Evaluating fitness:  
toward strengthening  
the study of  
adaptive evolution

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FITNESS
\( W, w \)

Contribution of individuals to following generation(s):

genetic, \( G \)

demographic, \( N \)

\( r, \lambda \)
• Environment-dependent differences among populations in $W$ can indicate past adaptation

• Variation in $W$ implies selection

• Correlation between $W$ and trait indicates selection on it

• Genetic variation in $W$ indicates population’s potential for further adaptation

• $W \rightarrow \lambda$ measures the growth rate of a population or a component of it
Distribution and abundance of organisms:

Population dynamics:
Adaptation of a population to its environment

Genetic composition:

Clarkia pulchella

\[
\text{G} \rightarrow \text{N}
\]
Adaptation of a population to its environment

Distribution and abundance of organisms

Population dynamics:

Genetic composition:

Community Genetics, Evo-demo
THE GENETIC FACTOR IN POPULATION ECOLOGY

L. C. BIRCH

Department of Zoology, University of Sydney, Sydney, Australia

INTRODUCTION

The ecological problem of populations has to do with the numbers of animals and what determines these numbers. The genetical problem of populations has to do with the kind or kinds of animals and what determines kind. These two disciplines meet when the questions are asked, how does the kind of animal (i.e., genotype) influence the numbers and how does the number of animals influence the kind, i.e., the genetical composition of the population? These questions are as much ecological as they are genetical.
FITNESS
W,w

Composite of outcomes at multiple stages of the life cycle,
“components of fitness”,
expressed sequentially
Total number of flower heads over 4 years
Problems for statistical analysis of fitness

1. No standard probability distribution approximates lifetime fitness.
Problems for statistical analysis of fitness

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2. Each fitness component for a given individual is conditional on the individual’s state for an earlier component of fitness.
Problems for statistical analysis of fitness

1. No standard probability distribution approximates lifetime fitness.
2. Each fitness component for a given individual is conditional on the individual’s state for an earlier component of fitness.
3. No single probability distribution is suitable for modeling all components of fitness.
<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survive to year?</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Bernoulli</td>
<td></td>
<td></td>
<td></td>
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<td>YES</td>
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<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
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</tbody>
</table>

**Flower? Bernoulli**

- NO
- YES
- YES
- NO
- YES

**Survive to year? Bernoulli**

- YES
- YES
- YES
- YES
- YES
- YES
Survive to year?
Bernoulli

Flower?
Bernoulli

Head count, Poisson

YES

Year 1 2 3 4 5 6

0 1 2 0 5

NO
YES
YES
NO
YES

YES → YES → YES → YES → YES → YES → YES
Year 1 2 3 4 5 6

Survive to year?
Bernoulli

Flower?
Bernoulli

Head count, Poisson

YES → YES → YES → YES → NO → NO
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<tbody>
<tr>
<td>Fruit count, Poisson</td>
<td></td>
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<td>206</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>Head count, Poisson</td>
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<td>1</td>
<td>0</td>
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Aster:
general analysis of life history data

\[ \sum_{j \in J} x_j \left[ \theta_j - \sum_{m \in S(j)} \psi_m(\theta_m) \right] - \sum_{j \in S(F)} x_{p(j)} \psi_j(\theta_j) \]

Geyer, Wagenius and Shaw, Biometrika, in press
Aster:
general analysis of life history data
to link
evolutionary and ecological study

• Employs a suitable probability model for each component of the life history.
Aster:
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• Employs a suitable probability model for each component of the life history.
• Explicitly models the dependence of each component on those expressed earlier.
Aster: general analysis of life history data to link evolutionary and ecological study

- Employs a suitable probability model for each component of the life history.
- Explicitly models the dependence of each component on those expressed earlier.
- Conducts inference via Maximum Likelihood.
Aster:
general analysis of life history data
to link evolutionary and ecological study

• Employs a suitable probability model for each component of the life history.
• Explicitly models the dependence of each component on those expressed earlier.
• Conducts inference via Maximum Likelihood.
• Is implemented in R statistical language, freely available. See http://www.stat.umn.edu/geyer/aster/
Aster: general analysis of life history data to link evolutionary and ecological study - an overview with examples:

• Comparing fitness among groups
• Inferring phenotypic and genetic selection
• Evaluating population growth

