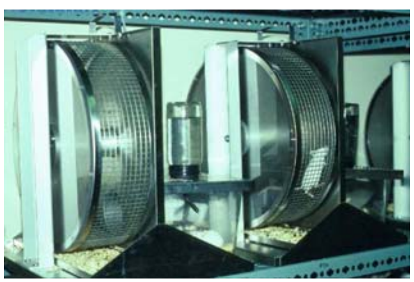
Evolution of the Integrated Phenotype: A Function-Valued Approach

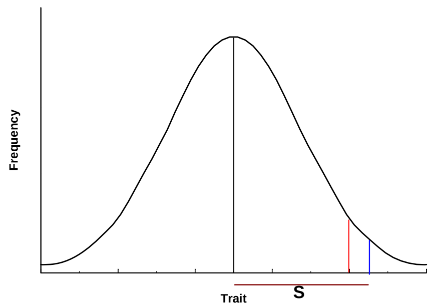


Outline

- Evolutionary quantitative genetics: univariate, multivariate and function-valued responses to selection
- Function-valued analyses
- Potential Projects
  - Rainbow trout
  - Flour beetles
  - Statistical comparative methods

Basic Quantitative Genetics

- For a continuous trait (e.g., body mass), if family relationships in the population are known, the phenotypic variance can be partitioned:
  - $V_P = V_G + V_E$
- Furthermore, V_G also can be partitioned:
  - $V_G = V_A + V_D + V_I$
- V_A is additive genetic variance = average effect of allelic substitution = the portion of V_G passed from parents to offspring



