Population pedigree process of the Chatham island black robin: A case of human-assisted spread of a maladaptive behavior in a critically endangered bird

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Parts are Joint work with: James Briskie, Marie Hale, Melanie Massaro, Don Merton, Anthony Poole

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Chatham Islands – Geography & Ecological History

Ecological History of Black Robins

Tests for Heritability of Rim-laying in 1980s

PVA with Behaviourally Realistic Population Pedigree Models

A Field Excursion
Part I
Population pedigree process of the Chatham island black robin

Chatham Islands – Geography & Ecological History

Map of Antarctica (English / French)
Chatham Islands (New Zealand)
Topographical Map
Chatham Islands (New Zealand)

- The Chatham Islands lie 767 kilometres south-east of mainland New Zealand.
- There are two main islands – Chatham Island and Pitt Island.
- and many smaller islands – including Little Mangere, Mangere and Rangatira.
- The islands have only emerged above sea level in the last 4 million years and are part of the Chathams rise connected below ocean to NZ.
- The climate is cool and wet with salt-laden winds all year round.
Chatham Islands (New Zealand)

Chatham Islands From Space

Chatham Is.
Rangatira
Pitt Is.
Mangere
Little Mangare
Chatham Islands (New Zealand)

Rangatira Island

- is the third largest island in the Chatham Islands
- covers an area of 218 hectares (539 acres)
- is a gazetted nature reserve since 1953
- is now home to many endemic species
- is home to black robins – saved from near extinction by team led by Don Merton in the 1980s
A Chatham island Black Robin in Rangatira today
Whaling, Sealing & Farming in islands of NZ

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- The environmental and ecological consequence on the Chatham islands was massive
- the accompanying sheep and cattle farming and the feral rabbits and pigs released by sailors resulted in over-grazing and destroyed the indigenous flora
- the introduced predators such as cats, rats and stoats destroyed the indigenous fauna (especially birds that evolved in the absence of land-based predators)
Species Discovery and Nature Reserves

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- As per Sir Charles Flemming’s recommendation Rangatira island was purchased by the Crown and made a nature reserve in 1954.
- The more ecologically devastated Mangare island was also turned into a nature reserve with an ecological restoration effort of native flora.
Species Recovery Program in 1980s

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- Managements ceased when the population reached about 100 birds
What is a Pedigree?

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- In the sequel, we will add temporal and spatial aspects to the classical notion of pedigree
Highly Loopied Black Robin Pedigree in 1980s

circle = female, square = male, triangle = unknown sex,
red circle = rim-layer, blue circle = non-rim-layer
Population pedigree process of the Chatham island black robin

Female Population Tree during Field Conservation in 1980s
Population pedigree process of the Chatham island black robin

Ecological History of Black Robins

Male Population Tree during Field Conservation in 1980s
Population pedigree process of the Chatham island black robin

Ecological History of Black Robins

Population Pedigree during Field Conservation in 1980s
Coalescent Sub-Pedigree of the 1989 population
Rim-laying Behaviour during Field Conservation in 1980s
Temporal Pedigree (with rim-layers) during 1980s
Population pedigree process of the Chatham island black robin

Ecological History of Black Robins

Rim-laying increases in 1980s

- Conservation Dilemma
  – when to cease management?
- Need managed pop. size to ↑
- But rim-laying trait also ↑
- Don Merton’s team ceased management when 50% of females were rim-layers by 1989

Our Question: Is rim-laying a heritable trait?
Rim-laying increases in 1980s
but between 2007 and 2011 (unmanaged phase) seems lower

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Tests for Heritability of Rim-laying in 1980s

1. A Simple test based on mother-daughter phenotypes
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3. Pedigree Conditional Phenotype Randomization test II
Mother-daughter Phenotype based Test

- Let Egg-laying Female $X_i = 1$ if she is rim-layer and 0 otherwise.
Mother-daughter Phenotype based Test

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- Null Hypothesis $H_0$: $X_1, X_2, \ldots, X_{62}$ i.i.d Bernoulli($p_1$) Random Variables
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- Alternative Hypothesis $H_1$: The Rim-laying Phenotype has a first-order Markov dependence on Mother’s trait

\[
P = \begin{bmatrix}
p_{0,0} & p_{0,1} \\
p_{1,0} & p_{1,1}
\end{bmatrix}
\]
Mother-daughter Phenotype based Test

DATA: Mother-Daughter Phenotype Branching Diagram for Black Robins in 1980s
Mother-daughter Phenotype based Test

- Under $H_1$: the MLE of the transition probability matrix is:

$$\hat{P} = \begin{bmatrix} \hat{\rho}_{0,0} & \hat{\rho}_{0,1} \\ \hat{\rho}_{1,0} & \hat{\rho}_{1,1} \end{bmatrix} = \begin{bmatrix} 0.583 & 0.417 \\ 0.360 & 0.640 \end{bmatrix}$$
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- **Under $H_0$:** Maximum Likelihood Estimate (MLE) of $\rho_1 = 0.508 = \frac{\text{fraction of rim-layers}}{\text{independent "Markov" chain with identical rows}}$
  
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  \hat{P} = \begin{bmatrix}
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- But this test ignores the pedigree within which phenotypes are expressible by genotypes in diploid individuals even under the simplest models of inherited Medelian traits
Pedigree Conditional Phenotype Randomization Test

Explain Idea on Board

Results:

**Table S1.** Proportion ($P$-value) of the null distribution of likelihoods calculated from randomized phenotypes (10,000 randomizations) being $\geq$ the likelihood value for the observed phenotypes, conditional on founder genotype combination and dominance model.