Charles Geyer
Department of Statistics
University of Minnesota

Stuart Wagenius
Chicago Botanic Garden

Julie Etterson
Biology Department
University of Minnesota-Duluth
THE VEGETATION OF STEARNS COUNTY
AT THE TIME OF THE PUBLIC LAND SURVEY

http://files.dnr.state.mn.us/ecological_services/mcbs/map_stearns.pdf
Current vegetation of Stearns Co, MN

Presettlement vegetation

http://files.dnr.state.mn.us/ecological_services/mcbs/map_stearns.pdf
Performance of a prairie mating system in a fragmented habitat: self-incompatibility and limited pollen dispersal in *Echinacea angustifolia*
Research goals

Quantify feedbacks between genetic composition and numerical abundance

G <---> N

in a severely fragmented prairie plant population;

Understand the implications of these feedbacks for its persistence and ongoing evolution.
Disruption of gene flow among fragments of a population……

• promotes drift: deleterious alleles may become more common

• increases autozygosity and thereby selection against recessive, deleterious alleles - ‘purging’

• facilitates adaptation to local conditions

How do these genetic processes balance and how do they interact with demography to affect individual fitness and the size and persistence of populations?
Research goals

Quantify feedbacks between genetic composition and numerical abundance

G \rightarrow N

in a severely fragmented prairie plant population;

Understand the implications of these feedbacks for its persistence and ongoing evolution.

• Do the remnant populations remain viable? individually? collectively?
• How can their persistence be enhanced?
Echinacea angustifolia, purple coneflower (Asteraceae)

• long-lived
• reproduces by seed
• self-incompatible
• non-specialized seed dispersal
• generalist pollinators

Photo by S. Wagenius
Total number of flower heads over 4 years
Total number of flower heads

Population
Aster models comparing fitness among remnant populations

Forest node graph
N plants in common field surviving and flowering in 3 yr

$N_T = 570$
Population

Mean number of flower heads

Observed and Expected Frequency Distributions

Head count over 4 years
Between fragments:
Within fragments, between plants:
Sib mating:

Common field

Cross treatments
Mortality over four years in relation to cross-level

Cross type***

within remnant

between remnant

2001

2002

2003

2004

% mortality

year
Size measures:

- **Length longest leaf (cm)**
- **Number of leaves**
- **Number of rosettes**

The graphs compare data from 2003 and 2004 across different cross types:
- **Between remnant**
- **Within remnant**
- **Sib-mated**

The graphs show trends and differences in the size measures for each cross type.
Aster analysis to assess effects of inbreeding/outcrossing on fitness as of age 4

- Cross type:
  - Between remnant
  - Within remnant
  - Sib mated

Progeny of sib mating ~ 40% lower fitness
Climate change:

Temperature

Precipitation

http://www.grida.no/climate/ipcc_tar/wg1/fig9-5.htm

Soil moisture change (Jun-Aug)

Manabe et al. 2004
Evolutionary potential of the annual legume, *Chamaecrista fasciculata*, in relation to global warming

Julie Etterson

*Chamaecrista fasciculata*

Fabaceae
Assessing the potential of a native plant to adapt in response to climate change

Chronosequence - projecting into future
Reciprocal transplant:
3 populations in 3 locations
Progeny of formal crosses (NC1) within each population
10,000 plants

Etterson 2004
Aster for phenotypic selection analysis to evaluate the relationship between fitness, \( W \) and traits, leaf number and specific leaf area.
Quadratic fitness surface estimated from aster model (MN pop in MN site)

Quadratic fitness surface via ordinary least squares (Lande and Arnold 1983)
Residuals vs. Fitted

Aster

OLS

Pearson residuals vs. fitted values

Fitted values
Distribution of additive genetic effects on fitness

MN population growing in KS

MN population growing in MN

Precise, quantitative comparison of mean fitness.
Powerful assessment of genotypic fitness differences.
Conclusions

• This joint analysis of life history is comprehensive, rigorously quantitative and statistically powerful.
Conclusions

- This joint analysis of life history is comprehensive, rigorously quantitative and statistically powerful.

- The approach allows for choice of distributions for appropriately modeling individual components of fitness.

- The approach remedies “poor” distributions of fitness.

- CJG has developed a package for carrying out the analysis in R (stat.umn.edu/geyer/aster/).
Acknowledgments

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UM Center for Community Genetics  
Chicago Botanic Garden

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UM Center for Community Genetics  
University of Minnesota-Duluth

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University of Minnesota

Janis Antonovics

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Field crews: