Hatchery reform science workshop

February 6 2020 | Olympia, WA

8:00 AM	Introductions
8:20 AM	Presentation – overview of hatchery reform science report
9:00 AM	General questions and discussion
9:45 AM	Break
10:00 AM	Broodstock management – presentation and discussion
11:30 AM	Public comment

A review of hatchery reform science in Washington State

Washington Fish & Wildlife Commission
Hatchery Reform Science Workshop
February 6, 2020
Olympia, WA

Joseph Anderson, Kenneth Warheit, Todd Seamons, Bethany Craig, and Alf Haukenes

Outline

Benefits

- Harvest
- Conservation

Risks

- Fishery risks
- Genetic
- Ecological

Reform

- Defining goals
- Broodstock management
- Program size
- Rearing and release strategies

Emerging Science

Conclusions

Harvest benefits

Salmon and steelhead fisheries subsidized by hatcheries

- Treaty rights
- Economic benefits
- Social benefits
- Cultural benefits

Conservation benefits

Conservation goals reflect spectrum of intervention urgency

- Prevent extinction
- Reintroduction
- Increase abundance of existing populations

Hatcheries have repeatedly

- Preserved a unique genetic lineage
- Increased abundance of naturally spawning, hatchery-origin fish

Few examples and sparse evidence for

- Transitioning to self-sustaining natural reproduction
- Increasing abundance of natural-origin fish

Fishery risks

- Fisheries typically target abundant hatchery populations
- Unintentional mortality to co-mingled natural populations
- Mark-selective fisheries are primary tool for limiting natural mortality, but constraints to their implementation
- Fisheries are often curtailed to protect weak natural populations; large scale hatchery production magnifies asymmetry between lost harvest opportunity and conservation gains
- Abundance of naturally spawning, hatchery-origin fish adds uncertainty to key harvest benchmarks

Genetic risks

Reduction in genetic diversity within a population

Homogenization – reduced diversity between populations

- Legacy of intentional transfers
- Unintentional straying to natural populations

Domestication

- Selection in hatchery vs. natural environment
- Relative reproductive success (RRS) research on fitness
- Conceptual foundation for hatchery reform broodstock management

Ecological risks

Competition

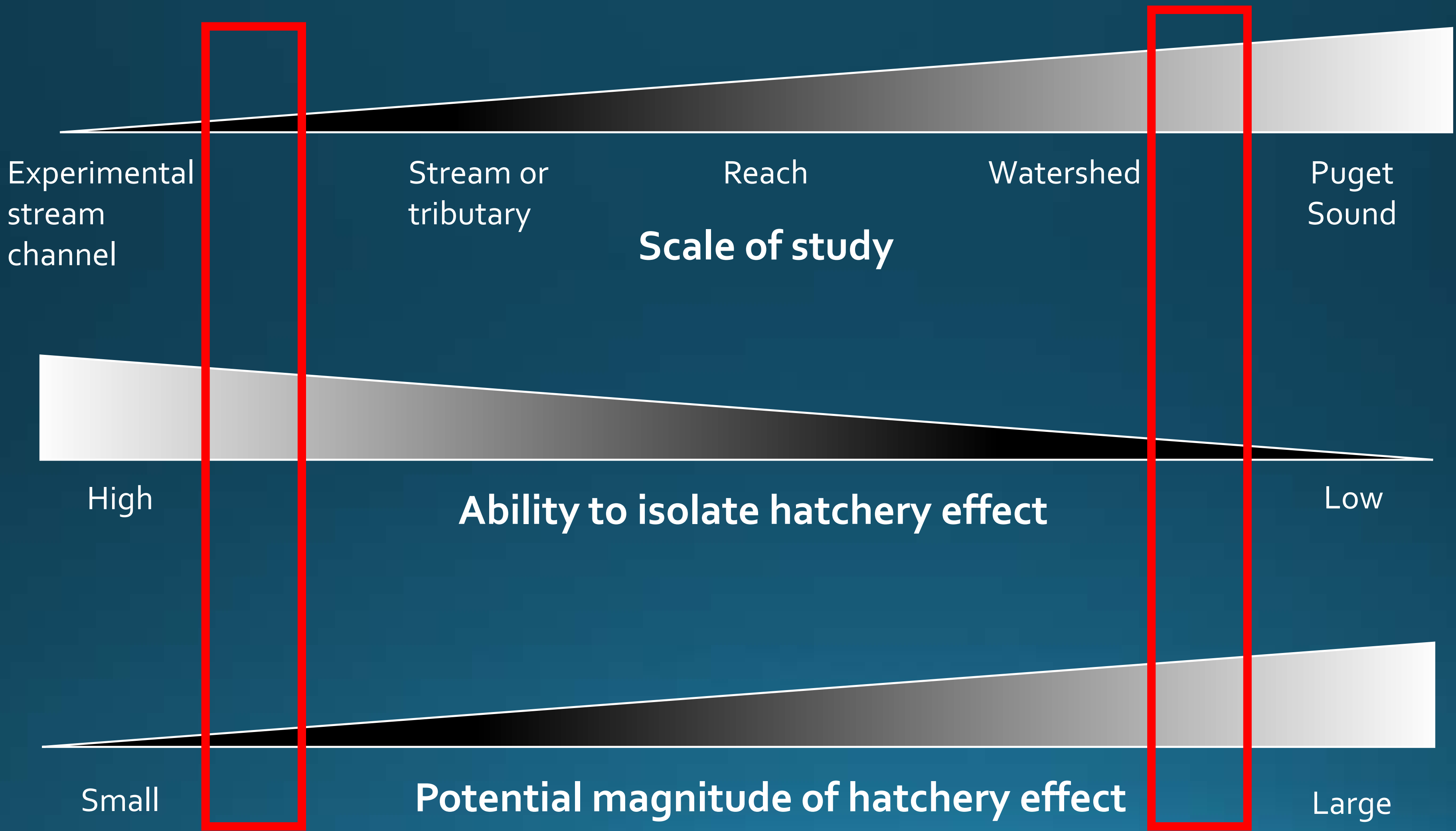
- Reduction in food or territories available to natural-origin fish
- Exceeding habitat rearing capacity, including marine environment

Predation

- Direct
- Indirect short term: predator attraction
- Indirect long term: boost predator populations

Evidence from correlative, retrospective analysis of population data

Investigating hatchery risks



Hatchery reform

"Hatchery reform" largely synonymous with work of Hatchery Scientific Review Group (HSRG)

Hatchery program goals – conservation or harvest

Broodstock management strategy

Segregated

Integrated

Hatchery reform

pHOS: proportion of naturally spawning fish that are hatchery-origin

pNOB: proportion of hatchery broodstock that are natural-origin

PNI: proportionate natural influence $\dfrac{pNOB}{pNOB + pHOS}$

0 % or low PNI indicates predominantly hatchery influence

100% or high PNI indicates predominantly natural influence

Hatchery reform

Biological significance

- Primary
- Contributing
- Stabilizing

Four phases of recovery

- Preservation
- Recolonization
- Local adaptation
- Viable natural population

pHOS and PNI goals

Natural Population		Hatchery Broodstock Management Strategy		
		Segregated	Integrated	
Biological significance	Recovery phase	pHOS	pHOS	PNI
Primary	Preservation	< 5 %	No target specified	No target specified
	Recolonization	< 5 %	No target specified	No target specified
	Local Adaptation	< 5 %	< 30 %	≥ 67 %
	Fully Restored	< 5 %	< 30 %	≥ 67 %

Hatchery reform

Program size – number of juvenile fish released

- Intertwined with all aspects of reform actions, risks and benefits
- Often informed by models

Rearing and growth strategies

- Natural growth regimes can reduce risks, but there may be trade-offs
- Research has focused on steelhead and yearling Chinook

Release strategies

- Hatchery releases often concentrated in non-native locations
- Long term trends towards releasing older, larger fish from hatcheries, often in a narrow window of time
- Acclimation ponds, volitional release can help reduce ecological risks

Emerging science

- Strong empirical and modeling support for fundamental concepts of broodstock management
  - Hatchery and natural environments present different selection pressures

- However, unequivocal, population-scale empirical evidence for a genetic component to fitness loss remains relatively rare
  - Requires multigenerational genetic analysis with census sampling
  - Legacy of hatchery introgression can limit measured fitness differences
  - No multigenerational study of fall Chinook capable of assessing inherited fitness loss

- Mixed results in cases studies examining response following termination of hatchery releases or exclusion of hatchery-origin fish

Emerging science

- Regarding conservation hatcheries
  - Smaller-scale case studies demonstrate potential for demographic benefits with low or minimal genetic costs
  - However, larger-scale syntheses across multiple rivers find little evidence for sustained increases in natural-origin abundance

- Indications of competition, notably in marine environment, in some but not all large-scale assessments of ecological interactions

- Experimental rearing and releases strategies hold potential for reducing risks of ecological interactions and straying

CONCLUSIONS

Three broad categories

- Overarching themes
- Broodstock management & HSRG recommendations
- Key knowledge gaps

Hatchery reform is but one of several factors requiring careful planning and aggressive implementation needed to achieve meaningful recovery of salmon populations

- Hatchery reform never intended or expected to achieve salmon recovery on its own

Overarching themes

Hatchery reform is largely aimed at reducing risk in a relative but not absolute sense

- We know actions such as reducing program size or increasing pNOB will reduce risk
- However, models and extensions of empirical studies lack sufficient precision to confidently, precisely predict hatchery impacts or fine-tune hatchery management
- Risk-risk trade-offs

Overarching themes

In WDFW's hatchery system, a focus on efficiency and maximizing abundance prevent widespread implementation of risk reduction measures

- Studies showing demographic benefits or minimal genetic risks generally conducted on small-scale conservation hatchery programs
- Majority of WDFW's hatchery programs large-scale, harvest programs
- Many risk reduction measures not compatible with production-oriented hatcheries

Overarching themes

The principles of reducing pHOS and increasing pNOB to achieve fitness gains in wild populations are well-founded, and should be fundamental goals in any hatchery reform management action

- Strong support for the principle that hatchery and natural environment present different selection pressures
- Measuring and controlling gene flow essential to managing genetic risks

Broodstock management & HSRG recommendations

Program size requires more careful scrutiny and scientific justification because it affects virtually every aspect of hatchery risks

- Where integrated population demographics are dominated by hatchery production, it is possible that declines in natural population abundance and fitness are unavoidable and severe in magnitude
- Limited evidence for ability to control pHOS by other means
- Ecological risks and genetic risk of homogenization also scale with program size
- Demographic dominance of hatchery-origin fish is commonplace

Broodstock management & HSRG recommendations

The HSRG's phased approach to recovery has strong conceptual merit, but its implementation has resulted in an absence of stricter, conservation oriented goals for many populations

- Four recovery phases recognizes spectrum of conservation intervention urgency
- No pHOS or PNI goals for natural populations in "preservation" or "recolonization" phases
- Implementation frequently confounds harvest and conservation goals
- Phase designations often lack measurable performance benchmarks

Broodstock management & HSRG recommendations

We recommend crafting a stand-alone monitoring and adaptive management plan for each hatchery program that quantifies both benefits and risks, and explicitly links hatchery performance metrics to potential operational changes

- Monitoring and adaptive management are critical tools for evaluating risks and benefits
- Considerable statewide investment in population monitoring
- However, application of data to decision making often suffers from absence of a clear monitoring and evaluation plan and adaptive management process
- We also recommend a more rigorous, consistent and intentional evaluation of cumulative hatchery effects across multiple hatchery programs operating within a geographic region

Broodstock management & HSRG recommendations

The absence of a landscape-level, replicated experiment prevents empirical assessment of hatchery reform effectiveness

- Population-scale experiments addressing conservation hatchery benefits provide some guidance
- However, strong need for population-scale experiment addressing effectiveness of hatchery reform measures and especially broodstock management at large scale harvest programs
- Hatchery releases common throughout most major river basins in Washington State, limiting opportunities for retrospective treatment-control study design
- In such a study, any improvements in population performance attributable to broodstock management likely to accumulate over generations

Knowledge gaps

Hatcheries have potential for large magnitude ecological impacts on natural populations that are not well understood, not typically evaluated and not measured

- Genetic risks have dominated hatchery-wild research and hatchery reform
- Natural habitats, including marine environment, will have some rearing capacity or limit to the number of salmon they can support
- Cannot assume hatchery production is entirely additive with natural production
- Marine capacity especially important for species that often rear in estuaries and nearshore habitats – chiefly Chinook salmon, chum salmon

Knowledge gaps

Understanding the role of life history diversity on hatchery-wild ecological interactions and ecosystem stability is a significant research need

- Hatcheries have narrowed life history diversity, both through a legacy of genetic homogenization and relatively narrow window of contemporary releases
- Food web impacts of pulsed hatchery releases poorly understood
- Life history diversity very important to ecosystem benefits of salmon, such as prey for orca

Knowledge gaps

Overall conclusion

- Our review supports the fundamental concepts and approach of hatchery reform
- However, we also identified knowledge gaps and challenges to coordinated implementation of scientific principles at a statewide scale
- In order to advance hatchery reform as a comprehensive program for developing scientifically defensible hatchery programs, these issues warrant dedicated, programmatic initiatives

QUESTIONS?

Genetic risks

Reduction in genetic diversity within a population

Homogenization – reduced diversity between populations

- Legacy of intentional transfers
- Unintentional straying to natural populations

Domestication

- **Selection in hatchery vs. natural environments**
- **Relative reproductive success (RRS) research**
- **Conceptual foundation for hatchery reform broodstock management**

Hatchery reform

"Hatchery reform" largely synonymous with work of Hatchery Scientific Review Group (HSRG)

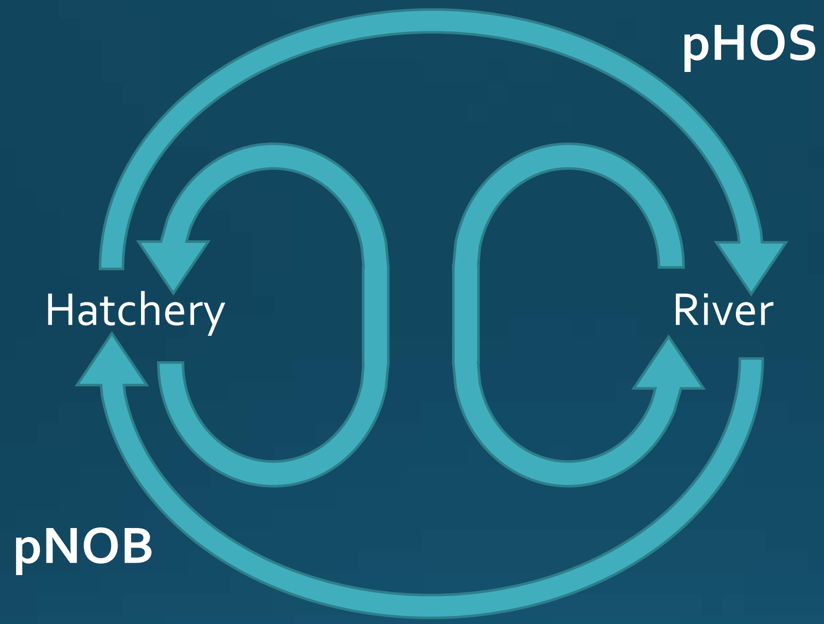
Hatchery program goals – conservation or harvest