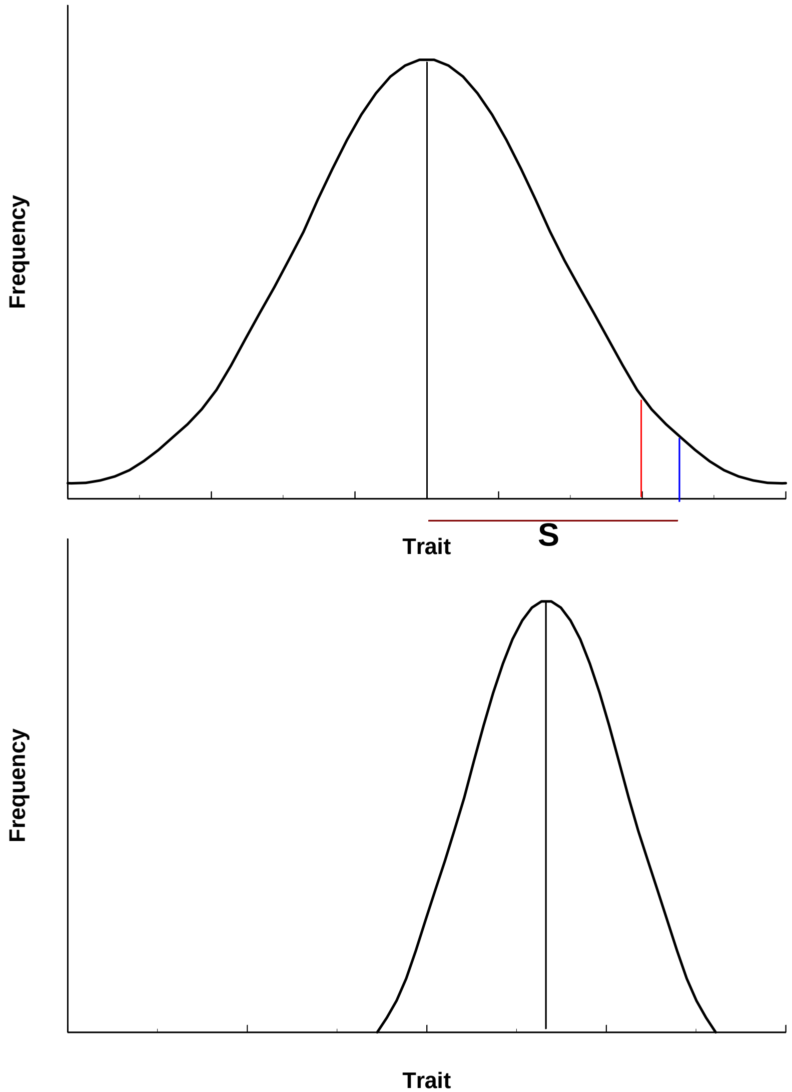
Univariate Response

- $R = h^2 s$

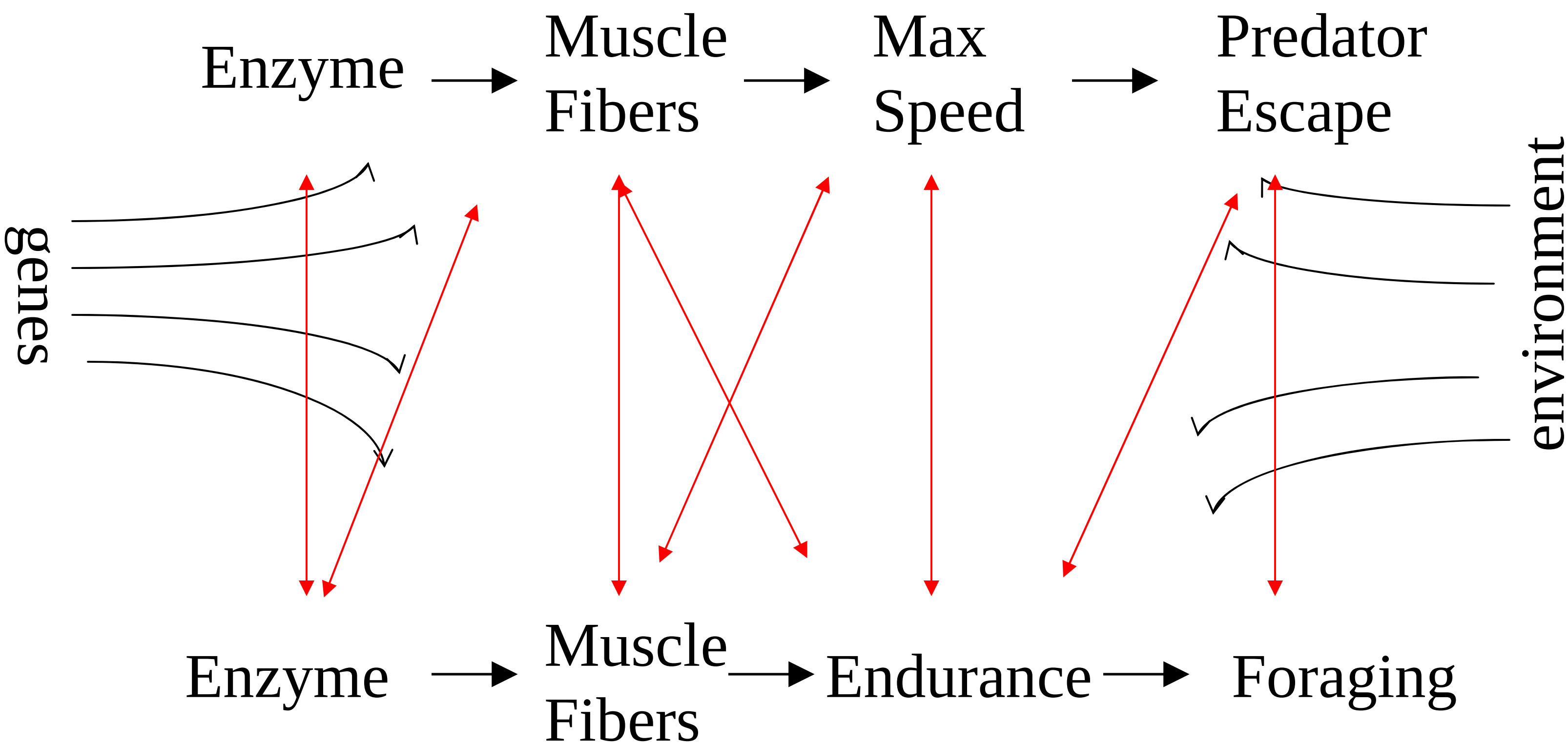
  $h^2 = V_A/V_P$ so

- $R = V_A(s/V_P)$

- Response requires fraction of variance to be genetic

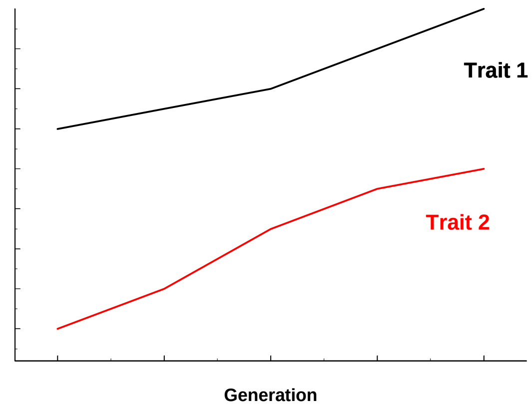


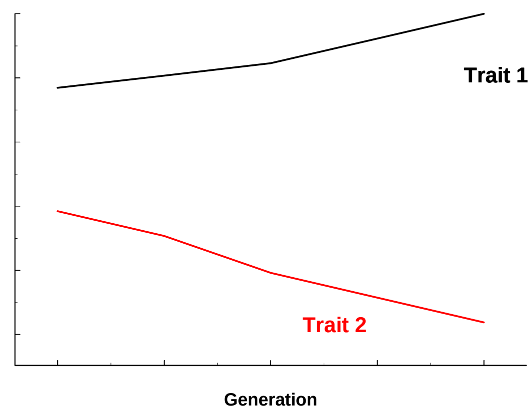
The Integrated Phenotype



Multi-Variate Response

- Trait 2 responds to selection on Trait 1.
- Depends on genetic covariance
  - Caused by:
    pleiotropy
    linkage diseq
  - Effects on evolution
    speed up
    constrain



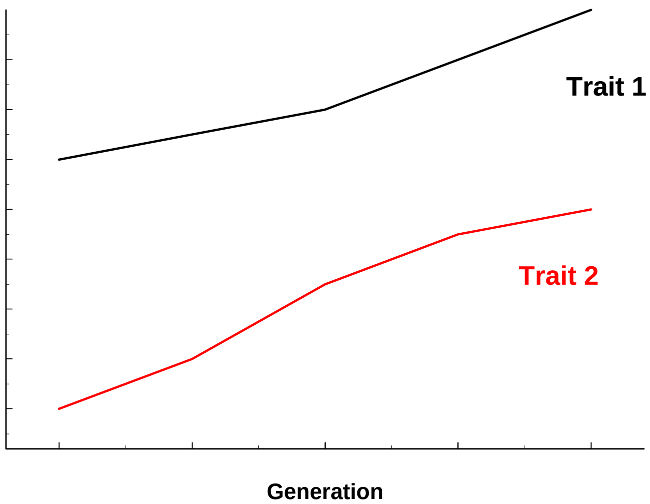


Multi-Variate Response

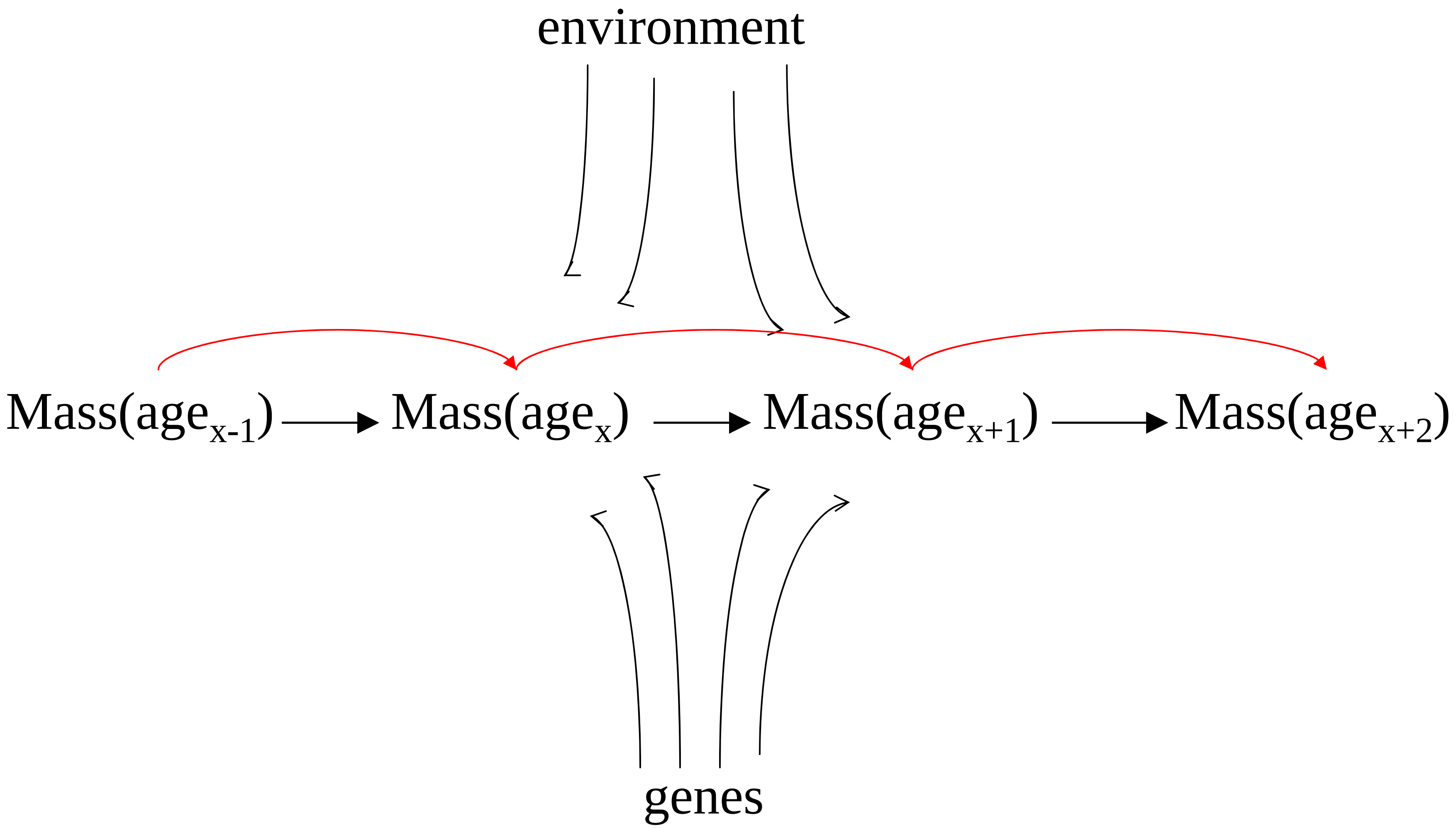
- $R = V_A(s/V_P)$

- $$\Delta\bar{\mathbf{z}} = \mathbf{G}\beta$$
  - β = selection gradient
  - **G** =

	trait1	trait2
trait1	σ_{11}	σ_{12}
trait2	σ_{21}	σ_{22}

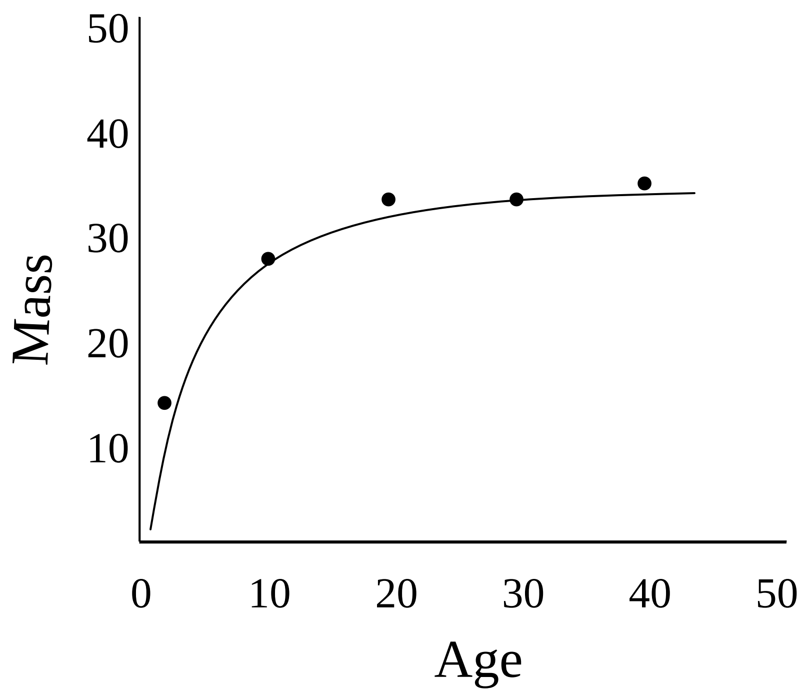


The Integrated Phenotype: Another View



Function-Valued Traits

- Any trait that can be described as a mathematical function of a continuous independent variable
  - ontogenetic trajectories
  - reaction norms
  - morphological shapes



