Alaska Hatchery Research Program: Study Question 3: Relative Reproductive Success Update

Kyle Shedd

Gene Conservation Laboratory

Alaska Department of Fish and Game

BOF Hatchery Committee Meeting

March 23, 2022

Alaska Hatchery Research Program

1) What is the genetic structure of pink and chum in PWS and SEAK?
2) What is the extent and annual variability of straying?
3) What is the impact on fitness (productivity) of natural pink and chum stocks due to straying hatchery pink and chum salmon?

Hatchery/Natural Fitness

Steelhead

Differential reproductive success of sympatric, naturally spawning hatchery and wild steelhead trout (*Oncorhynchus mykiss*) through the adult stage

Jennifer E. McLean, Paul Bentzen, and Thomas P. Quinn

MOLECULAR ECOLOGY

Reduced reproductive success of hatchery coho salmon in the wild: insights into most likely mechanisms

VÉRONIQUE THÉRIAULT,* GREGORY R. MOYER,*† LAURA S. JACKSON,‡ MICHAEL S. BLOUIN‡ and MICHAEL A. BANKS*

Genetic Effects of Captive Breeding Cause a Rapid, Cumulative Fitness Decline in the Wild

Hitoshi Araki,* Becky Cooper, Michael S. Blouin

Effective population size of steelhead trout: influence of variance in reproductive success, hatchery programs, and genetic compensation between life-history forms

HITOSHI ARAKI,* ROBIN S. WAPLES,† WILLIAM R. ARDREN,*‖ BECKY COOPER* and MICHAEL S. BLOUIN*

biology letters

Conservation biology

Carry-over effect of captive breeding reduces reproductive fitness of wild-born descendants in the wild

Hitoshi Araki*,†, Becky Cooper and Michael S. Blouin

Transactions of the American Fisheries Society

Diminished Reproductive Success of Steelhead from a Hatchery Supplementation Program (Little Sheep Creek, Imnaha Basin, Oregon)

Evann A. Berntson *, Richard W. Carmichael, Michael W. Flesher, Eric J. Ward & Paul Moran

PNAS

Genetic adaptation to captivity can occur in a single generation

Mark R. Christie*, Melanie L. Marine*, Rod A. French, and Michael S. Blouin*

Chinook

Use of Parentage Analysis to Determine Reproductive Success of Hatchery-Origin Spring Chinook Salmon Outplanted into Shitike Creek, Oregon

JASON BAUMSTEIGER[1]

DAVID M. HAND[2] AND DOUGLAS E. OLSON

ROBERT SPATEHOLTS[2] AND GEOFF FITZGERALD[3]

WILLIAM R. ARDREN[4]

Factors influencing the relative fitness of hatchery and wild spring Chinook salmon (*Oncorhynchus tshawytscha*) in the Wenatchee River, Washington, USA

Kevin S. Williamson, Andrew R. Murdoch, Todd N. Pearsons, Eric J. Ward, and Michael J. Ford

MOLECULAR ECOLOGY

Supportive breeding boosts natural population abundance with minimal negative impacts on fitness of a wild population of Chinook salmon

MAUREEN A. HESS,* CRAIG D. RABE,† JASON L. VOGEL,‡ JEFF J. STEPHENSON,* DOUG D. NELSON† and SHAWN R. NARUM*

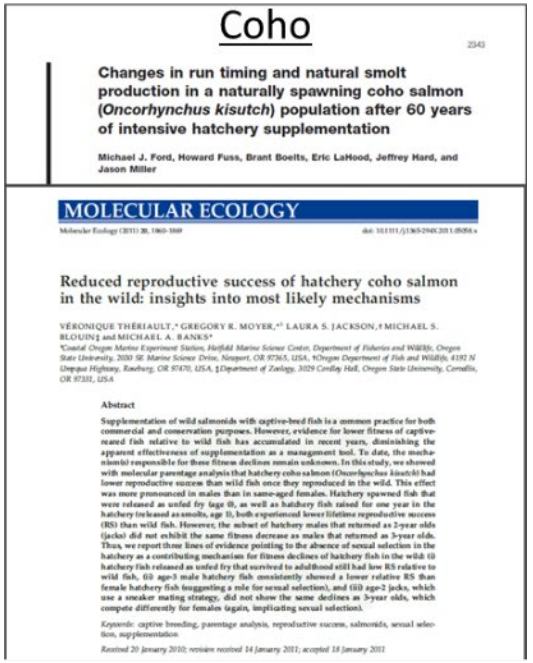
Evolutionary Applications

ORIGINAL ARTICLE

Reproductive success of captively bred and naturally spawned Chinook salmon colonizing newly accessible habitat

Joseph H. Anderson,[1,2,*] Paul L. Faulds,[2] William I. Atlas[1,4] and Thomas P. Quinn[1]

Coho



Changes in run timing and natural smolt production in a naturally spawning coho salmon (*Oncorhynchus kisutch*) population after 60 years of intensive hatchery supplementation

Michael J. Ford, Howard Fuss, Brant Boelts, Eric LaHood, Jeffrey Hard, and Jason Miller

MOLECULAR ECOLOGY

Reduced reproductive success of hatchery coho salmon in the wild: insights into most likely mechanisms

VÉRONIQUE THÉRIAULT,* GREGORY R. MOYER,*† LAURA S. JACKSON,‡ MICHAEL S. BLOUIN‡ and MICHAEL A. BANKS*

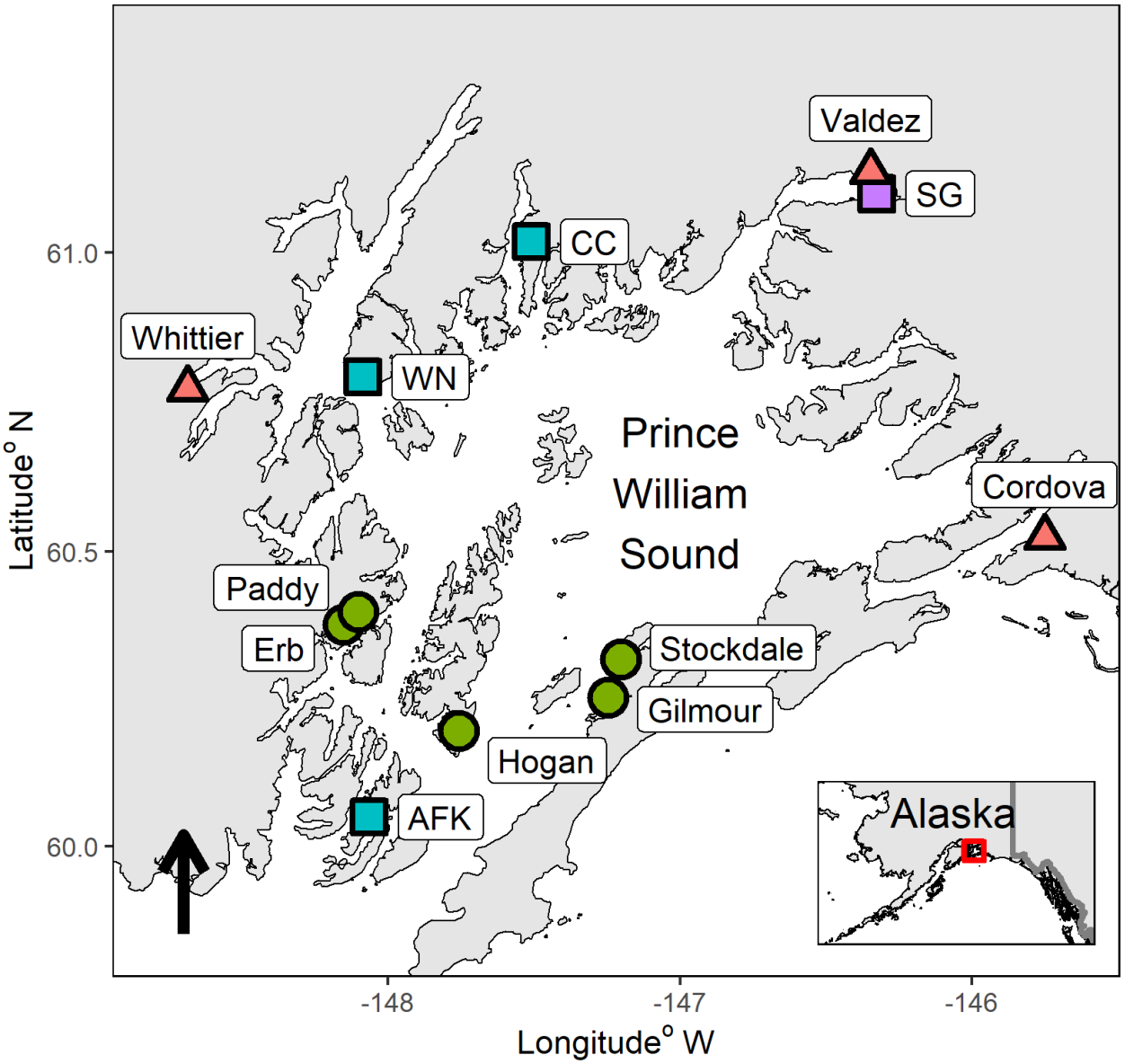
Chum

Reproductive behavior and relative reproductive success of natural- and hatchery-origin Hood Canal summer chum salmon (*Oncorhynchus keta*)

Barry A. Berejikian, Donald M. Van Doornik, Julie A. Scheurer, and Richard Bush

AHRP Fitness Study: PWS Pink Salmon

AHRP Streams in PWS



VFDA = Valdez Fisheries Development Association
PWSAC = Prince William Sound Aquaculture Corporation

Fitness = Reproductive Success

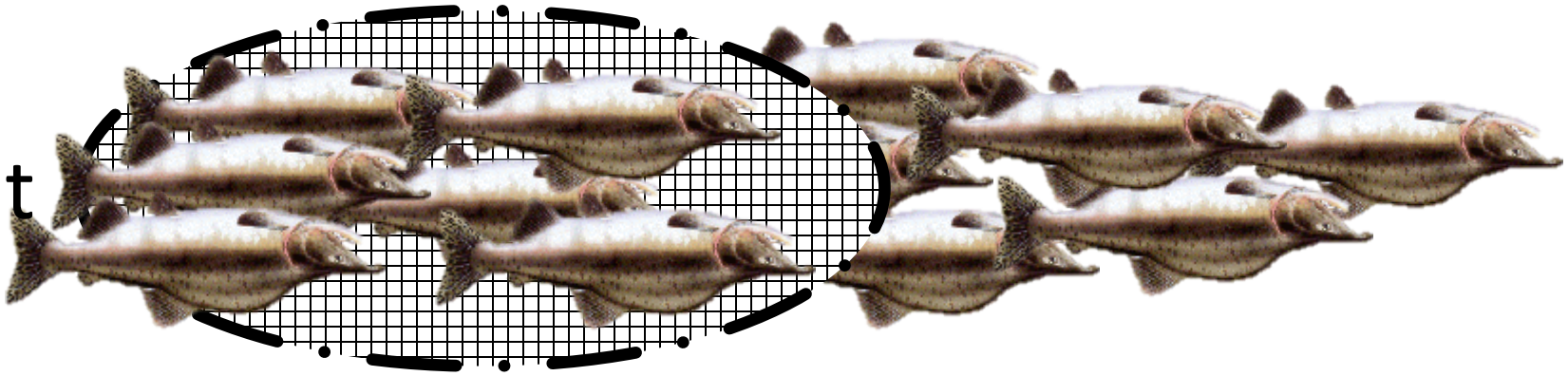
Parent 

Measuring Reproductive Success

Parent

Measuring Reproductive Success

Parent



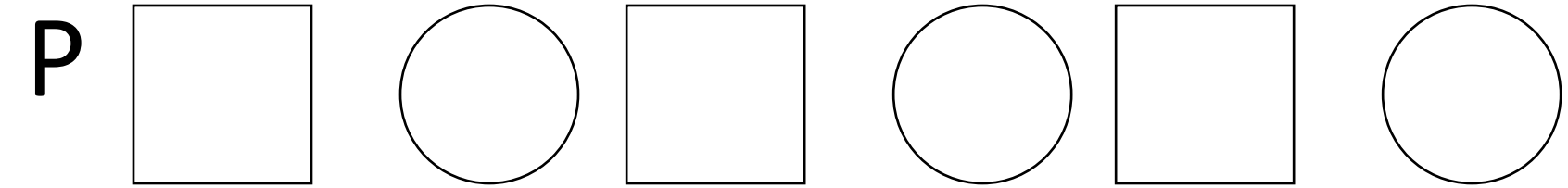
Measuring Reproductive Success

Parent

- Carcass sampling
  - Body length
  - Date
  - Location
  - Otolith
  - Tissue

Photo credit: Brad von Wichman

Measuring Reproductive Success



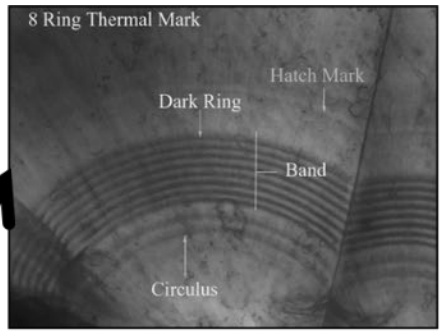
Male

Female

Measuring Reproductive Success

P

Photo credit: David Janka



Hatchery-origin

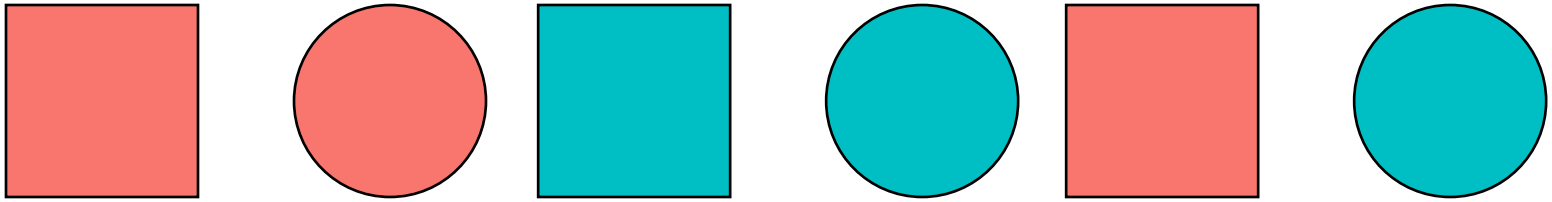