Broodstock management strategy

Segregated

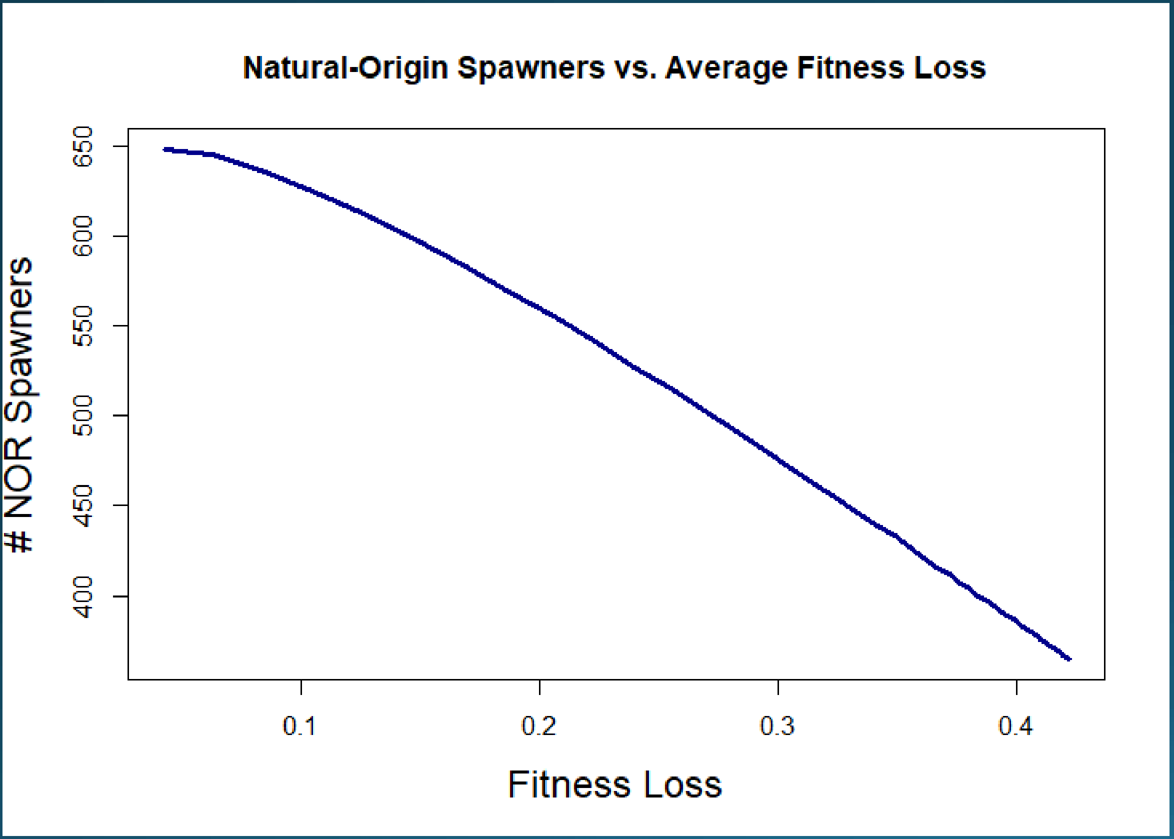
Integrated

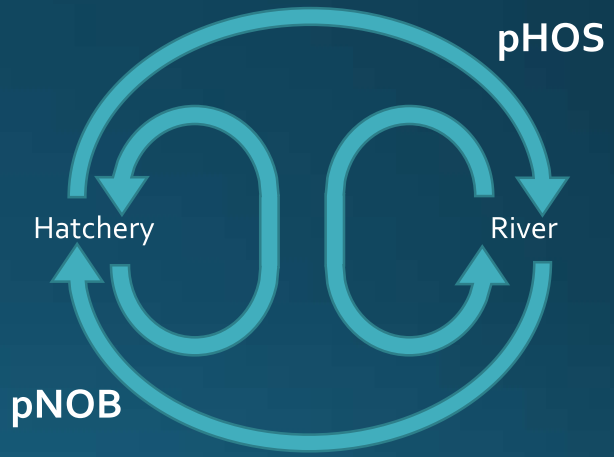
Integrated Program



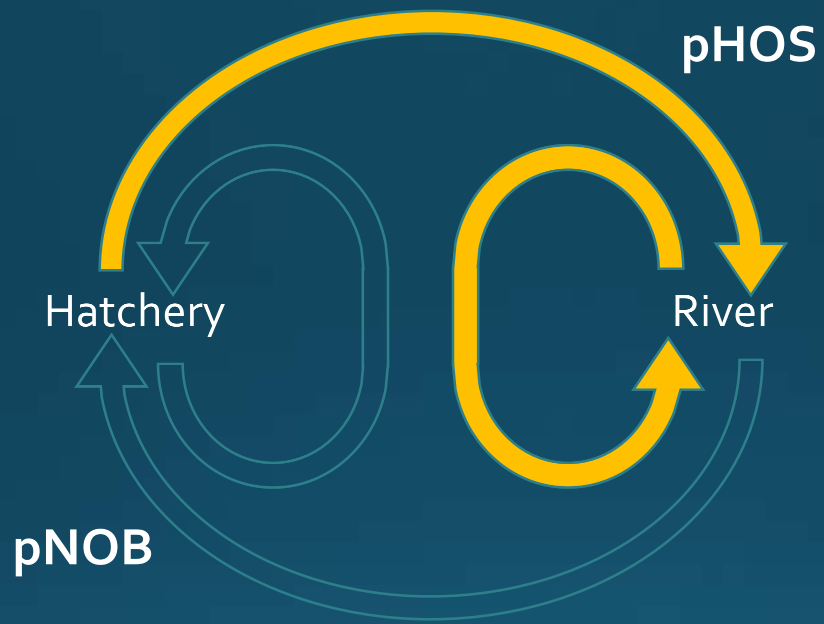
- Integrated hatchery programs are SINGLE populations
  1. Relative reproductive success (RRS) of HOS spawning naturally
  2. Consequences of that RRS and pNOB on viability of population

Fitness: for a population is its overall productivity

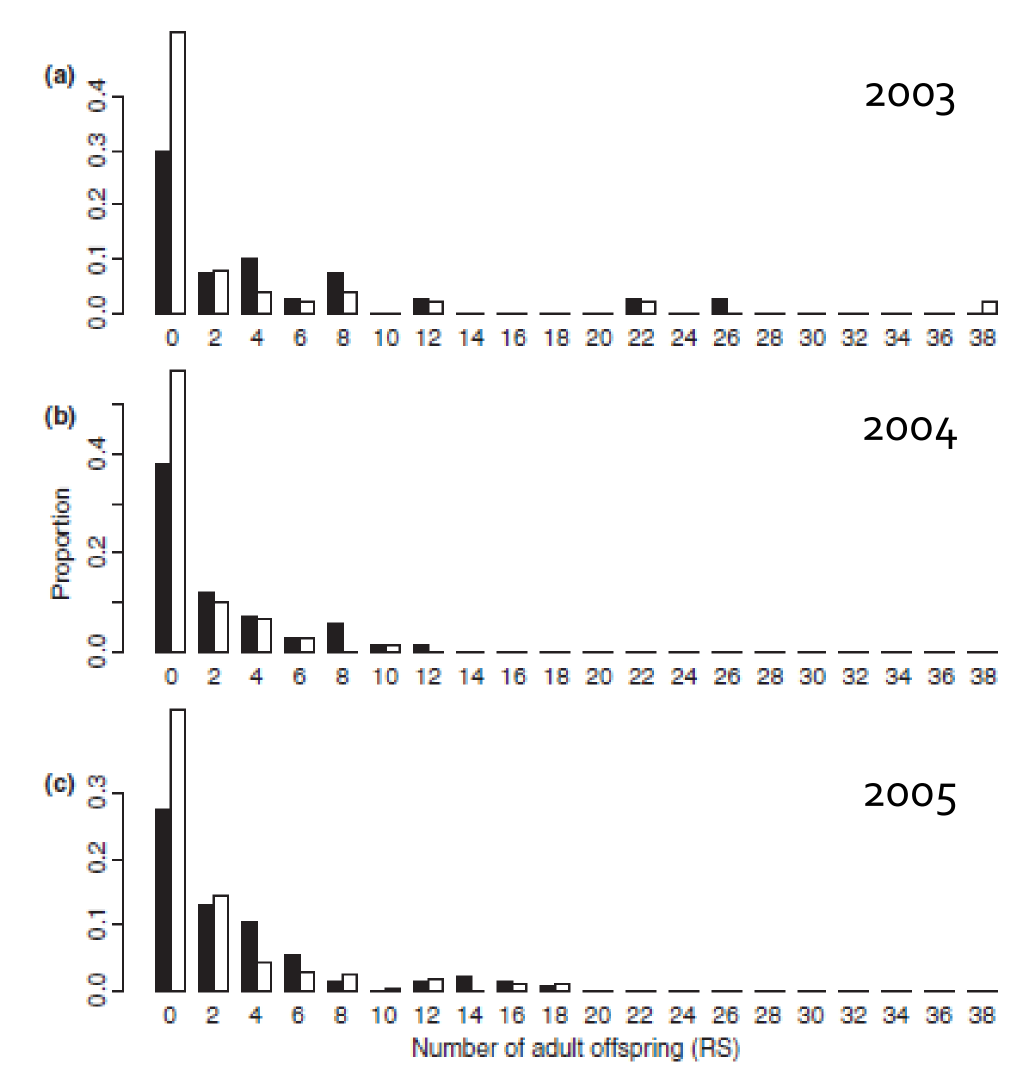




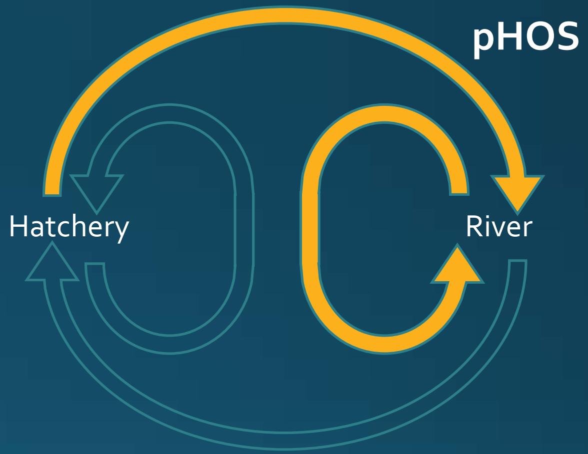
Relative Reproductive Success (RRS)



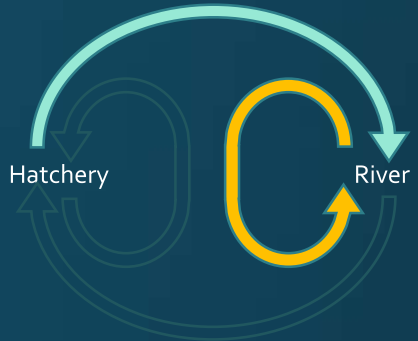
- Reproductive success (RS): # offspring per parent or parent-pair
- Offspring can be measured at any life stage
- RRS compares natural spawning RS-Hatchery to RS-Natural

