Evaluating fitness: toward strengthening the study of adaptive evolution

Ruth G. Shaw
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FITNESS
W,w

Contribution of individuals to following generation(s):

genetic, G

demographic, N
r, λ

FITNESS
W

- Environment-dependent differences among populations in W can indicate past adaptation

- Variation in W implies selection

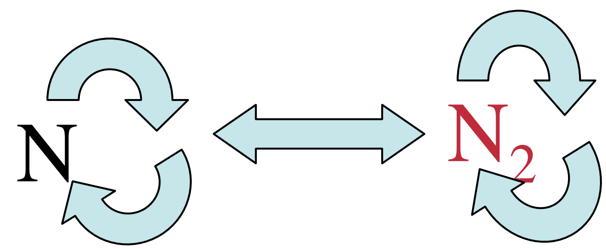
- Correlation between W and trait indicates selection on it

- Genetic variation in W indicates population's potential for further adaptation

- W -> λ measures the growth rate of a population or a component of it

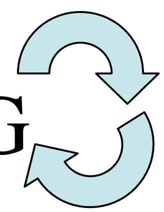
Distribution and abundance of organisms:

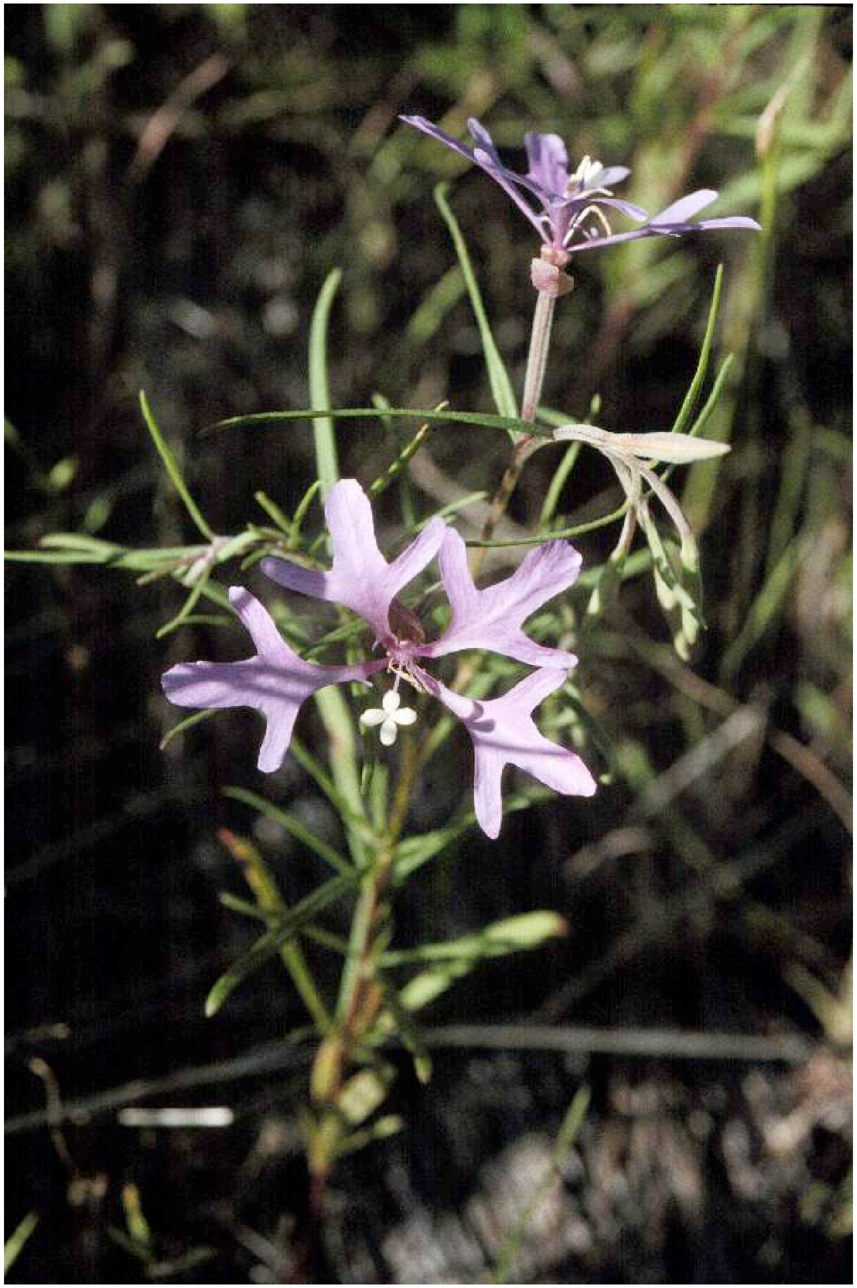
Population dynamics:



Adaptation of a population to its environment

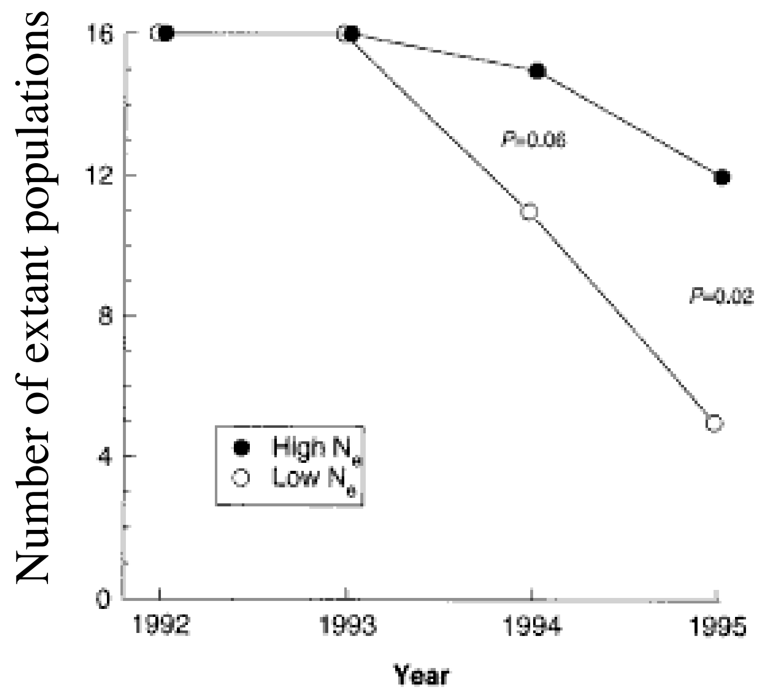
Genetic composition: G





Clarkia pulchella

G --> N



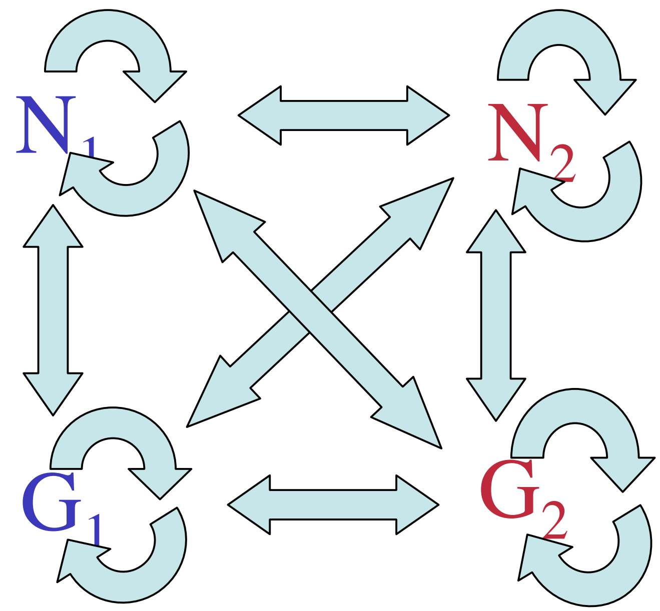
Newman and Pilson 1997 Evolution.

Adaptation of a population to its environment

Distribution and abundance of organisms

Population dynamics:

Genetic composition:



Community Genetics, Evo-demo

THE
AMERICAN NATURALIST

Vol. XCIV January-February, 1960 No. 874

THE GENETIC FACTOR IN POPULATION ECOLOGY

L. C. BIRCH
Department of Zoology, University of Sydney, Sydney, Australia

INTRODUCTION

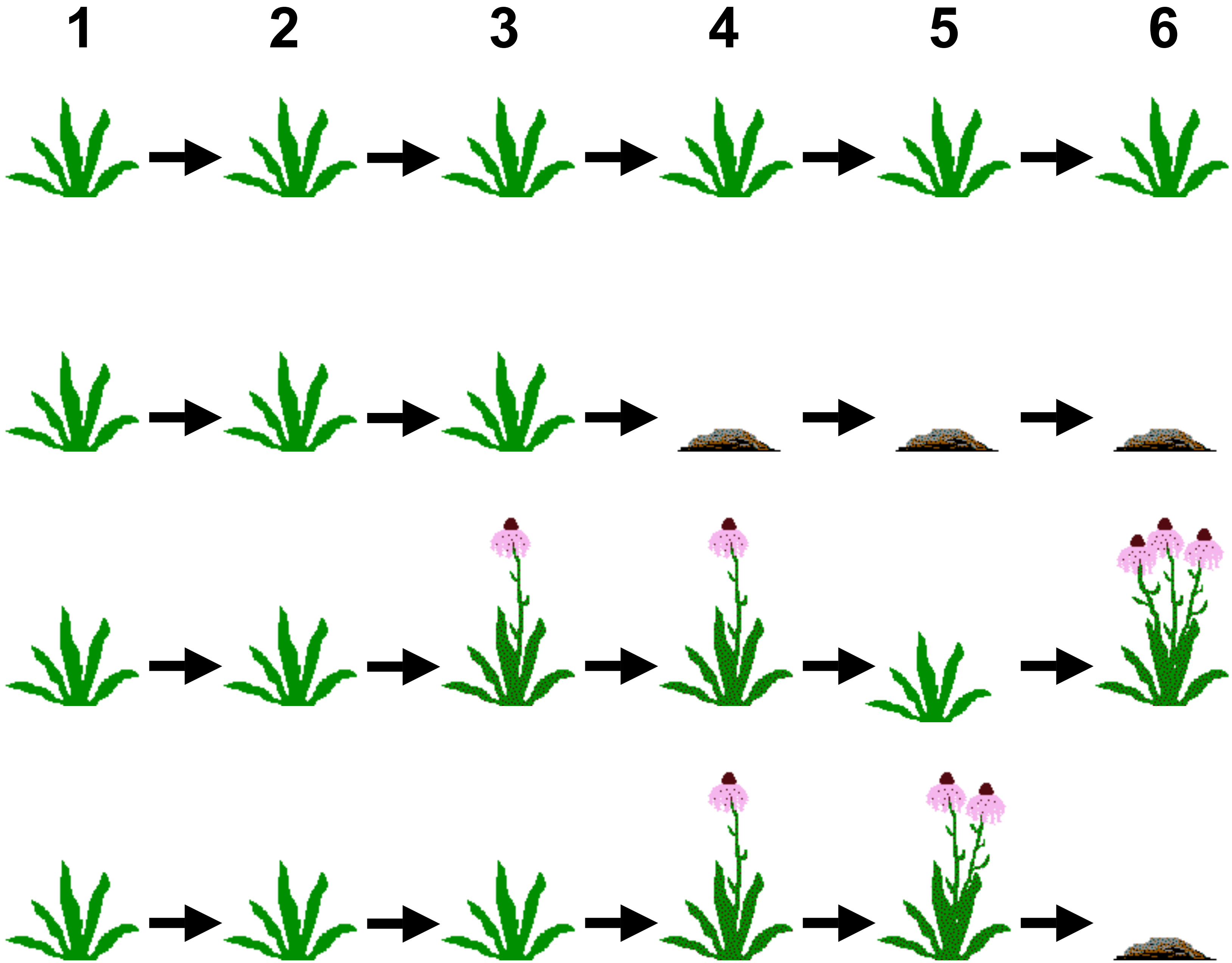
The ecological problem of populations has to do with the numbers of animals and what determines these numbers. The genetical problem of populations has to do with the kind or kinds of animals and what determines kind. These two disciplines meet when the questions are asked, how does the kind of animal (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.

