Life is change: how it differs from the rocks

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Gulf of Maine Research Institute
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“Biological existence is an iterative process between genes, individuals and the environment”

(Whitman and Agrawi, in Phenotypic Plasticity of Insects. 2009)

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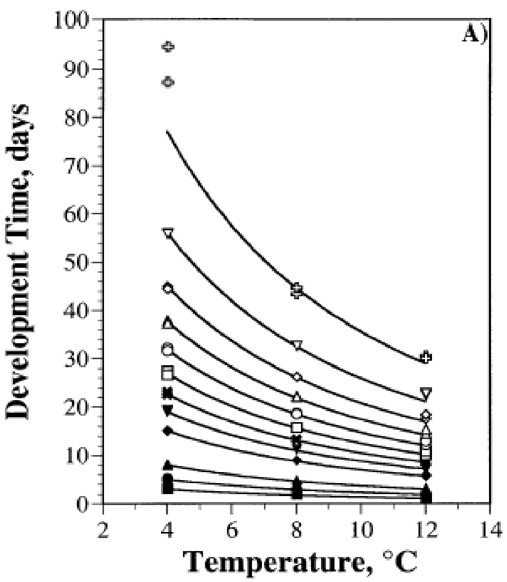
My perspective

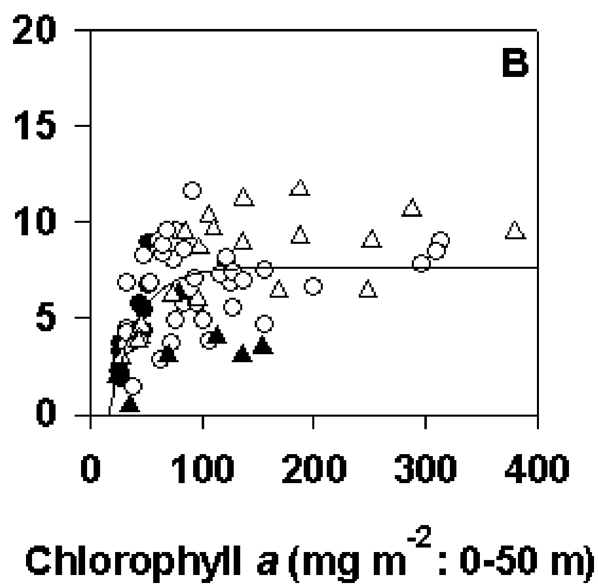
- GLOBEC: effects of change on animal populations
- Coupled physical biological modeling:

The local change in population abundance =
birth rate – mortality rate + immigration – emigration

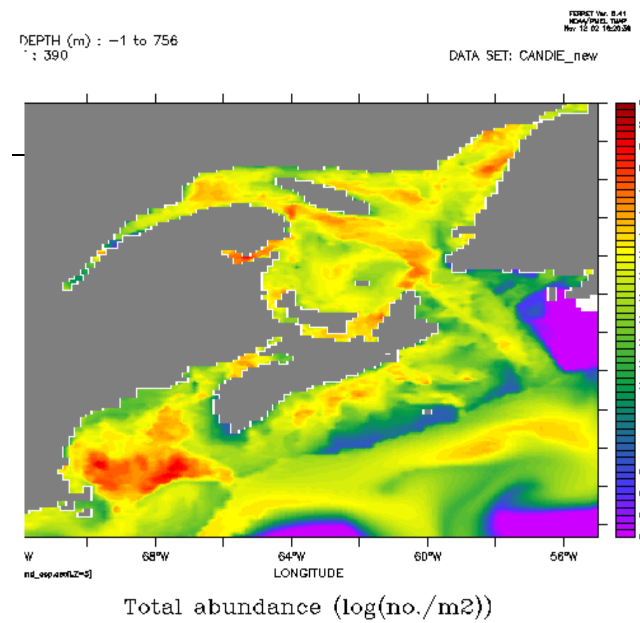
- Modeling life cycles using <u>mean</u> population vital rates



Campbell et al. 2001



Runge et al. 2006



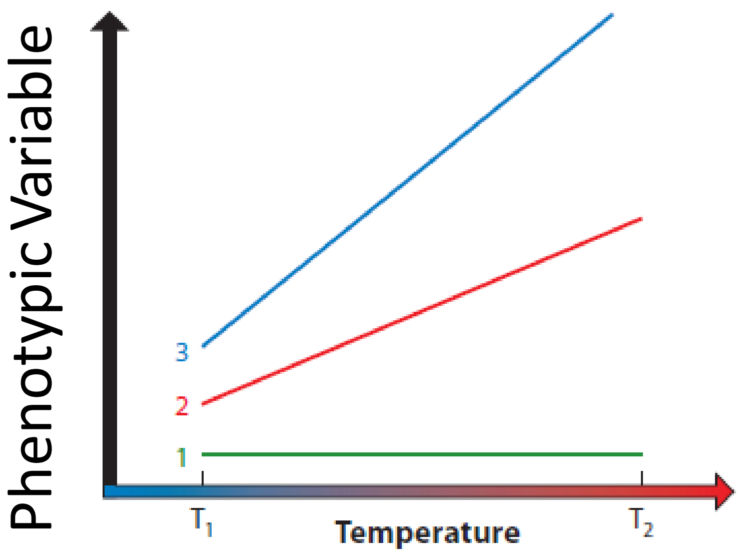
Zakardjian et al. 2003

What is the role of individual variability? To what extent can phenotypic plasticity and adaptation shift mean functional rates and life history traits, and what do we do about that?

1. What do I mean by individual variability?
2. How much can individual variation within a population change cohort production?
3. Can individual variability lead to rapid adaptation?
4. Does local adaptation result in differences in phenotypic plasticity among populations?
5. What is the potential for genetic and non-genetic (epigenetic) processes to drive shifts in life history traits including functional vital rate responses?
6. The way forward

1. Reaction norms: phenotypic plasticity

Phenotypic variable : an observable characteristic of an individual resulting from the interaction of its genotype with the environment, e.g. a life history trait or bioenergetic rate



Plasticity: The capacity of a single genotype to exhibit a range of phenotypes in response to variation in the environment: Ve

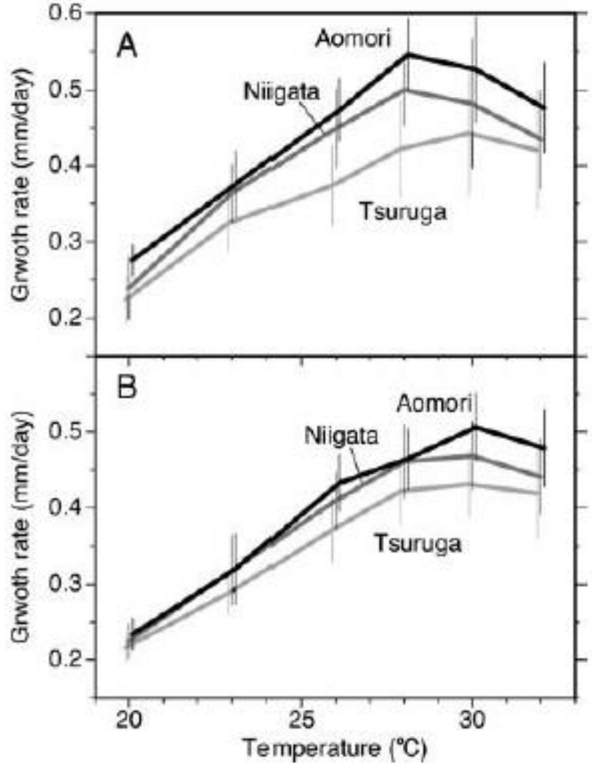
Variability in Plasticity across genotypes: difference in slope and intercept (Vgxe)

$$Vp = Vg + Ve + Vg_xe + error$$

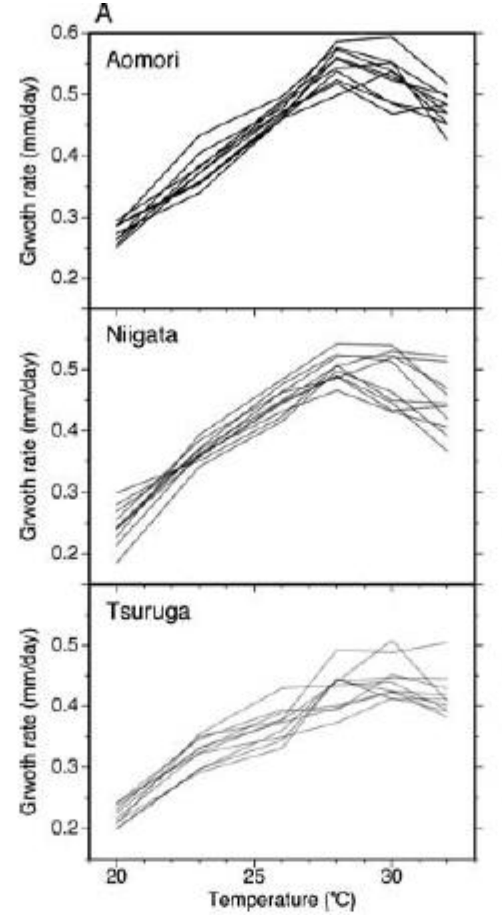
Dam, H. Evolutionary Adaptation of Marine Zooplankton to Climate Change. Annu. Rev. Mar. Sci. 2013. 5:349-70

There is variation within and between populations
A quantitative genetics experiment with a marine fish

Three populations of medaka fish with latitudinal gradient in the Sea of Japan



Population-average thermal reaction norms for growth rate on y-axis. Temperature on x-axis



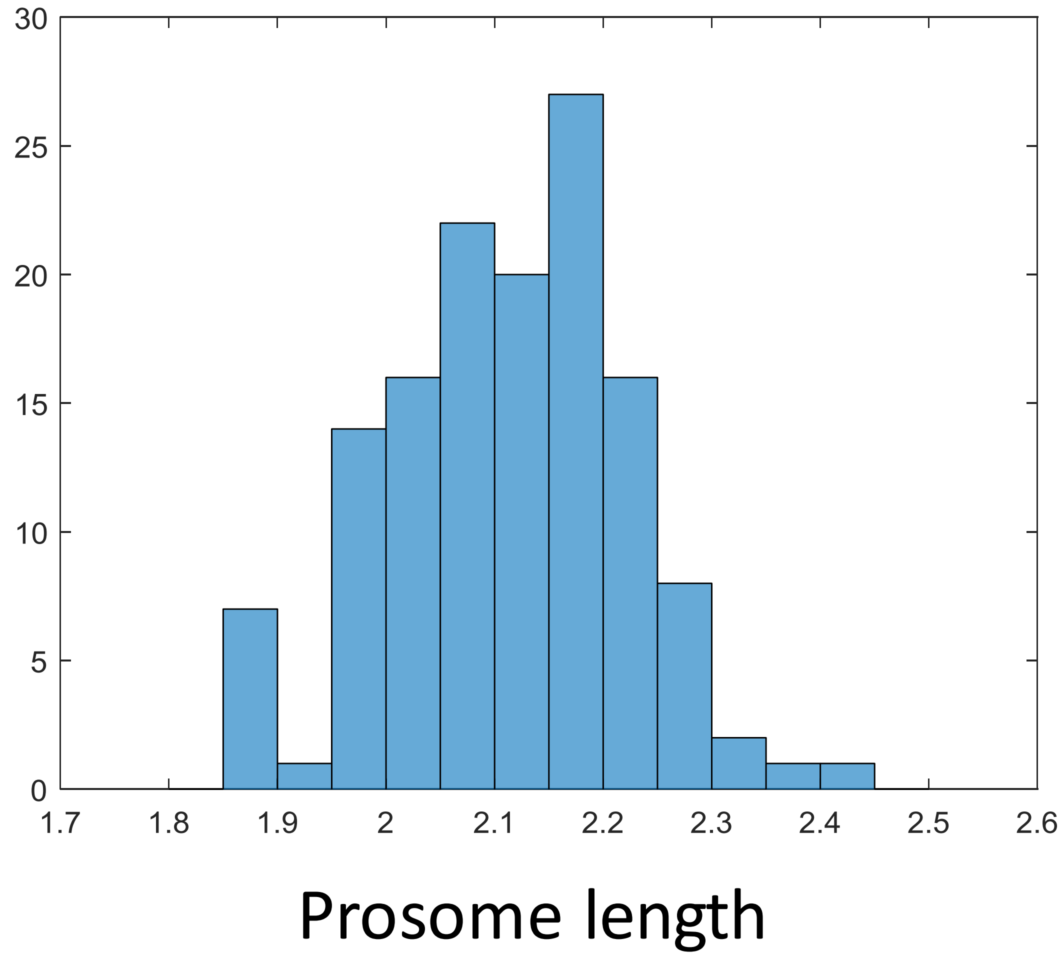
Family –average thermal reaction norms, showing within- population variability

Yamahira et al. 2007. Evolution. 61: 1577-1589

Individual variation in body size of stage CV *C. finmarchicus*

- Individuals cultured from egg to CV in lab under same temperature and superabundant food conditions

- Coefficient of variation = 7.1%

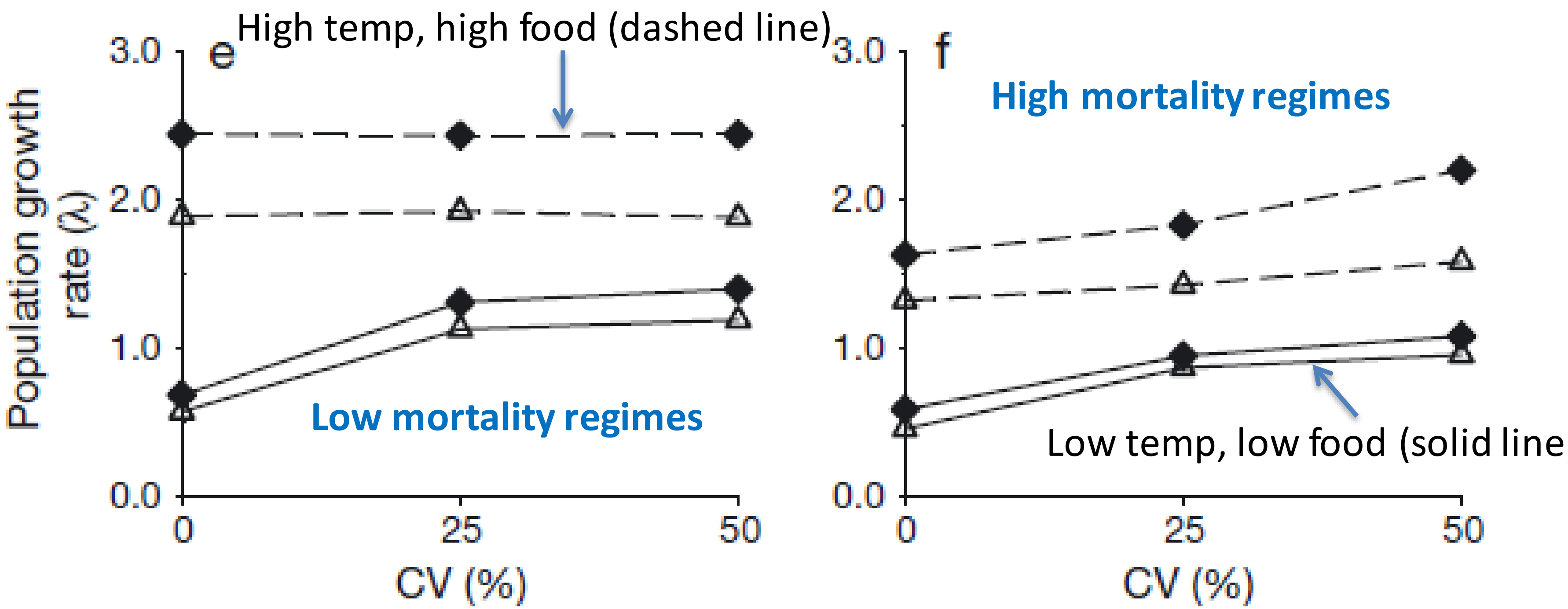


Data from study by Runge et al. 2016. ICES J. Mar. Sci. 73 (3): 937-950.

2. Effect of individual variability on population growth rate

- Study by C. Richmond, K. Rose and D. Breitburg: Mar. Ecol. Prog. Ser. 2013. 486: 59-78.
- Using an individual based model, they investigated effects of phenotypic variation in bioenergetic parameters on population growth rate of an *Acartia* species.
  - **0%, 25% and 50% Coefficient of Variation (CV)** about **4 parameters** depicting **feeding** functional response, **development time** and **metabolic rate**. Parameters allowed to vary freely simulating random or correlated genetic variation with respective CV constraint
  - Different mortality regimes
  - Two cases: High food, high temp. (optimal) and low food, low temp. (stress)
  - Each run with 10,000 individuals to start, covering the range of variability

Richmond et al. (2013): example results



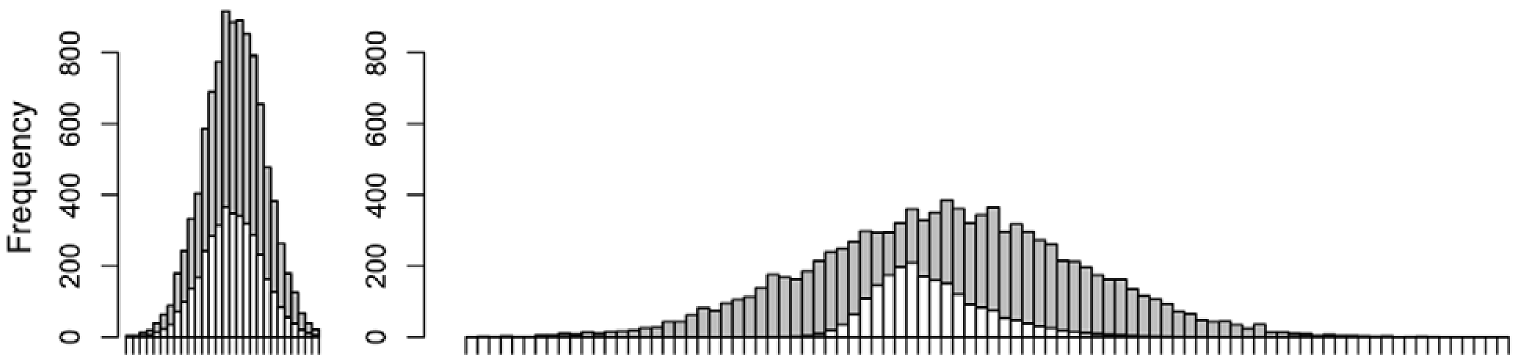
Under low mortality, optimal temperature and food, individual variability had little effect on population growth rate. However under high mortality and/or low temperature and low food, individual variability in bioenergetic parameters can have a substantial effect on pop. growth rate.

3. The extent of individual variability and can it lead to rapid adaptation?

- Phenotypic variation in a trait is different among species, for example larval mussel and sea urchin body size
- Full-factorial breeding design shows both additive genetic variation and maternal effects in low and high CO_2 treatments.
- Breeder's equation shows that sea urchin larvae had faster evolutionary rate because of greater phenotypic variability.

Mussel larvae

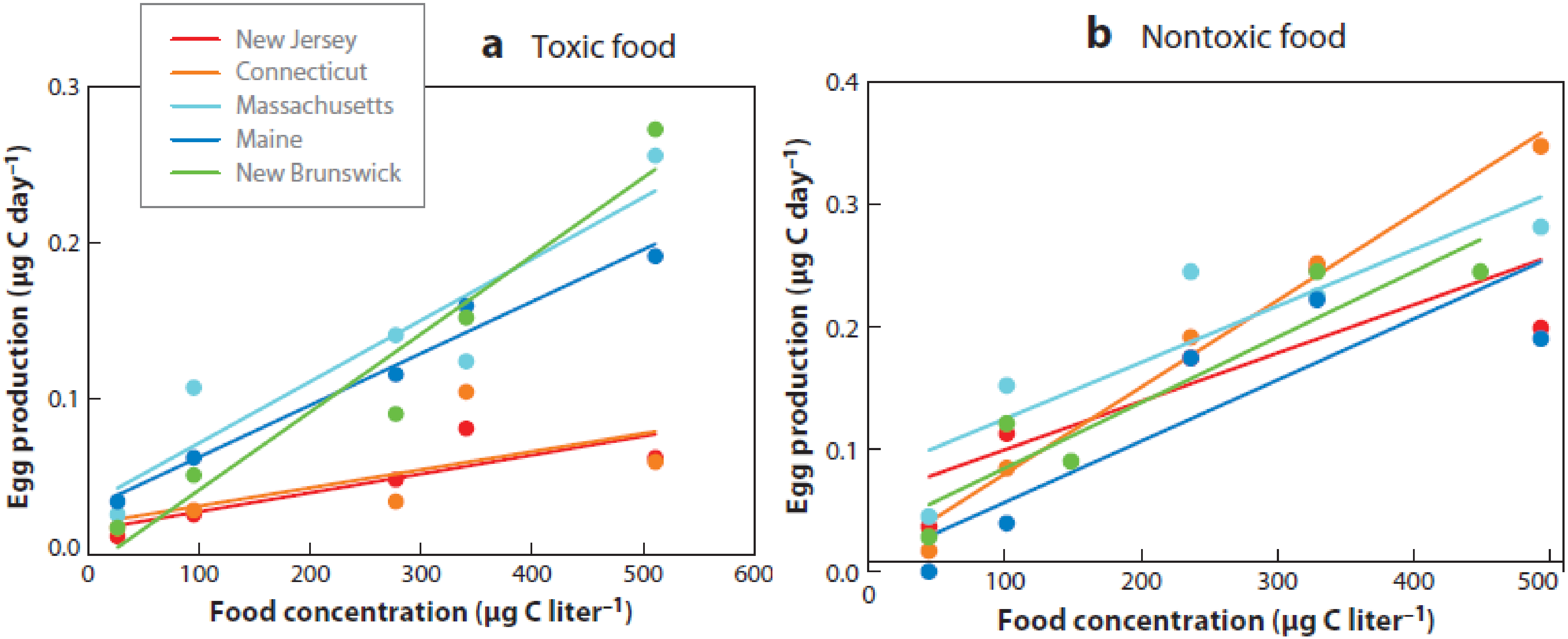
Sea urchin larvae



Index of body size

Sunday et al. 2011 PLoS One. 6(8): e22881

4. Local adaptation can result in differences in phenotypic plasticity among populations: *Acartia* adapts to toxic algae

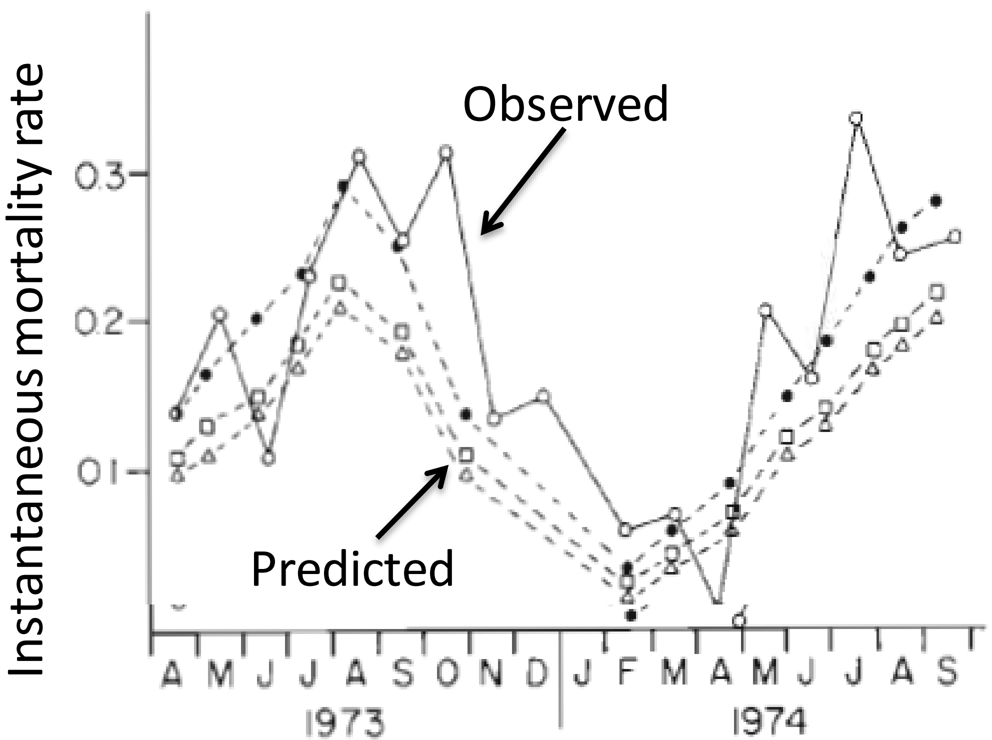


Populations in Massachusetts , Maine and New Brunswick, where toxic algal blooms occur, show local adaptation to toxic algae in reaction norms for egg production rate. Results from common garden experiment (multiple generations, same conditions).

Colin and Dam 2007. 6: 875-82.

5. The potential for genetic and non-genetic (epigenetic) driven shifts in life history traits and functional responses

- Interplay among genes, enzyme activities, hormonal controls and environment within individuals suggests that any bioenergetic rate or life history trait may change under selective pressure



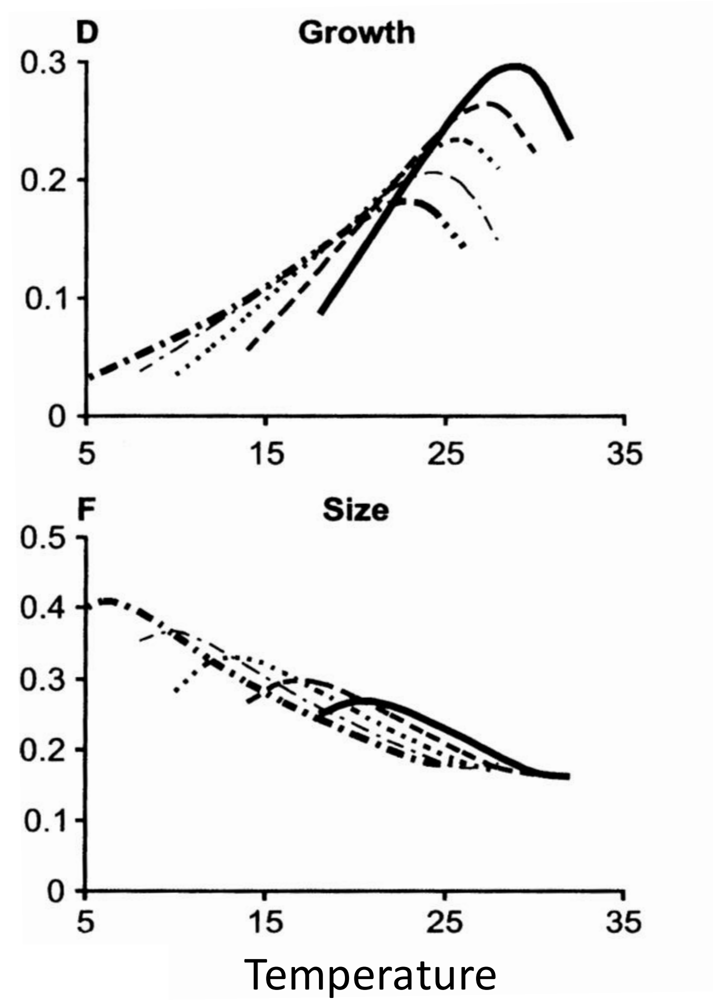
Myers and Runge 1983. MEPS 11:189-194

Example: development time-temperature relationship

- Mortality rates of *Acartia clausii* (Landry's data) predicted from growth and development rates using life history theory
- The only way this works is if the reactive norm for development is under adaptive control

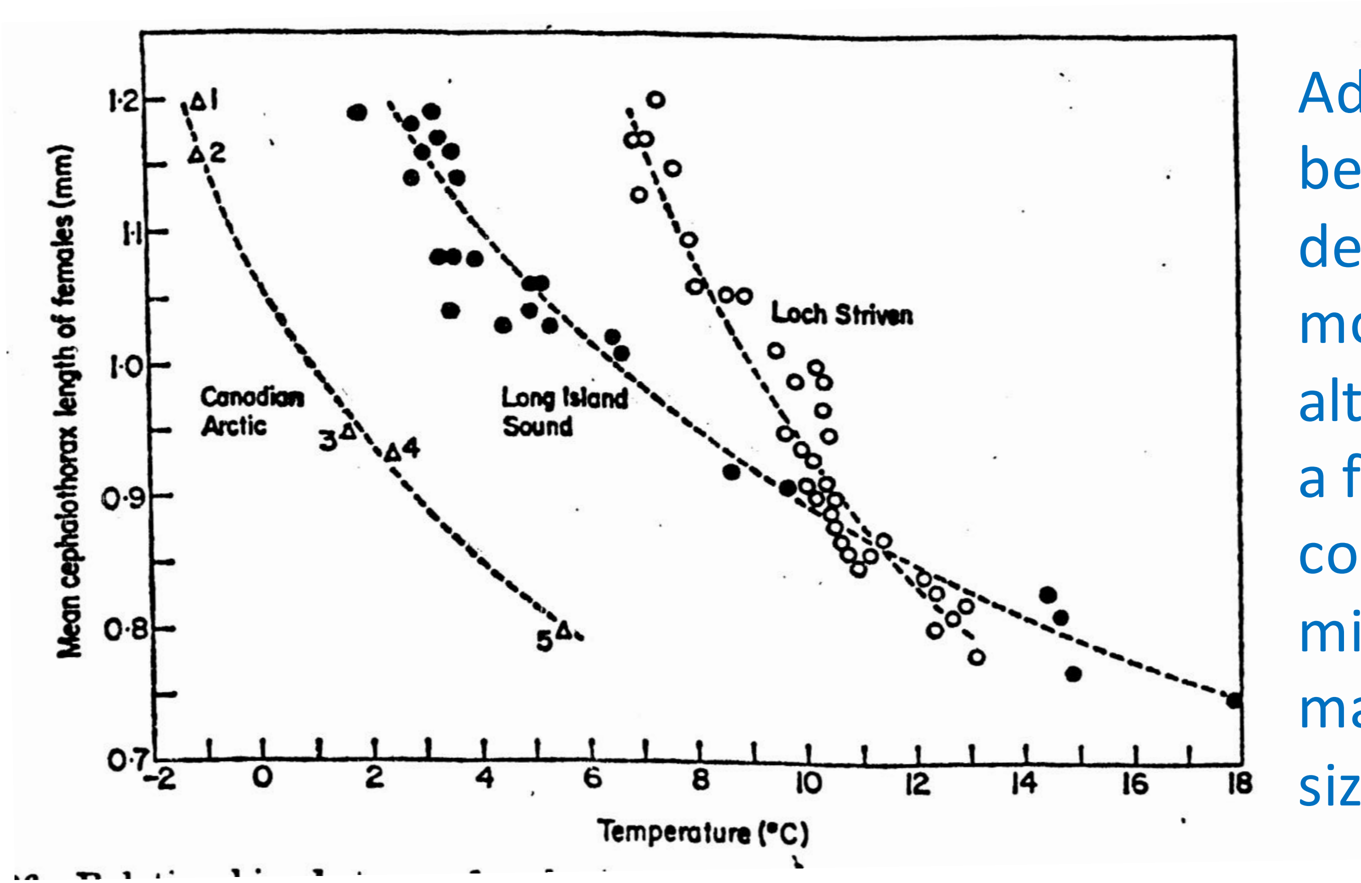
Temperature dependence of bioenergetic rates is likely not a thermodynamic constraint

- Rates are not necessarily constrained by an underlying temperature coefficient based on the Arrhenius activation energy and Boltzmann's constant (e.g. Metabolic Theory).
- Alternatively, the Sharpe-Schoolfield equation allows for genetic and phenotypic variation by adding parameters for control enzyme activity states.



de Jong and van der Have. 2009. p.523-588 in Whitman and Ananthakrishnan (eds) Phenotypic plasticity of insects.

Variation in body size of *Pseudocalanus* females



Adaptive interplay between growth, development and mortality rates, although perhaps a fundamental constraint on minimum and maximum body size?

Corkett and McLaren. 1979. Biology of *Pseudocalanus*. Adv.Mar. Biol. 15: 1-231.
Runge and Myers. 1986. Syllogeus. 58: 443-457.

6. The way forward: observations and experiments (see Sunday et al. 2014. TREE 29: 117-125)

- Observe individual phenotypic variability
  - Ideally under same environmental conditions
- Measure standing genetic diversity in response traits
  - Quantitative genetics to assess variation,heritability and trade-offs
  - Model organisms (*Acartia;* others in zooplankton*?)*
- Use genomics to identify standing genetic variation
  - Need to know associations between loci and traits
  - Relate genetic variability to fitness
- Conduct evolution experiments
  - Experimental natural selection over multiple generations
  - Artificial selection: experimenter selects individuals with different traits
- Investigate evidence of evolution in nature
  - Local adaptation across gradients
  - Transplant experiments

Models: predicting evolution and species and population responses to climate forcing

- Observe how well present models perform in predicting future: compare with observations: Does individual variability really make a difference?
  - In coupled p-b models, take approach of Richmond et al., using realistic CV about vital rates parameters
- Genetic algorithm approach to estimate parameters maximizing fitness under environmental stress. (Record et al. 2010. J. Mar. Systems. 82: 96-110).
  - Use these parameters in population dynamics models: do they make a difference?
- Models exploring evolution of traits

This highlights the importance of good observing programs- the need to know how life is changing

- Biological existence (the interplay between genes, individuals and environment) is so complex, our models and predictions can only give impressions of what is to come
- An appeal to support collection, data distribution and analysis of time series observing data at local, regional and global scales

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