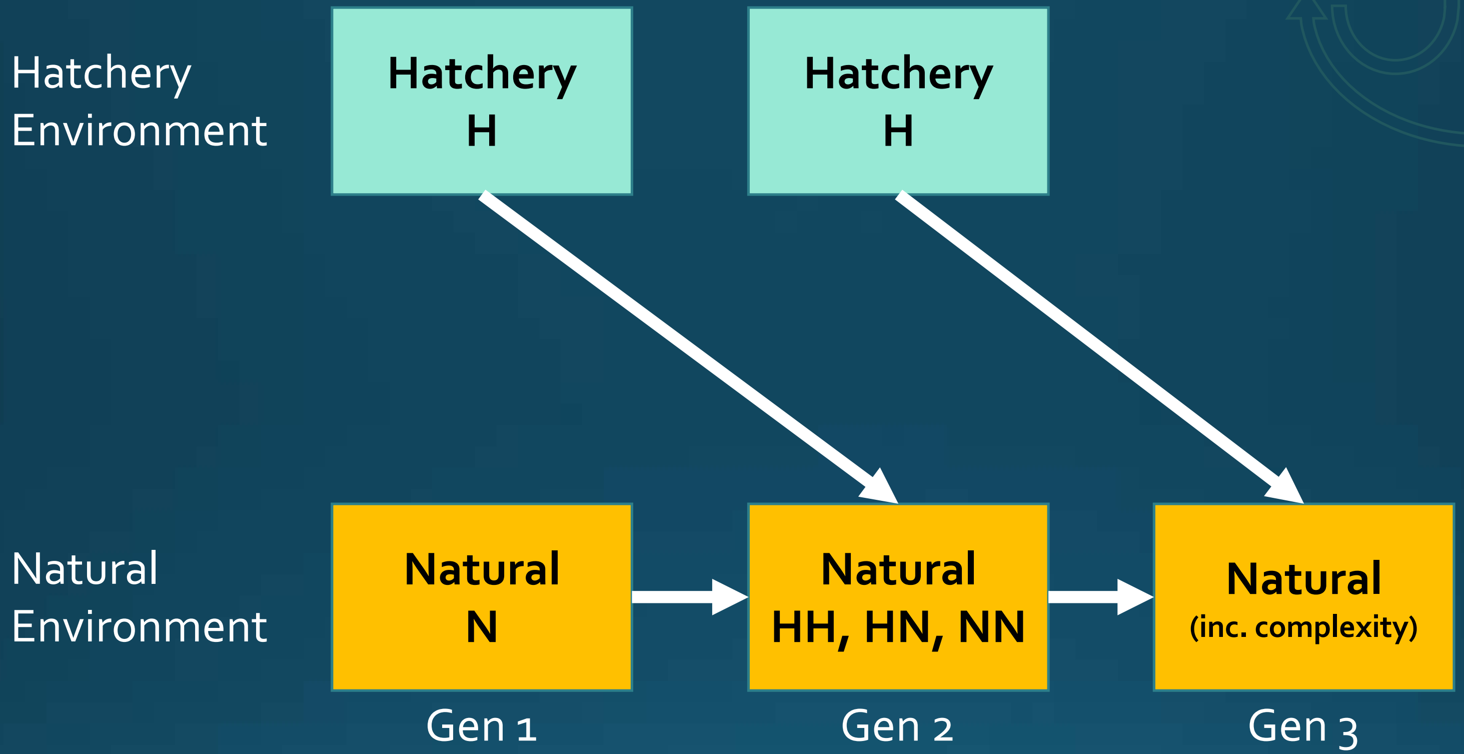


Coho (Cedar R, WA): Anderson et al. 2010

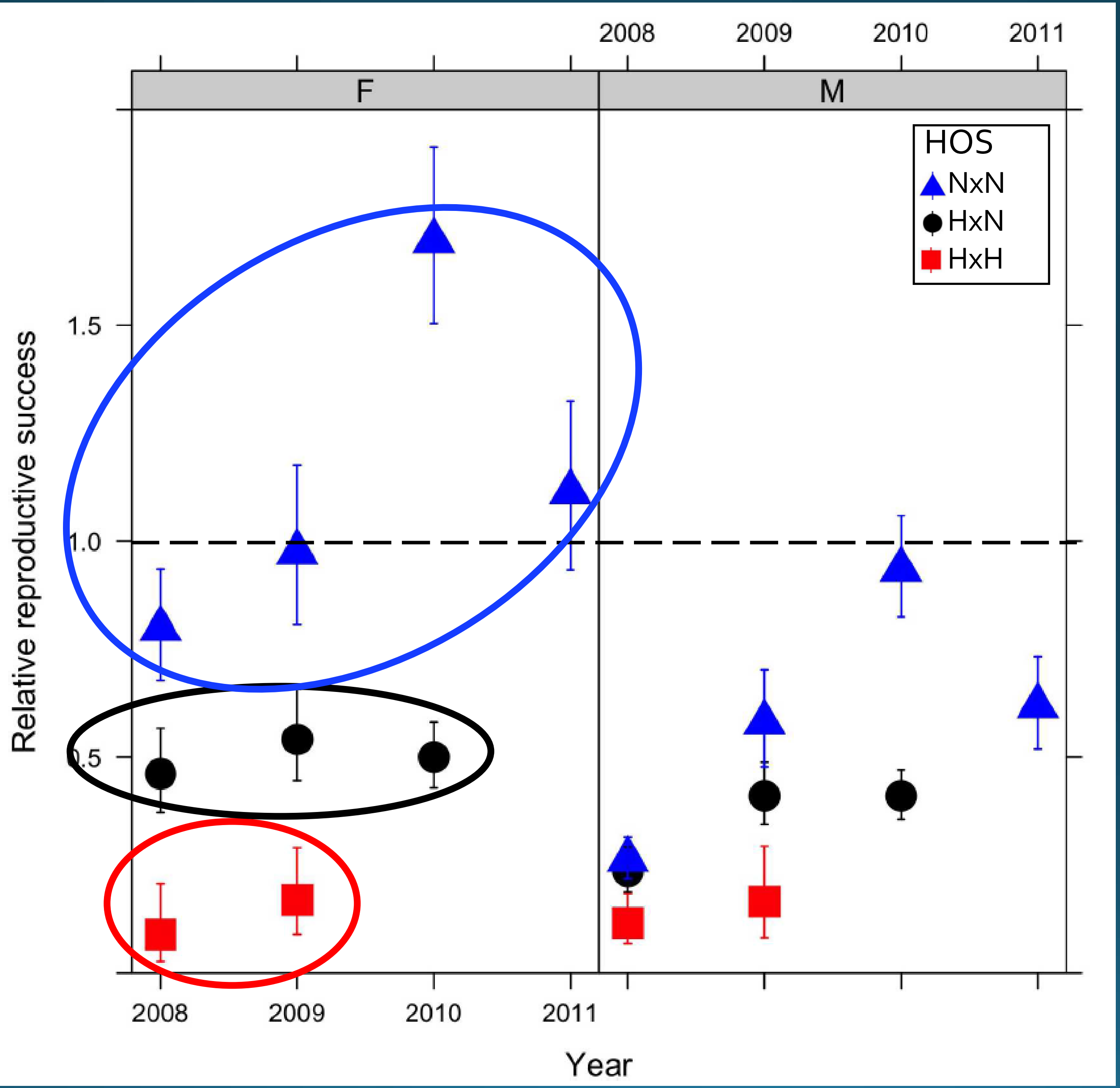


Measuring RRS



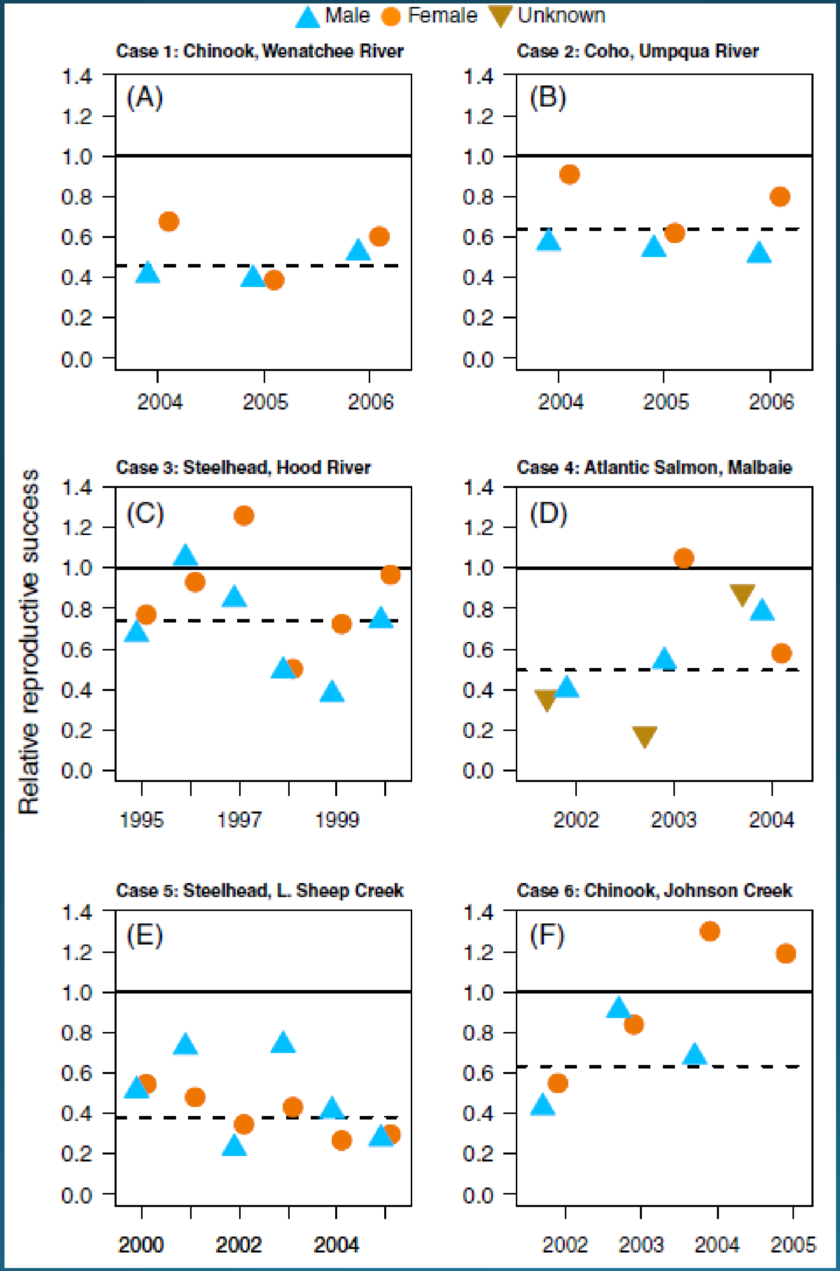


1. RRS: assigning offspring to parents (remember the zeros)
2. Parents of adult offspring in Gen 2 experienced difference life histories
3. Parents of adult offspring in Gen 3 experiences same life histories
4. RRS in Gen 2 affected by both environments and genetics. Less environ in Gen 3
5. Lineage compositions become more complex when increasing generation



