Major processes that shape Brook Trout genetic structure

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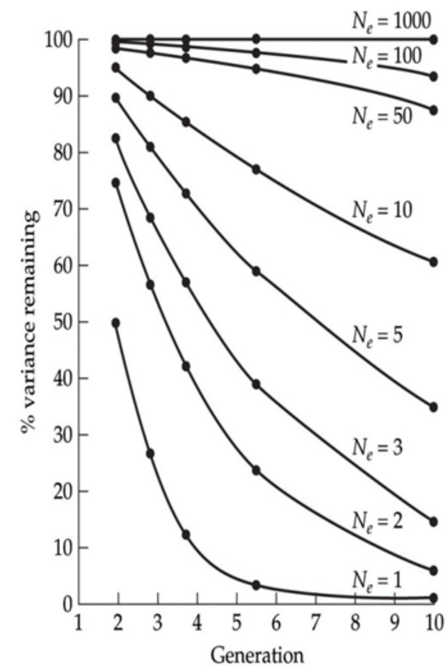
Brook trout and population genetic processes

- At all points in their natural history, Brook Trout would be subject to population genetics processes:
  - Mutation
  - Migration
  - Selection
  - Random genetic drift
  - Inbreeding
  - Coadaptation
- Let's consider these processes in the context of the natural (and un-natural) history of Brook Trout

Random genetic drift

- As they hung on in their glacial refugia, they would have been subject to random genetic drift…
- Random changes in allele frequency due to:
  - Founder effects
  - Sampling of breeders
  - Sampling of gametes
- Small populations lose genetic variation more rapidly than large populations.



Random genetic drift

- Recolonization of the deglaciated landscape likely involved rather few individuals, leading to founder effects.
  - These few founders could not have had all the genetic variation that was in the population from which they dispersed.

- Random drift is a non-selective force.
  - Populations tend to lose rare alleles.
  - Some of these lost alleles may have adaptive value.

Random genetic drift

- Concept of effective population size, N_e.
  - Relates to how much genetic variation a population can transmit, given sex ratio among breeders, variation in breeding success and occurrence of any demographic bottlenecks.

- Estimation of N_e :
  - N_e can be estimated directly if we know these demographic parameters.
  - N_e can be estimated indirectly from genotype frequencies

Population genetic processes

- Finite populations *lose* genetic variation – how can they *gain* new variation?
  - Mutation
  - Gene flow

Mutation

- = Spontaneous change in genetic coding
- The *ultimate* source of all genetic variation

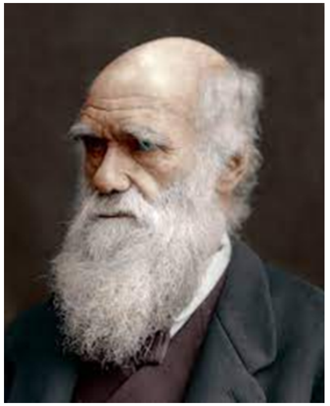
- Most mutations are *not* adaptive in the ecological or genetic contexts in which they arise
- Most mutations are *lost* to selection or drift
- Some mutations *are* adaptive and critical to evolutionary adaptation
- Note that large populations lose fewer mutations to drift, which aids in their persistence

Migration

- *Genetically effective* migration = movement from population of birth to another population, followed by reproduction
- Sometimes termed *gene flow*

- Links populations genetically
- Often contributes variation of adaptive value

Selection



- = Differential survival and reproductive success of different phenotypes and underlying genotypes
- *Critical* to adaptive evolution!
- The *rate* of adaptive evolution depends on:
  - selection intensity,
  - heritability of trait,
  - allele frequencies at fitness-related loci,
  - mode of selection…
- We don’t generally know which genes are acted upon by selection (though we are making progress on that!)

Coadaptation

- Sometimes, fitness depends upon expression of certain *combinations* of alleles at fitness-related loci, termed *coadapted gene complexes.*
- Combinations arise by chance, and are retained by natural selection, a process termed *coadaptation*.

- Coadaptation may be driven by:
  - Adaptation to local ecological conditions (more on that later)
  - Combinations of alleles across genome that simply work best together

Outbreeding depression

- When differentially coadapted populations interbreed, it can lead to *breakdown* of coadapted gene complexes, or *outbreeding depression*
  - E.g., following interbreeding of stocked with wild trout

Multiple processes can act simultaneously!

- These processes may be in dynamic tension within a population, e.g.:
  - Mutation and drift how many alleles may be maintained in a population
  - Selection and migration clinal variation of allele frequency
  - Selection and random drift loss of variation due to random drift can overwhelm natural selection and lead to loss of adaptive potential

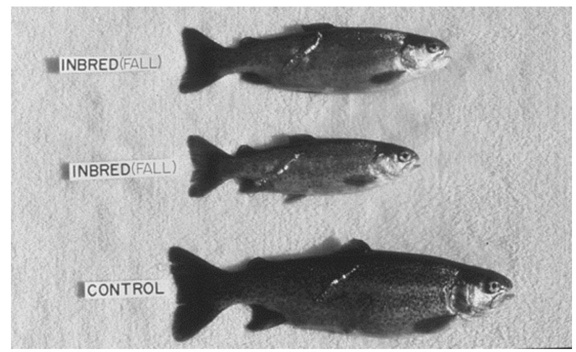
Processes may be mutually reinforcing!

- Small, isolated populations may lose variation by drift and also be subject to inbreeding
  - Case study: Florida panther showed kinked tails, cryptorchid males, low breeding success

  - Introduction of new genetic material increased genetic variation, led to outcrossing, reversed these problems
  - Termed *genetic rescue*

Inbreeding

- = Mating among relatives
- Can lead to loss of fitness = *inbreeding depression,* affecting:
  - Survival
  - Growth
  - Reproductive traits
  - Disease resistance
  - Etc.



- Can be calculated for individuals if the pedigree is known
- Can be estimated for populations from genotype frequencies at genetic marker loci

Inbreeding

- Over deep time, an isolated population can adapt to inbreeding by purging maladaptive alleles.

Owens pupfish

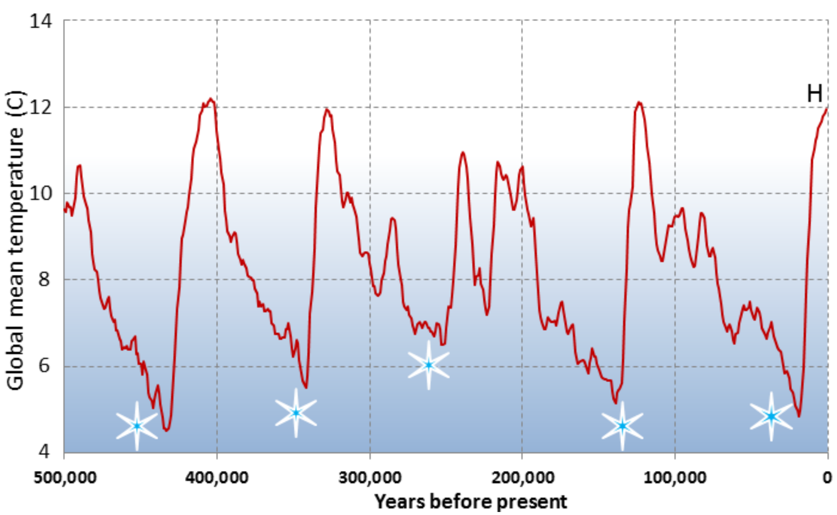
- Recently isolated populations, however, would be expected to suffer from inbreeding depression.

Natural history of Brook Trout

Population genetic processes are superimposed on deeper patterning from natural history

Natural history of Brook Trout

- North America has been subject to a cycle of glaciation and deglaciation, affecting all life

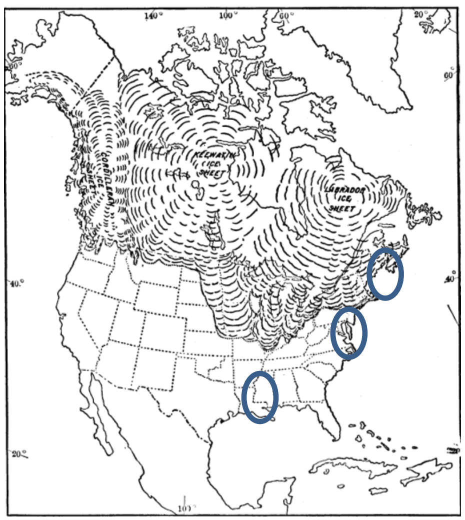


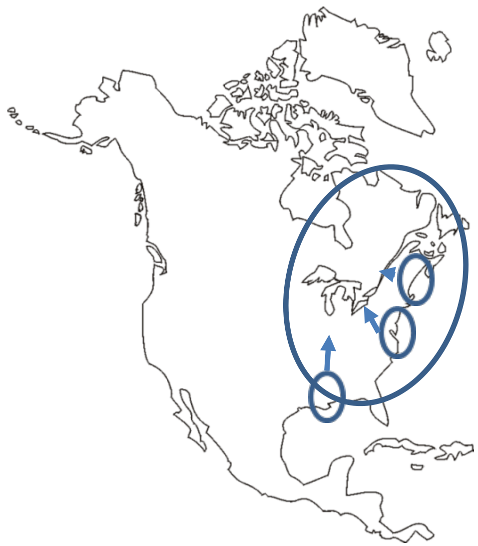
Historical temperature variation and ice ages

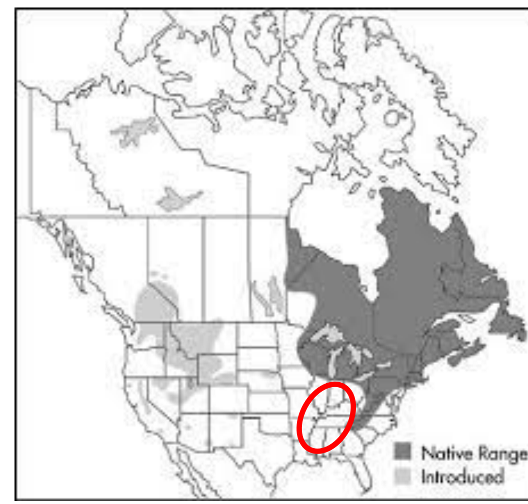
North America 18,000 YBP

Natural history of Brook Trout

- Glaciation contraction of distribution into glacial refugia
- Deglaciation recolonization of the landscape



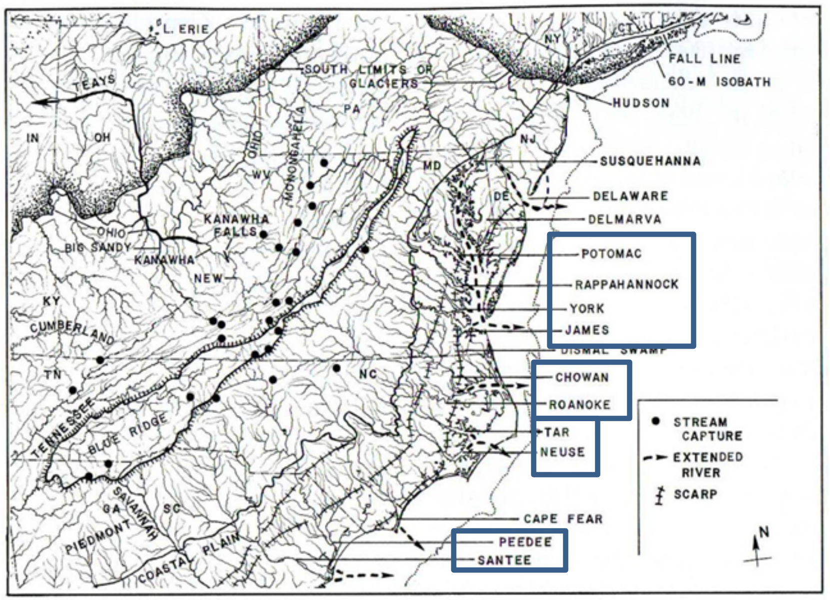




- This dynamic has shaped the deepest patterning of the population genetic structure of brook trout

Post-glacial dispersal of Brook Trout

- How did Brook Trout cross drainage divides?
- Stream capture:
    - The dots show locations of over twenty known stream-capture events in our region
- Local inland flooding
- Coastal dispersal:
    - Brook trout are marine dispersers
    - Some now-separate rivers were joined during the Pleistocene:
        - All rivers entering Chesapeake Bay
        - Roanoke and Chowan rivers
        - Tar and Neuse rivers
        - Pee Dee and Santee rivers



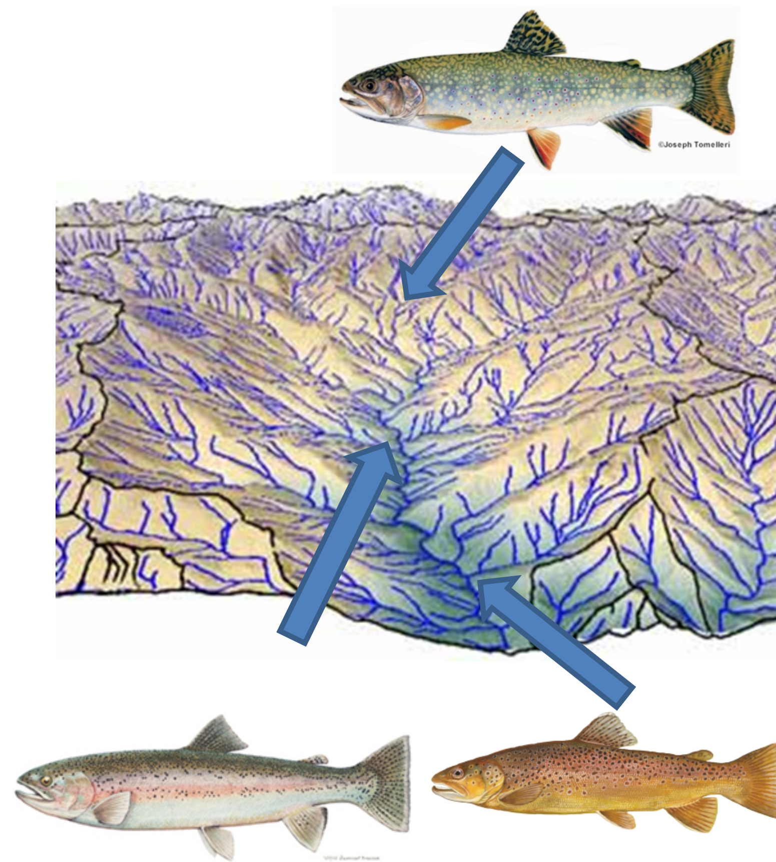
Population genetic patterning

- “Deep” patterning comes from natural historical processes…
- …Onto which recent population genetic processes add their signatures…

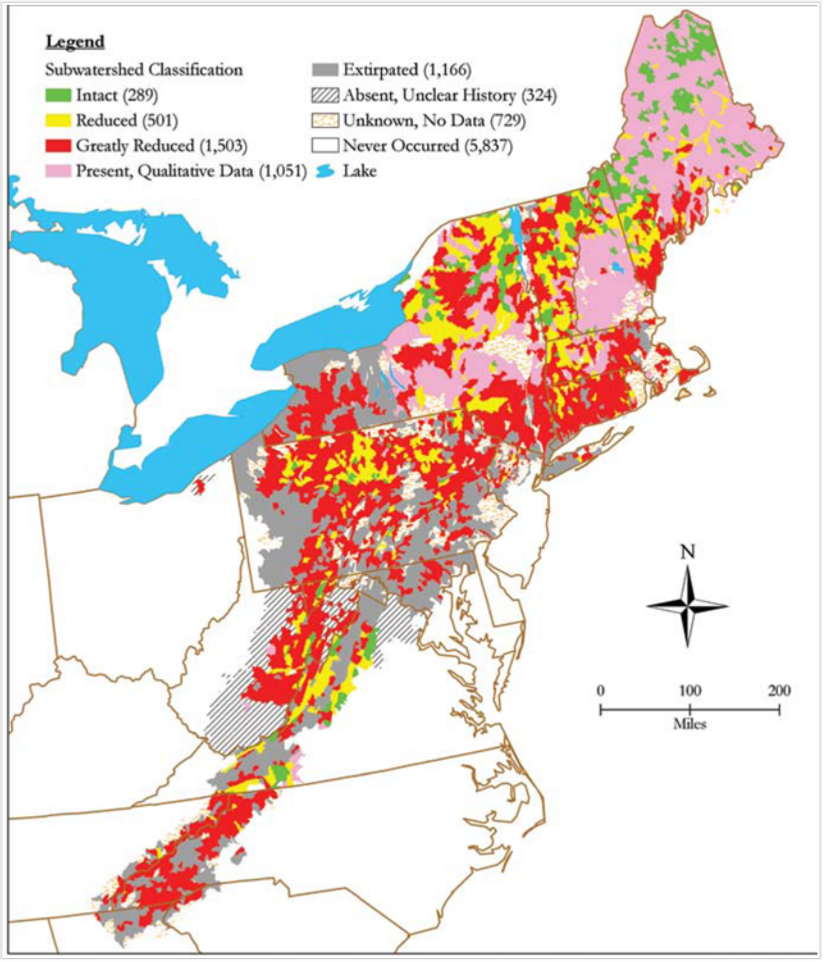
- …And onto which anthropogenic impacts add their own signatures…

Un-natural history of Brook Trout

- European colonization of North America, population growth, overexploitation, habitat alteration, introduction of non-native species ⍰
  - fragmentation of habitat
  - loss of populations
  - isolation of populations



The distribution and genetic structure of Brook Trout have been impacted by these anthropogenic effects



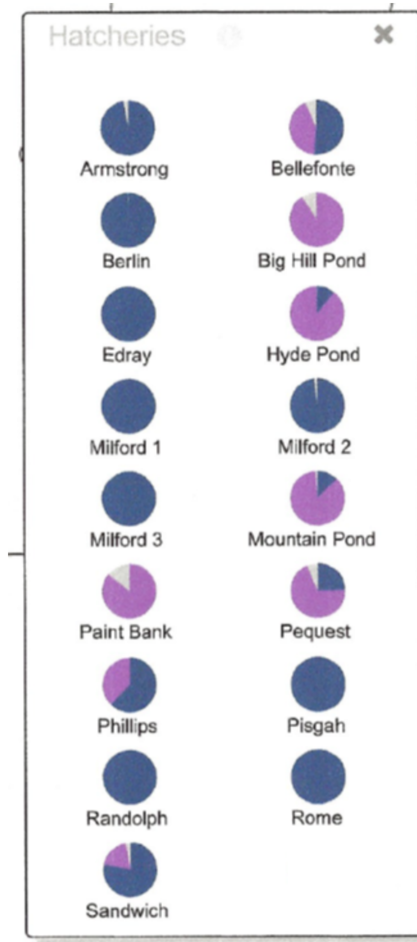
- EBTJV Brook Trout extirpated from 21% of historic range
- Many local populations now isolated
  - Heightened drift and inbreeding
  - Smaller populations have less capacity for evolutionary adaptation.
- And there's another issue…

Stocking of Brook Trout

- To reverse the decline of the species, wide-spread stocking began in the mid-1800s

Hatchery strains of Brook Trout

- What is a "strain"?
  - *Not* a population genetic concept
  - It's a *breeder's* concept – a population that has been held in culture for at least three generations that has predictable performance under specified conditions.
  - There's a Brook Trout strain registry (H. Kincaid, 1990s) laying out founding resources, breeding history, and key performance characters
  - Strains often transferred between hatcheries, crossed, …
- Most Brook Trout strains are from the Northeast
- Before genetic differentiation was recognized, brook trout of a few narrow origins were widely stocked…



Origins of Brook Trout hatchery strains, $K = 10$

Impacts of hatchery Brook Trout

- Ecological impacts from competition?
- Interbreeding?
  - Effects can range from eventual loss of hatchery background, to stable introgression, to replacement of native populations.
  - Insights from recent data…

- Genetic impacts from introgression?
  - Loss of local adaptation?
  - Results from Rainbow Trout suggest that this is plausible:
    - Araki et al. 2007. Genetic effects of captive breeding cause a rapid, cumulative fitness decline in the wild. Science, 318:100–103.
    - Araki et al. 2009. Carry-over effect of captive breeding reduces reproductive fitness of wild-born descendants in the wild. Biol. Lett., 5:621–624.
  - Could introgression compromise the viability of native populations?

A view to the future

- From a genetic viewpoint, *what are our goals for management of Brook Trout?*
  - Maintain short-term viability
  - Maintain long-term adaptive potential
    - Especially in the face of anthropogenic impacts, including climate change
    - Note that mutation is just too slow to replace variation lost to drift in small, isolated populations