some superiority (or particular allele)

- $Q$ = a matrix describing aging

- $P$ = matrix describing transmission of genes
  - $P = R + Q$

- $m_t = P \ m_{t-1} + Rn_{t-1}$

- $m$ vector of allele frequency in each age class

- $n$ vector to describe inserting allele or superiority
### GeneFlow

<table>
<thead>
<tr>
<th>g1</th>
<th>g2</th>
<th>g3</th>
<th>g4</th>
<th>g5</th>
<th>g6</th>
<th>g7</th>
<th>g8</th>
<th>g9</th>
<th>g10</th>
<th>g11</th>
<th>g12</th>
<th>g13</th>
<th>g14</th>
<th>g15</th>
<th>g16</th>
<th>g17</th>
<th>g18</th>
<th>g19</th>
<th>g20</th>
<th>g21</th>
<th>g22</th>
<th>g23</th>
<th>g24</th>
<th>g25</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0.5</td>
<td>0</td>
<td>0.33333</td>
<td>0.08333</td>
<td>0.30556</td>
<td>0.11111</td>
<td>0.27314</td>
<td>0.13889</td>
<td>0.251543</td>
<td>0.156636</td>
<td>0.236368</td>
<td>0.169496</td>
<td>0.225609</td>
<td>0.178498</td>
<td>0.21805</td>
<td>0.184849</td>
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<td>0.189324</td>
<td>0.208962</td>
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<td>0.196265</td>
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**Allele frequency in the limit, from on ‘insertion’ of superiority (or an allele) = 1/(L_m + L_f)**

Geneflow mainly useful for initial part of an action, otherwise can use Rendel and Robertson
Cumulative Discounted Expressions  CDE

Value (V) in year t is worth now V \cdot c \quad \text{where } c=1/(1+d)^t

d = \text{discount rate}
c = \text{discount factor}

Expression in age class i in year t is \( m(i)_t = E_{it} \)

Net Present Value of Sum of expression over 25 years

\[
\text{CDE} = \sum_{t=1}^{25} \sum_{i=1}^{nac} E_{it} c_t
\]
(allele) frequency of one unit of superiority as expressed in commercial herd

The fate of superiority from commercial bull vs a stud bull

Noting that a commercial bull also transmits the superiority from a stud bull ?!
(allele) frequency of one unit of superiority as expressed in commercial herd

<table>
<thead>
<tr>
<th>Discount rate</th>
<th>CDE comm bulls</th>
<th>CDE stud sires</th>
<th>Sum of all future expressions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.99</td>
<td>3.93</td>
<td></td>
</tr>
<tr>
<td>0.05</td>
<td>0.78</td>
<td>1.96</td>
<td></td>
</tr>
<tr>
<td>0.08</td>
<td>0.68</td>
<td>1.37</td>
<td></td>
</tr>
</tbody>
</table>

Cumulative Discounted Expressions - CDE

Effect of discounting
## Value of selecting Stud Sires and Comm bulls

### Value of a superior bull

\[
\text{Value} = \text{Selection Difference} \times \text{Nr.Progeny} \times \text{expression per progeny}
\]

<table>
<thead>
<tr>
<th>Type</th>
<th>Difference</th>
<th>Nr. Progeny</th>
<th>Expression per Progeny</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comm bull</td>
<td>+1.4</td>
<td>100</td>
<td>0.68</td>
<td>$95</td>
</tr>
<tr>
<td>Stud Sire</td>
<td>+3.0</td>
<td>400</td>
<td>1.37</td>
<td>$1,644</td>
</tr>
</tbody>
</table>

Sum of all future expressions:

Cumulative Discounted Expressions
Can also use simple method: $dG$/year, and cumulate

<table>
<thead>
<tr>
<th>yr1</th>
<th>yr2</th>
<th>yr3</th>
<th>yr4</th>
<th>yr5</th>
<th>yr6</th>
</tr>
</thead>
<tbody>
<tr>
<td>selection round 1</td>
<td>selection round 2</td>
<td>selection round 3</td>
<td>selection round 4</td>
<td>selection round 5</td>
<td></td>
</tr>
</tbody>
</table>