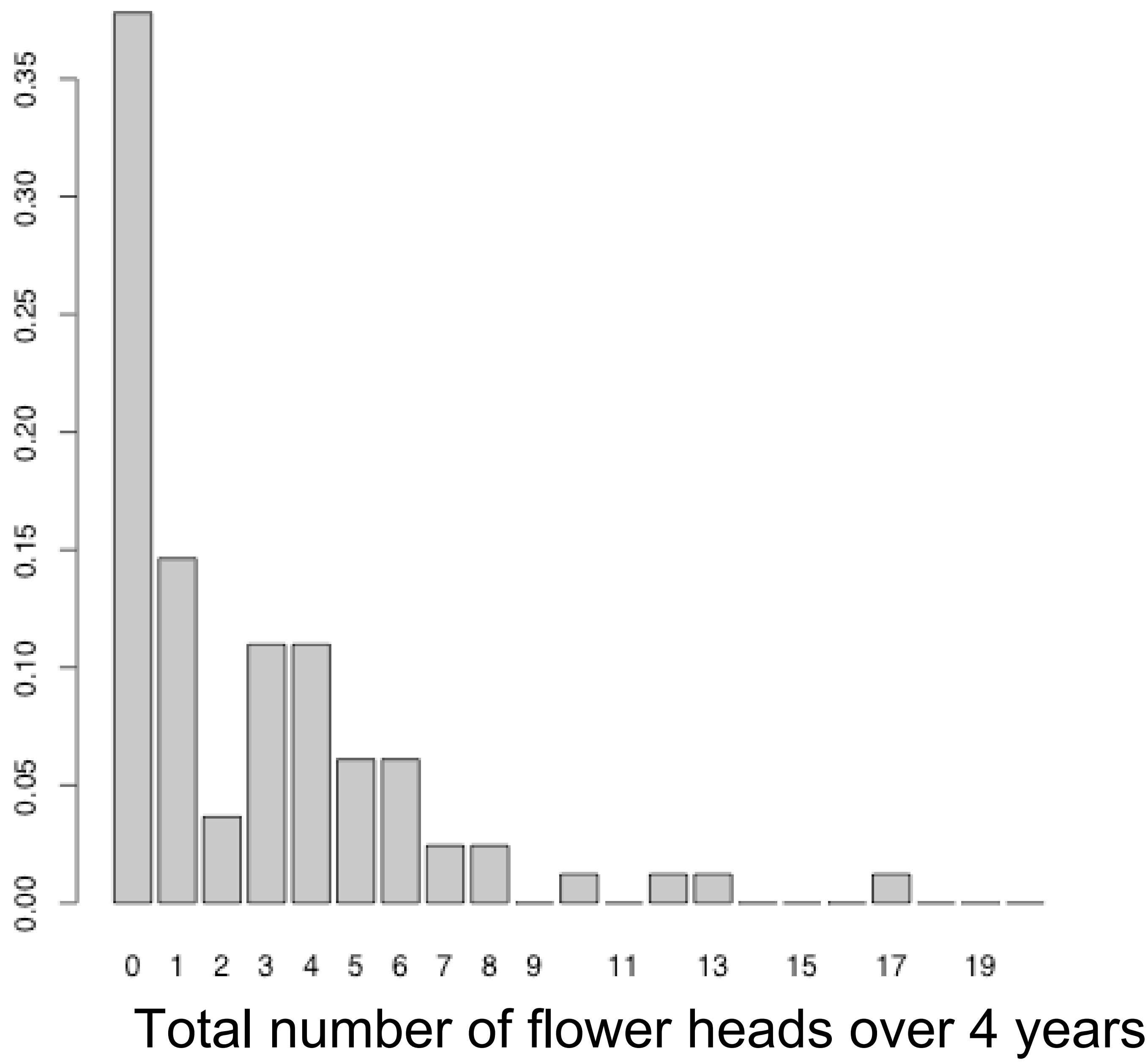
FITNESS
W,w

Composite of outcomes at multiple stages of the life cycle,

"components of fitness",

expressed sequentially

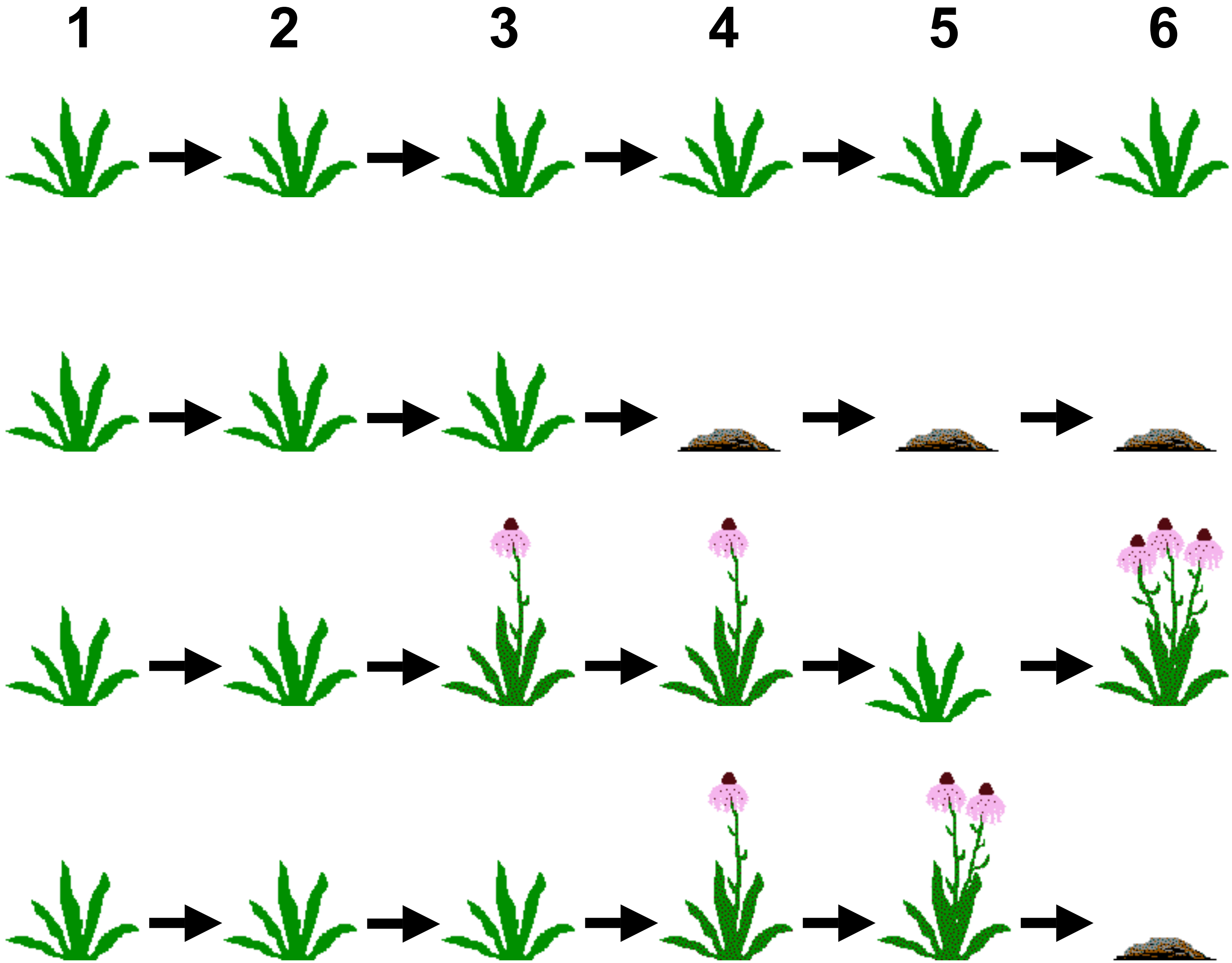




0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0 1 2 3 4 5 6 7 8 9 11 13 15 17 19
Total number of flower heads over 4 years

Problems for statistical analysis of fitness

1. No standard probability distribution approximates lifetime fitness.


1
2
3
4
5
6

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.

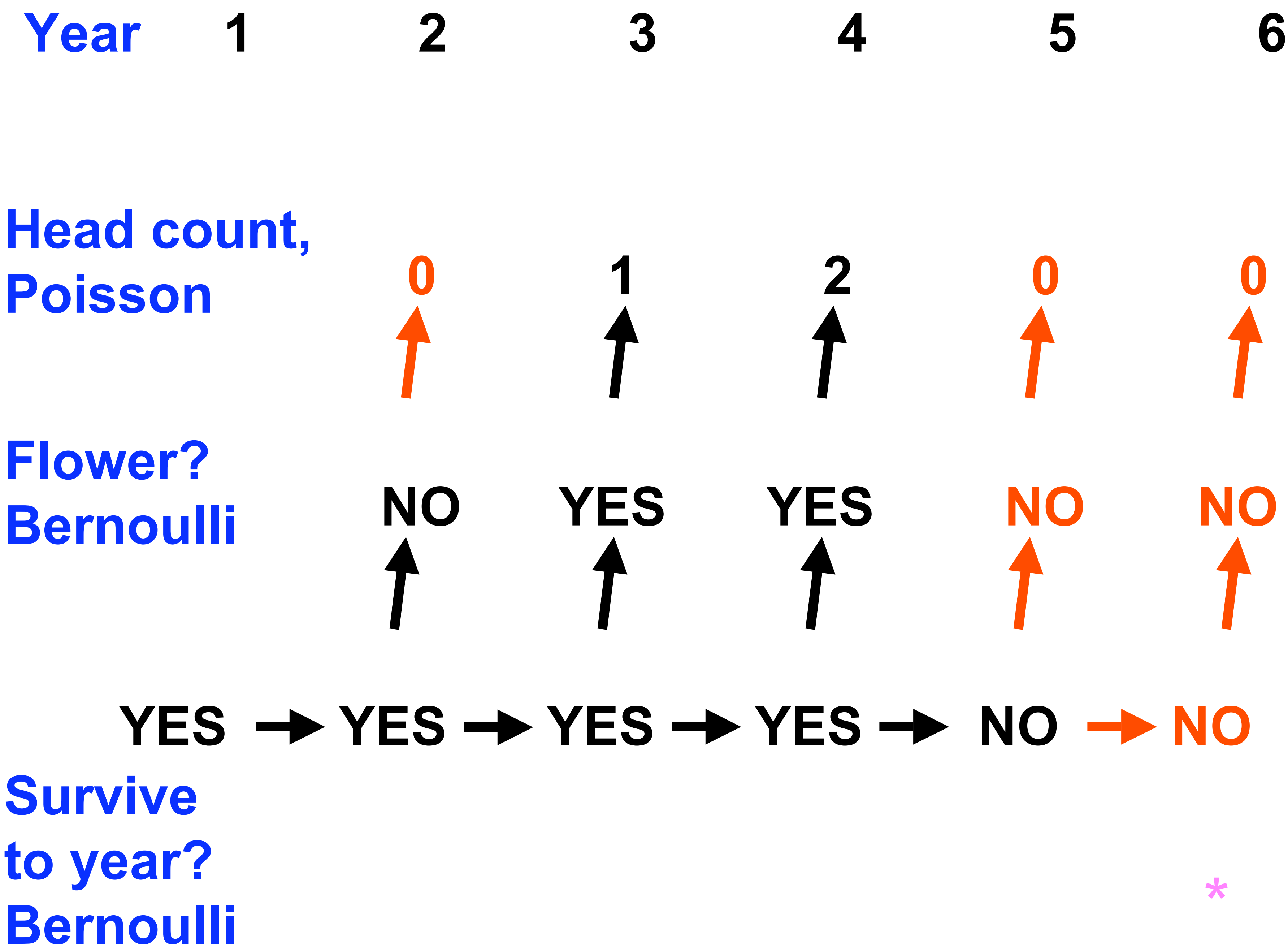
Year	1	2	3	4	5	6

YES → YES → YES → YES → YES → YES

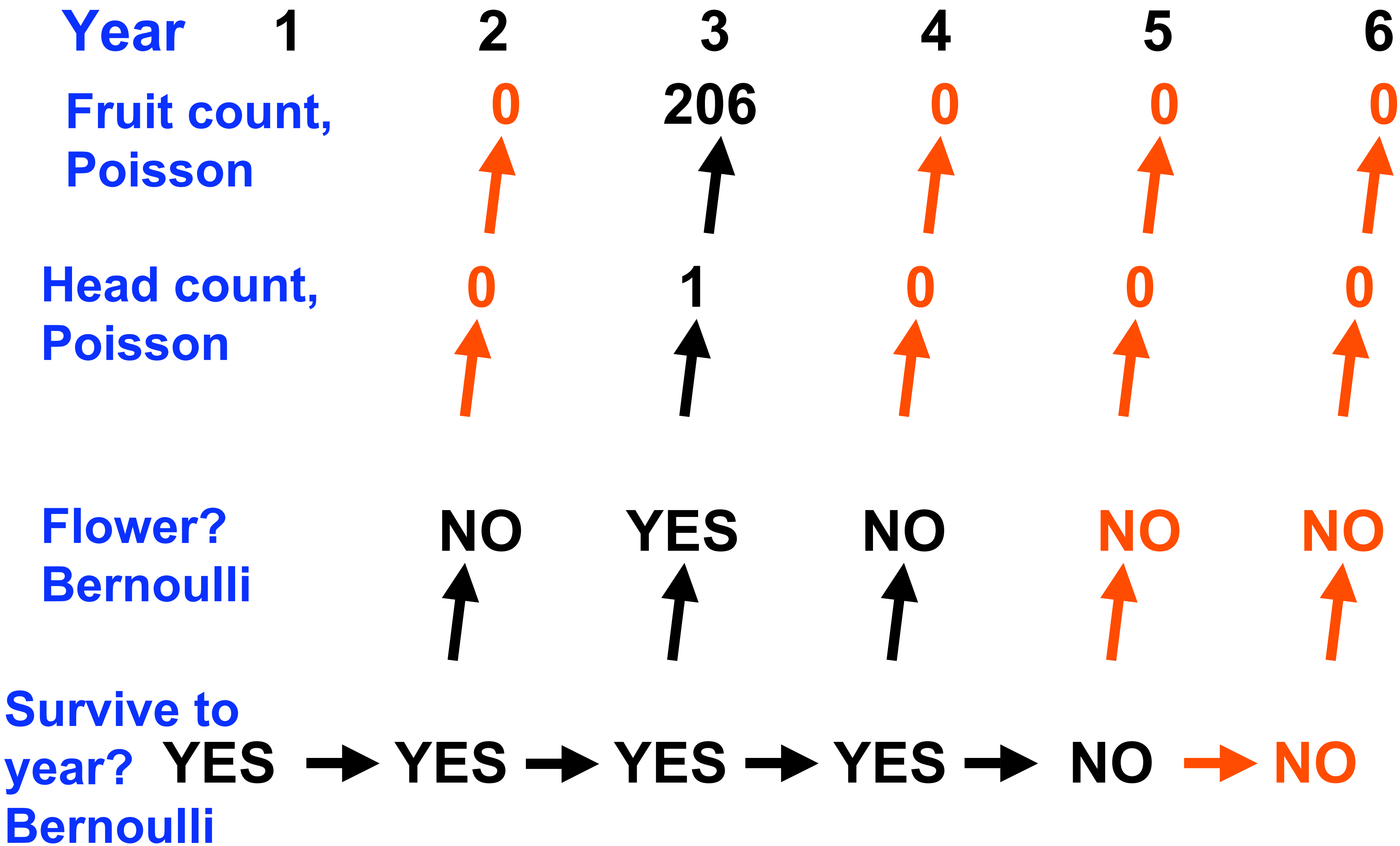
Survive
to year?
Bernoulli

Year	1	2	3	4	5	6
Flower? Bernoulli		NO	YES	YES	NO	YES
Survive to year? Bernoulli	YES →	YES →	YES →	YES →	YES →	YES

Year	1	2	3	4	5	6
Head count, Poisson		0	1	2	0	5
Flower? Bernoulli		NO	YES	YES	NO	YES
Survive to year? Bernoulli	YES →	YES →	YES →	YES →	YES →	YES



Year
1
2
3
4
5
6
Head count,
Poisson
0
1
2
0
0
Flower?
Bernoulli
NO
YES
YES
NO
NO
YES
YES
YES
YES
NO
NO
Survive
to year?
Bernoulli
*


Year
1
2
3
4
5
6
Fruit count, Poisson
0
206
0
0
0
Head count, Poisson
0
1
0
0
0
Flower? Bernoulli
NO
YES
NO
NO
NO
Survive to year? Bernoulli
YES
YES
YES
YES
NO
NO

Problems for statistical analysis of fitness

1. No standard probability distribution approximates lifetime fitness.
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3. No single probability distribution is suitable for modeling all components of fitness.