No thermal mark

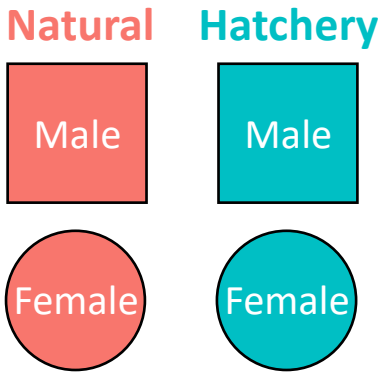
Natural-origin

Male

Female

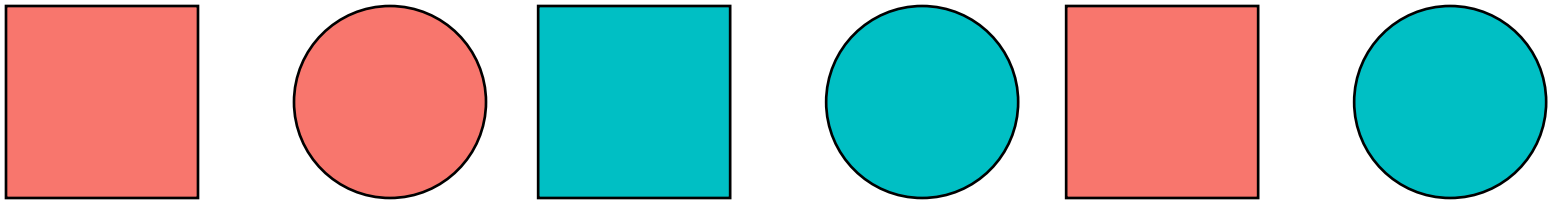
Measuring Reproductive Success

P 



Measuring Reproductive Success

P



return to stream

Offspring

harvest

stray

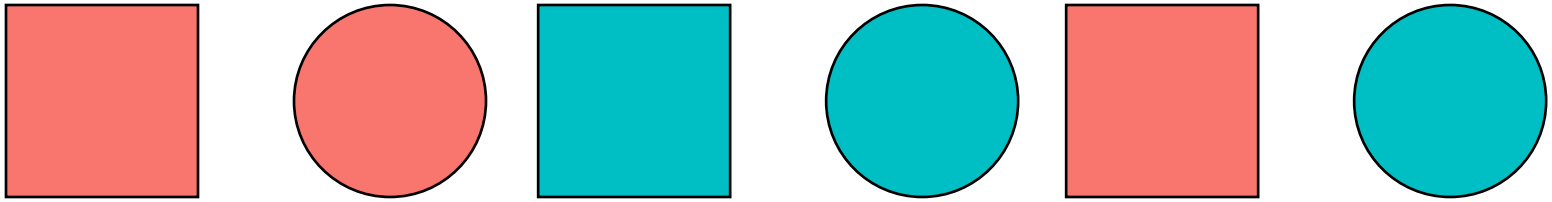
Natural Hatchery

Male Male

Female Female

Measuring Reproductive Success

P



O

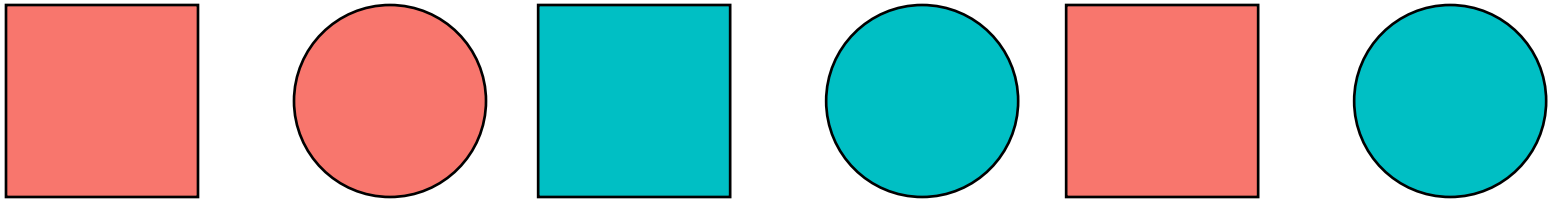
Natural **Hatchery**

Male Male

Female Female

Measuring Reproductive Success

P



O

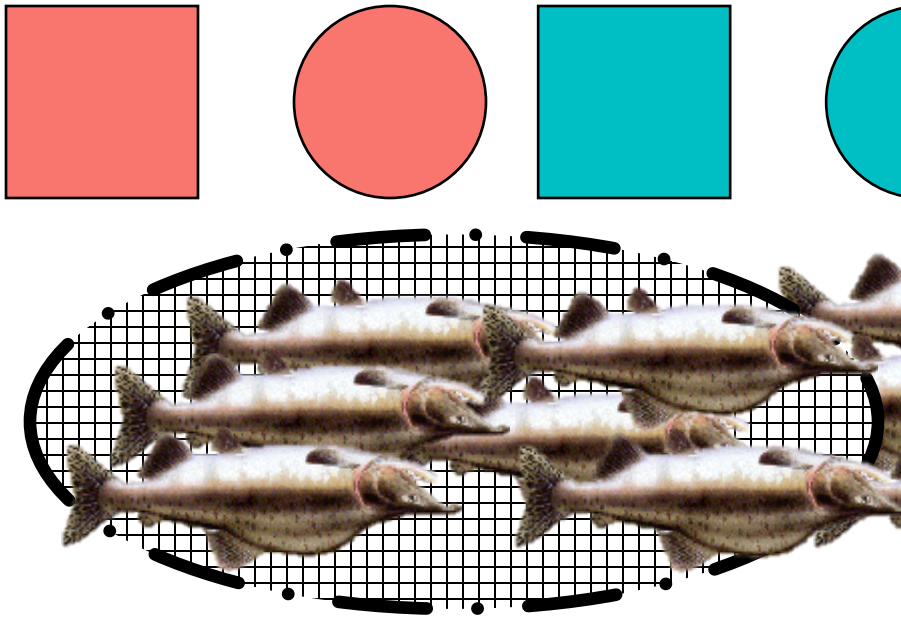
Natural **Hatchery**

Male Male

Female Female

Measuring Reproductive Success

P



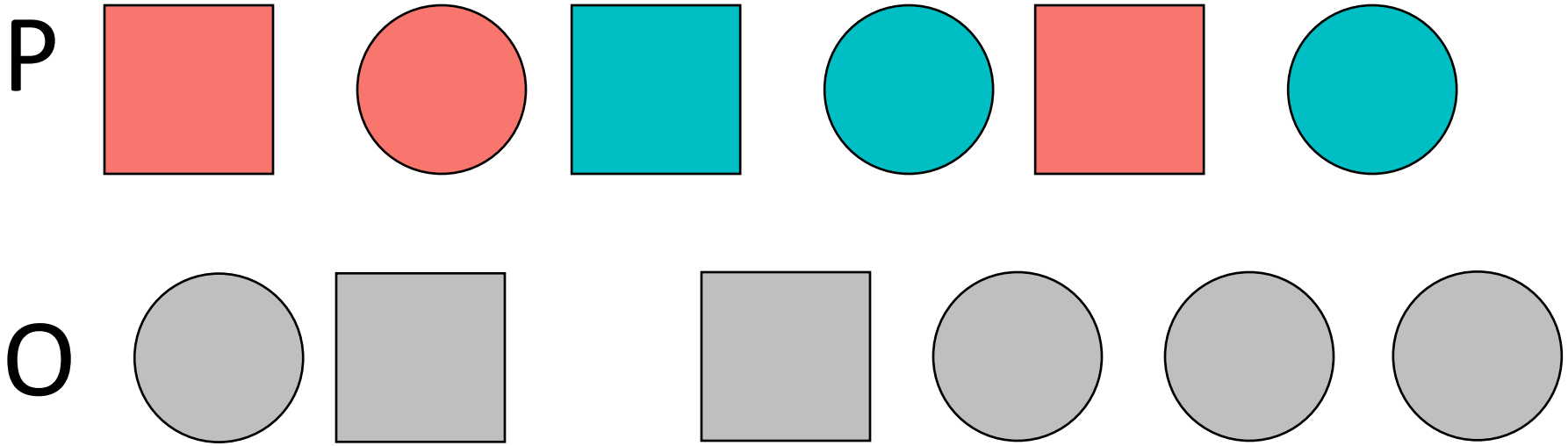
O

Natural **Hatchery**

Male Male

Female Female

Measuring Reproductive Success



Natural **Hatchery**

Male Male

Female Female