NOS RS

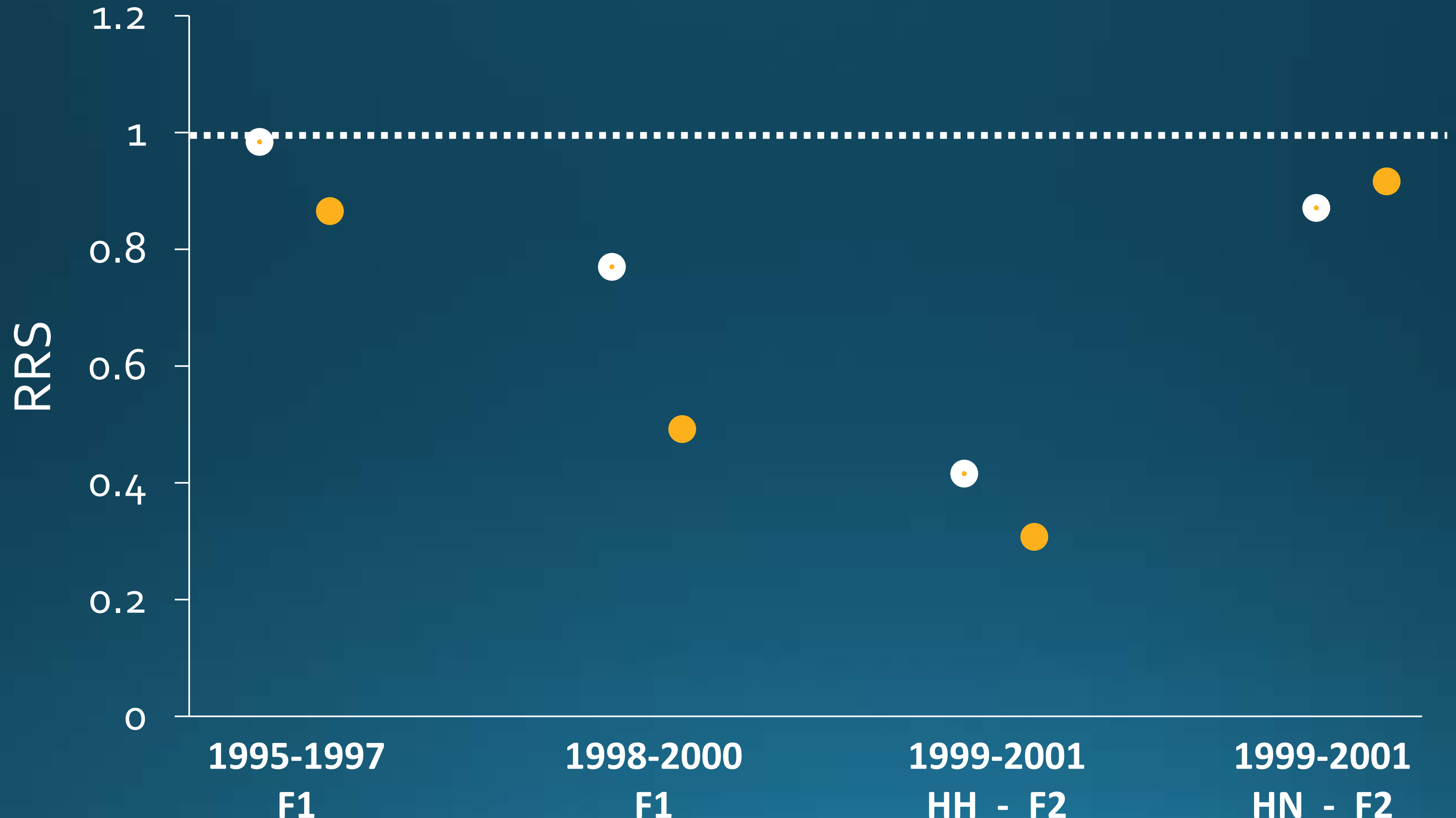
Steelhead (Wenatchee R, WA): Ford et al. 2016



Christie et al. 2014

Steelhead (Hood River, OR)

Araki et al. 2007a, 2007b, 2009



Chinook (Johnson Creek, ID)

Janowitz-Koch et. al. 2019

RRS Summary

- Different studies – different results
  - Species
  - Hatchery-natural integration prior to study
  - Environment vs. genetic effects
  - Size of program
  - Broodstock management (e.g., Johnson Ck. pNOB = 100%)
  - Year effect
- More studies show lower RRS for hatchery-origin or hatchery-lineage fish
  - RRS: NN > HN > HH

Broodstock management

Proportion natural spawners that are hatchery origin

Proportion hatchery broodstock that are natural origin

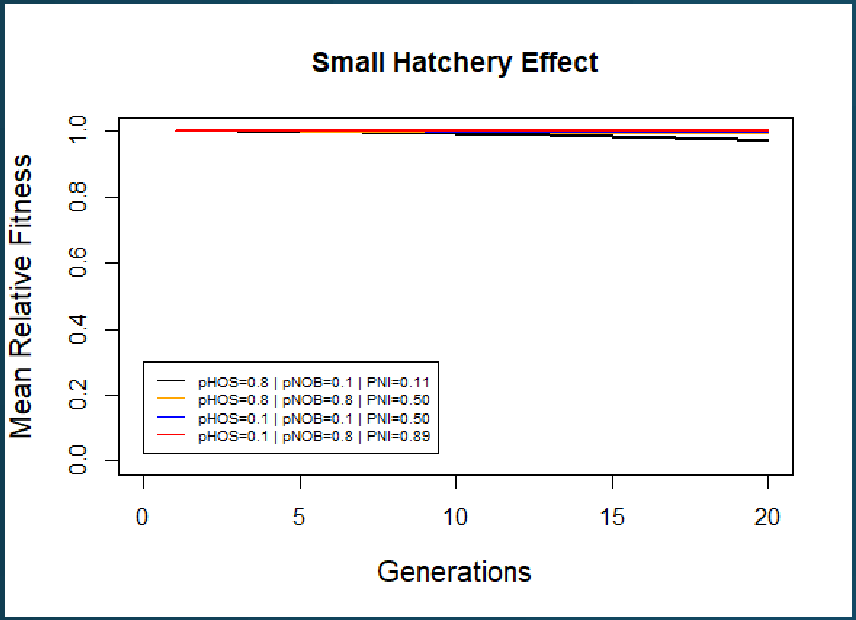
$$\text{PNI} = \frac{\text{pNOB}}{\text{pNOB} + \text{pHOS}}$$

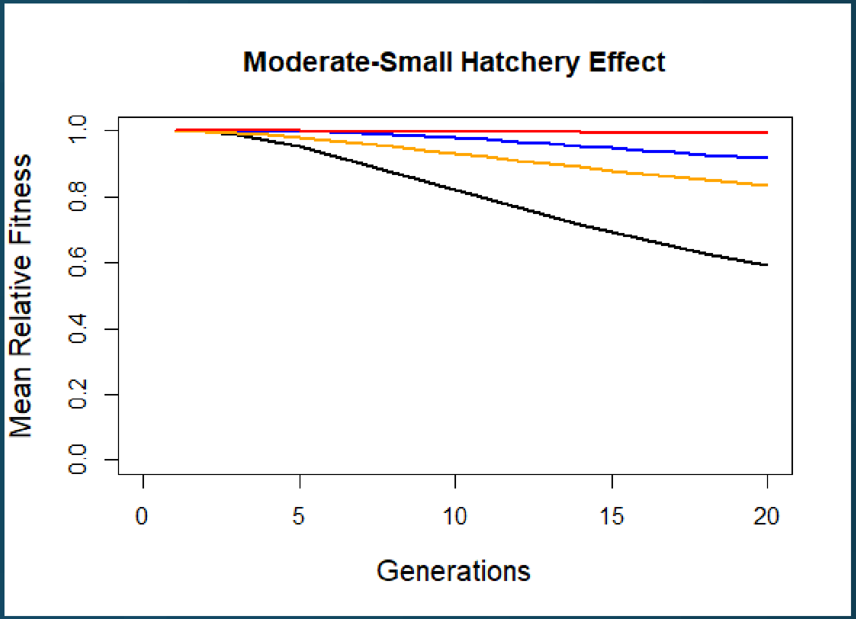
Modeling pHOS and pNOB
(Ford Model)

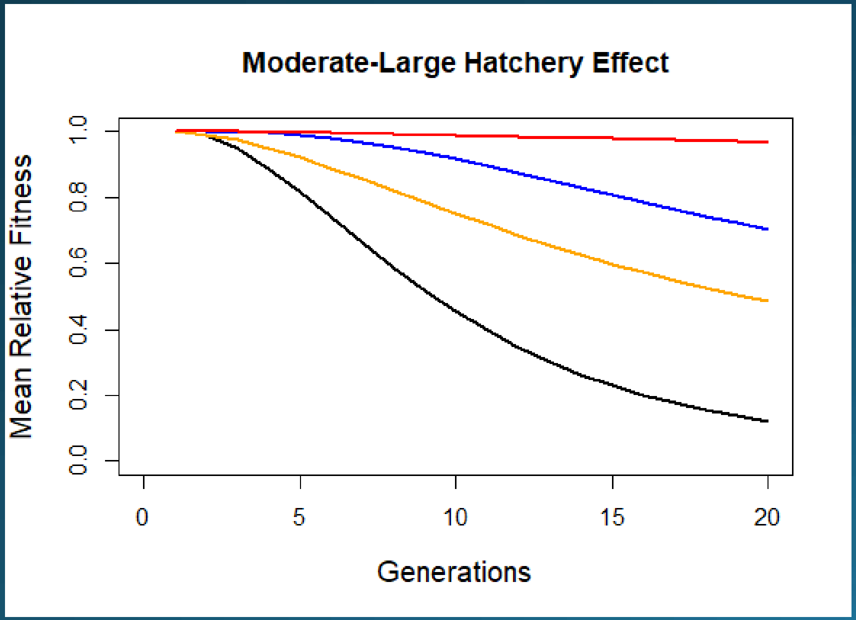
Fitness: for a population is its overall productivity

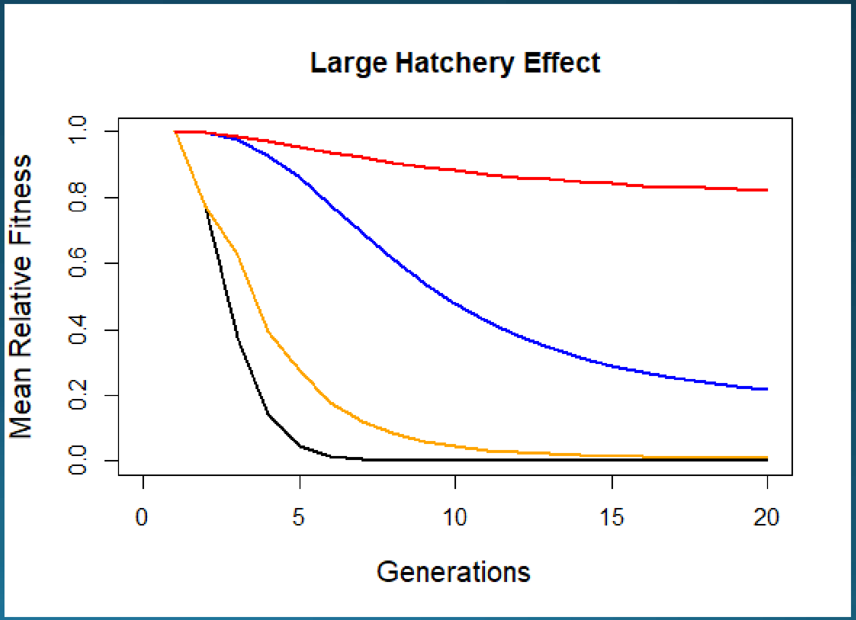
Hatchery Effect {
- Strength of natural selection
- Selective difference between hatchery and wild environments

- Heritability of the trait subjected to natural selection
- pHOS and pNOB
- Demographic
  - Beverton-Holt recruit function
  - Growth rate
  - Carrying Capacity

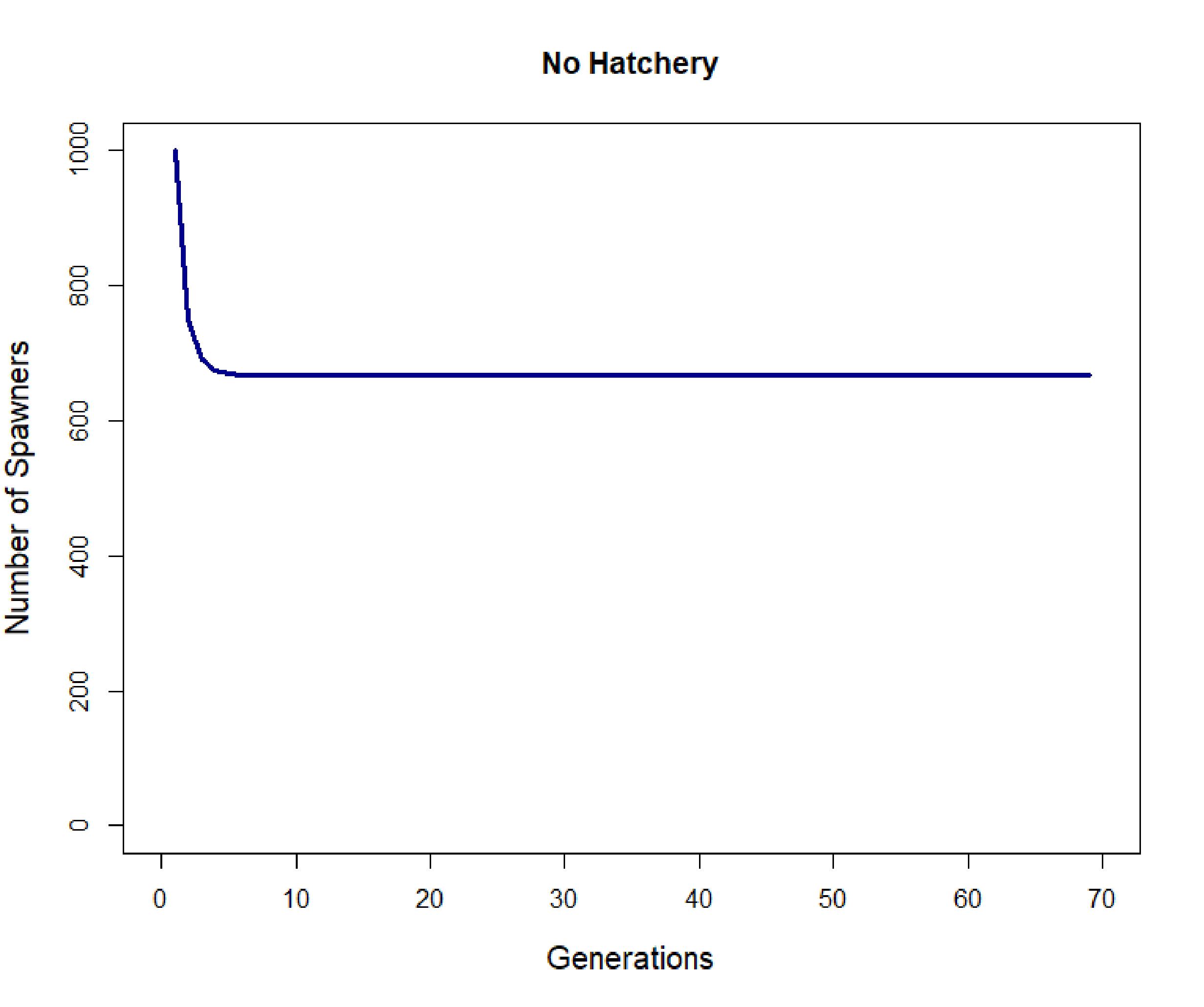

Small Hatchery Effect
Mean Relative Fitness
0.0
0.2
0.4
0.6
0.8
1.0
pHOS=0.8 | pNOB=0.1 | PNI=0.11
pHOS=0.8 | pNOB=0.8 | PNI=0.50
pHOS=0.1 | pNOB=0.1 | PNI=0.50
pHOS=0.1 | pNOB=0.8 | PNI=0.89
0
5
10
15
20
Generations


Moderate-Small Hatchery Effect
Mean Relative Fitness
0.0
0.2
0.4
0.6
0.8
1.0
0
5
10
15
20
Generations


Moderate-Large Hatchery Effect
Mean Relative Fitness
0.0
0.2
0.4
0.6
0.8
1.0
0
5
10
15
20
Generations

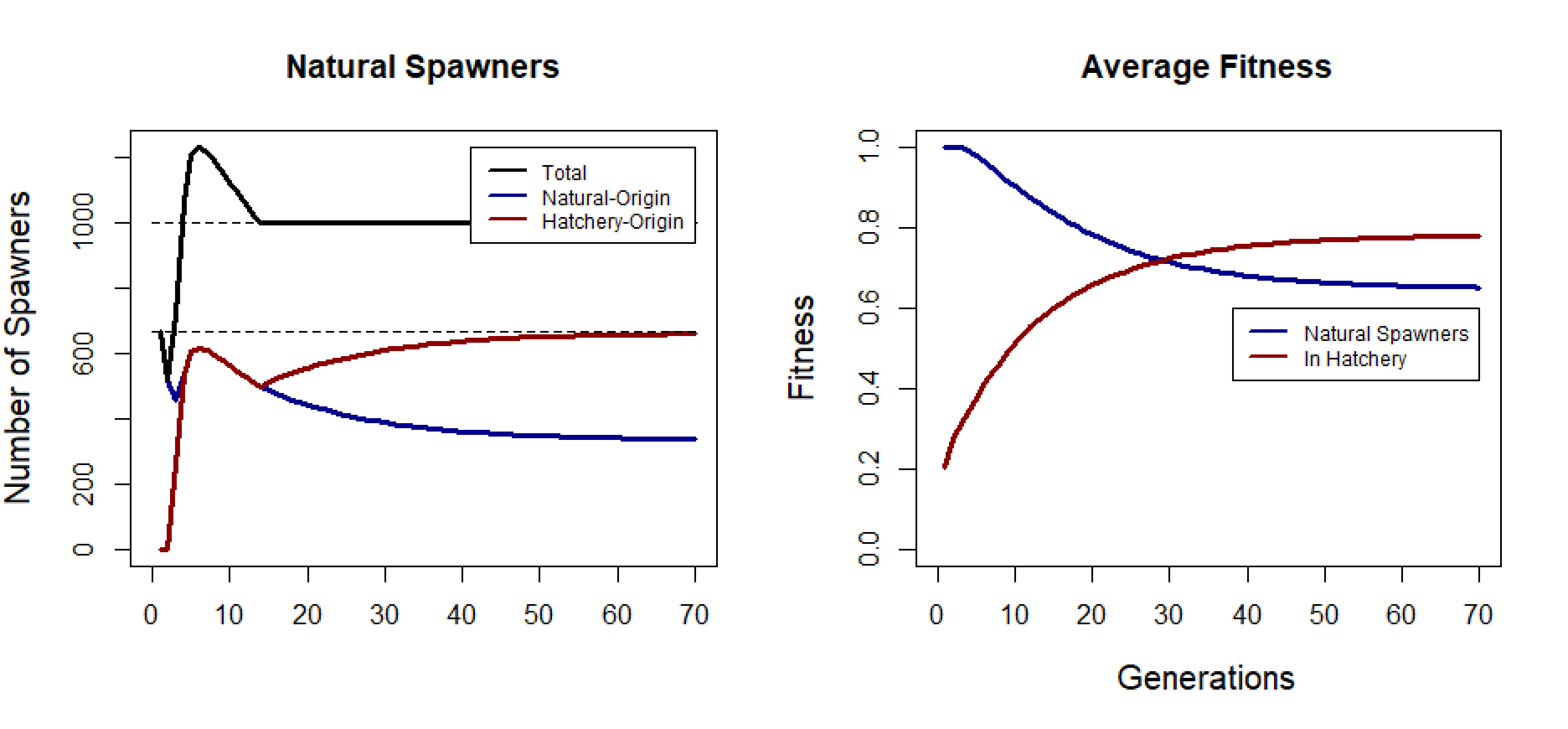

Large Hatchery Effect
Mean Relative Fitness
0.0
0.2
0.4
0.6
0.8
1.0
0
5
10
15
20
Generations

