The Speed of Adaptation
Why should we care about the speed of adaptation?

- Climate change: organisms must adapt or move.

Forest composition
current and projected ranges of beech trees in North America

Source: US Environmental Protection Agency (EPA), 1998.
Why should we care about the speed of adaptation?

- Climate change: organisms must adapt or move.
- **Habitat degradation: organisms must adapt.**

[Map of North America with human impact indicators]

http://maps.grida.no/go/graphic/human_impact_north_amERICA

Feral Goats on Santa Catalina Island

Catalina Island Mahogany
Why should we care about the speed of adaptation?

- Climate change: organisms must adapt or move.
- Habitat degradation: organisms must adapt.
- **Selective harvesting:** decline in freq. of selected traits.

Why should we care about the speed of adaptation?

- Climate change: organisms must adapt or move.
- Habitat degradation: organisms must adapt.
- **Selective harvesting:** decline in freq. of selected traits.

Why should we care about the speed of adaptation?

- Climate change: organisms must adapt or move.
- Habitat degradation: organisms must adapt.
- **Selective harvesting:** decline in freq. of selected traits.

Why should we care about the speed of adaptation?

- Climate change: organisms must adapt or move.
- Habitat degradation: organisms must adapt.
- **Selective harvesting:** decline in freq. of selected traits.

Why should we care about the speed of adaptation?

- Climate change: organisms must adapt or move.
- Habitat degradation: organisms must adapt.
- **Selective harvesting:** decline in freq. of selected traits.
Why should we care about the speed of adaptation?

- Climate change: organisms must adapt or move.
- Habitat degradation: organisms must adapt.
- Selective harvesting: decline in freq. of selected traits.
- Invasive species: rapid adaptation may facilitate spread.

**Microarray Comparisons:**
- 5% of genes show differential expression in weeds
- Genes that respond to stress or to abiotic and biotic stimulus are over-represented.
Why should we care about the speed of adaptation?

- Climate change: organisms must adapt or move.
- Habitat degradation: organisms must adapt or move.
- Selective harvesting: decline in freq. of selected traits.
- Invasive species: rapid adaptation may facilitate spread.
- Ex situ conservation: captive organisms may become domesticated.

Reduction in egg size in captive chinook salmon (Heath et al., 2003)
Why should we care about the speed of adaptation?

- Resistance evolution: pests may evolve resistance to antibiotics, herbicides, and pesticides.
What is the sustainable rate of adaptation?
What is the sustainable rate of adaptation (theory)?

Two approaches:

- Rate beneficial mutations become established

![Bar chart showing the number of generations between allelic substitutions for different rates of beneficial mutations per generation. The x-axis represents beneficial mutations per generation (population size x mutation rate; Nunney, 2003), and the y-axis represents generations between allelic substitutions. The chart compares monogenic and polygenic adaptation.]
What is the sustainable rate of adaptation (theory)?

Two approaches:

- Rate beneficial mutations become established
- Rate of adaptive phenotypic change

- Large populations: "a few percent" of a phenotypic standard deviation per generation (Lynch, 1996).

- Small populations: < 1% of a phenotypic standard deviation per generation (Burger and Lynch, 1995).
Why so slow?

- Depletion of beneficial genetic variation
- Cost of selection (Haldane, 1957)
  - The rate of adaptation is limited by the number of selective deaths that have to occur to replace one allele with another.
  - If selection is too strong, the population will go extinct.
  - Density-dependent “soft” selection provides a buffer against extinction.
Factors that affect speed of adaptation

- Large Populations: \( \uparrow \) beneficial mutations
- Large Number of Genes: \( \uparrow \) beneficial mutations
- High Rate of Recombination (in large populations)
- Strong Selection: \( \uparrow \) initial rate of adaptation
- Constant Selection

- Small Populations: \( \downarrow \) beneficial mutations, drift, inbreeding depression
- Fluctuating selection
- Low trait heritability

- Gene flow: increases variability, but reduces efficiency of selection
- Genetic correlations
The speed of adaptation (empirical data)

1) Rate of beneficial amino acid substitutions

- Total Map Length (R)
  - Generations between amino acid substitutions
  - 0
  - 10
  - 100
  - 1,000
  - 10,000
  - 100,000
  - 1,000,000

- Bacteria
- Drosophila
- Sunflowers
- Humans
2) Rate of adaptive phenotypic change
- per year = Darwins
- per generation = Haldanes

Haldane = one phenotypic standard deviation per generation
Time to first flowering in *Brassica rapa*. Haldanes = 0.039 for Dry site and 0.101 for Wet site (Franks et al., 2007).
Contemporary Rates of Phenotypic Change

Conclusions

• Short term rates can be very high
• Long term rates consistent with theory (< few % of a phenotypic standard deviation per generation)
• Decline in rates over time:
  - fluctuating selection
  - approach to new optima
  - depletion of genetic diversity

(Kinnison and Hendry, 2001)
Can Organisms Adapt Fast Enough to Cope with Predicted Climate Change?

Approach: Analyze phenotypic differences along latitudinal clines

- 133 clines
- Calculated phenotypic standard deviations per degree of latitude
Phenotypic Differences Along Latitudinal Clines

- **Animals**:
  - $N = 116$
  - Median $= 0.145$

- **Plants**:
  - $N = 17$
  - Median $= 0.131$

**Graph**

- Y-axis: Percent of Total
- X-axis: Phenotypic Standard Deviations per Degree of Latitude
Phenotypic Change Needed to Cope with Climate Change

- Climate projections necessitate range changes of 2.5 - 5.0 degrees in latitude per century.

- Minimum rate of adaptive phenotypic change of 0.36-0.72 phenotypic standard deviations per century.

- Caveats:
  - traits representative?
  - multiple traits
  - genetic correlations
  - genetic constraints
  - causes of range limits?
  - migration

90% of taxa

Small populations

Large populations

Generation time (years)
Conclusions

• The good: adaptation will ameliorate effects of climate change, at least for organisms with short generation times.

• The bad: adaptation will not provide much help for organisms with long generation times.

• The ugly: elephants may lose their tusks harvested fish will get smaller weeds will get weedier captive populations will be domesticated pathogens may win the arms race