Measuring Reproductive Success

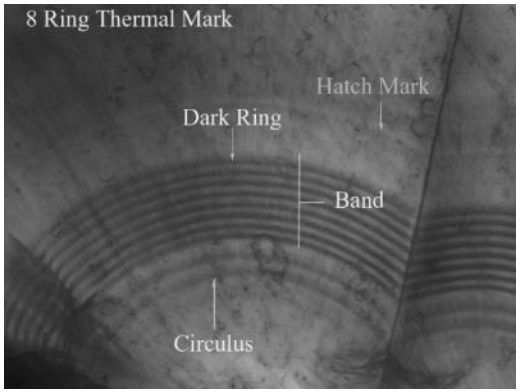
P

O

Natural Hatchery

Male Male

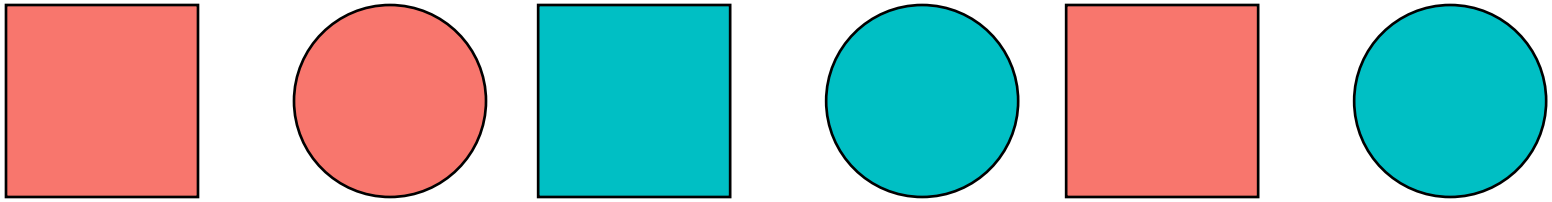
Female Female



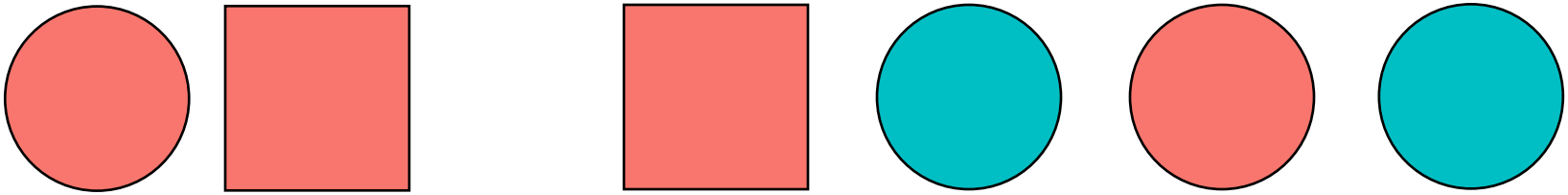
Hatchery-origin

Measuring Reproductive Success

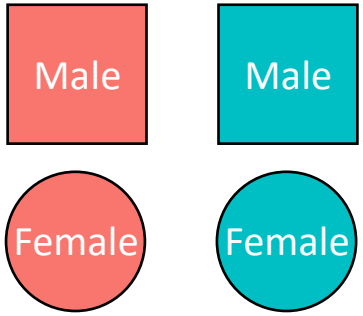
P



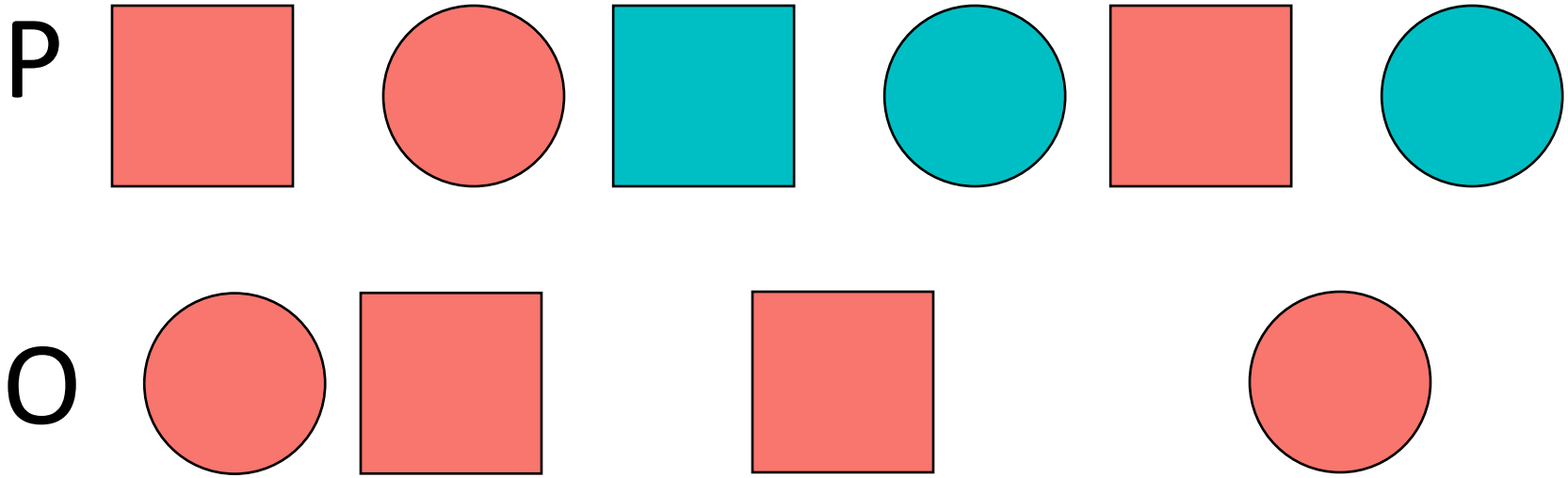
O



Natural **Hatchery**



Measuring Reproductive Success



Natural **Hatchery**

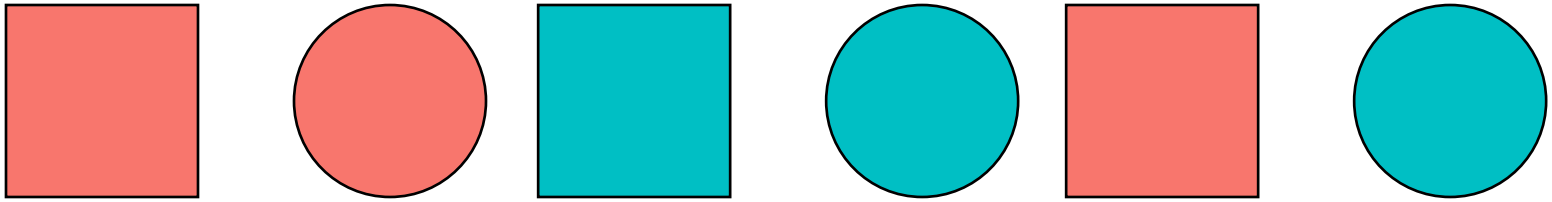
Male Male

Female Female

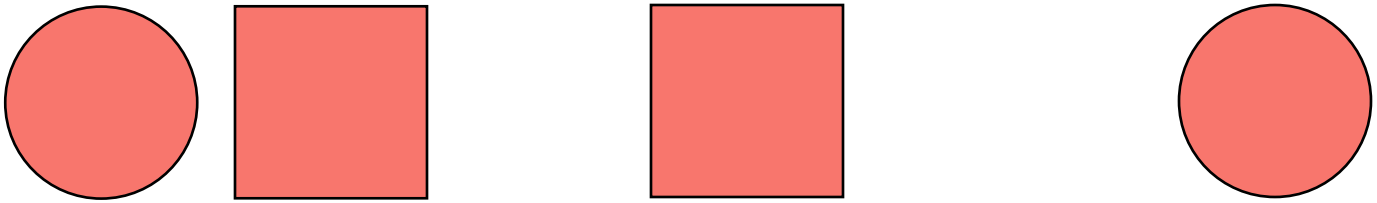
Hatchery-origin fish are not genotyped in the offspring generation because they have a known origin.

Measuring Reproductive Success

P



O



Natural **Hatchery**

Male Male

Female Female

298 markers

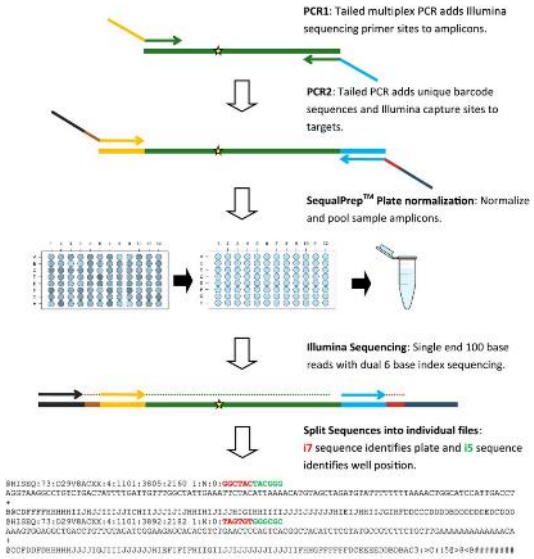
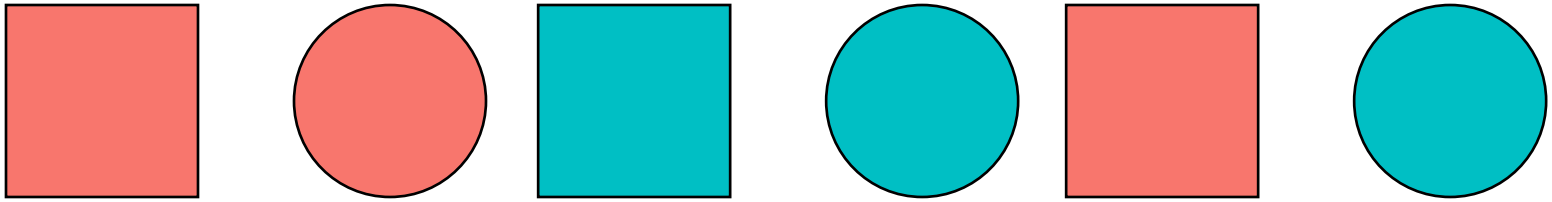


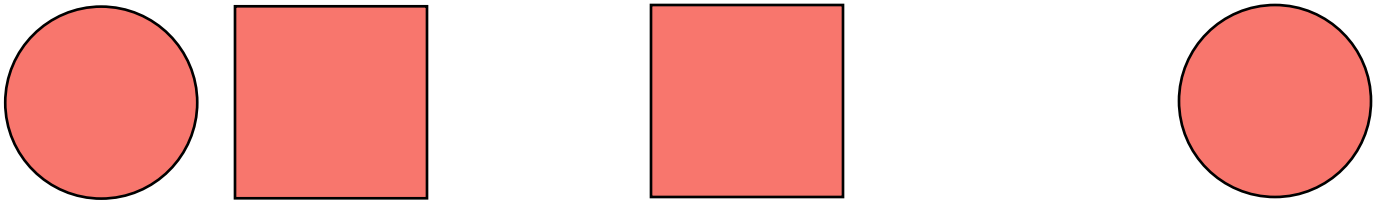
Figure 1 – Campbell et al. 2015

Measuring Reproductive Success

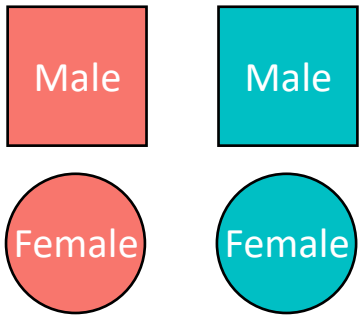
P



O



Natural Hatchery



298 markers

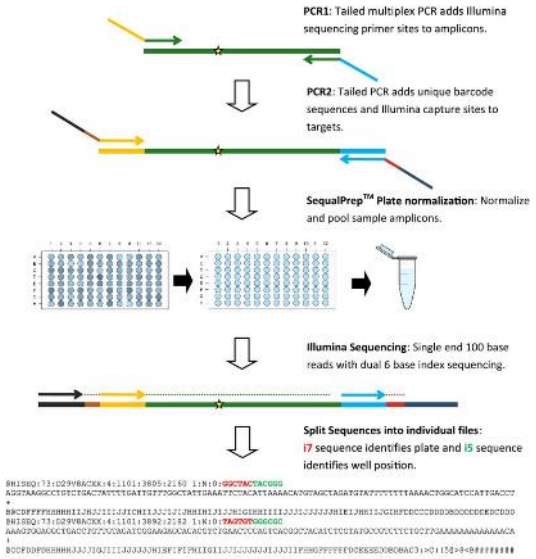
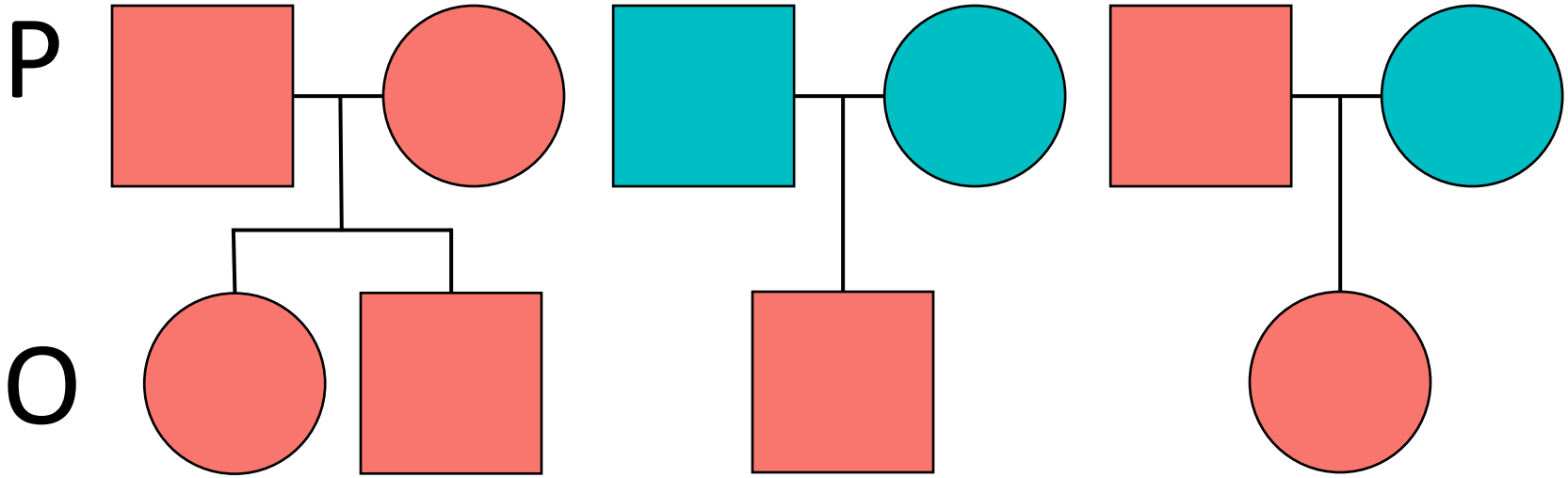


Figure 1 – Campbell et al. 2015

Riester et al. 2009

Measuring Reproductive Success

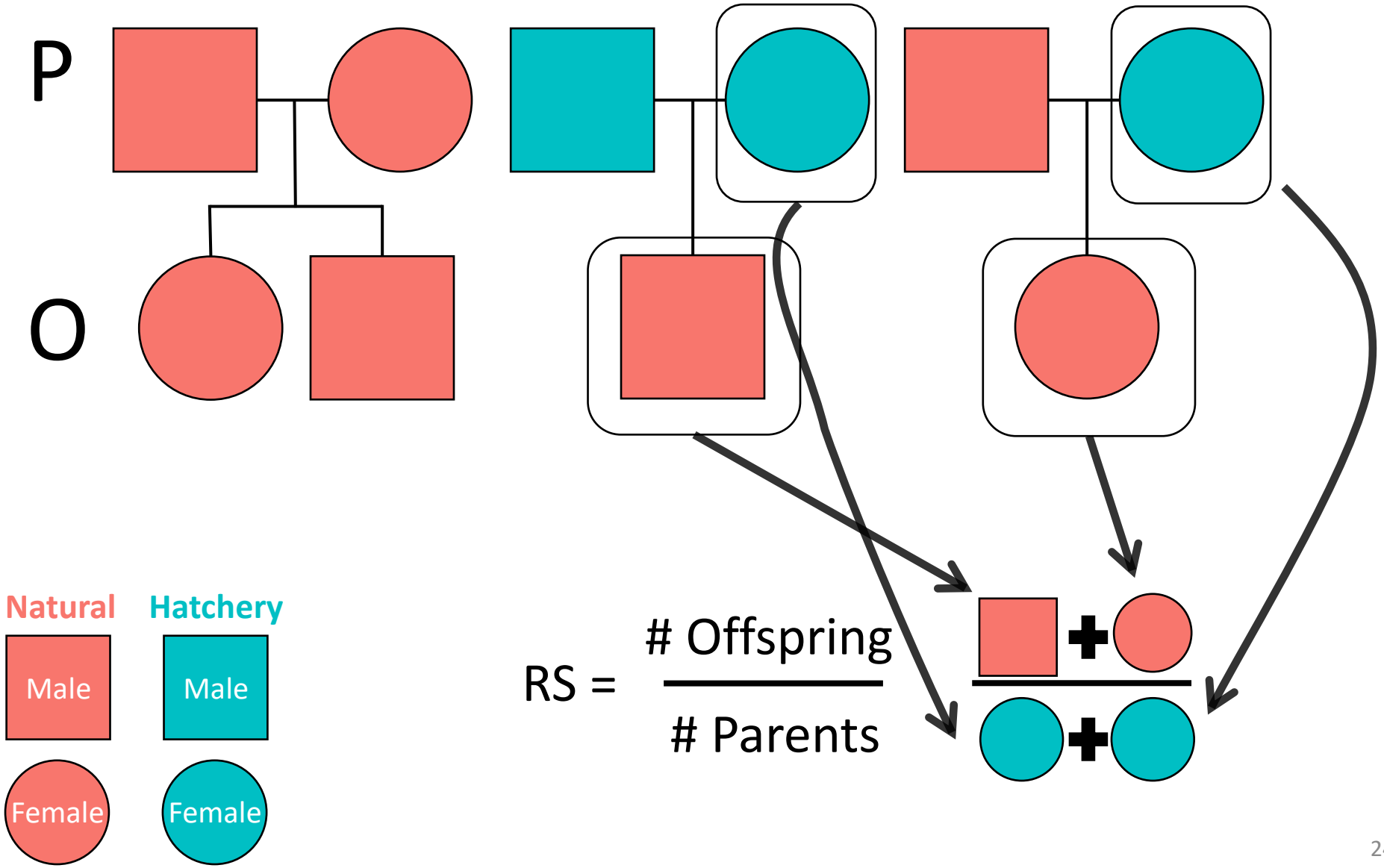


Natural Hatchery

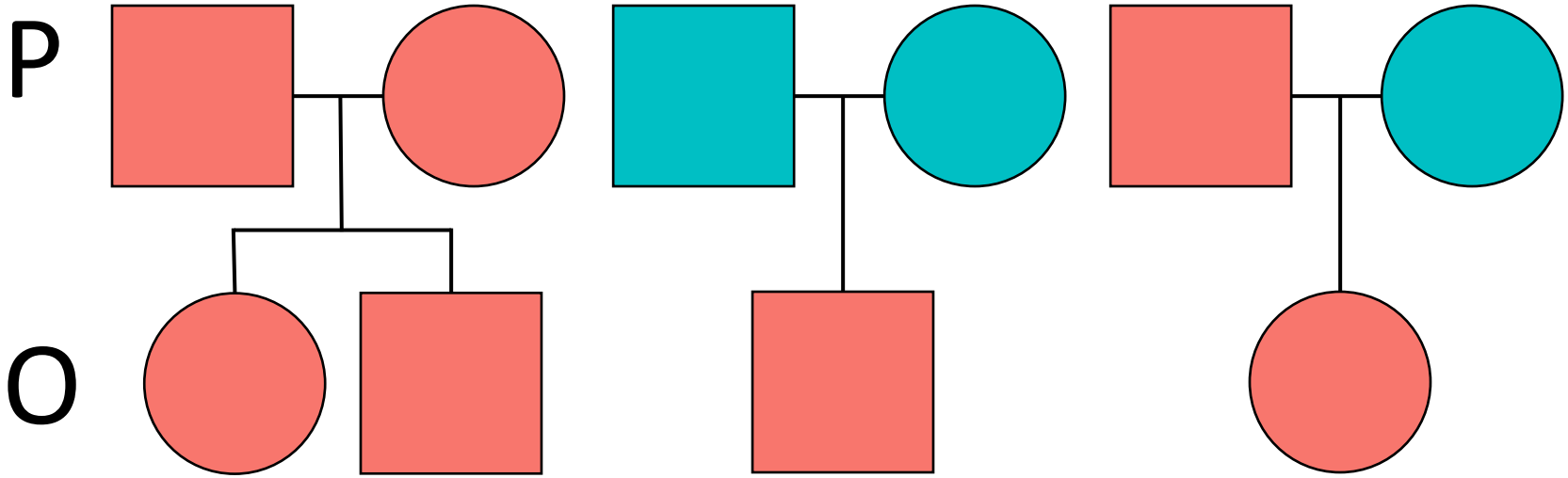
Male Male

Female Female

Measuring Reproductive Success



Measuring Reproductive Success



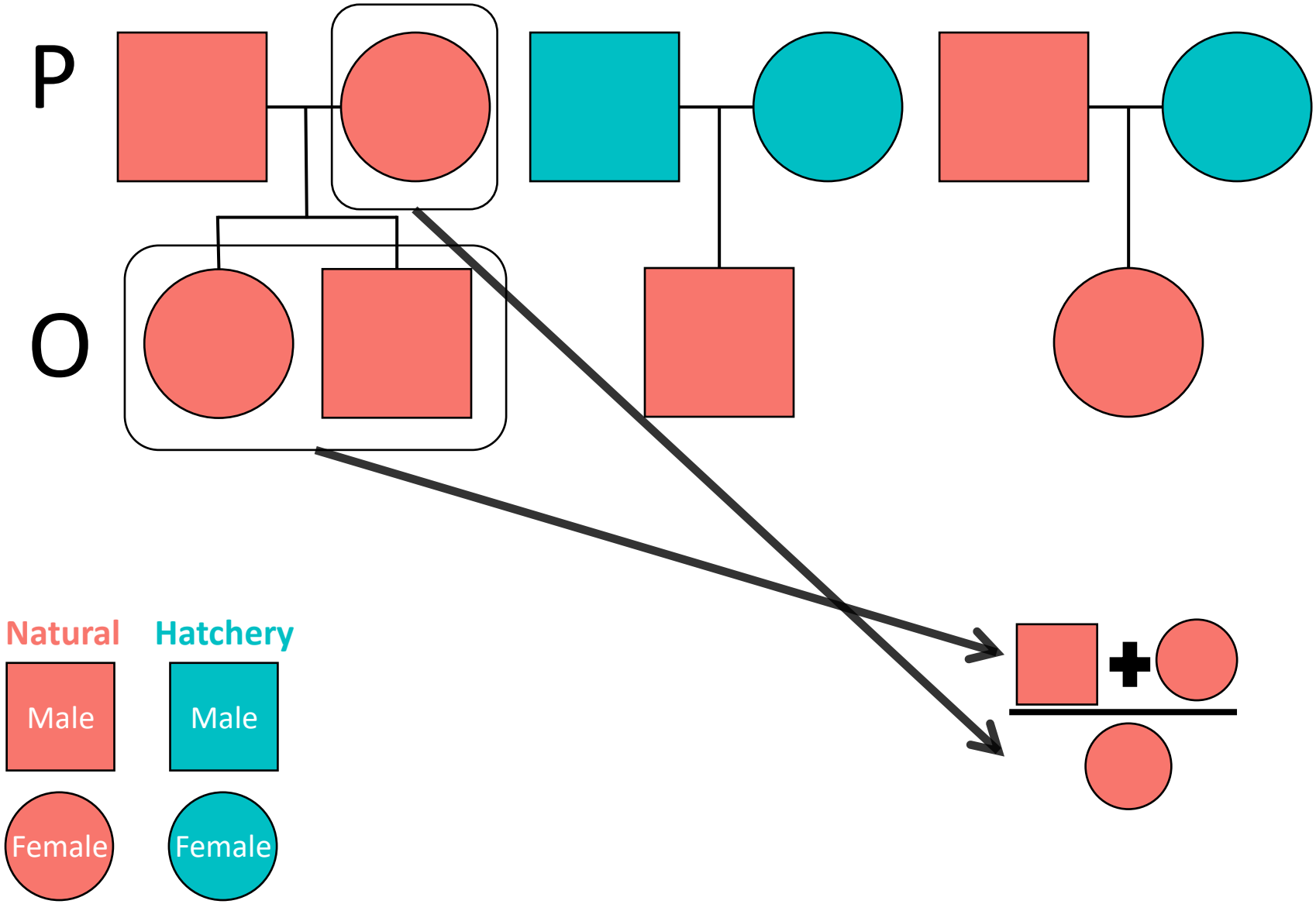
$RS_{H\ Female} = 1$

Natural Hatchery

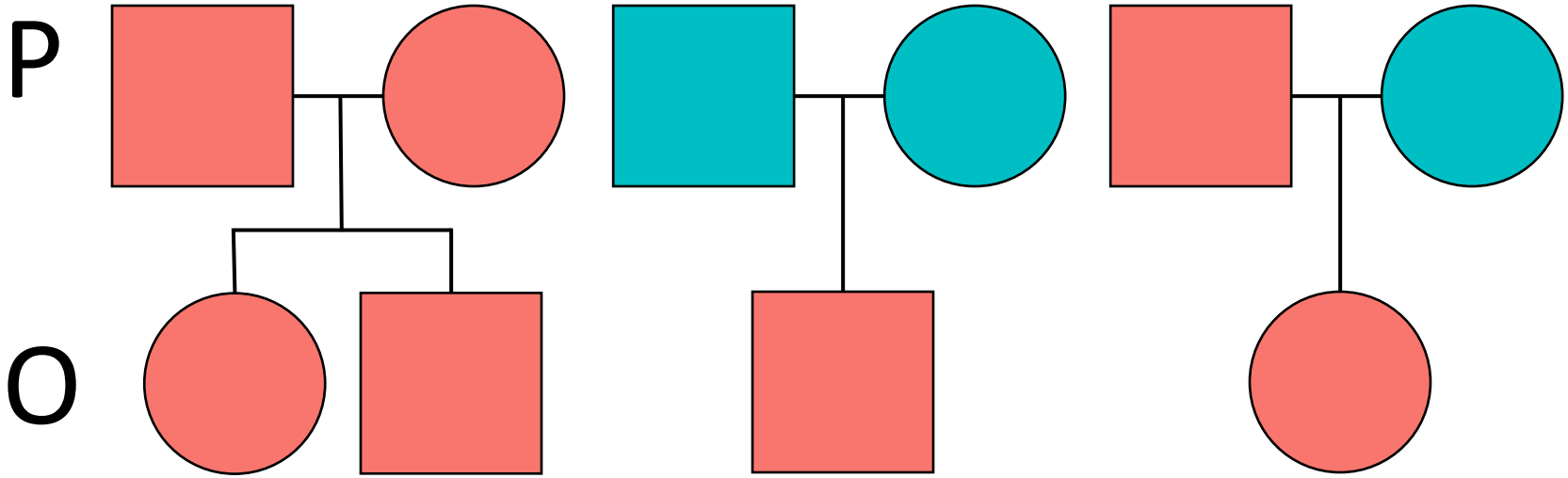
Male Male

Female Female

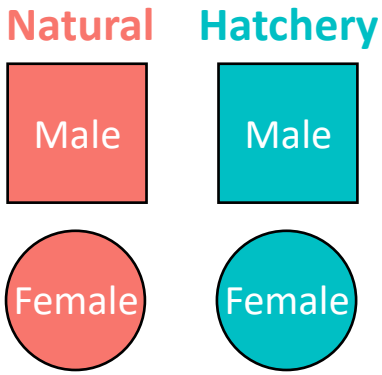
Measuring Reproductive Success



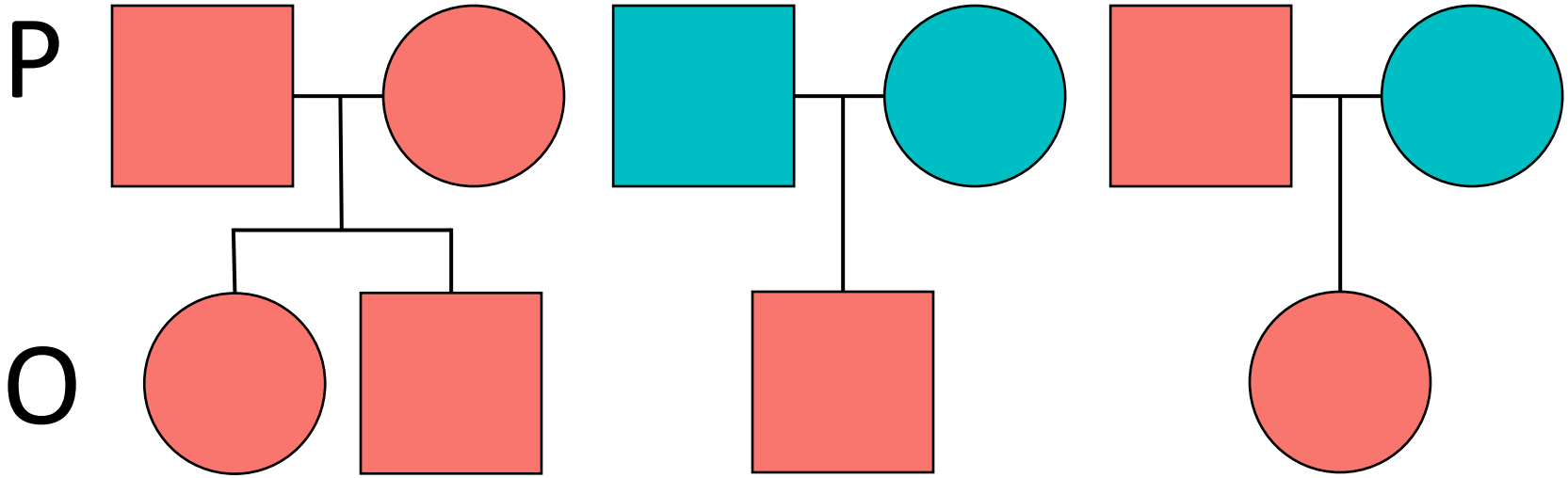
Measuring Reproductive Success



$RS_{N\ Female} = 2$ $RS_{H\ Female} = 1$



Measuring Reproductive Success



$RS_{N\ Female} = 2$ $RS_{H\ Female} = 1$

Natural Hatchery

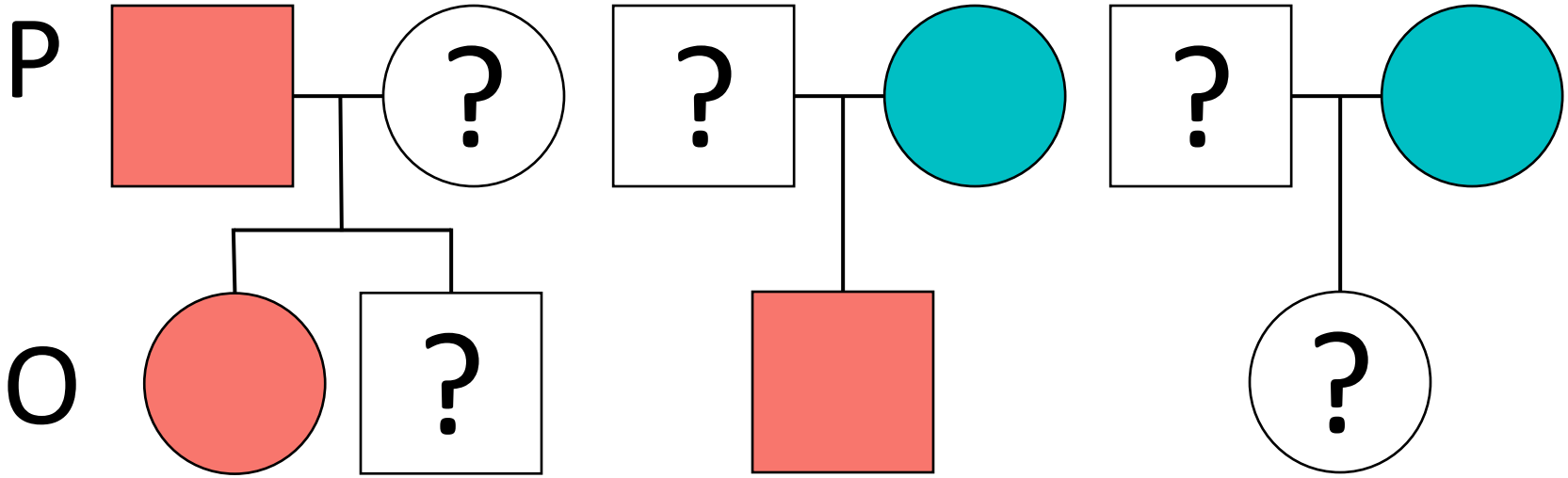
Male Male

Female Female

Relative Reproductive Success (RRS)

$$RRS = \frac{1}{2} = 0.5$$

Measuring Reproductive Success



Natural Hatchery

Male Male

Female Female

Relative Reproductive Success (RRS)