$= dG$/yr
Cost - Benefit of a breeding program

- **Commercial producers**
  - 10 million ewes
  - Cost/head: $10
  - Benefit: $20 M

- **Multipliers**
  - 0.5 million ewes
  - dG/ewe: $2

- **Nucleus**
  - 50,000 ewes
  - Cost: $0.5 M

No GS

Genetic lag
Economic evaluation of breeding programs

Benefit:   \(dG.N\) accumulates each year
Cost   \(C\)
Future returns are discounted: \(\frac{1}{r^t}\) in year \(t\) \((N.t.dG - C).\frac{1}{r^t}\)

<table>
<thead>
<tr>
<th>year</th>
<th>Genetic Mean ($)</th>
<th>Benefit (M)</th>
<th>Cost (M)</th>
<th>discount factor</th>
<th>NPV (M$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>1.00</td>
<td>-0.50</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>20</td>
<td>0.5</td>
<td>0.95</td>
<td>18.57</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
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<td>0.91</td>
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<tr>
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<td>0.5</td>
<td>0.82</td>
<td>65.40</td>
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<tr>
<td>6</td>
<td>5</td>
<td>100</td>
<td>0.5</td>
<td>0.78</td>
<td>77.96</td>
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<td>7</td>
<td>6</td>
<td>120</td>
<td>0.5</td>
<td>0.75</td>
<td>89.17</td>
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<tr>
<td>8</td>
<td>7</td>
<td>140</td>
<td>0.5</td>
<td>0.71</td>
<td>99.14</td>
</tr>
</tbody>
</table>

Example:
Comm = 10 Million sheep
\(dG = $2/\text{head/annum}\)
Cost = 500k
Cost - Benefit of a breeding program

Genetic improvement

Nucleus
50,000 ewes

Multipliers
0.5 million ewes

Commercial producers
10 million ewes

Genetic lag

dissemination

<table>
<thead>
<tr>
<th></th>
<th>Cost/head</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>No GS</td>
<td>$10</td>
<td>$0.5 M</td>
</tr>
<tr>
<td>With GS</td>
<td>$50</td>
<td>$2.5 M</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$20 M</td>
<td>$22 M</td>
</tr>
</tbody>
</table>
Cost-Benefit industry wide

3 tier benefit

<table>
<thead>
<tr>
<th></th>
<th>No GS</th>
<th>GS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost dG</td>
<td>$0.5 M</td>
<td>$2.5 M</td>
</tr>
<tr>
<td>dG</td>
<td>$20 M</td>
<td></td>
</tr>
<tr>
<td>$22 M</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NPV Industry

50k Nuc cows
20M Comm
Cost-Benefit Stud

2 tier benefit

NPV Stud

Cost
No GS $5 k
GS $17.5 k
dG $5 k
$20 k
$22 k

500 cows
Nuc
10k Comm

2 tier benefit

une
Comparing simply $dG/yr$ vs GFLOW
Cost - Benefit of breeding programs

Commercial producers
20 million cows

Multipliers
1 million cows

Nucleus
50,000 cows

Genetic improvement

Genetic lag

dG/cow

Cost/head

No GS
$10

GS
$60

dG/cow

$2

$2.2
3 tier benefit

Cost-Benefit industry wide

<table>
<thead>
<tr>
<th></th>
<th>No GS</th>
<th>GS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$0.5 M</td>
<td>$1.65 M</td>
</tr>
<tr>
<td>dG</td>
<td>$40 M</td>
<td>$44 M</td>
</tr>
</tbody>
</table>

NPV Industry

50k Nuc cows
20M Comm
Cost-Benefit Stud

### 2 tier benefit

<table>
<thead>
<tr>
<th>GS</th>
<th>No GS</th>
<th>GS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$5k</td>
<td>$17.5k</td>
</tr>
<tr>
<td>dG</td>
<td>$20k</td>
<td>$22k</td>
</tr>
</tbody>
</table>

NPV Stud

- 500 Nuc cows
- 10k Comm
summary

• Can calculate additional gain on a per bull basis, assuming returns in commercial progeny

• Those figures depend on
  – Additional accuracy
  – Age structure
  – Herd parameters such as weaning rate, mating rate, prop. Sold