<table>
<thead>
<tr>
<th>Founder Female x Male</th>
<th>Model</th>
<th>$P$-value (95% Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aa x AA</td>
<td>Recessive</td>
<td>0.0108 (+/- 0.0020)</td>
</tr>
<tr>
<td>AA x Aa</td>
<td>Recessive</td>
<td>0.0211 (+/- 0.0028)</td>
</tr>
<tr>
<td>Aa x Aa</td>
<td>Recessive</td>
<td>0.1686 (+/- 0.0073)</td>
</tr>
<tr>
<td>aa x Aa</td>
<td>Dominant</td>
<td>0.8362 (+/- 0.0073)</td>
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</table>
Conclusions - Part I

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- Such human-assisted spread of maladaptive traits poses the conservation dilemma.
- In the case of black robins the managers seemed to have succeeded by stopping management when half the population were rim-layers.
- Merton suspected rim-laying was heritable (persn. commn. to Massaro).
Conclusions - Part I contd...

- Our research group at Canterbury (with Briskie, Hale, Massaro and Poole) have developed tests to establish that rim-laying during 1980s is likely to be a heritable trait.
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- To appreciate the intensity of field operations and limitations of biomathematical models read: *The black robin: saving the world’s most endangered bird*, David Butler and Don Merton, Oxford University Press, 1994.
Part II
Current Research - disclaimers

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- i.e., I’ll try to show that every “turf-holding”, “mate-alluring”, “love-making” and “chick-rearing” event counts in the field!!!
Population Viability Analysis (PVA) in Conservation

- PVA = computer program that uses Monte Carlo methods to guess the probability of extinction of a population under a given management scenario for a given species
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- PLAN: use field data on the Black Robin Population to build behaviourally realistic pedigree models for bi-parental territorial species for use in more realistic PVA.
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- VISION: Integrate behavioural ecology with population pedigrees for subsequent molecular evolutionary genetics
Notions of Molecular continuums within Population Pedigrees

a homotopy between Kingman Coalescent Trees and Chang’s Pedigree (RS & Bhalchandra Thatte)

Zygotic, cytoplasmic, karyotic and sub-karyotic pedigrees of a Wright-Fisher population with five eukaryotic diploid individuals
39 Connected Components (sub-pedigrees) in Pedigree Survey 2007-2011
All 39 Connected Components (sub-pedigrees) in Pedigree Survey 2007-2011
111 Maternal Life-Line Components in Pedigree Survey 2007-2011
Life-Lines of all 107 Mothers in Pedigree Survey 2007-2011
117 Paternal Life-Line Components in Pedigree Survey 2007-2011
Life-Lines of all 113 Fathers in Pedigree Survey 2007-2011
Population pedigree process of the Chatham island black robin
PVA with Behaviourally Realistic Population Pedigree Models

Male Territory Graphs by year

2009 (eye-balled by a ball graph)
Male Territory Graphs by year

2010 (eye-balled by a ball graph)
Male Territory Graphs by year

2011 (eye-balled by a ball graph)
Male Territorial Dynamics – yearly nest site relocation
Male / Female yearly nest to nest distance

sex-specific distance between home nest and first nest
Male / Female yearly nest to nest distance

sex-specific distance between nest at age $\geq 1$ and next nest
Male / Female yearly nest to nest distance

- Permutation Test to Reject $H_0 : \text{male dist} = \text{female dist}$ (10$^5$ MC samples)
- Strongly reject $H_0$ for home to first nest (pv = 0.00025)
- Fail to reject $H_0$ for nest at age $\geq 1$ to next nest (pv = 0.14)

male / female distance from home nest to first nest
male / female distance from nest at age $\geq 1$ to next nest
Need Models of Spatio-temporal Population Pedigrees
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Conclusions - Part II

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- I hope to have convinced you that the field data for small threatened populations is far from simplistic mathematical assumptions such as random mating.

- The effect of such assumptions on extinction probability computations in PVA is the natural judge.

- PLAN: continue to work on Part 2 next year during my visit to CMAP in 2013.
Conclusions - Part II

- Population viability Analyses use Branching Process Models and Simulations to determine the status of a threatened species
- I hope to have convinced you that the field data for small threatened populations is far from simplistic mathematical assumptions such as random mating
- The effect of such assumptions on extinction probability computations in PVA is the natural judge
- Besides possibly robustifying PVA using realistic models of pedigree processes we believe such models will pave the way for the fusion of behavioural ecology and evolutionary genetics
- PLAN: continue to work on Part 2 next year during my visit to CMAP in 2013
Thank you!