Genetics of small populations

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Issues relevant to small populations

Loss of genetic diversity
Characterizing population size (previous session)
Inbreeding (previous session)
Drift
Population fragmentation
Breeding strategies for conservation
Loss of genetic diversity

Less genetic diversity → less ability to evolve in response to environmental change

Threats include:
- Extinction of populations or species
- Inbreeding resulting in less heterozygosity
- Loss of alleles due to sampling
- Selection leading to allele fixation

(Frankham, 2002)

The main reason for loss of genetic diversity is restricted effective population size (Ne) over a number of generations

Creation of genetic diversity

Genetic variation can be created by
- New mutations
- New epistatic gene combinations
Small populations

Small population size lead to inbreeding and drift

Inbreeding results from the joining of gamettes with alleles that are IBD & leads to:
- Genetic similarity within small populations

Drift results from random sampling of gamettes & leads to:
- Random change in allele frequencies
- Genetic divergence between fragmented populations

Population fragmentation

Base population

Sub-populations

Divergence between the fragmented populations due to drift

Generation 0  Generation 1  Generation 2  Generation 3

Small populations
Drift at a single locus level

At the single locus level, genetic divergence (drift) is the variance in allele frequency between sub-populations.

For example, $p=q=0.5$, $N_e_{\text{sub-pop}}=10$

<table>
<thead>
<tr>
<th>Generation</th>
<th>0</th>
<th>$t=1$</th>
<th>$t=10$</th>
<th>$t=100$</th>
<th>$t=\text{infinity}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_q_{\text{Between}}$</td>
<td>0</td>
<td>0.0125</td>
<td>0.10</td>
<td>0.2485</td>
<td>0.25 $(pq^*)$</td>
</tr>
<tr>
<td>$V_q_{\text{Within}}$</td>
<td>0.25 $(pq^*)$</td>
<td>0.2375</td>
<td>0.15</td>
<td>0.0015</td>
<td>0</td>
</tr>
<tr>
<td>$V_q_{\text{Total}}$</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Change in allele frequency due to drift

For example, $p=q=0.5$, $N_e(\text{sub-pop})=100$
Drift increases trait variation across lines

In previous graph, total variation in allele frequency remained stable

However, each sub-population is moving towards fixation (i.e. aa or AA, not aA), which results in an increase in trait variance

At the continuous trait level, genetic divergence (drift) is the variance between the trait means of the different sub-populations
- this can be predicted for traits of neutral fitness

Bristle number for sub-populations of fruit fry.

Effect of population size (N) on the divergence and the rate of fixation of populations

http://www.wcater.edu/biology/infoless/Drift.html
Effects of drift and F following population fragmentation

Sub-populations will become divergent due to drift.
  • increased genetic variance between the sub-populations

Within a sub-population individuals will become more alike due to inbreeding.
  • reduced genetic variance within the sub-populations

Problem

The 'lesser spotted blue newt' habitat the marshy environment of the Forgotten Flatlands.

The flatlands were drained, resulting in fragmentation into 6 small sub-populations.

Given that migration is not possible, what are the likely outcomes?
Answer: fate of the newts

Sub-populations become distinctive from each other: some are more blue, some have more spots

Variance within a sub-population is lower than in the original population: newts within a location look similar

Whilst total variation is now greater than before, F within each sub-population is increasing. This may lead to extinction of a sub-population, and possibly a net reduction in variance.

Maintaining genetic variation within populations

Attention to merit

- Merit may be adaptability, disease resistance, fecundity
- Can select parents of the next generation to result in a change in merit (directional selection) or not

Attention to Ne / diversity

- Both F and drift are effected by Ne
- Equalising the contribution of each family to the next generation increases Ne
- Can apply concept of optimal contribution theory
- Migration is also important
Balancing genetic merit & diversity

Select few individuals as parents of the next generation:
- Strong directional selection (high genetic gain) \textit{but}
- Low Ne $\rightarrow$ high inbreeding and drift

Select many individuals as parents of the next generation:
- Weak directional selection (low genetic gain) \textit{but}
- High Ne $\rightarrow$ low inbreeding and drift

Maintaining genetic variation over populations

Need to determine both which sub-populations to select, and which individuals within these sub-populations

In some cases crossing between sub-populations may be advantageous
- e.g. when one population has few animals of one sex
- to re-create genetic variance

But it can also be detrimental (loss of adaptive alleles - 'outbreeding depression')
IAEA regional training course on selective breeding & gene technologies

Selection for merit

Selection for genetic variance

Small populations
A simulated example

- 12 breeds with 1000 animals available in each
- Resources to conserve 120 animals only
- Genetic variation both within and between breed was determined by molecular markers (5 microsatellite loci with a maximum of 5 alleles each)
- Diversity is taken as: $V_{\text{within-breed}} + 5 \times V_{\text{between-breeds}}$
- Merit of each breed has been quantified
- Need to determine which breed to select and which animals within the breed: maximise merit + λ diversity

*Chaiwong and Kinghorn, AAABG 13: 365
Results – # of individuals selected from each population

<table>
<thead>
<tr>
<th>weight on diversity (%)</th>
<th>Population number</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Merit</td>
<td>108</td>
</tr>
<tr>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>23</td>
<td>-</td>
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<tr>
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<td>69</td>
<td>6</td>
</tr>
<tr>
<td>110</td>
<td>12</td>
</tr>
<tr>
<td>225</td>
<td>11</td>
</tr>
</tbody>
</table>

λ is Weight on diversity

Summary

Breeding strategies for conservation aim to balance genetic merit and diversity but should also accommodate other constrains e.g. cost of transportation.

Within a sub-population this can be managed by the application of optimal contribution theory.

Over populations you need to consider which sub-population and which animals within a sub-population.

Small populations