Application of conservation genetic principles to salmon recovery

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Today's talk

- Background population genetic principles
- Address some questions regarding application of genetic principles to recovery:
  - Source populations and preserving genetic integrity
  - Preservation of existing stocks and demographic issues
  - Effective population size of source populations
  - Using hatchery (domesticated?) stocks for recovery
  - Risks of inbreeding and outbreeding
  - Expectations of time needed for natural selection to create a naturalized stock*

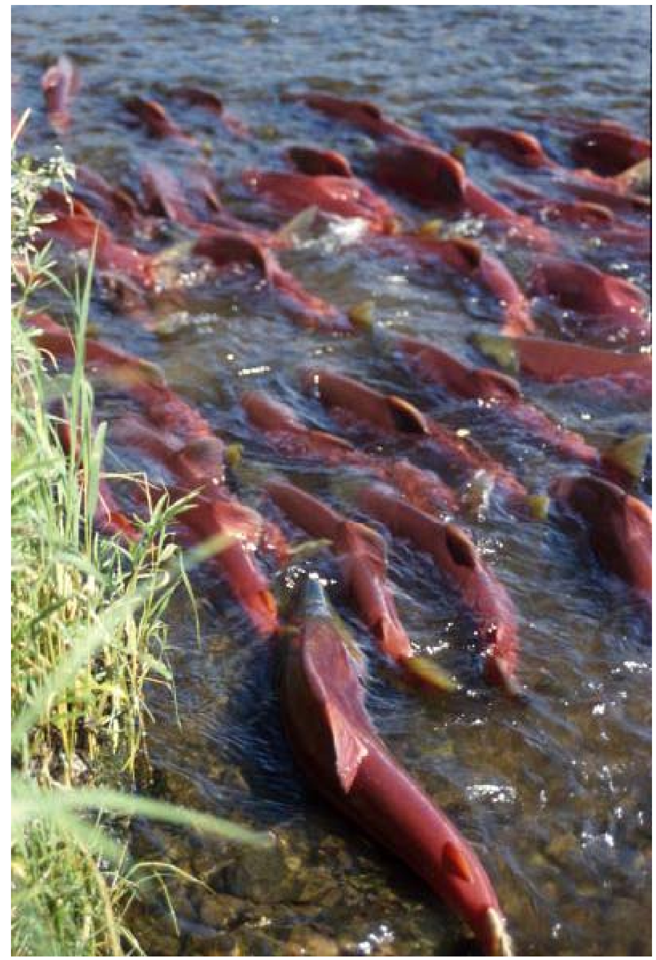
Genetics is of fundamental importance to the long-term conservation of species

- Substantial genetic diversity, both within and between populations is a characteristic of healthy species
- Genetic diversity represents the basis for adaptive evolution, and is evidence of adaptation to local conditions by individual populations.
- Loss of this diversity, through extirpation of local populations, fragmentation of previously inter-connected populations, and careless selection of breeding stock for hatcheries represent serious threats to long-term species survival

(NRC 1996)

Population genetics (def.)

- A field of biology that studies the genetic composition of biological populations, and the changes in genetic composition that result from the operation of various factors, including natural selection.



The goal of conservation:

- *Keep the building blocks of evolution to increase the probability of recovery,*
- *Preserve ancestral/historical lineages in historical patterns, amplifying the "right fish" (genotypes),*
- *Attain long-term population viability.*

The "Extinction Vortex"

(Gilpin & Soule´ 1986)

- A situation in which genetic traits and environmental conditions combine to result in gradual extinction
- Fragmentation, metapopulation degradation, low effective population size, loss of diversity

http://conservationbytes.com/2008/08/25/the-extinction-vortex

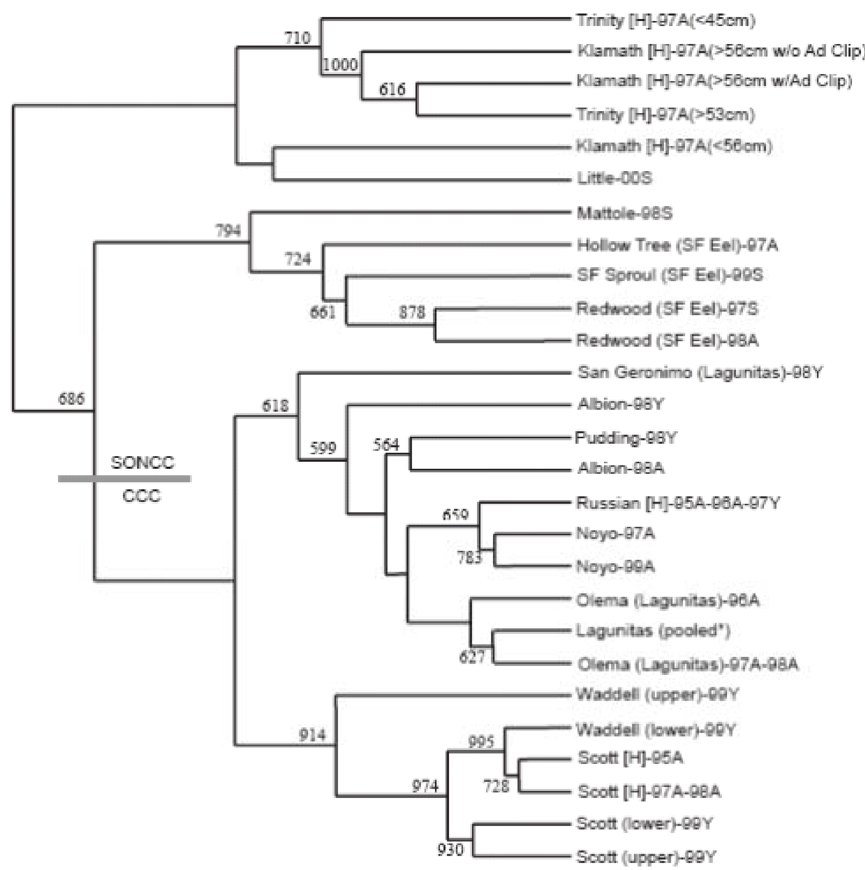
Genetic diversity: pattern and amount

- Geographic population structure (*among* population diversity)
- Level of background diversity you have to work with (*within* population diversity)

Determine relationships among stocks and how much diversity you have to work with

Patterns of genetic diversity distribution

- Homing results in local populations that breed among themselves more than with other groups
- Selection, genetic drift, founder effects, and low migration rates result in “geographically structurec populations”
  - Generally, distant populations are more different from one another than neighboring populations
  - Differentiation often cited as evidence of “local adaptation”
- Local populations are best for recovery efforts



NOAA Tech. Memo, NMFS-SWFSC-382 Figure 2.1

Strategy for conservation of genetic resources depends on distribution of genetic diversity:

- Loss of a single population in an *undifferentiated species* could be inconsequential
- Loss of a single population in a *highly differentiated species* could represent loss of a substantial portion of overall genetic resources

Genetically distinct local populations are characteristic of salmon species, so retaining local stocks can be important

Amount of diversity you have to work with depends on historical and present states of :

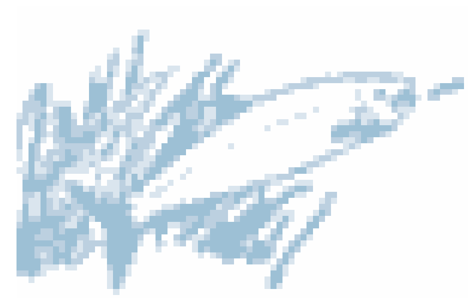
- Abundance (population size)
- Bottlenecks
- Migration and metapopulation dynamics

Population size is one of the most important determinants of the ability of a population to retain genetic diversity

- Small populations are more likely to have high levels of random genetic change
- In small populations, reduced genetic diversity can result from action of
  - genetic drift
  - Inbreeding
  - Founder effects
  - Demographic bottlenecks

Effective population size (N_e)

- Used to express information about the expected rates of random genetic change due to inbreeding and genetic drift.
- The size of a hypothetical population that has the same amount of random change (due to drift or inbreeding) as the actual population experiences.



Effective Population Size Example

A population of N=100 individuals with an N_e=10 has the same amount of inbreeding/drift as we would expect of a population with 10 individuals.

This population is acting like a much smaller one genetically.

This population is also losing genetic diversity at a higher rate than we would expect if $N=N_e$.

Factors that influence N_e

- Sex Ratio
- Change in population size over time
- Variation in reproductive success (family size)

N_e is generally less than N_c

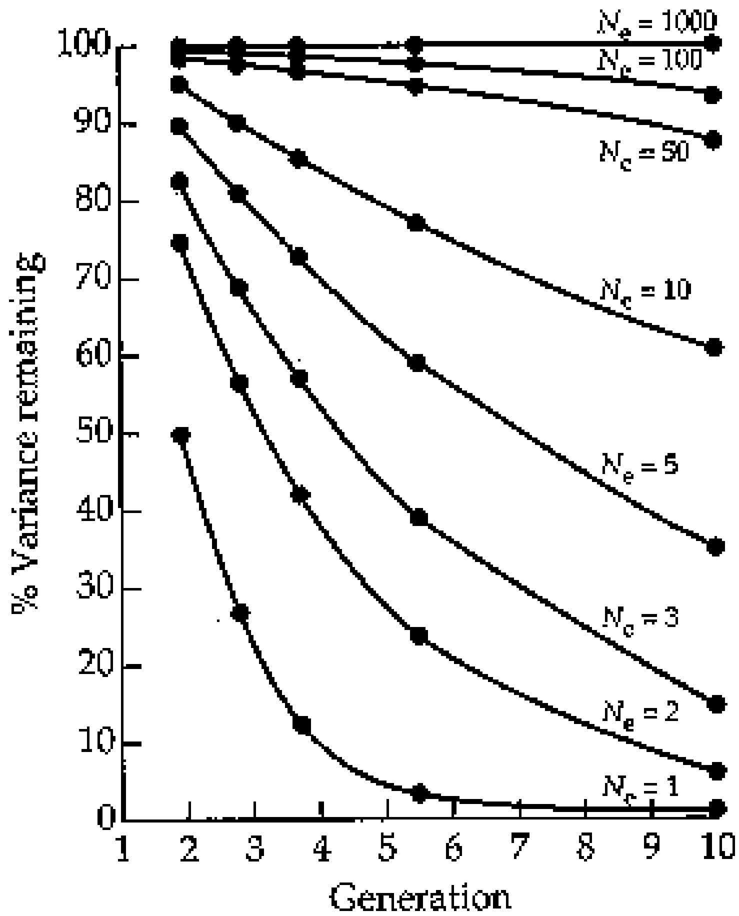


Figure 6.7 Average percentage of genetic variance remaining over 10 generations in a theoretical, idealized population at various genetically effective population sizes (N_e). Variation is lost randomly through genetic drift.

- Larger populations (higher N_e) retain more genetic variation than small ones over time
- Very small populations lose diversity much faster than large ones
- So, if you want to retain diversity, start with larger populations *(a problem with conservation programs)*

50-500-5,000 Rule

- Effective population size should not be allowed to drop below—
  - ***50 per generation*** in the short term to prevent inbreeding depression
  - ***500 per generation*** for avoidance of long-term loss of genetic variation (through genetic drift)
  - ***5,000 per generation*** to maintain potentially adaptive genetic variation

What does this mean?

- A population of 50 returning adults per generation may be judged minimally adequate to avoid the immediate effects of inbreeding.

  BUT, we would be less confident that a population of that size would be big enough to retain genetic/adaptive variation over the long run.

N_e for source populations

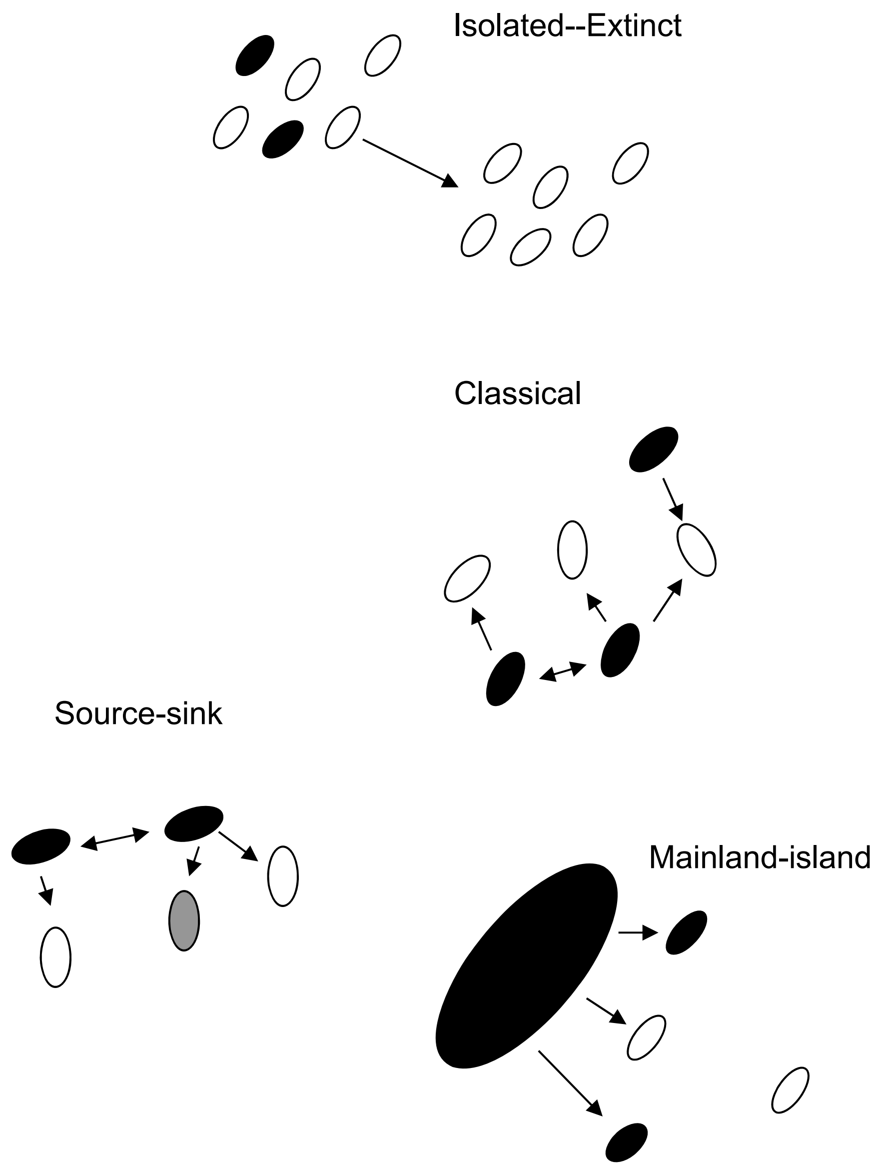
- Sources for artificial propagation (conservation) programs should have as high an N_e as possible without affecting viability of the donor stock
  - Producing large numbers of hatchery fish from small numbers of parents can *reduce* the overall N_e of the HO+NO population, even if total population size (HO+NO) is larger (Ryman-Laikre Effect)

Fragmented distribution and metapopulation dynamics

- Metapopulation: A set of populations (or subpopulations) connected by some amount of migration among them
- Declining species frequently have fragmented distributions with impaired metapopulation dynamics
  - i.e., once connected populations become isolated and fewer migrants move between them

Dispersal pattern

- No dispersal– isolation, high probability of extinction
- Low/intermediate dispersal– Classical (Levins) metapopulation
- Frequent dispersal– patchy distribution
  - Source-sink metapopulation
  - Mainland-island metapopulation



Metapopulation persistence depends critically on ***colonization rate*** which in salmonids is tied to ***straying***

- Straying in salmonids is known to decrease with distance from the natal stream. Therefore, fragmentation and isolation decrease the probability that a distant source can provide strays that will repopulate a locally extinct stream.
- Coho salmon have an (almost) obligate 3 year life cycle. Therefore, natural reestablishment of an extinct brood year depends almost entirely on strays from other places.

Genetics of source populations and preserving genetic integrity

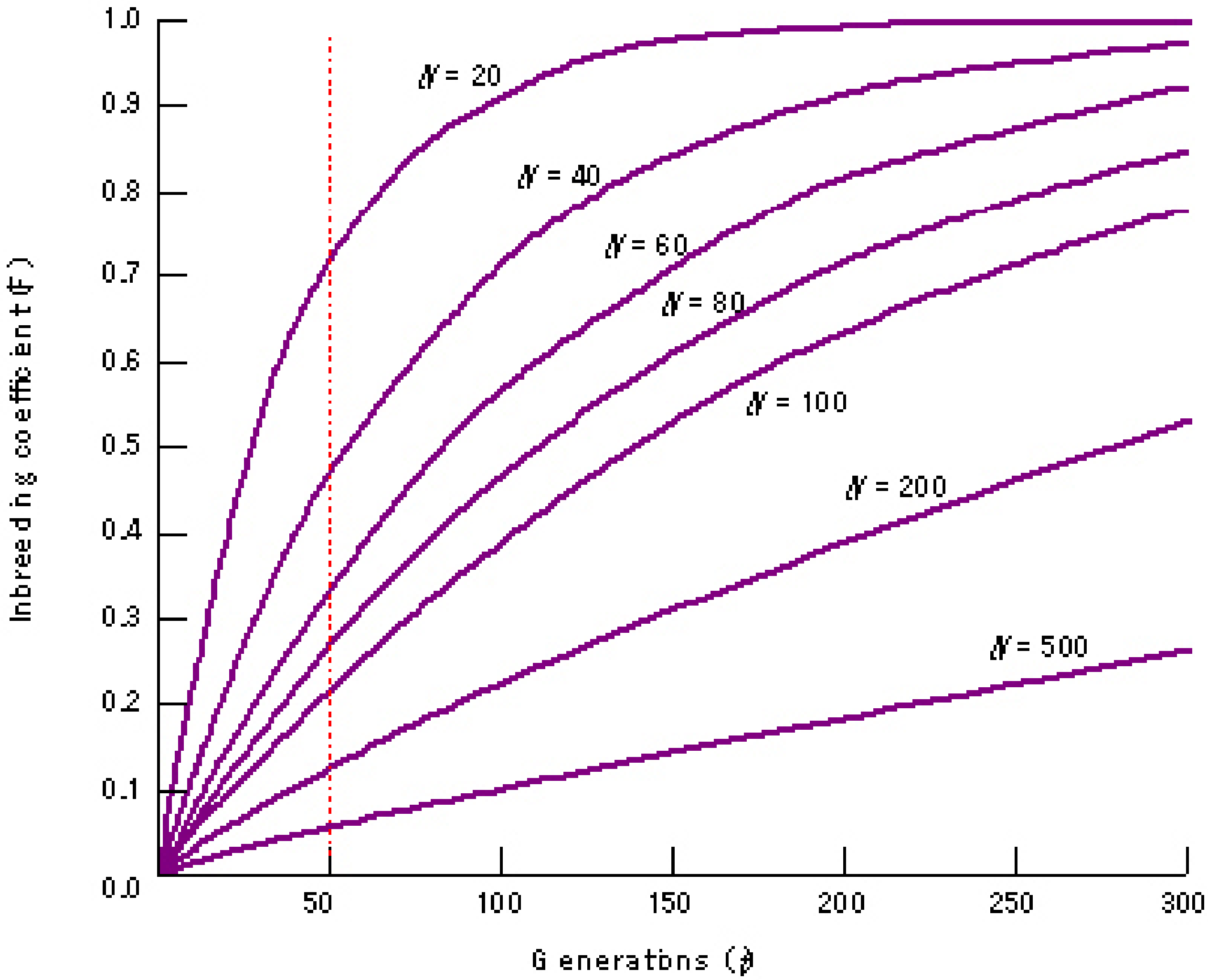
- Is there anything left to preserve?
  - A very small and isolated population can be “functionally extinct” before all of them are gone
  - A very small population over all brood years may not retain any significant population level diversity
  - A very small population may not retain adaptive features, and likely has little adaptive potential
  - Amplification of small numbers of individuals can cause more harm than good
- Potential for natural migration from a nearby genetically and ecologically similar stock?
- Potential for natural stock improvement with artificial propagation supplementation over time (phased approach to recovery)

Balancing genetic integrity of target stock while increasing population size (reducing demographic risk)

- Careful genetic stock management– minimize inbreeding and drift (genetically informed spawning)
- Maximize N_e in hatchery and N_e/N_b ratio (≥ 1)
- Phased approach: gradually increase NO spawners, NO incorporation in hatchery, realistic interim NOS targets

Inbreeding

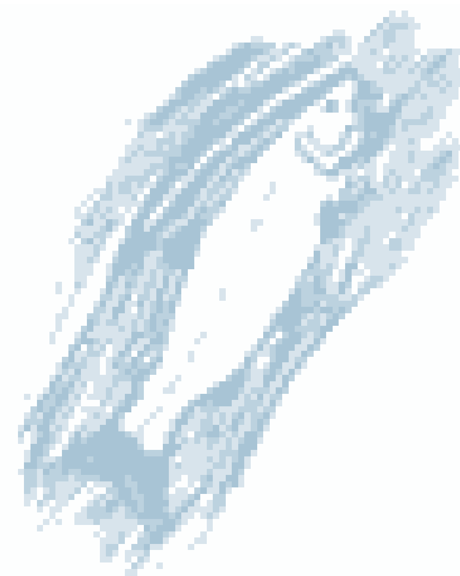
- ***Inbreeding*** occurs when close relatives mate
- Associated with low abundance and low migration from other populations
- In virtually all cases, inbreeding causes a shift in mean phenotypes in a direction that causes a reduction in fitness. This is called ***inbreeding depression***
- For small populations, should assume that inbreeding is a problem



Inbreeding is much more of a problem in small populations than in large ones

Outbreeding depression -

- A reduction in fitness that results from mating among unrelated or distantly related individuals
  - Loss of local adaptation; or
  - Breakup of favorable gene combinations that work together to confer fitness
- Distance may be a factor, but not completely reliable



Outbreeding enhancement

- "Hybrid vigor"– mixing an inbred stock with a different stock masks deleterious recessives in first generation offspring.
  - This may or may not persist through subsequent generations.
  - In later generations, "hybrid breakdown" can occur through outbreeding depression. If this occurs, it can get worse with each generation.

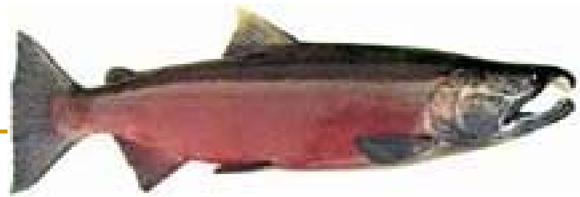
One of the main questions in conservation biology–

Whether to keep genotypes of parental populations intact, or whether to introduce different genotypes from other populations to deal with the cumulative effects of inbreeding.

- "Genetic Rescue"— controversial
- If imperiled population is very small and has been small for a long time, then existing genotypes may have very limited recovery potential.

Risks of inbreeding and outbreeding

- When population is small, should assume that inbreeding is a significant problem
- Artificial propagation that eliminates mate choice exacerbates inbreeding potential
  - In nature, mechanisms for avoidance of mating with close relatives
- Inbreeding can be minimized by careful genetic management of spawning
- Even if you can minimize inbreeding of broodstock, if background diversity is low then inbreeding will still be an issue



Risks of inbreeding and outbreeding (continued)

- Although using native local stock is preferred, if stock has experienced bottlenecks, population size is low, and potential for natural migration is low, outbreeding with a nearby genetically similar stock may be considered.
  - Potential for loss of diversity through outbreeding depression should be weighed against that for inbreeding
  - Potential for outbreeding enhancement should be weighed against that for inbreeding- and outbreeding depression

Risks of hatchery supplementation: Fitness and productivity loss

- Inbreeding
- Outbreeding
- Dometication selection
  - Selection in Captivity (adaptation to hatchery)
  - Relaxation of Selection
- Elimination of mate choice

Domestication selection -

- Natural selection that operates on a population during artificial propagation to produce adaptations to the culture environment (Doyle 1983).
- Domestication selection typically requires more than one complete life cycle to produce a permanent phenotypic response.
- Domestication selection tends to eliminate fish that cannot adapt well to the captive environment, which may include some fish that are well-adapted to their natural environment.

Risks and benefits of using hatchery stocks for recovery

- Domestication selection (and other genetic mechanisms) may reduce productivity of NOS
  - Consider whether NOS may have a better chance of recovery without influence of HO fish
- Demographic increase (+ outbreeding enhancement/genetic rescue) from adding HO fish may compensate for reduced productivity if NO population is very small
  - But, at some point, there must be a transition from big HO/small NO to small-no HO/large NO for this to work.
  - Otherwise you just have a hatchery run. May result in extinction of non-hatchery influenced NO component.

Summary

- Source populations should ideally be native fish from the stream where supplementation is to occur. Hatchery population should be integrated.
  - Small target/donor populations pose significant problems
- If that is not possible, then nearby, genetically and ecologically similar sources can be contemplated.
- Imperiled stocks almost always have already experienced a drastic reduction in population size and genetic diversity.
  - In many cases, e.g., when a few to no individual are returning each year, it is debatable whether there is anything left to “save.”

The End