Multivariate Methods Can Be Used to Evaluate F-V Traits

- Each measure treated as an independent trait
- Genetic variance-covariance matrix (**G**) estimated for measured ages
- $$\Delta\bar{\mathbf{z}} = \mathbf{G}\beta$$

	day1	day3	day5
day1	σ_{11}	σ_{13}	σ_{15}
day3	σ_{13}	σ_{33}	σ_{35}
day5	σ_{15}	σ_{35}	σ_{55}

Function-Valued Response

- $R = V_A(s/V_P)$

- $$\Delta\bar{\mathbf{z}} = \mathbf{G}\beta$$

- $$\Delta\bar{z}(T) = \int G(T,\theta)\beta(\theta)d\theta$$

Advantages of Function-Valued Approach

- Order and spacing of measures utilized
- Can interpolate between measures
- Genetic variances and covariances can be estimated for *all* ages
- Data can be collected at *any* age
- More efficient-less data needed
- G function can be decomposed

Decomposition of *G* function

- Equivalent to PCA analysis of **G** matrix
- Eigenfunctions
  - Continuous counterpart of eigenvectors
  - Describes principle axes of variation
- Eigenvalues
  - Describes the amount of genetic variance in particular axis of variation

Potential Project I: Flour Beetles

- G functions of larval growth curves
- Identify genetic directions of highest and lowest potential response to selection
- This summer: Initiate selection experiments
- Measure life history traits traits

PURPOSE

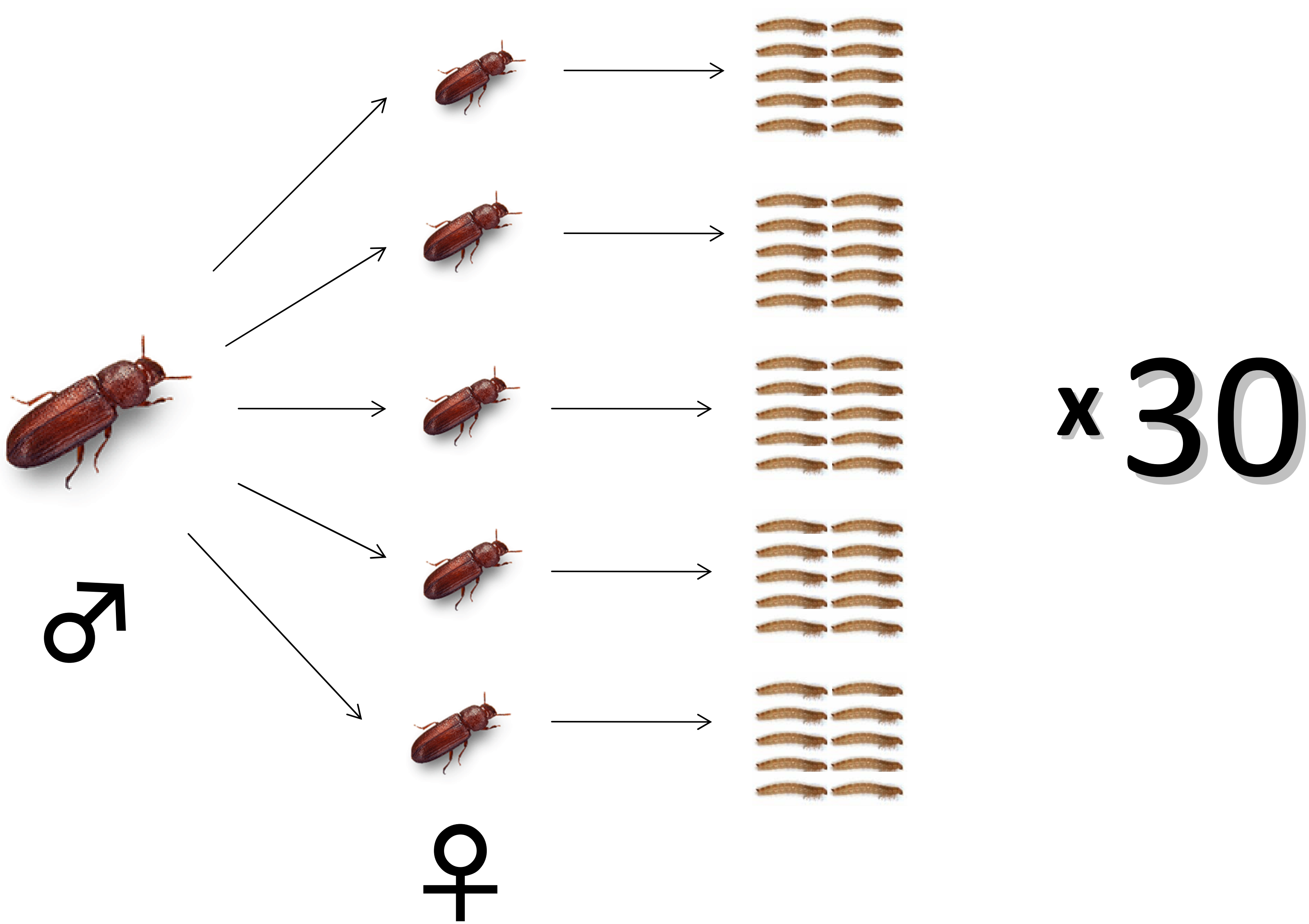
- Measure body mass curves in larval *Tribolium casteneum*
- Estimate *G* function, Eigenfunctions
- Predict potential responses to selection
- Predict correlated responses

http://entnemdept.ufl.edu/teneb/Tenebrio_larva_1.jpg

Why use *Tribolium*?

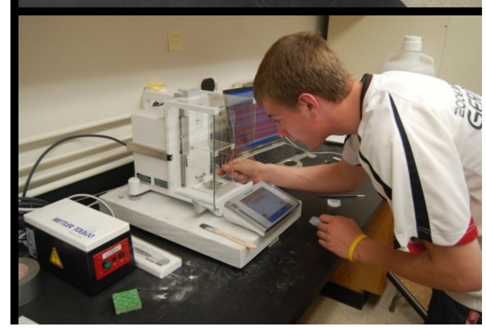
- Relatively small size
- Fast generational turnover
- Limited flying ability
- Distinct life stages
- Entire genome sequenced
- Low-cost culture