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:
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.

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- Conducts inference via Maximum Likelihood.

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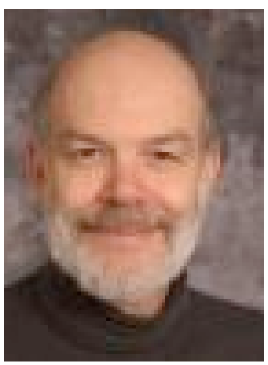
- Employs a suitable probability model for each component of the life history.
- Explicitly models the dependence of each component on those expressed earlier.
- Conducts inference via Maximum Likelihood.
- Is implemented in R statistical language, freely available. See http://www.stat.umn.edu/geyer/aster/

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

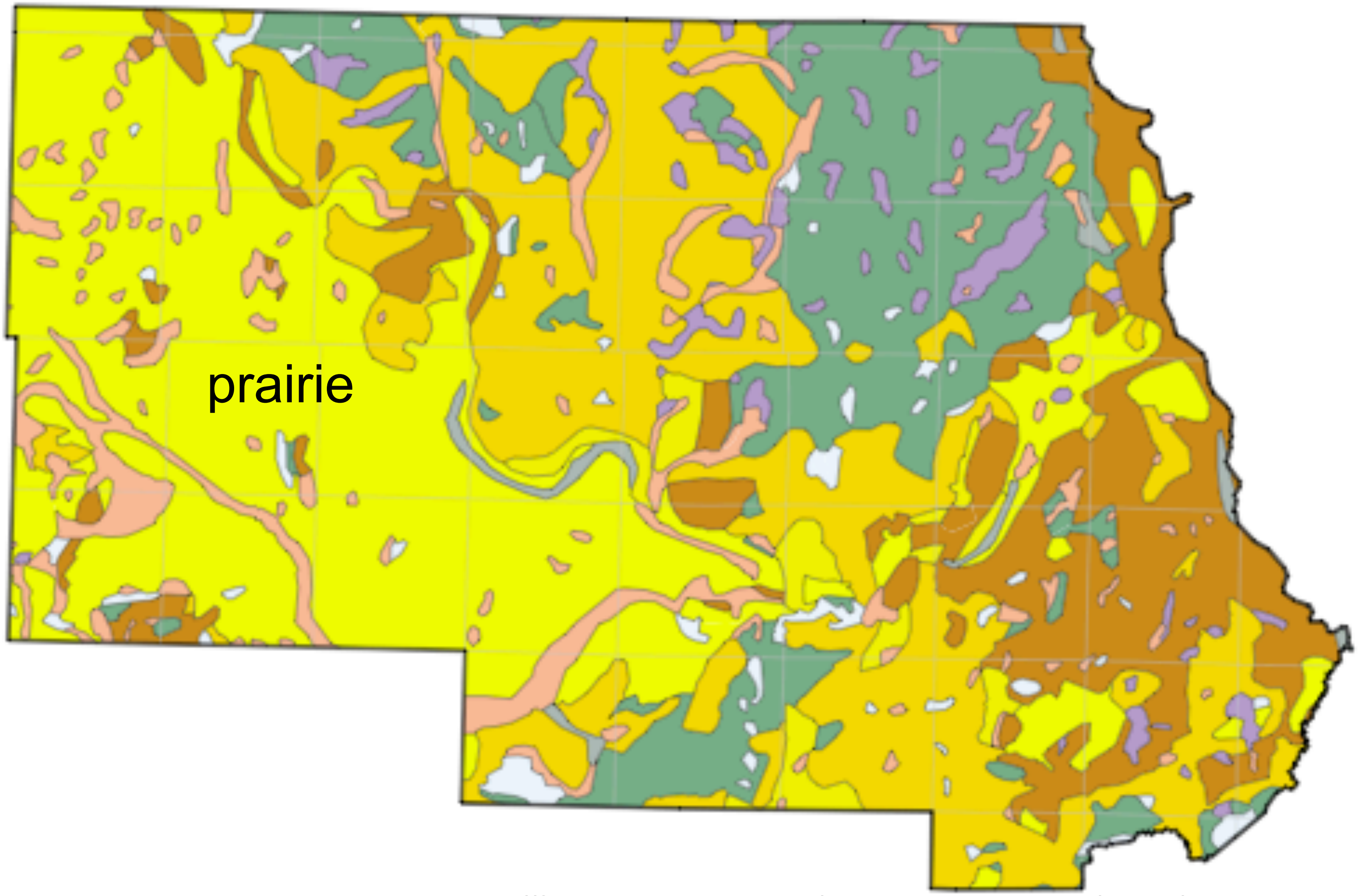


Charles Geyer
Department of Statistics
University of Minnesota

Stuart Wagenius
Chicago Botanic Garden

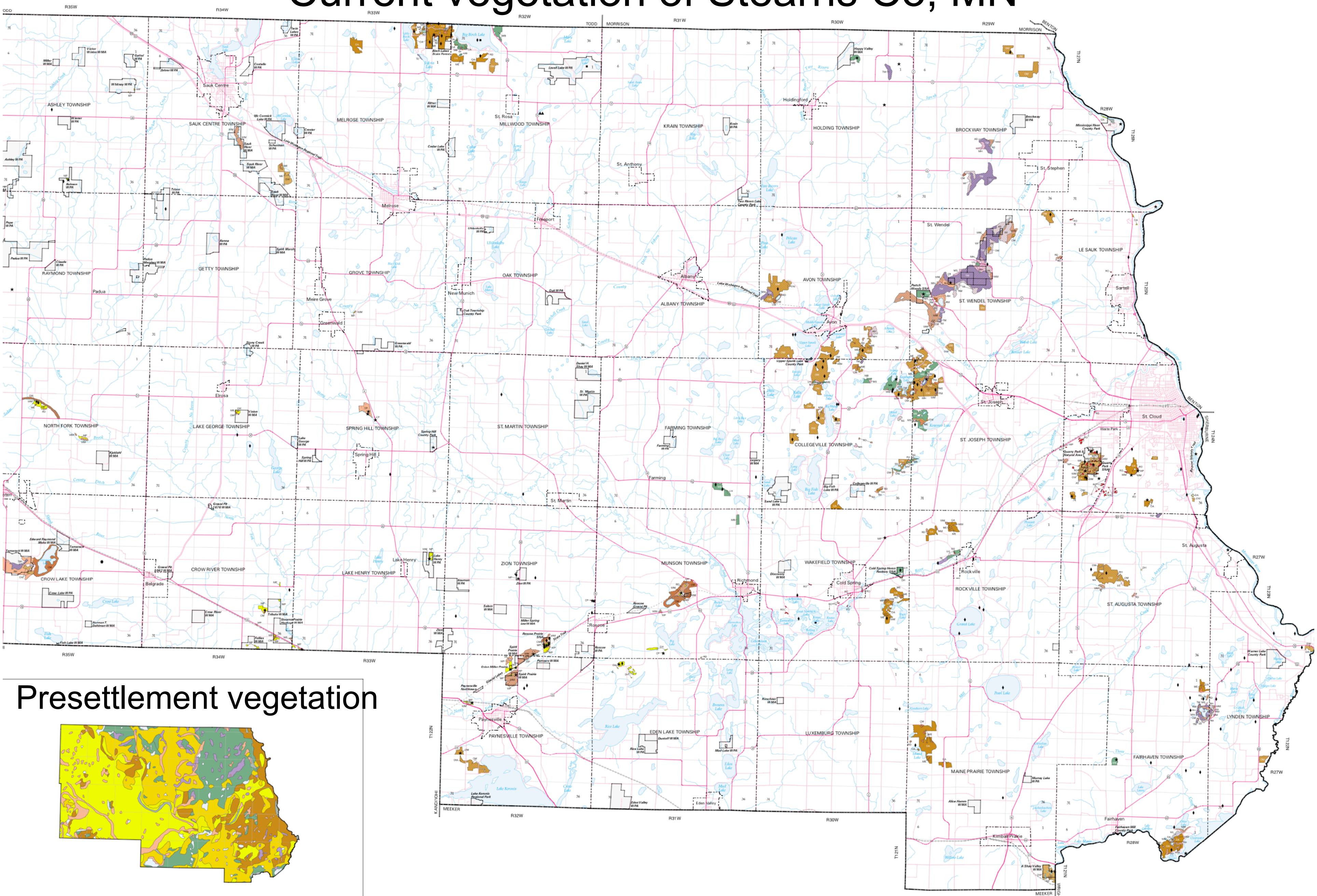
Julie Etterson
Biology Department
University of Minnesota-Duluth

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

<u>**Quantify**</u> 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

<u>**Quantify**</u> 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.

- Do the remnant populations remain viable? individually? collectively?
- How can their persistence be enhanced?

Echinacea angustifolia, purple coneflower (Asteraceae)

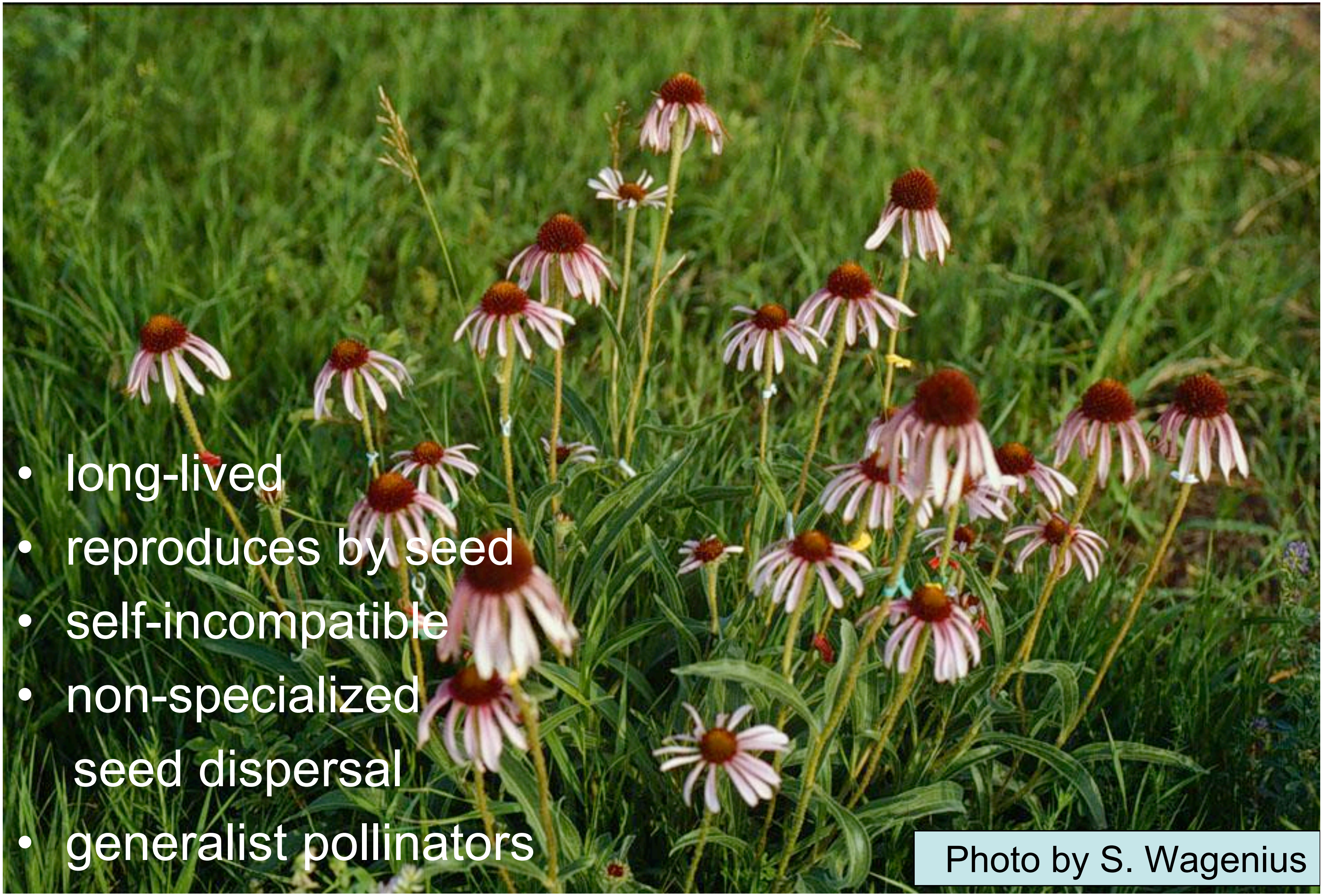
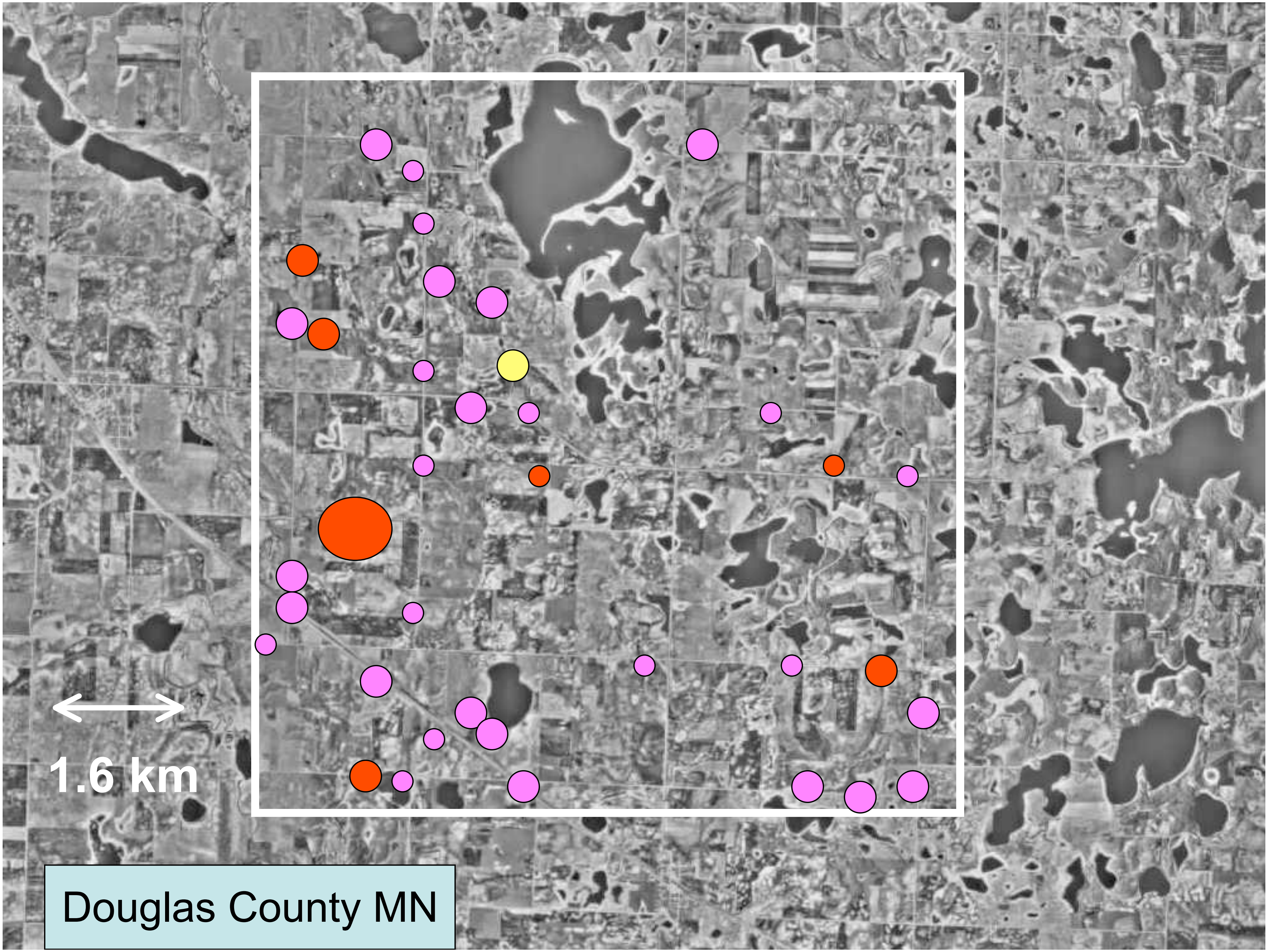