Starting Conditions



r – wild: 3
Heritability: 0.5
k – wild: 1000
Nat. pop: 667

Add Hatchery



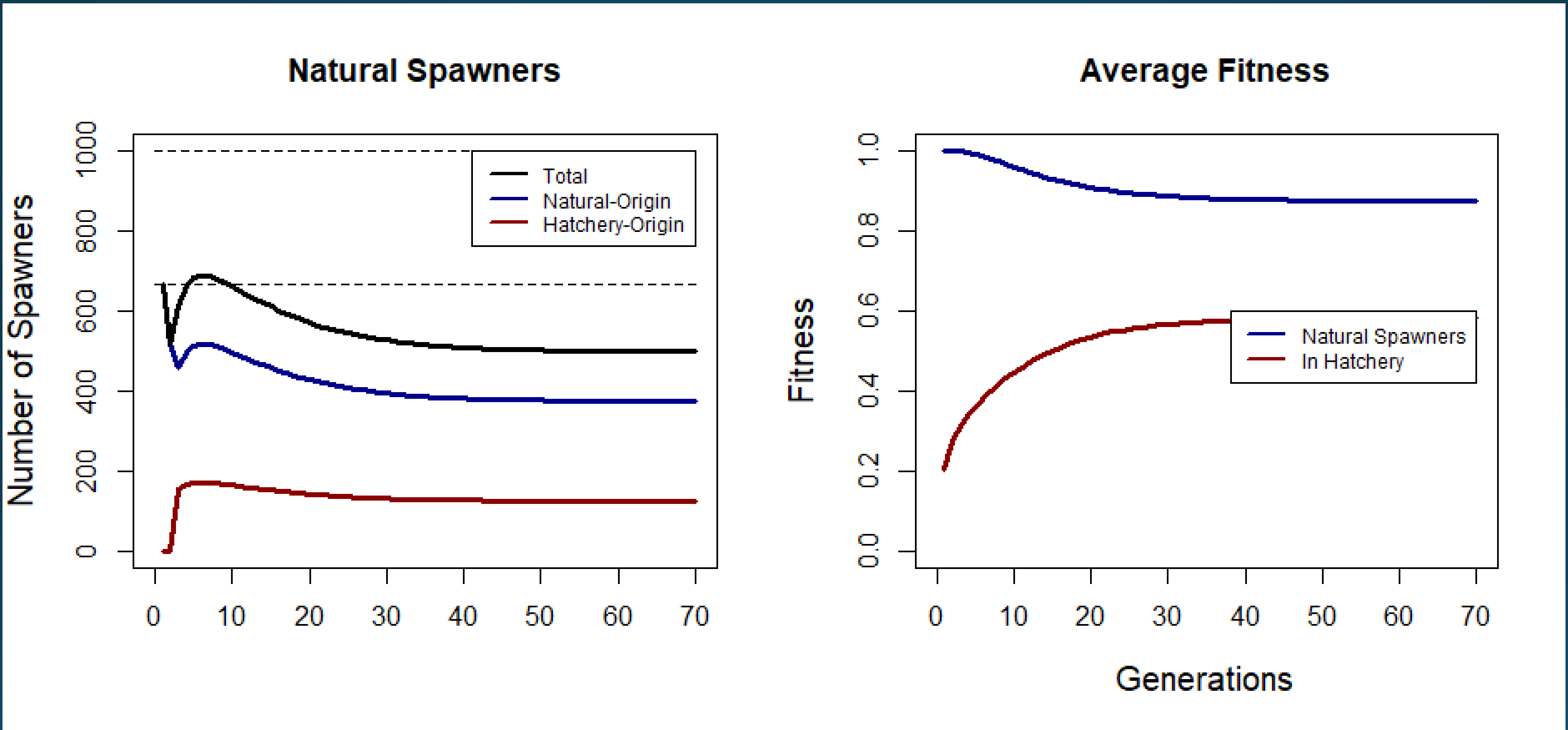
Program size: 300
Control pHOS: True

pNOB: 0.5
pHOS: 0.5

r – hatchery: 10
r – wild: 3
Hatchery effect: Mod-small

Heritability: 0.5
k – wild: 1000
Nat. pop: 667

Cut pHOS in half



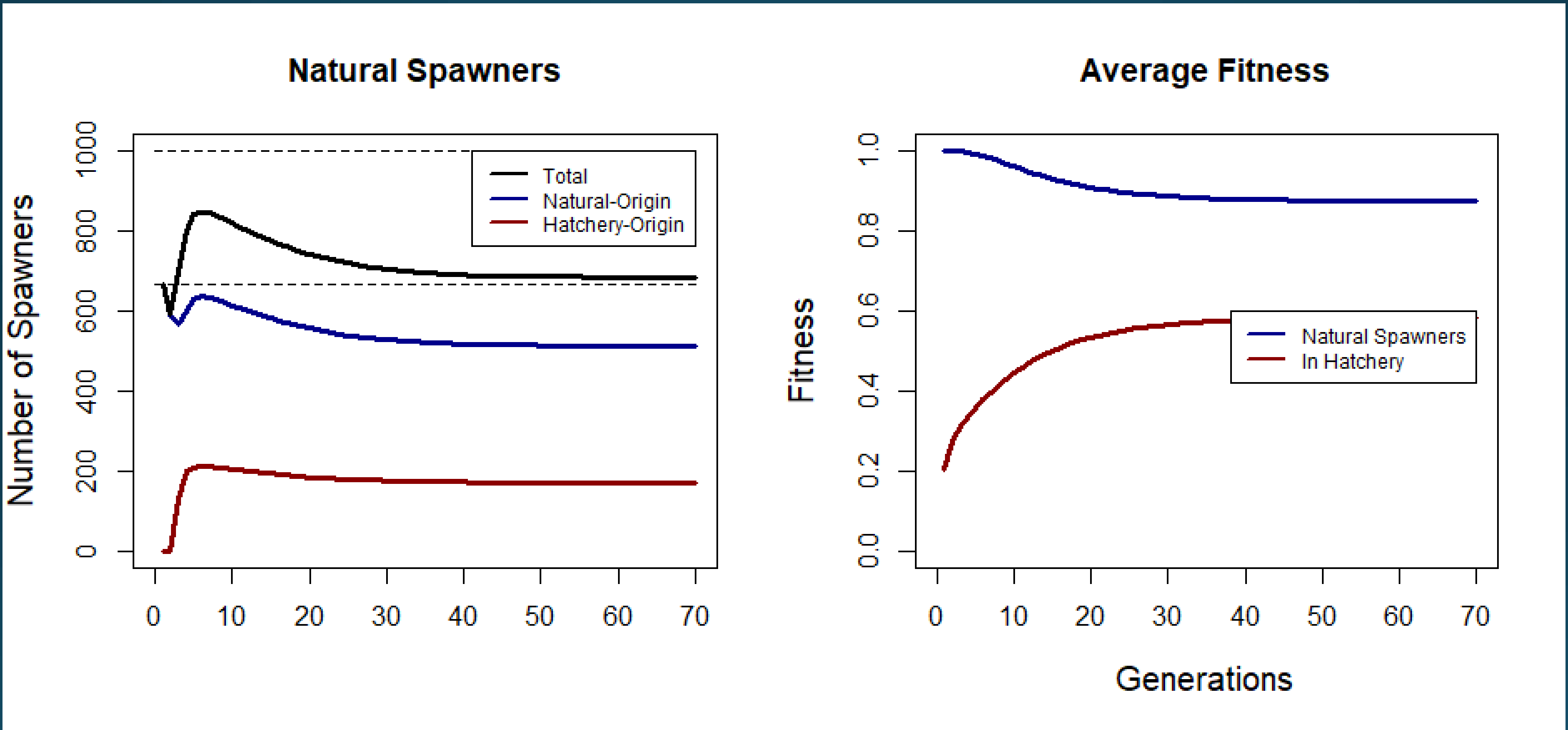
Program size: 300
Control pHOS: True

pNOB: 0.5
pHOS: **0.25**

r – hatchery: 10
r – wild: 3
Hatchery effect: Mod-small

Heritability: 0.5
k – wild: 1000
Nat. pop: 667

Cut program in half



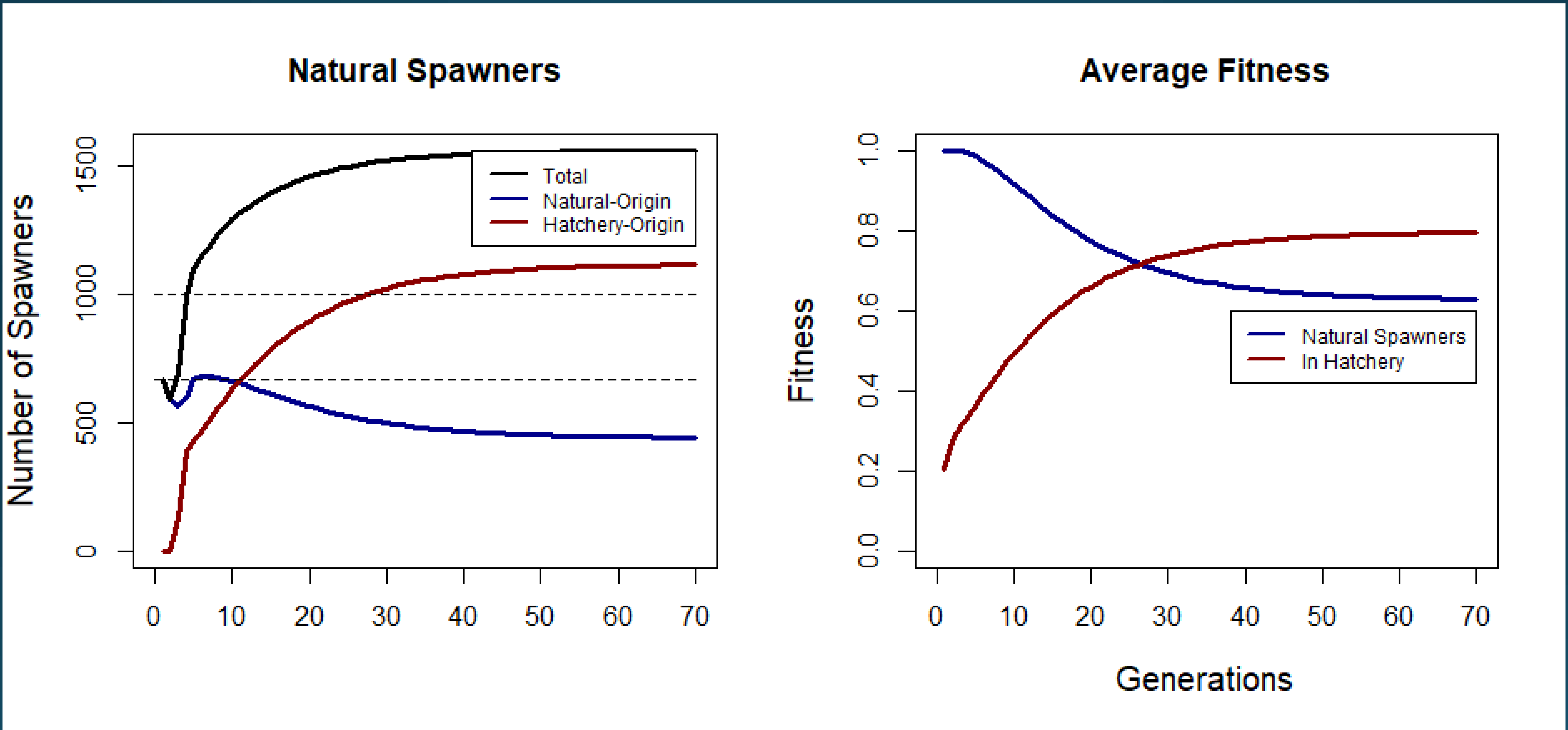
Program size: **150**
Control pHOS: True

pNOB: 0.5
pHOS: 0.25

r – hatchery: 10
r – wild: 3
Hatchery effect: Mod-small

Heritability: 0.5
k – wild: 1000
Nat. pop: 667

Can't control pHOS



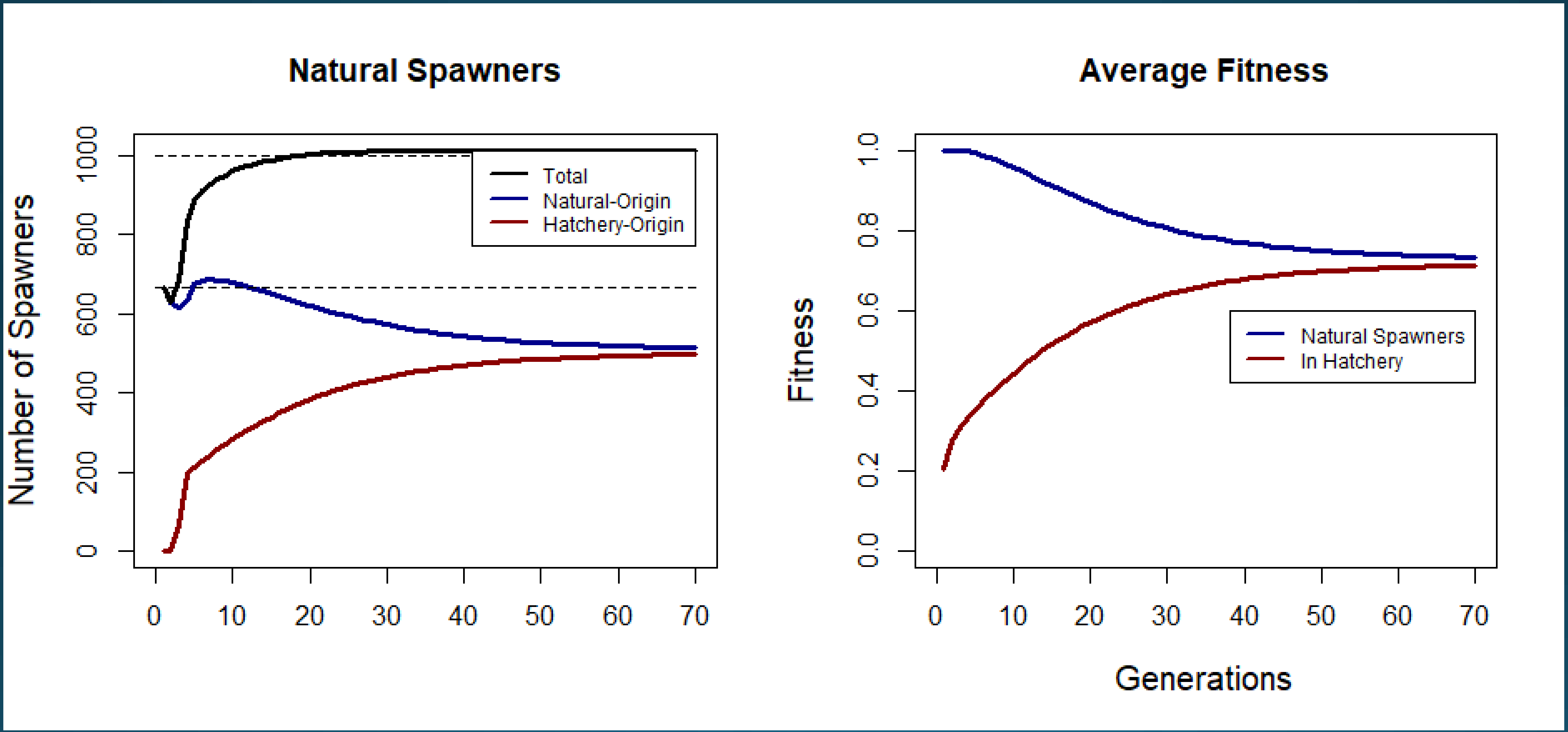
Program size: 150
Control pHOS: **FALSE**

pNOB: 0.5
pHOS: 0.25

r – hatchery: 10
r – wild: 3
Hatchery effect: Mod-small

Heritability: 0.5
k – wild: 1000
Nat. pop: 667

Cut program in half . . . again



Program size: **75**
Control pHOS: FALSE

pNOB: 0.5
pHOS: 0.25

r – hatchery: 10
r – wild: 3
Hatchery effect: Mod-small

Heritability: 0.5
k – wild: 1000
Nat. pop: 667

Broodstock management
Take-home message

- **Cut pHOS**
  - Improved natural fitness
  - Lower number of natural spawners (fewer HOS)
  - Surplus hatchery fish
- **Cut program size**
  - Increased number of natural spawners (fewer NOR taken as broodstock)
  - Reduced amount of surplus hatchery fish
- **Can’t adequately control pHOS**
  - Majority of fish on spawning grounds = hatchery origin
  - Lower natural fitness
  - Number of spawners exceed carrying capacity, putting production at risk
  - Cutting program size is the only way to reduce HOS

Hatchery Reform

- Balance among hatchery production, pHOS, and pNOB
- The correct balance requires social and biological compromises
  - Numbers of fish on spawning grounds
  - Fitness of those fish
  - Numbers of fish available for fisheries
- To maintain productive natural spawning
  - Fitness loss from hatchery production needs to be minimized
    - Lower pHOS
    - Reduce program size
    - [increase pNOB]
- Hatchery production needs to be sized appropriately – based on explicit goals

Ceist?

(Questions . . . Scottish Gaelic)