Half -Sib Mating Design

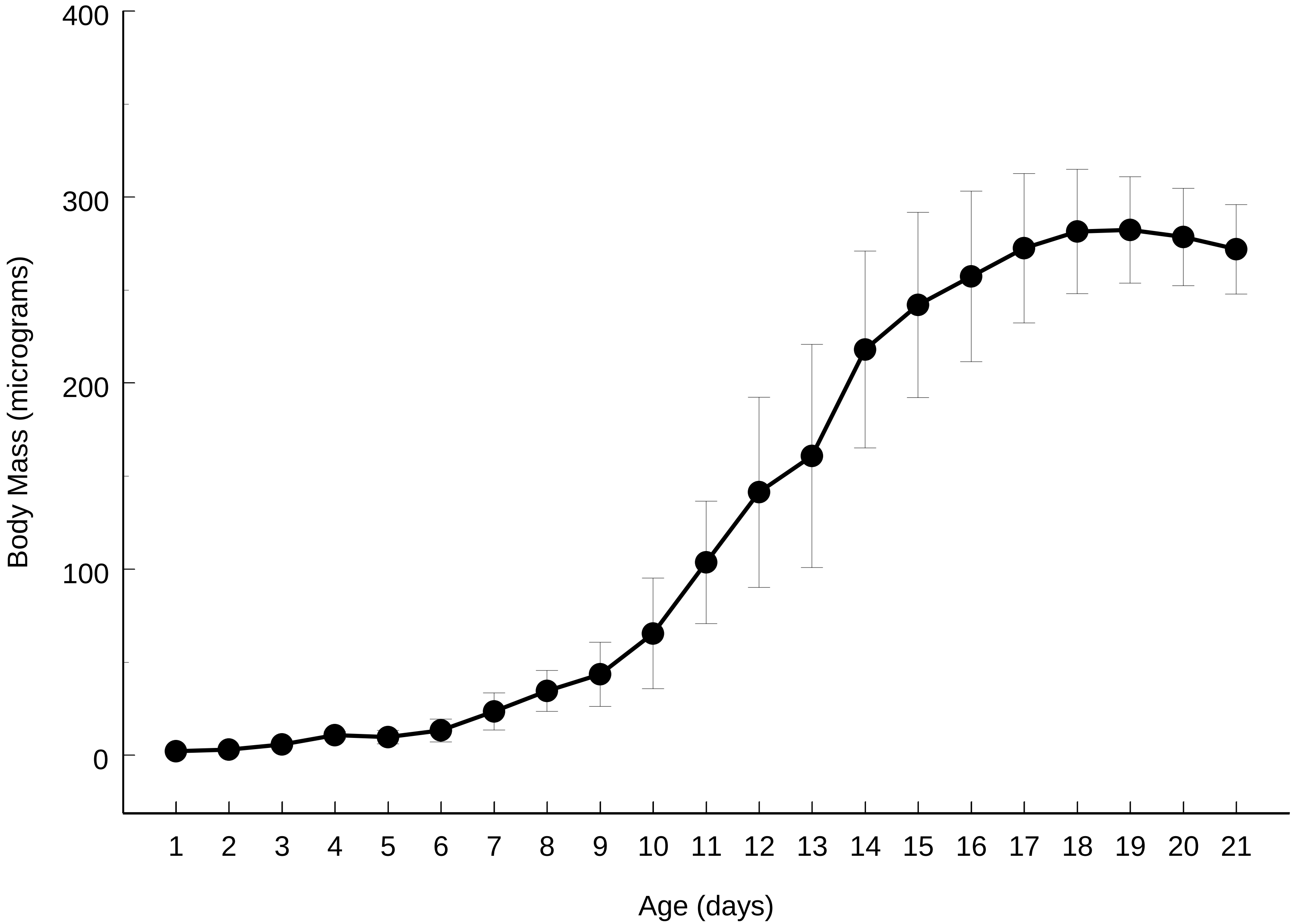


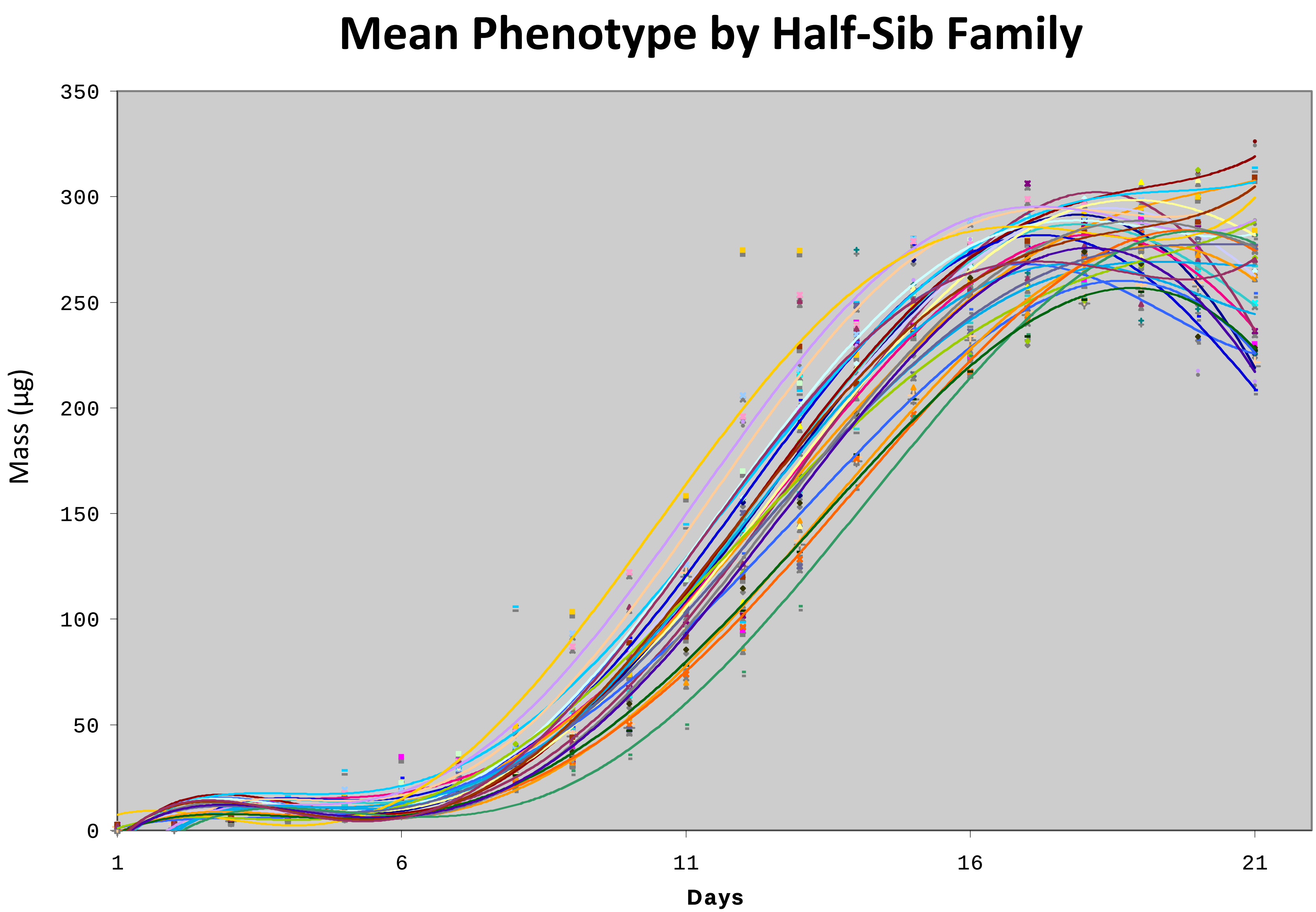
METHODS

- Virgin adults from previous culture
- Females randomly assigned to males
- Allowed to mate for 4 days
- Isolated, checked daily for larvae
- Offspring measured every 3 days
- Mass measured after pupation
- Dates of pupation and eclosion recorded