Photo by S. Wagenius


1.6 km
Douglas County MN

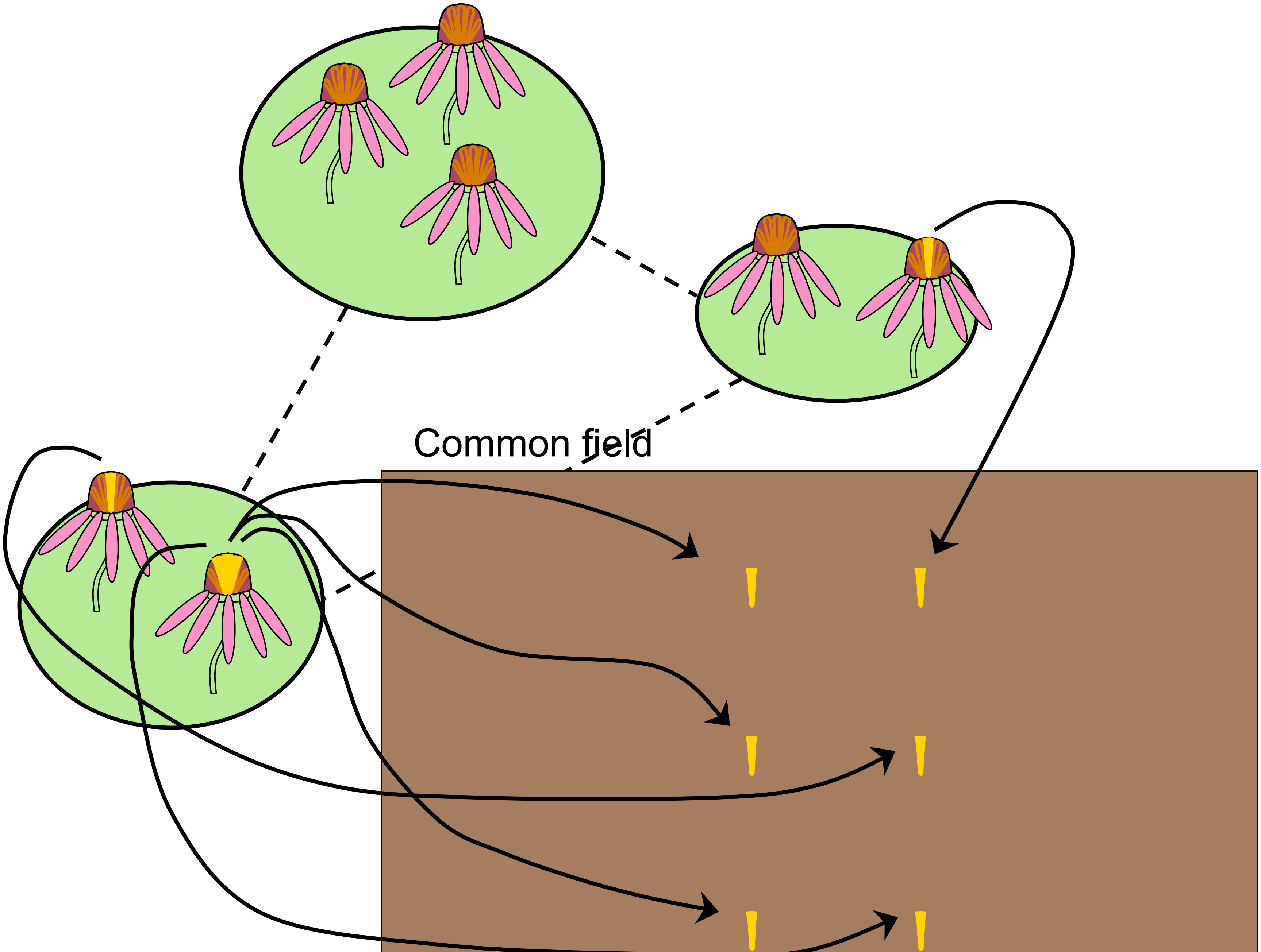
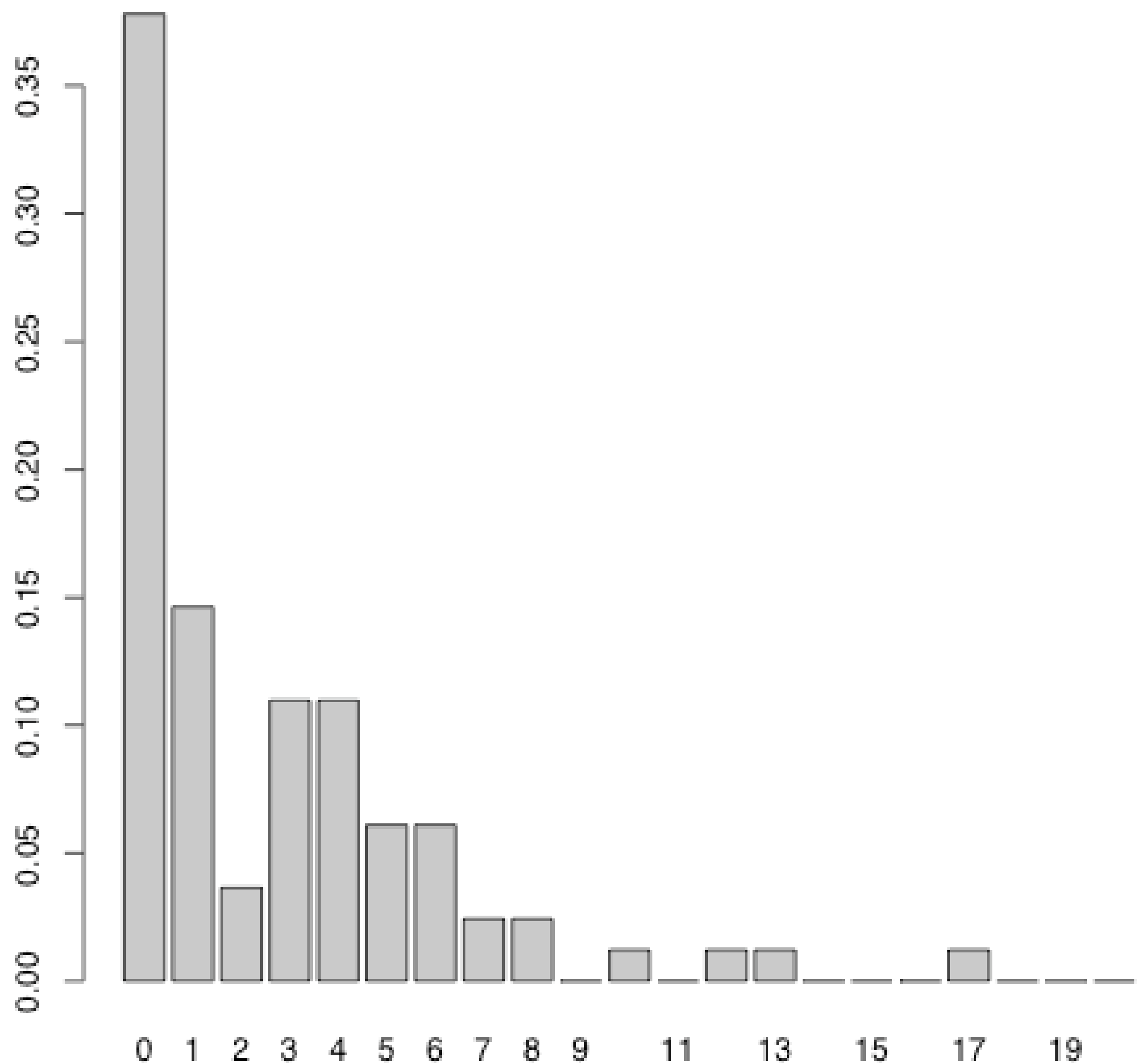
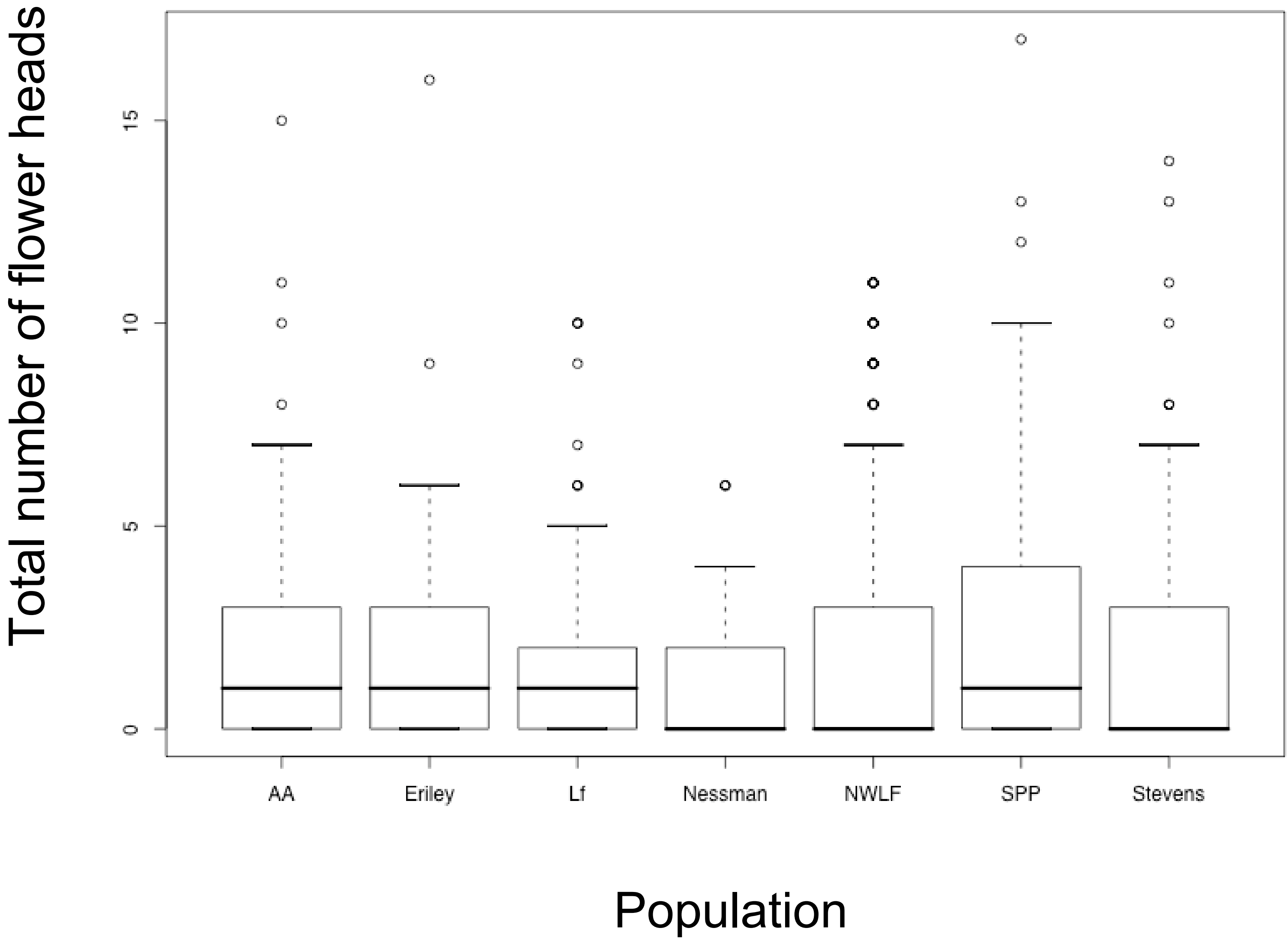

Common field


Photo by H. Hangelbroek

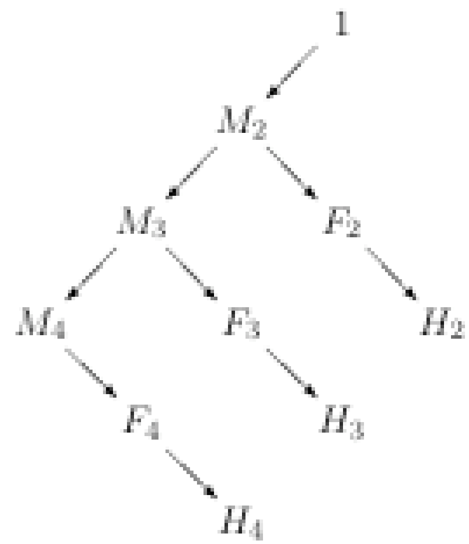


SPP

Total number of flower heads over 4 years

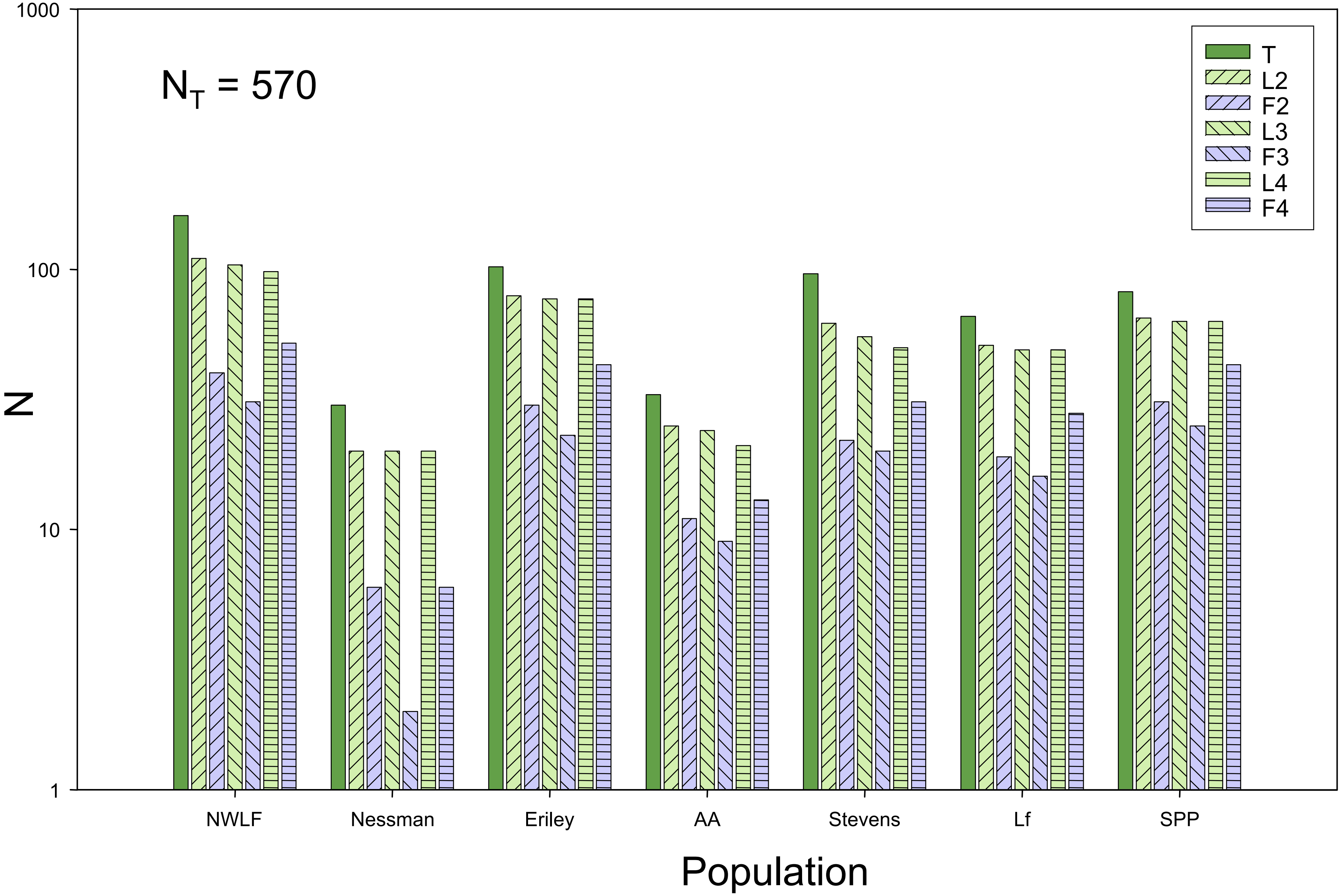

Total number of flower heads
0
5
10
15
AA
Eriley
Lf
Nessman
NWLF
SPP
Stevens
Population

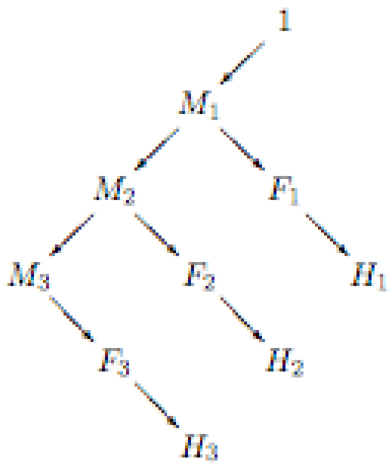
Aster models comparing fitness among remnant populations

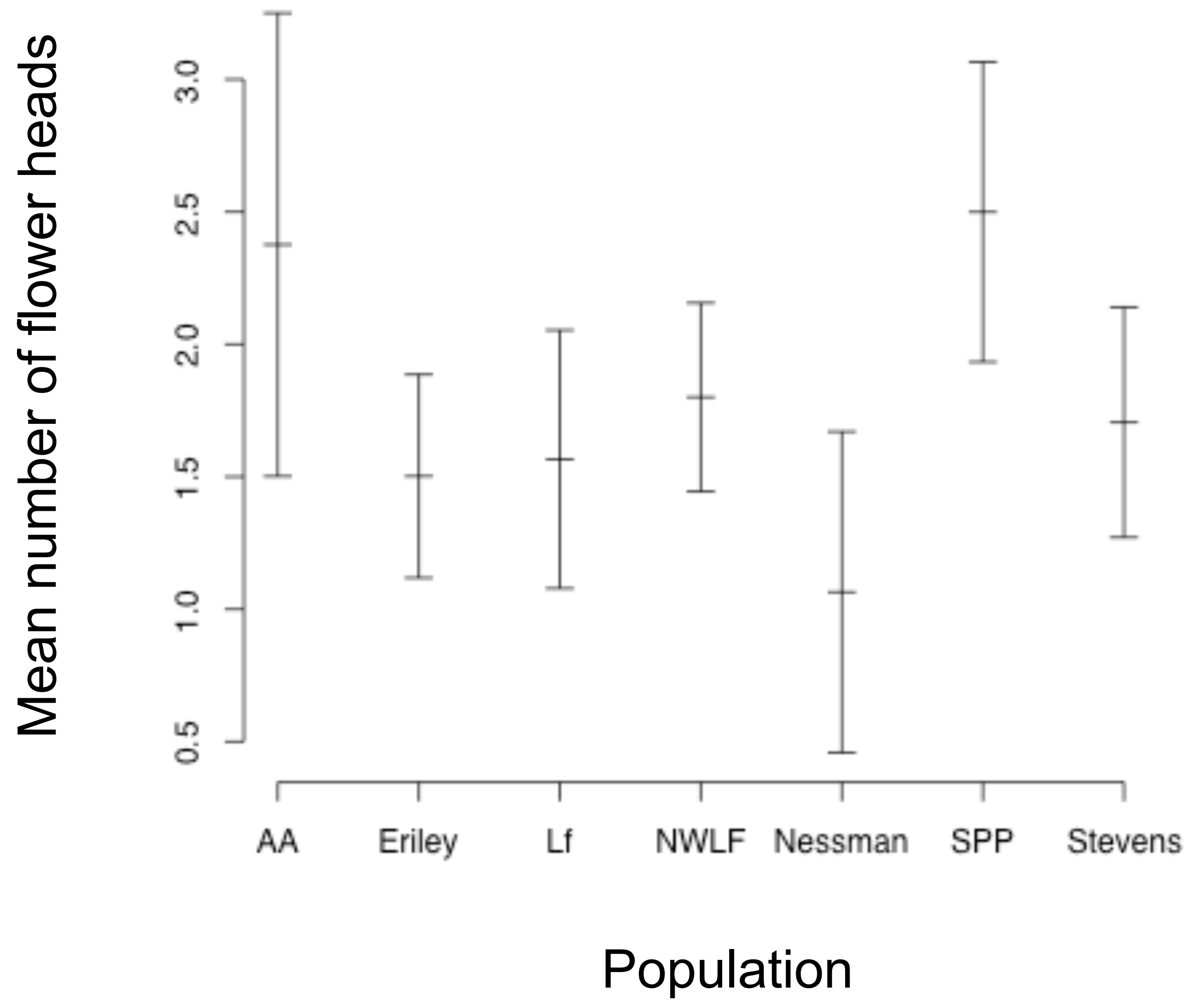


Forest node graph

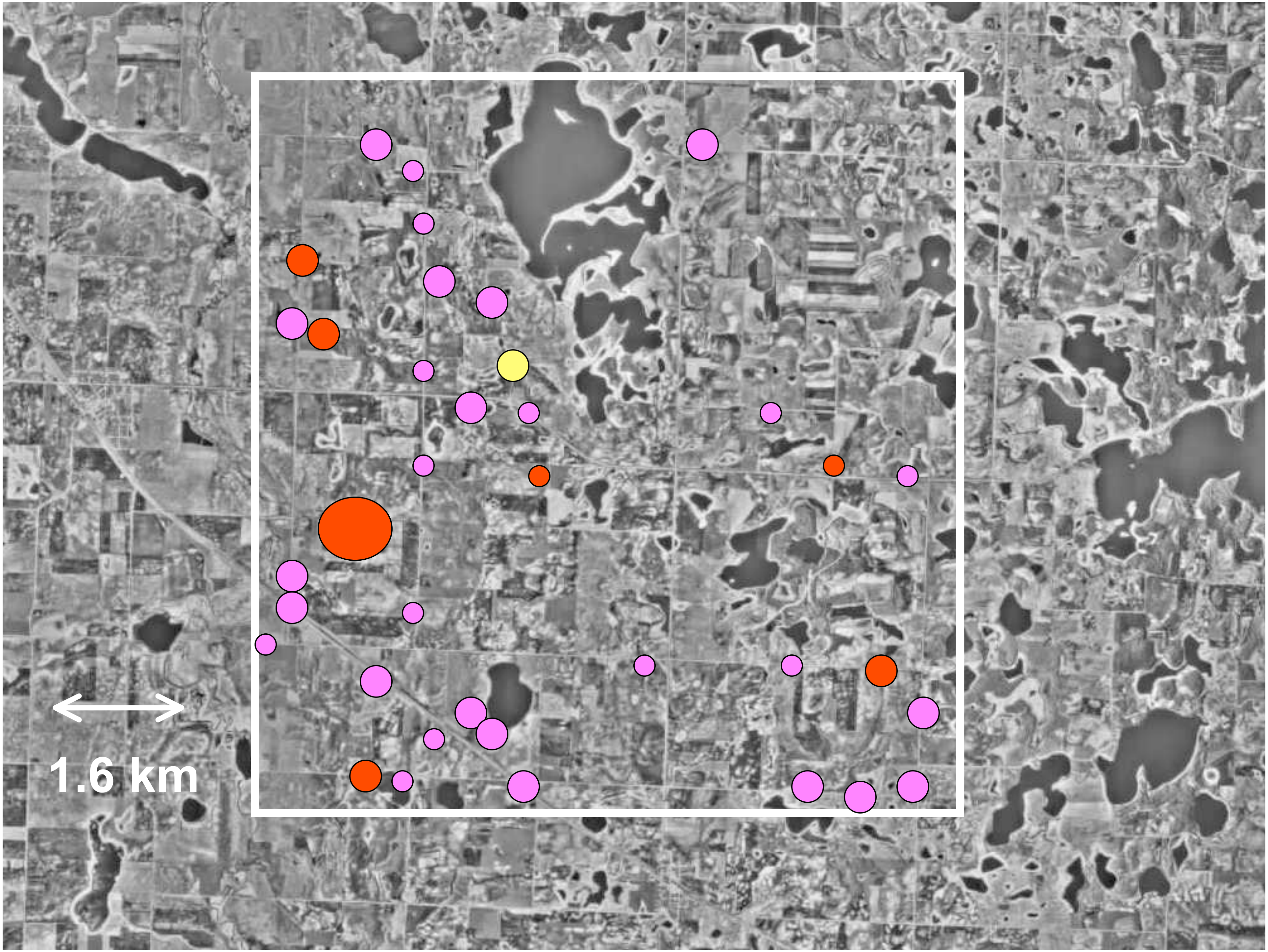
N plants in common field surviving and flowering in 3 yr







Geyer, Wagenius and Shaw 2007. Biometrika


1.6 km

Observed and Expected Frequency Distributions

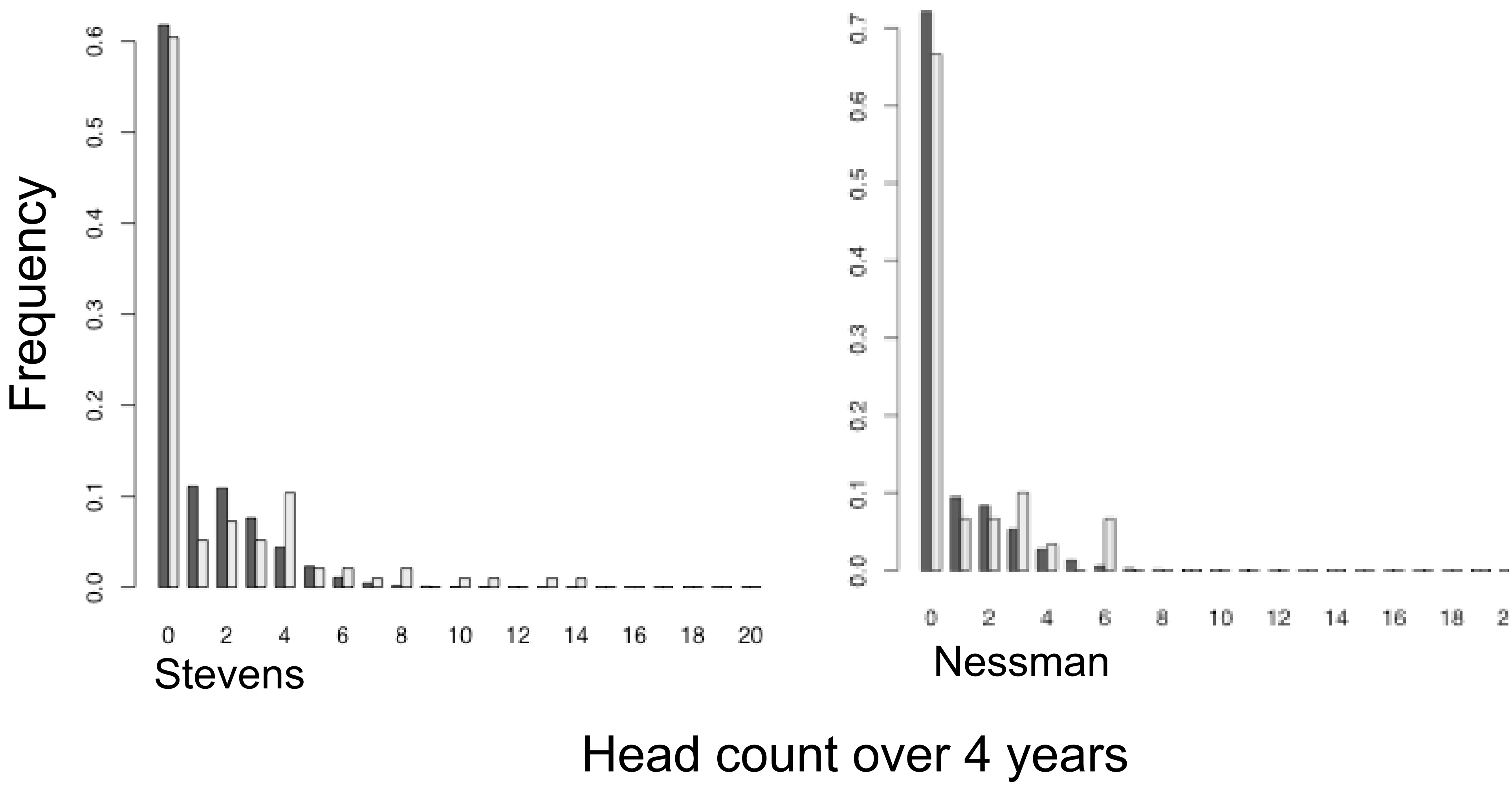
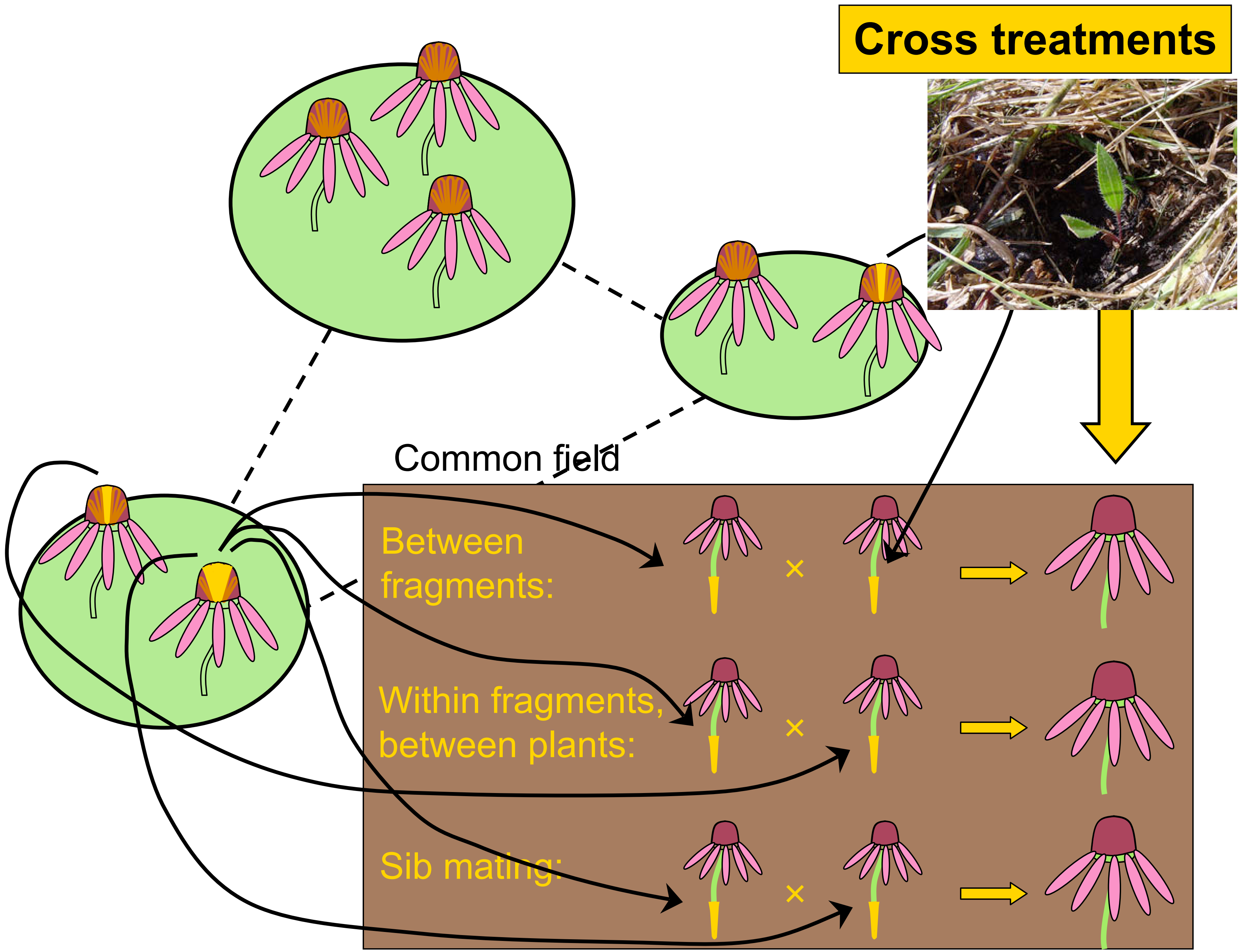
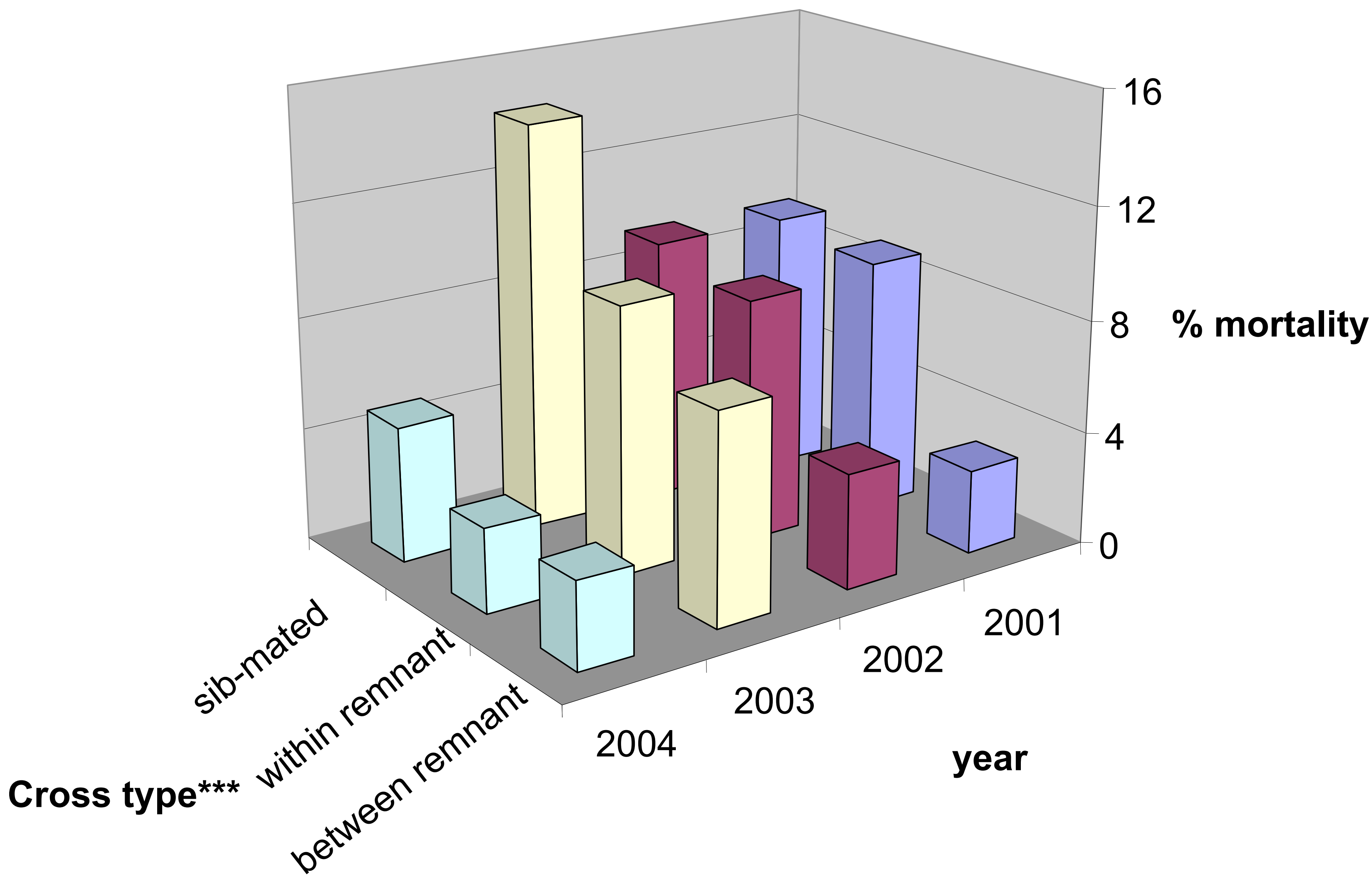


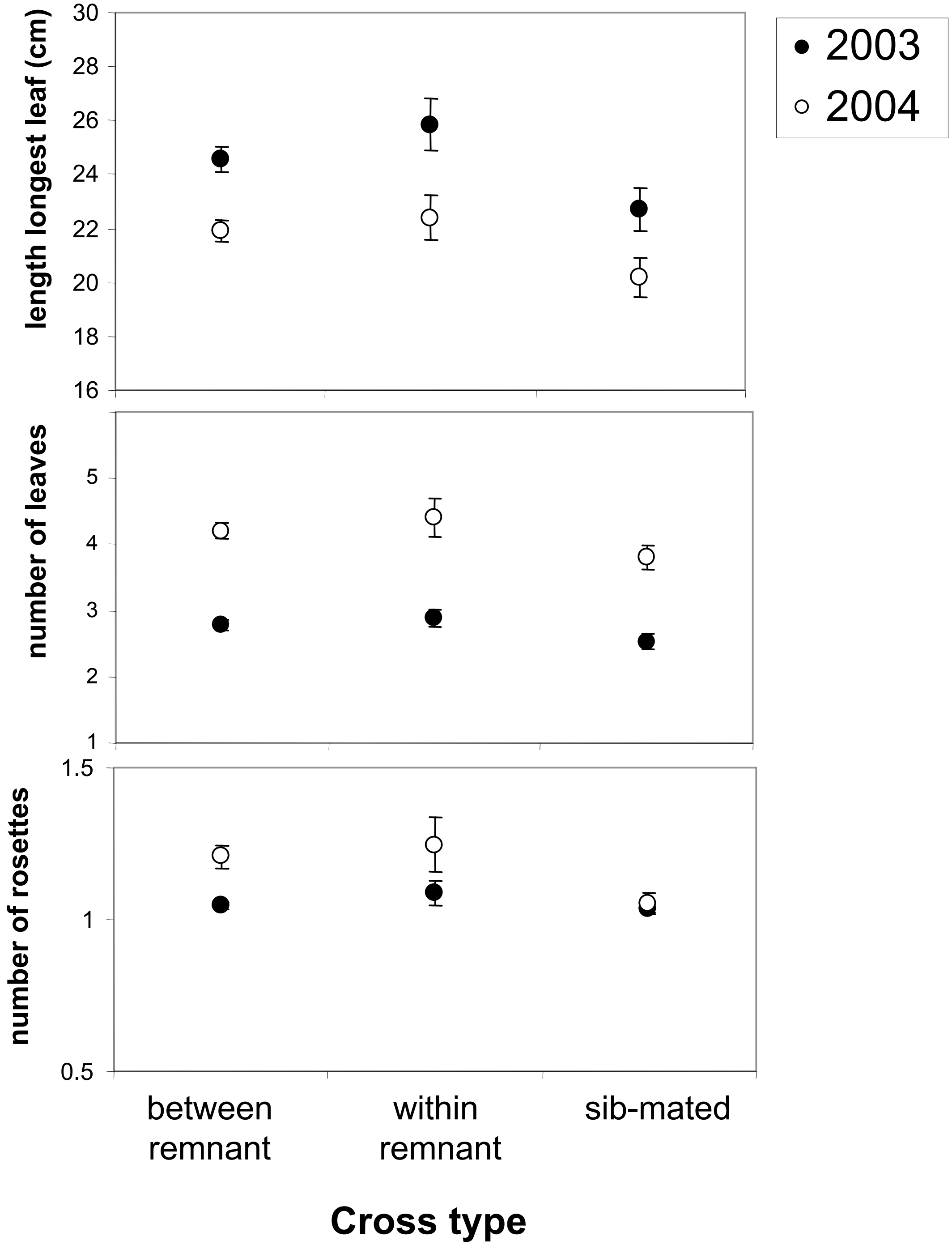

Photo by H. Hangelbroek


Cross treatments
Common field
Between fragments:
Within fragments, between plants:
Sib mating:

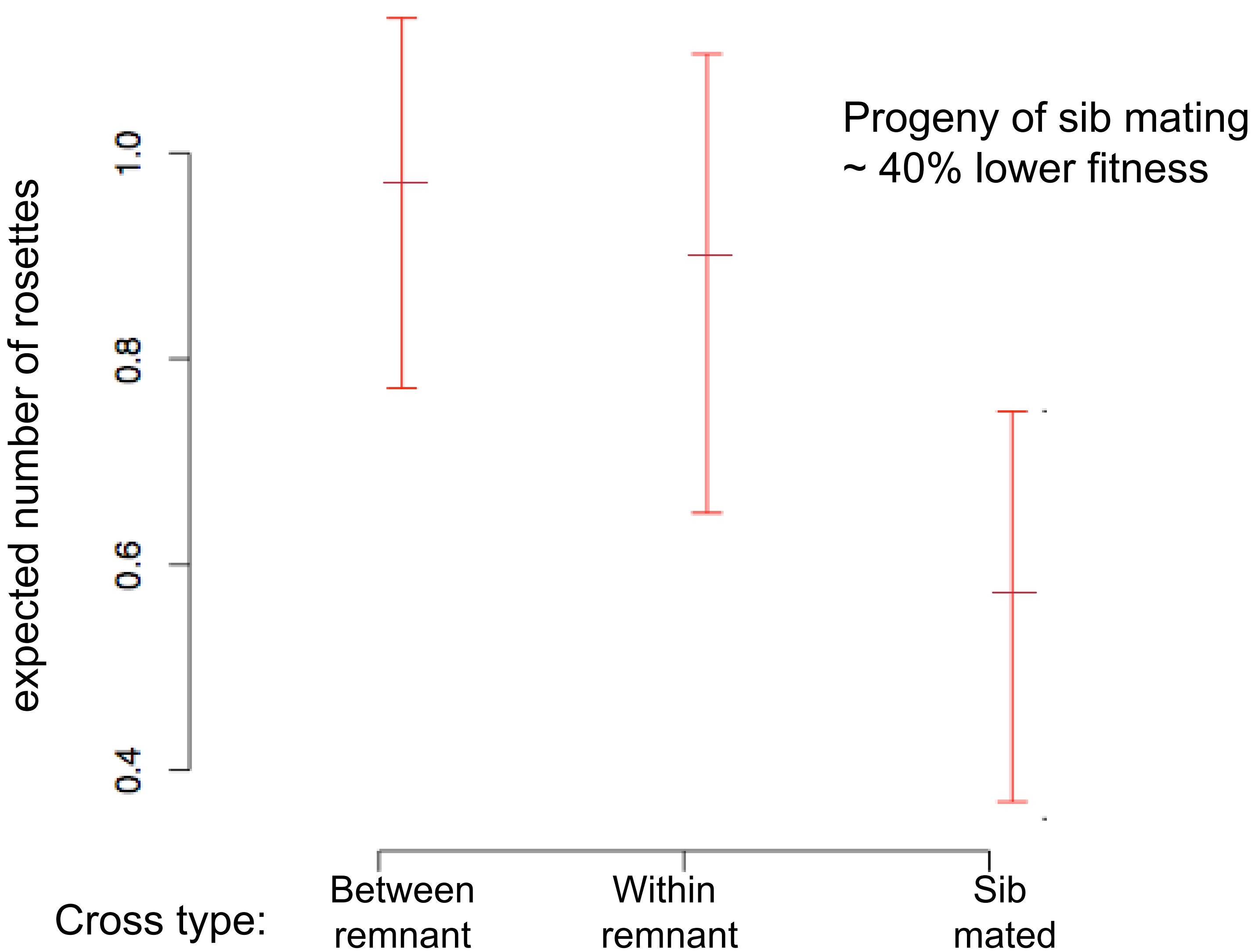
Mortality over four years in relation to cross-level



Size measures:

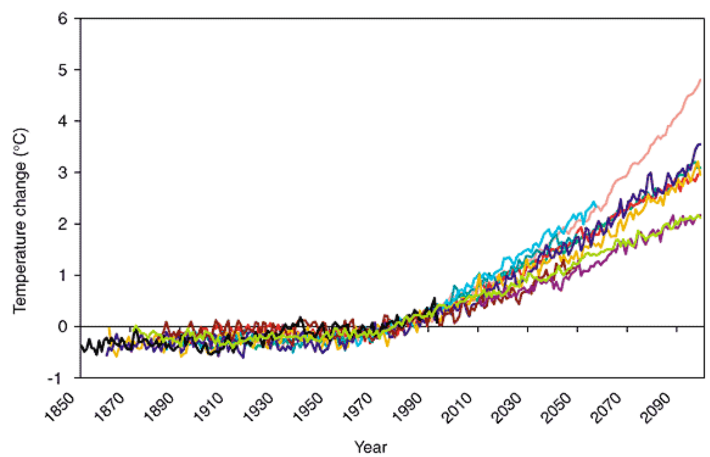


Aster analysis to assess effects of inbreeding/outcrossing on fitness as of age 4



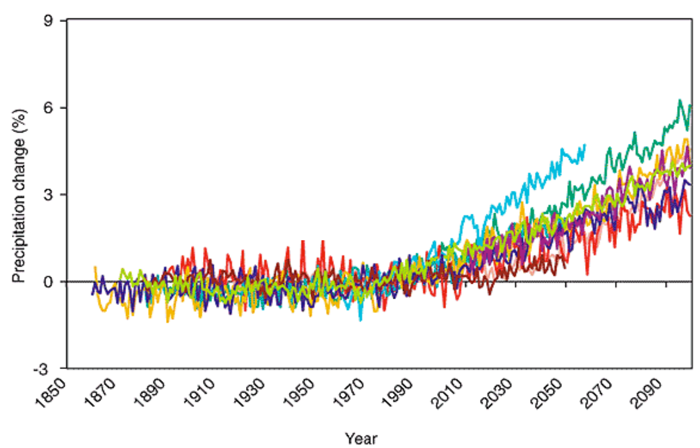
Climate change:

Temperature

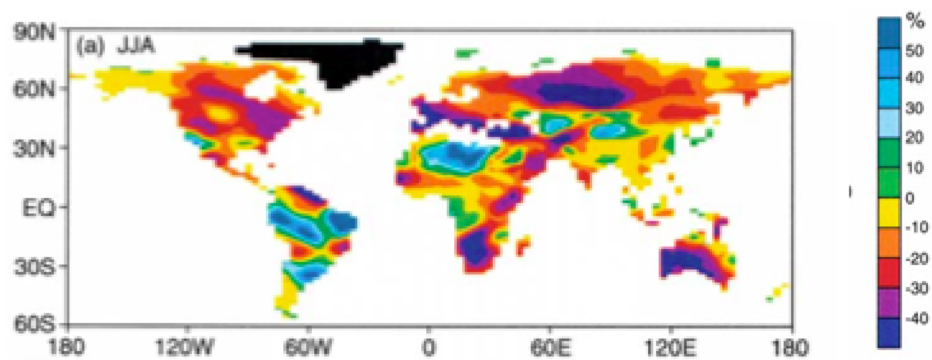


http://www.grida.no/climate/ipcc_tar/wg1/fig9-5.htm

Precipitation



Soil moisture change (Jun-Aug)



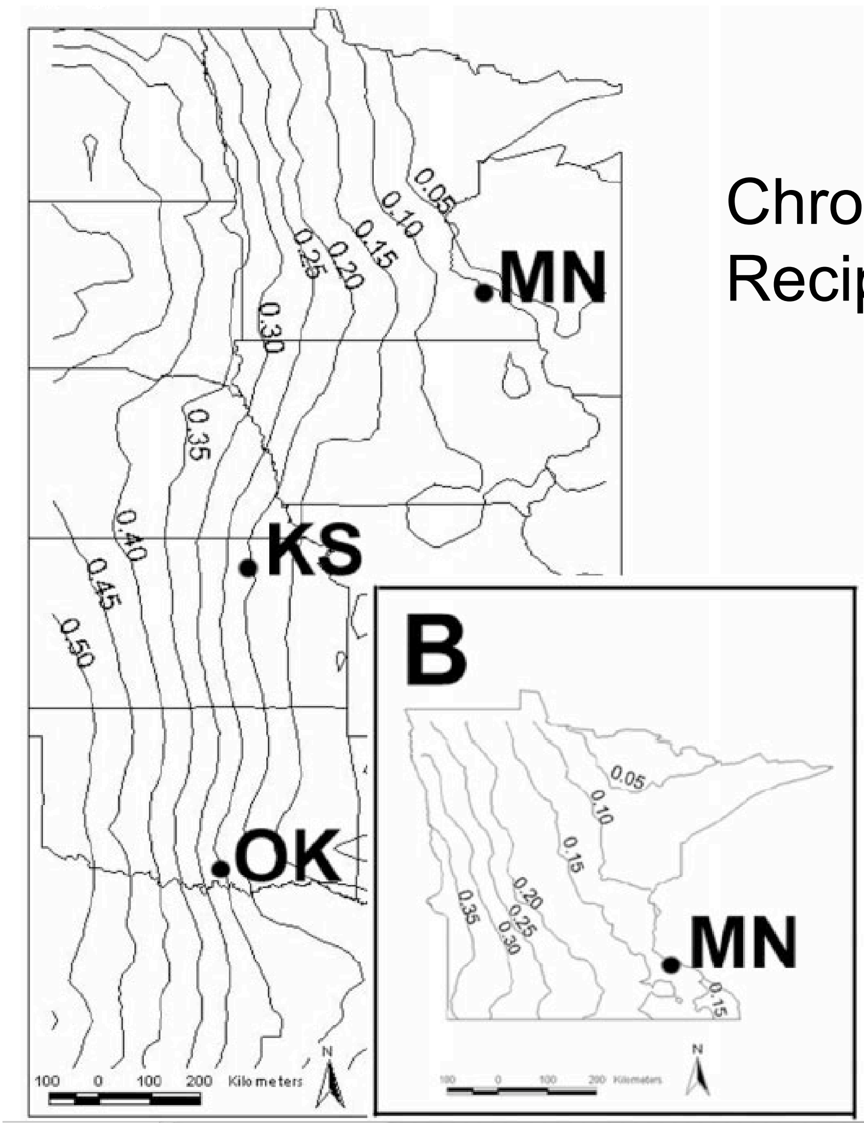
Manabe et al. 2004

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



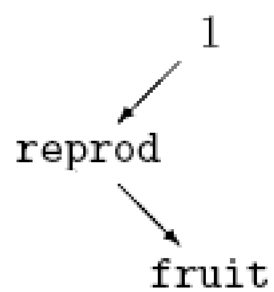
Chronosequence - projecting into future

Reciprocal transplant:

- 3 populations in 3 locations
- Progeny of formal crosses (NC1) within each population
- 10,000 plants