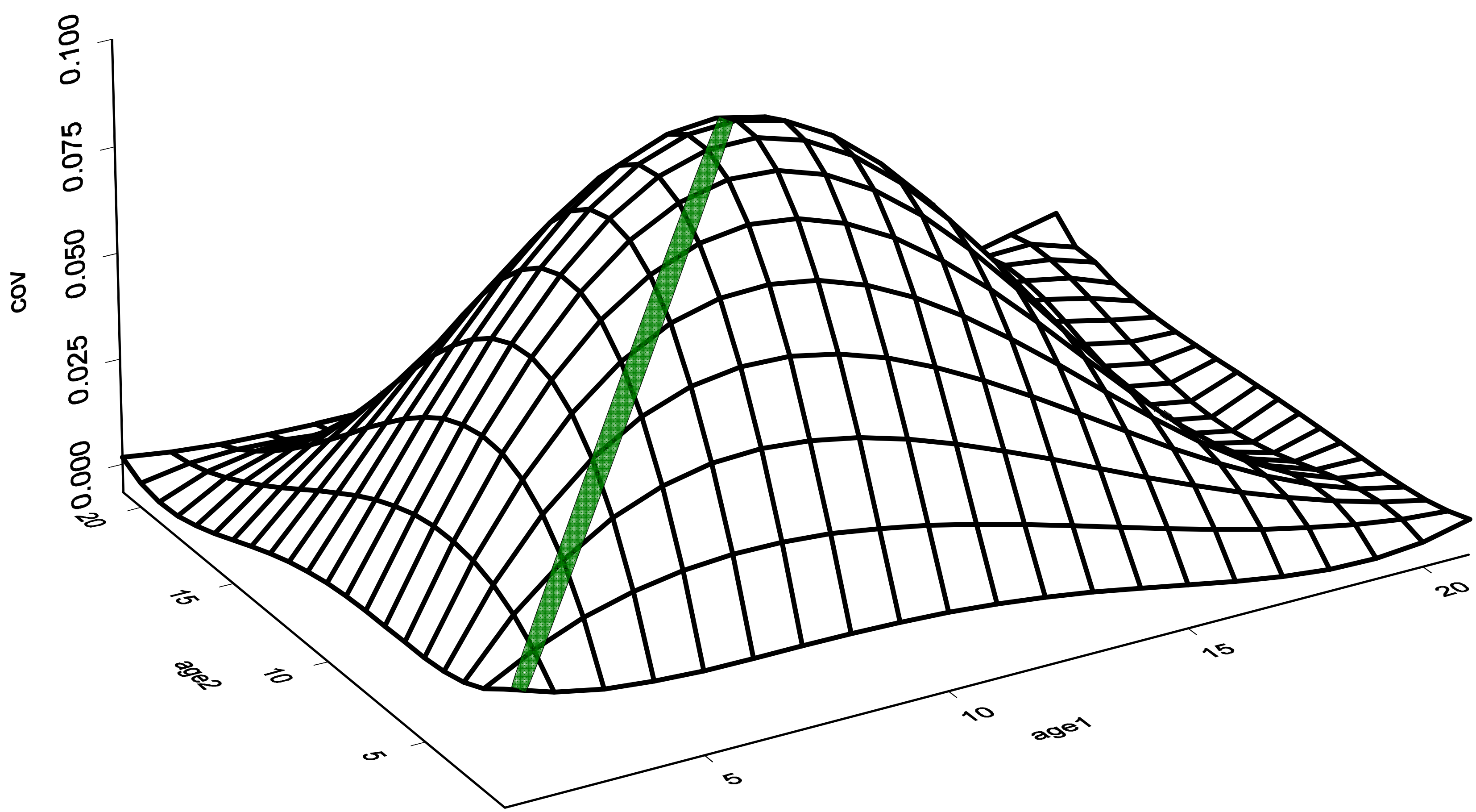


Overall Mean Phenotype

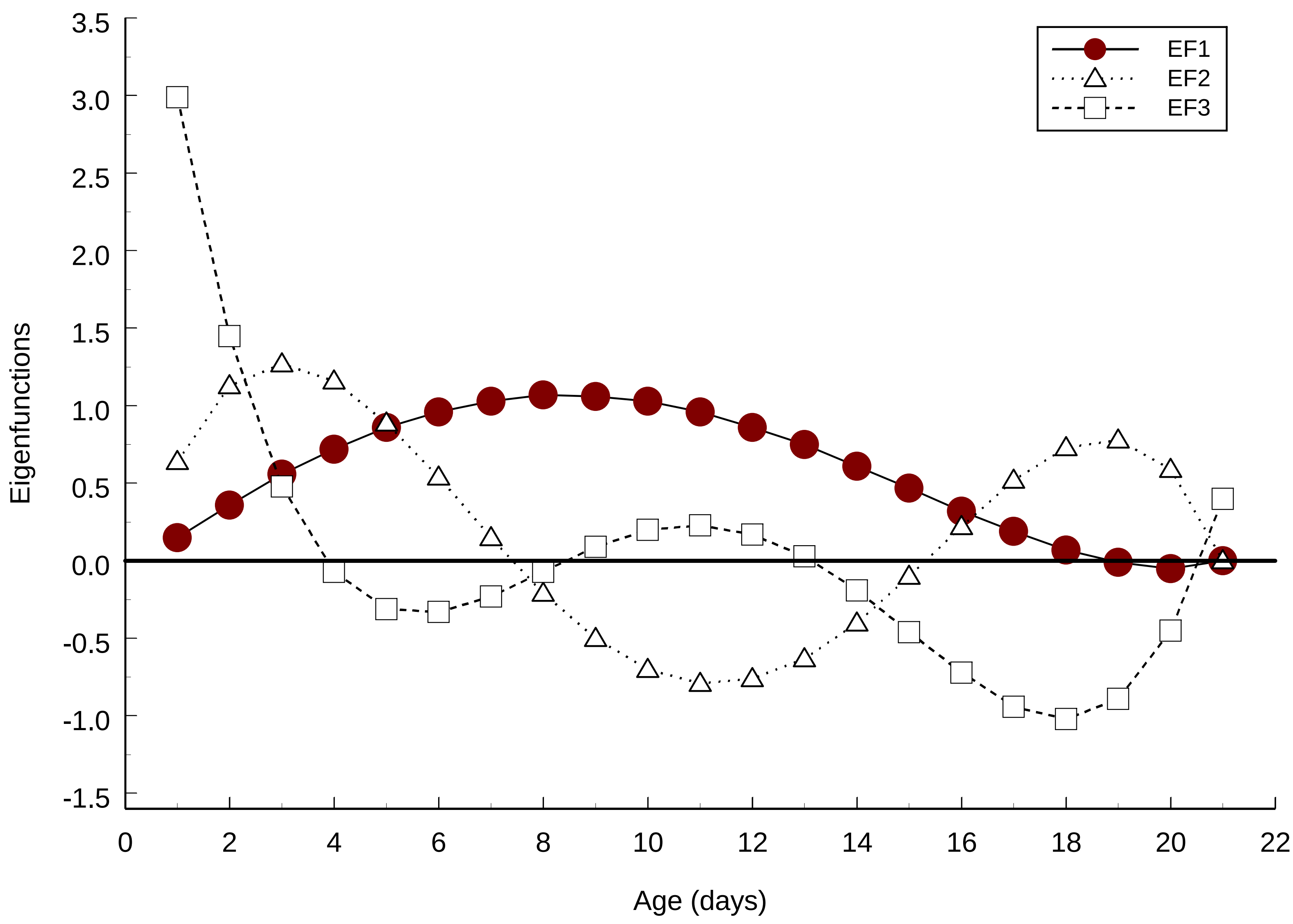



Mean Phenotype by Half-Sib Family
Mass (µg)
350
300
250
200
150
100
50
0
1
6
11
16
21
Days

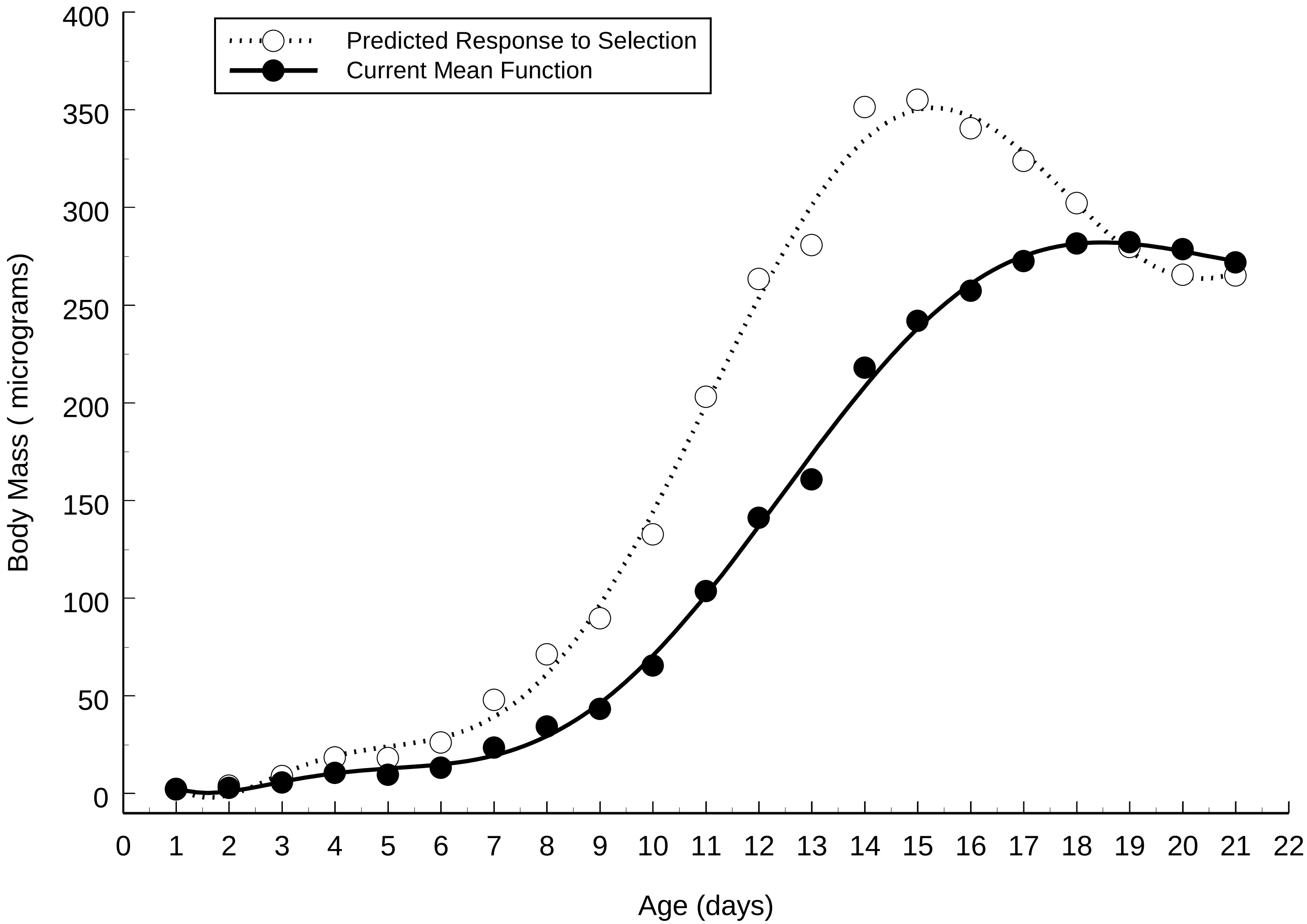
Additive Genetic Covariance Function



Eigenfunctions



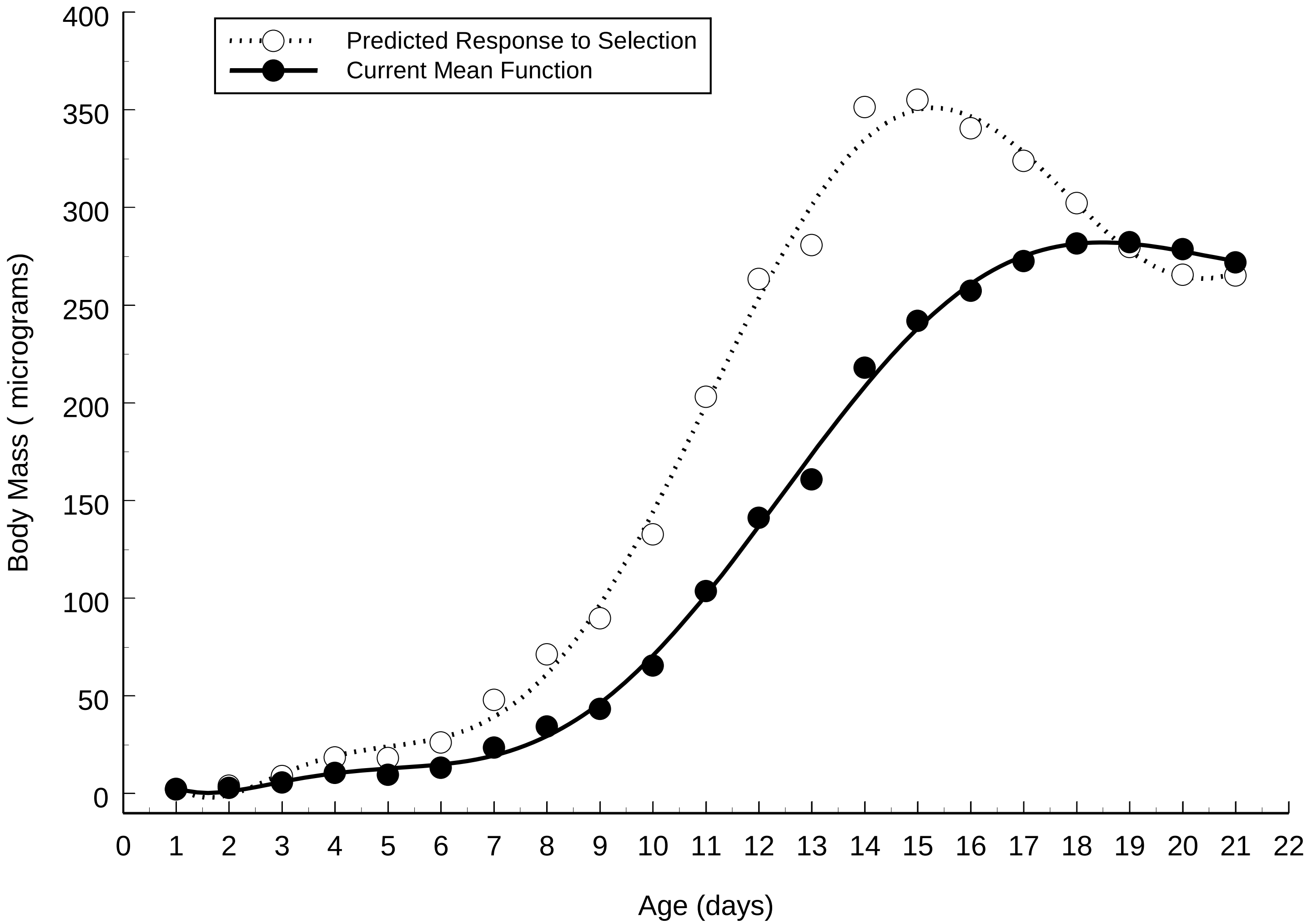
Response to Selection



Additive Genetic Correlations

	Day 2 Mass	Day 10 Mass	Day 16 Mass	Pupal Mass	Larval Period	Pupal Period
Day 2 Mass	**0.808** (0.118)	0.802 (0.070)	0.752 (0.107)	0.557 (0.136)	-0.399 (0.145)	0.463 (0.235)
Day 10 Mass	0.802 (0.070	**0.641** (0.120)	0.688 (0.119)	0.347 (0.160)	-0.775 (0.083)	0.606 (0.230)
Day 16 Mass	0.752 (0.107)	0.688 (0.119)	**0.496** (0.104)	0.866 (0.058)	-0.375 (0.153)	0.264 (0.246)
Pupal Mass	0.557 (0.136)	0.347 (0.160)	0.866 (0.058)	**0.530** (0.110)	0.048 (0.167)	0.175 (0.255)
Larval Period	-0.399 (0.145)	-0.775 (0.083)	-0.375 (0.153)	0.048 (0.167)	**0.469** (0.099)	-0.586 (0.219)
Pupal Period	0.463 (0.235)	0.606 (0.230)	0.264 (0.246)	0.175 (0.255)	-0.586 (0.219)	**0.165** (0.090)

Response to Selection



Potential Project II: Rainbow Trout

- Evolutionary trade-offs between growth and swim curves
- Differences in growth and swim curves between domesticated and wild fish
- Swim and growth curves in native vs. non-native temperatures

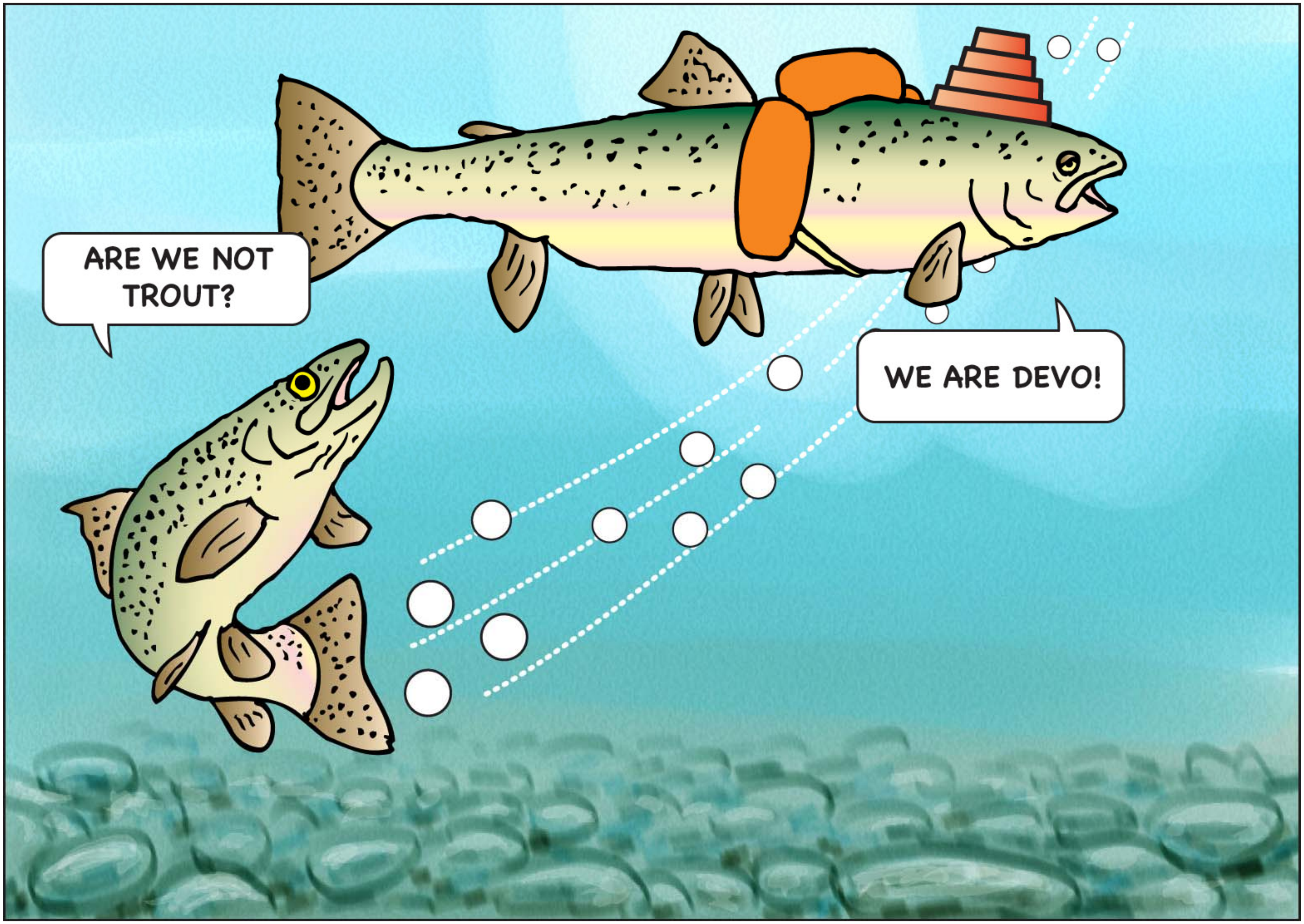
Evolutionary Trade-Offs with Body Size

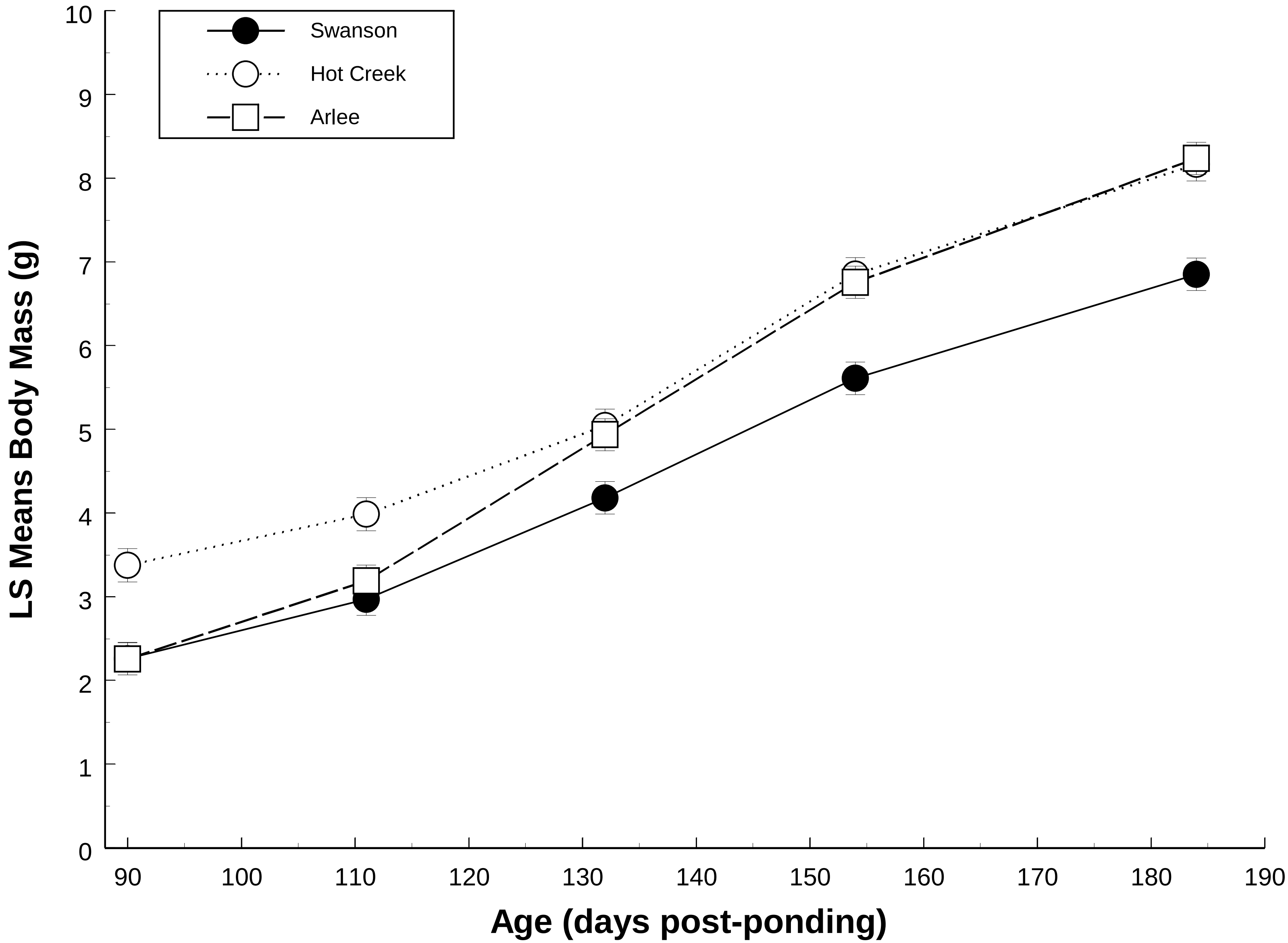
- Large body size positively correlated with Darwinian fitness in many animal species
- But, still high V_A for size and growth in natural populations of animals-why?
- Trade-offs between size/growth and other components of fitness?


DEVO

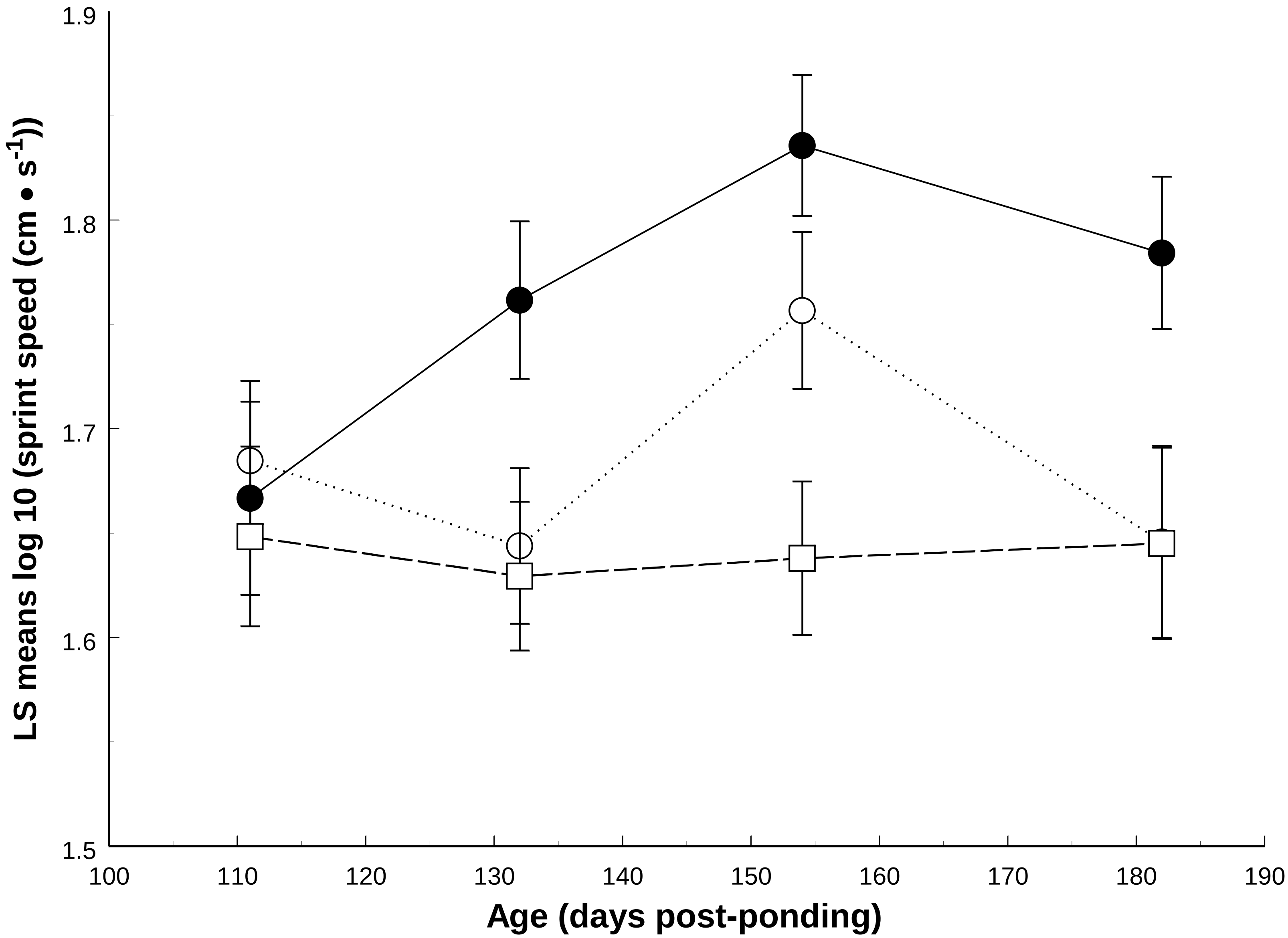
Domestication Trade-offs in Trout

- Long term selection for high growth in hatchery populations
- May decrease other components of fitness
- Almost certainly other domestication-related trait evolution in hatcheries
- Hypothesis: highly domesticated fish will be larger but be poor swimmers compared to wild fish

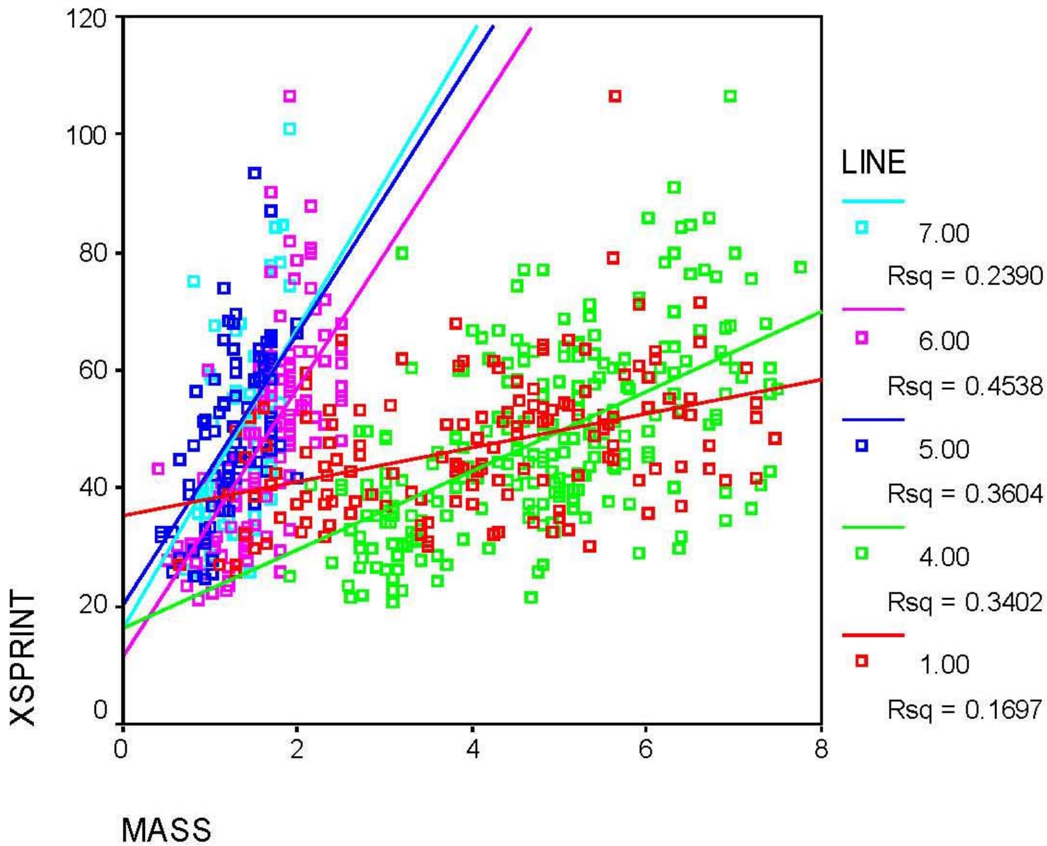

ARE WE NOT TROUT?
WE ARE DEVO!



Swanson
Hot Creek
Arlee
LS Means Body Mass (g)
Age (days post-ponding)
0
1
2
3
4
5
6
7
8
9
10
90
100
110
120
130
140
150
160
170
180
190



1.9
1.8
1.7
1.6
1.5
100
110
120
130
140
150
160
170
180
190
LS means log 10 (sprint speed (cm • s-1))
Age (days post-ponding)



120
100
80
60
40
20
0
XSPRINT
0
2
4
6
8
MASS
LINE
7.00
Rsq = 0.2390
6.00
Rsq = 0.4538
5.00
Rsq = 0.3604
4.00
Rsq = 0.3402
1.00
Rsq = 0.1697

Potential Project III: Development of Statistical Methods

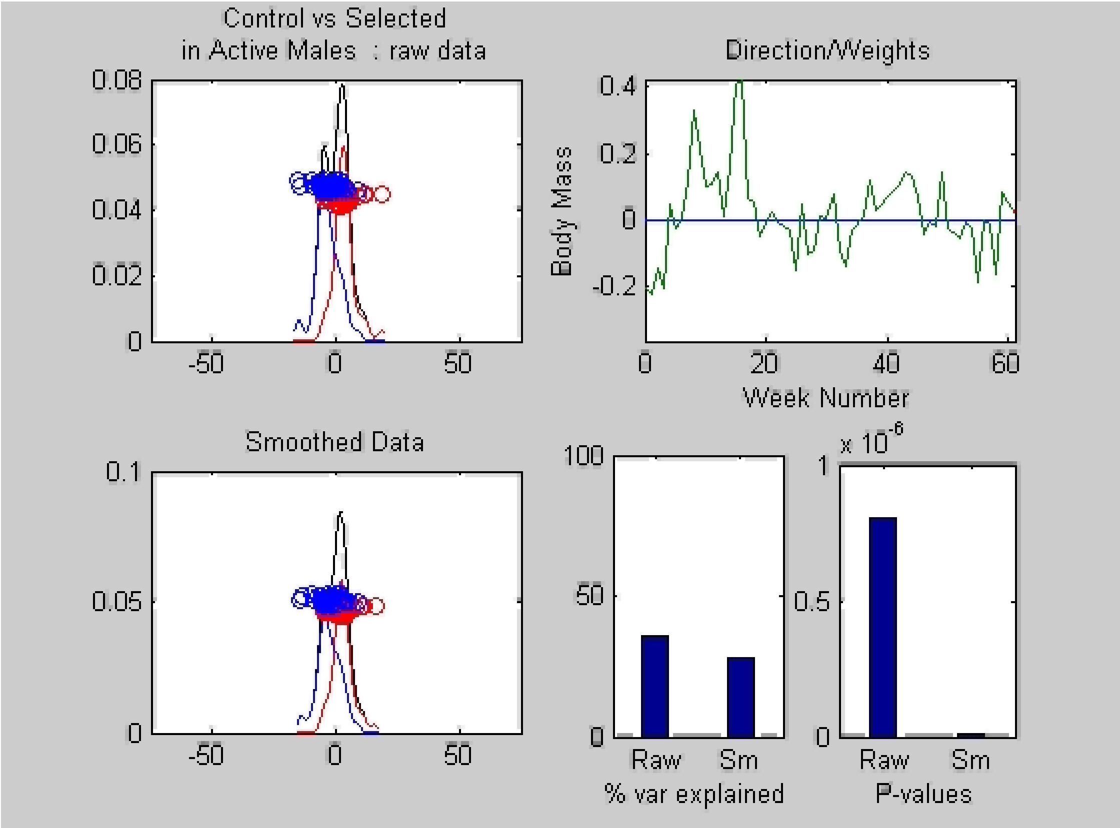
- Comparison of phenotypic trajectories
  - Mouse data
  - Trout data
  - Flour beetle data

- Comparison of genetic variance-covariance functions
- Estimate covariance between FV trait and landmark trait

DWD: Distance Weighted Discrimination

- DWD is a fancy discriminate analysis.
- Each mouse, input a vector of body masses of length p and the group membership (sel vs ctrl).
- The output is a vector of weights of length p, and scores for each mouse= weighted average of body mass with weights given in the vector. The vector is calculated to show the greatest difference between the two groups. Weights plotted: x axis = 1, 2, ..., p, y axis gives the p weights.

Comparing Body Mass Phenotypic Trajectories in Active Males



Potential Project IV: Oxidative Stress in Rainbow Trout

- Functional effects of hypervariability in SOD-1 enzyme in rainbow trout
- Genetic basis of variation in SOD-1 activity and oxidative damage
- Effects of oxidative stress in aquaculture

Significance of Variation in *SOD-1*

- SOD-1 is an anti-oxidant enzyme that helps prevent oxidative damage to DNA and cell membranes
- Variation in *SOD-1* associated with dozens of diseases (e.g., ALS, cancer)
- Rainbow trout highly variable at *SOD-1*
- Hatchery trout exposed to high levels of oxidative stress

SOD-1 Plan in Trout

- Do clones differ in SOD-1 enzyme activity? Prelim data say yes.
- Do clones differ in DNA and membrane damage:
  - At young ages
  - At old ages
  - **After oxygen stress treatment**
- Map QTLs for SOD-1 activity and oxidative damage