Etterson 2004

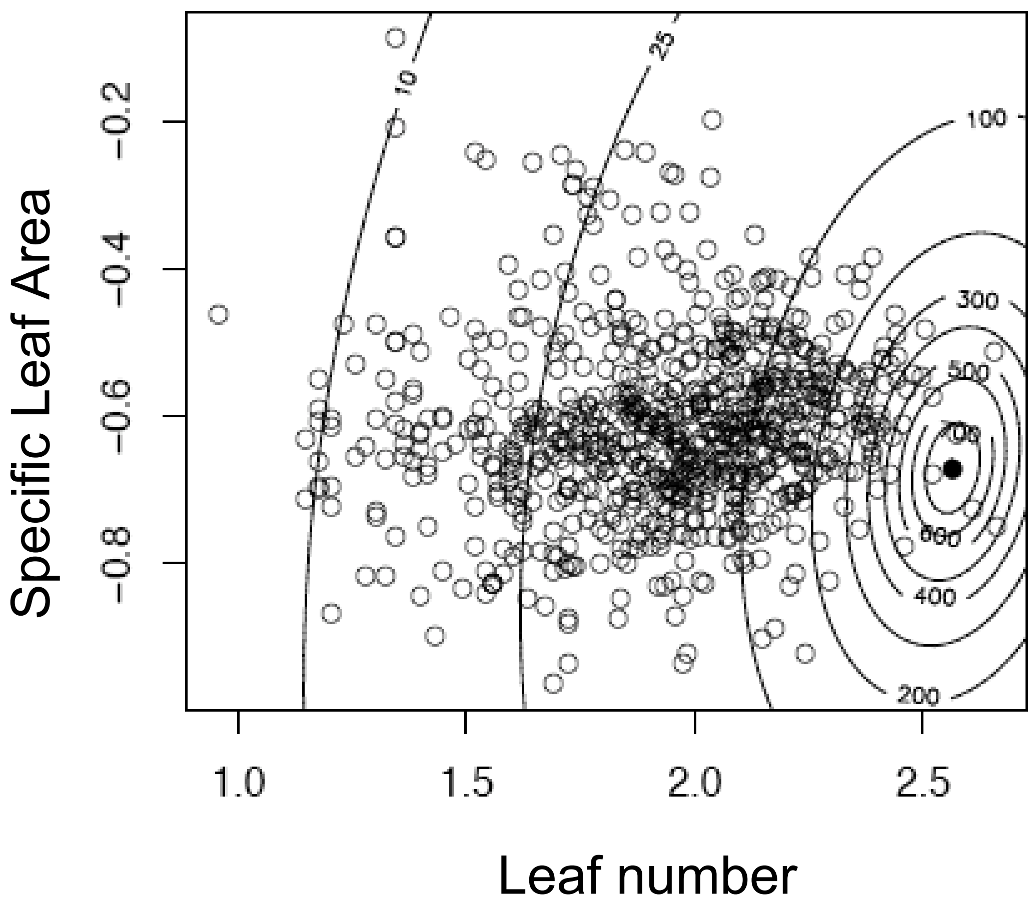
Aster for phenotypic selection analysis to evaluate the relationship between fitness, W



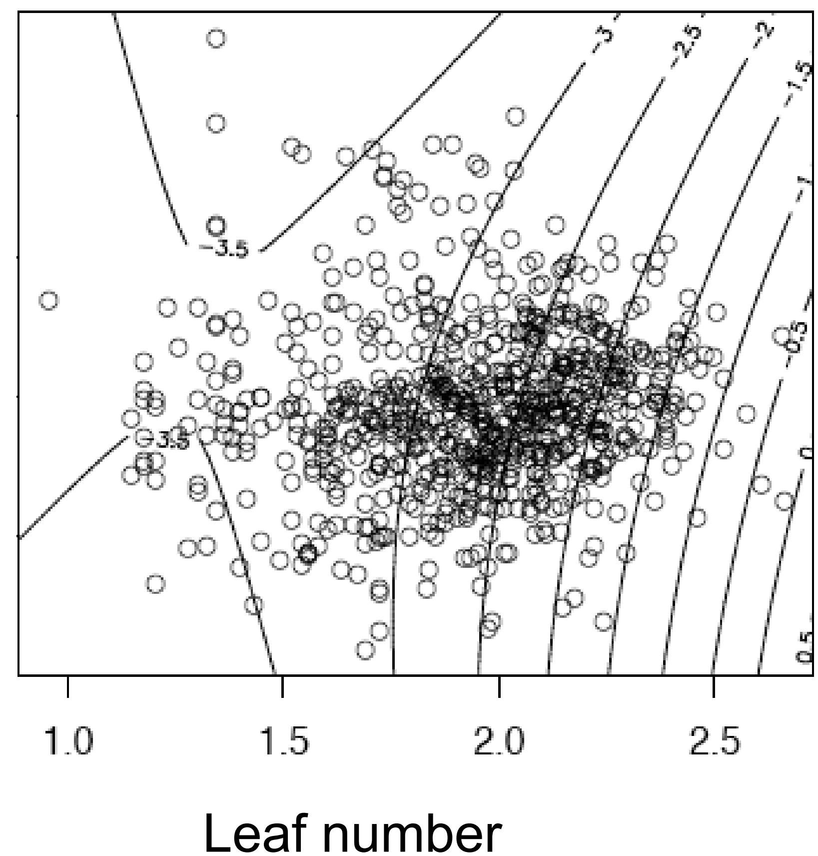
and traits, leaf number and specific leaf area.

Quadratic fitness surface estimated from aster model

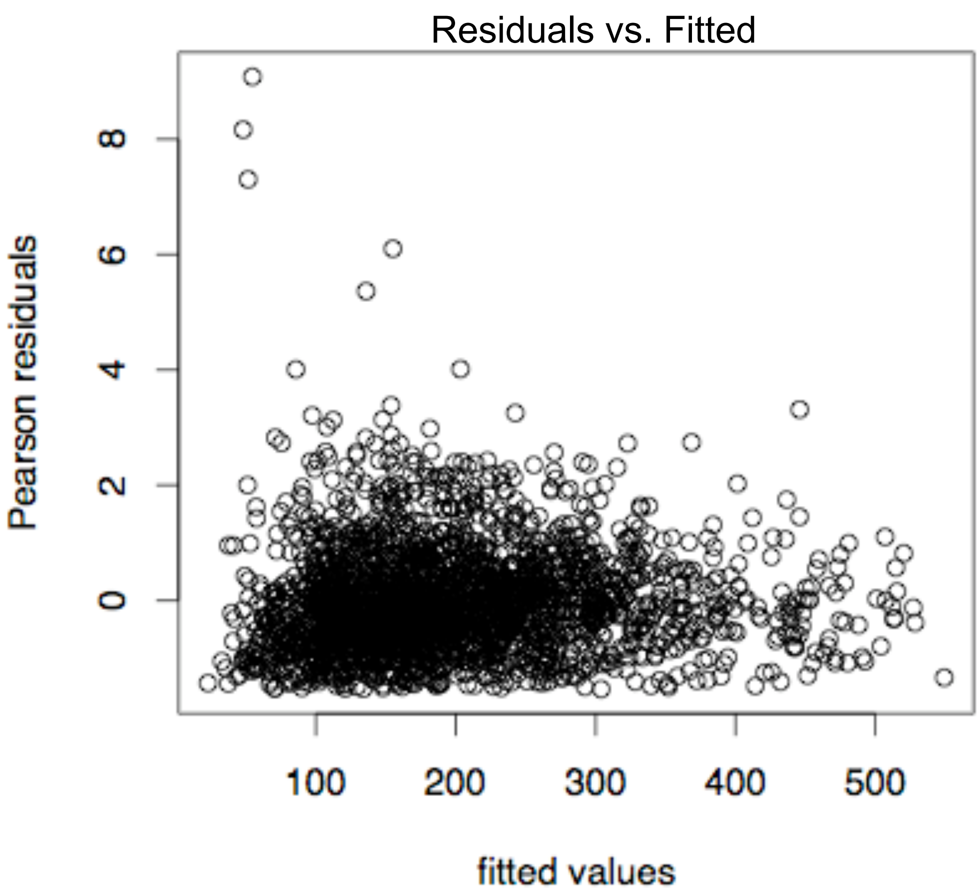
(MN pop in MN site)



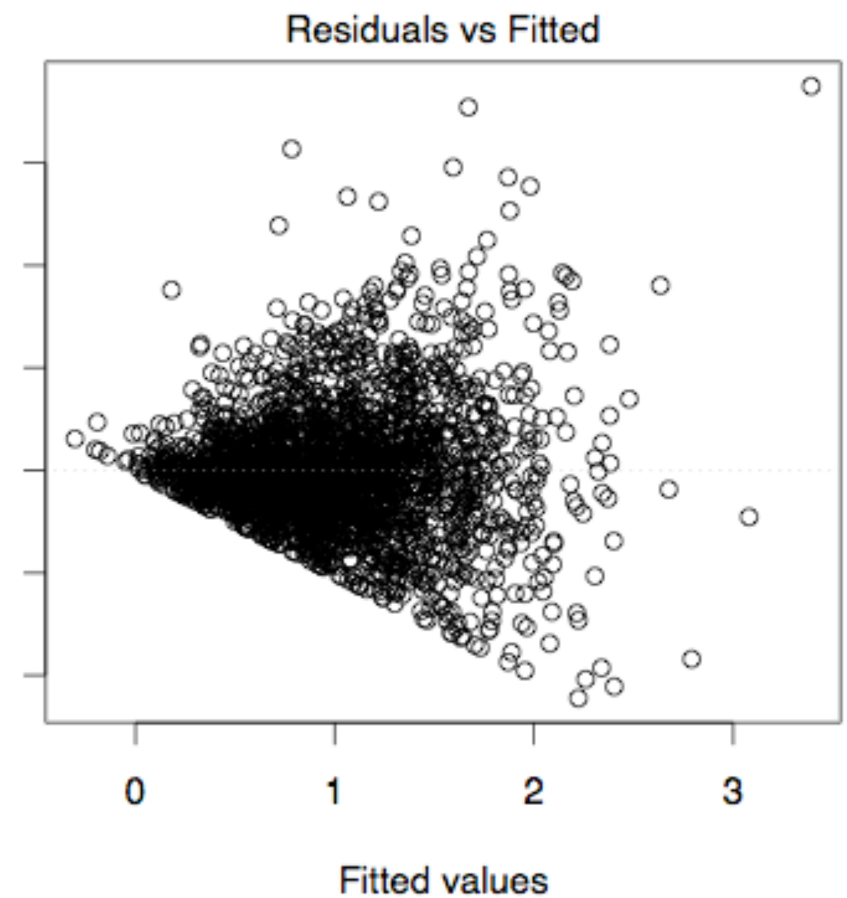
Quadratic fitness surface via ordinary least squares (Lande and Arnold 1983)



Aster

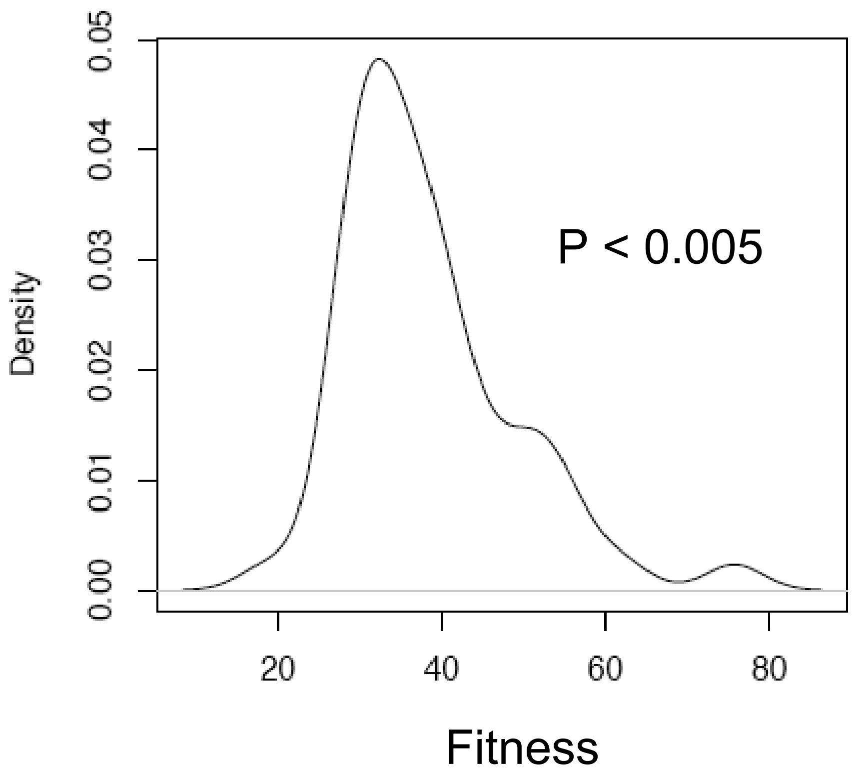

Residuals vs. Fitted
Pearson residuals
0
2
4
6
8
100
200
300
400
500
fitted values

OLS

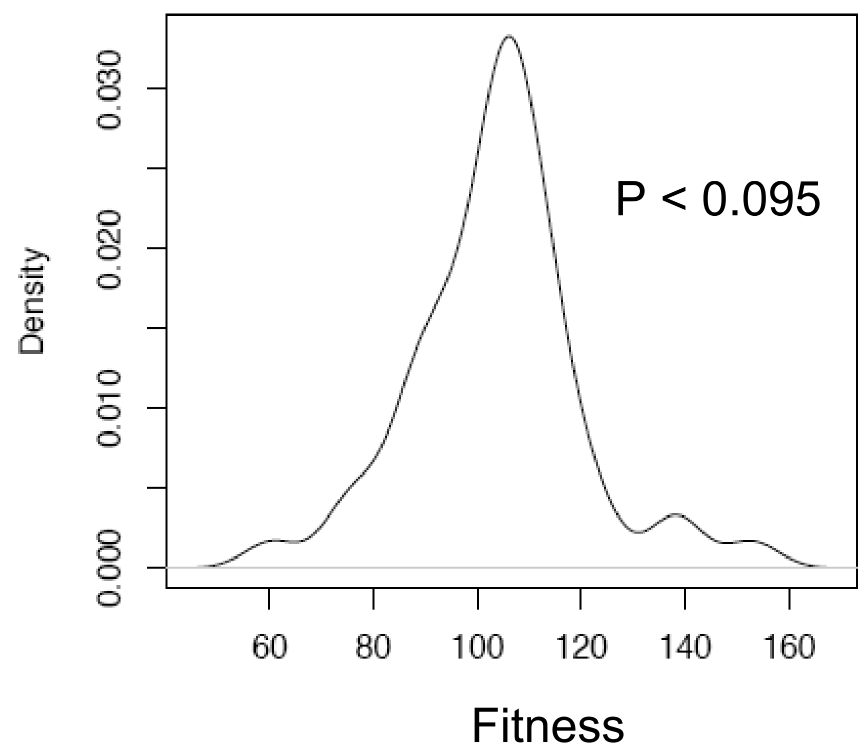

Residuals vs Fitted
0
1
2
3
Fitted values

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

Stuart Wagenius

UMCenter for Community Genetics

Chicago Botanic Garden

Julie Etterson

UMCenter for Community Genetics

University of Minnesota-Duluth

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Janis Antonovics

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