$$\mathbf{RRS} = \frac{\overline{RS}_{Hatchery}}{\overline{RS}_{Natural}}$$

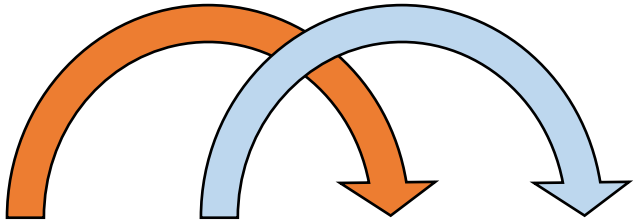
AHRP Streams in PWS

Stream	2013	2014	2015	2016	2017	2018	2019
Hogan	P	P	P,O	P,O	P,O,G	O,G	O,G

P – parents
O – offspring
G – grand-offspring

Odd-lineage
Even-lineage

AHRP Streams in PWS

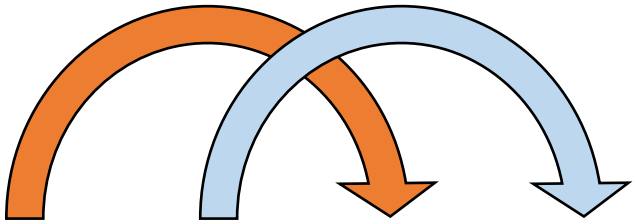


Stream	2013	2014	2015	2016	2017	2018	2019
Hogan	P	P	P,O	P,O	P,O,G	O,G	O,G

P – parents
O – offspring
G – grand-offspring

Odd-lineage
Even-lineage

AHRP Streams in PWS



Stream	2013	2014	2015	2016	2017	2018	2019
Hogan	P	P	P,O	P,O	P,O,G	O,G	O,G

P – parents
O – offspring
G – grand-offspring

Odd-lineage

Even-lineage

AHRP Streams in PWS

Stream	2013	2014	2015	2016	2017	2018	2019	2020
Hogan	P	P	P,O	P,O	P,O,G	O,G	O,G	
Stockdale	P	P	P,O	P,O	P,O,G	O,G	O,G	
Gilmour		P	P	P,O	P,O	O,G	O,G	
Paddy	P	P	P,O	P,O	O,G	P,O,G		O,G
Erb	P	P	P,O	P,O	O,G	P,O,G		O,G

P – parents

O – offspring

G – grand-offspring

Odd-lineage

Even-lineage

>235K samples!

AHRP Streams in PWS

Presented 2019

Stream	2013	2014	2015	2016	2017	2018	2019	2020
Hogan	P	P	P,O	P,O	P,O,G	O,G	O,G	
Stockdale	P	P	P,O	P,O	P,O,G	O,G	O,G	
Gilmour		P	P	P,O	P,O	O,G	O,G	
Paddy	P	P	P,O	P,O	O,G	P,O,G		O,G
Erb	P	P	P,O	P,O	O,G	P,O,G		O,G

P – parents

O – offspring

G – grand-offspring

Odd-lineage

Even-lineage

>235K samples!

AHRP Streams in PWS

Presented 2020

Stream	2013	2014	2015	2016	2017	2018	2019	2020
Hogan	P	P	P,O	P,O	P,O,G	O,G	O,G	
Stockdale	P	P	P,O	P,O	P,O,G	O,G	O,G	
Gilmour		P	P	P,O	P,O	O,G	O,G	
Paddy	P	P	P,O	P,O	O,G	P,O,G		O,G
Erb	P	P	P,O	P,O	O,G	P,O,G		O,G

P – parents

O – offspring

G – grand-offspring

Odd-lineage

Even-lineage

>235K samples!

AHRP Streams in PWS

Presented 2020

Stream	2013	2014	2015	2016	2017	2018	2019	2020
Hogan	P	P	P,O	P,O	P,O,G	O,G	O,G	
Stockdale	P	P	P,O	P,O	P,O,G	O,G	O,G	

Shedd, K.R., Lescak, E.A., Habicht, C., Knudsen, E.E., Dann, T.H., Hoyt, H.A., Prince, D.J. and Templin, W.D. 2022. Reduced relative fitness in hatchery-origin Pink Salmon in two streams in Prince William Sound, Alaska. Evolutionary Applications. https://doi.org/10.1111/eva.13356

G – grand-offspring

AHRP Streams in PWS

Presenting 2022

Stream	2013	2014	2015	2016	2017	2018	2019	2020
Hogan	P	P	P,O	P,O	P,O,G	O,G	O,G	
Stockdale	P	P	P,O	P,O	P,O,G	O,G	O,G	
Gilmour		P	P	P,O	P,O	O,G	O,G	
Paddy	P	P	P,O	P,O	O,G	P,O,G		O,G
Erb	P	P	P,O	P,O	O,G	P,O,G		O,G

P – parents

O – offspring

G – grand-offspring

Odd-lineage

Even-lineage

>235K samples!

Average Reproductive Success

Stockdale 2014/2016

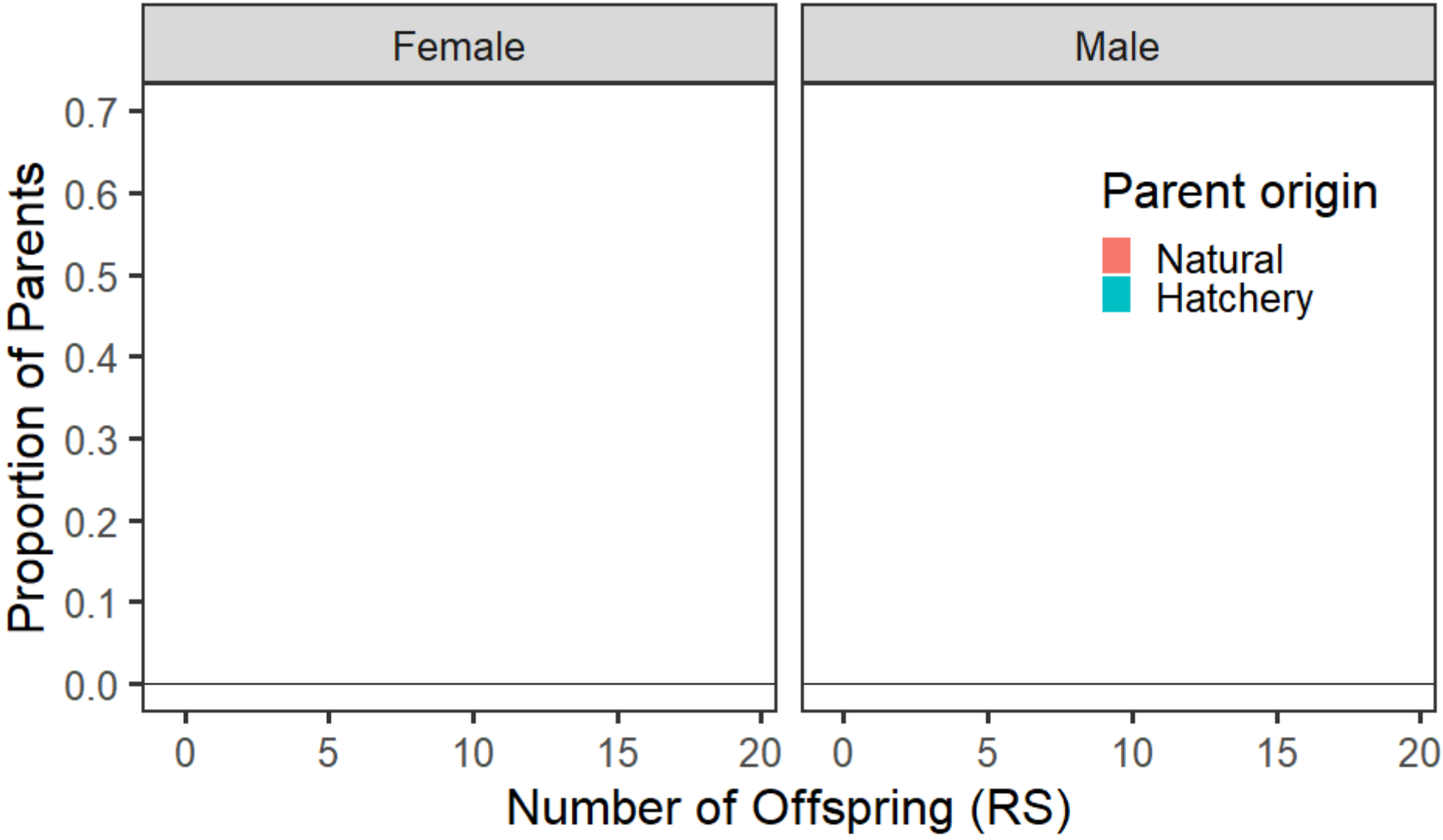
Female	2014 Parents	2016 Offspring	Average RS
Hatchery	**230**	**196**	**0.85**
Natural	**221**	**448**	**2.03**

RRS = 0.42

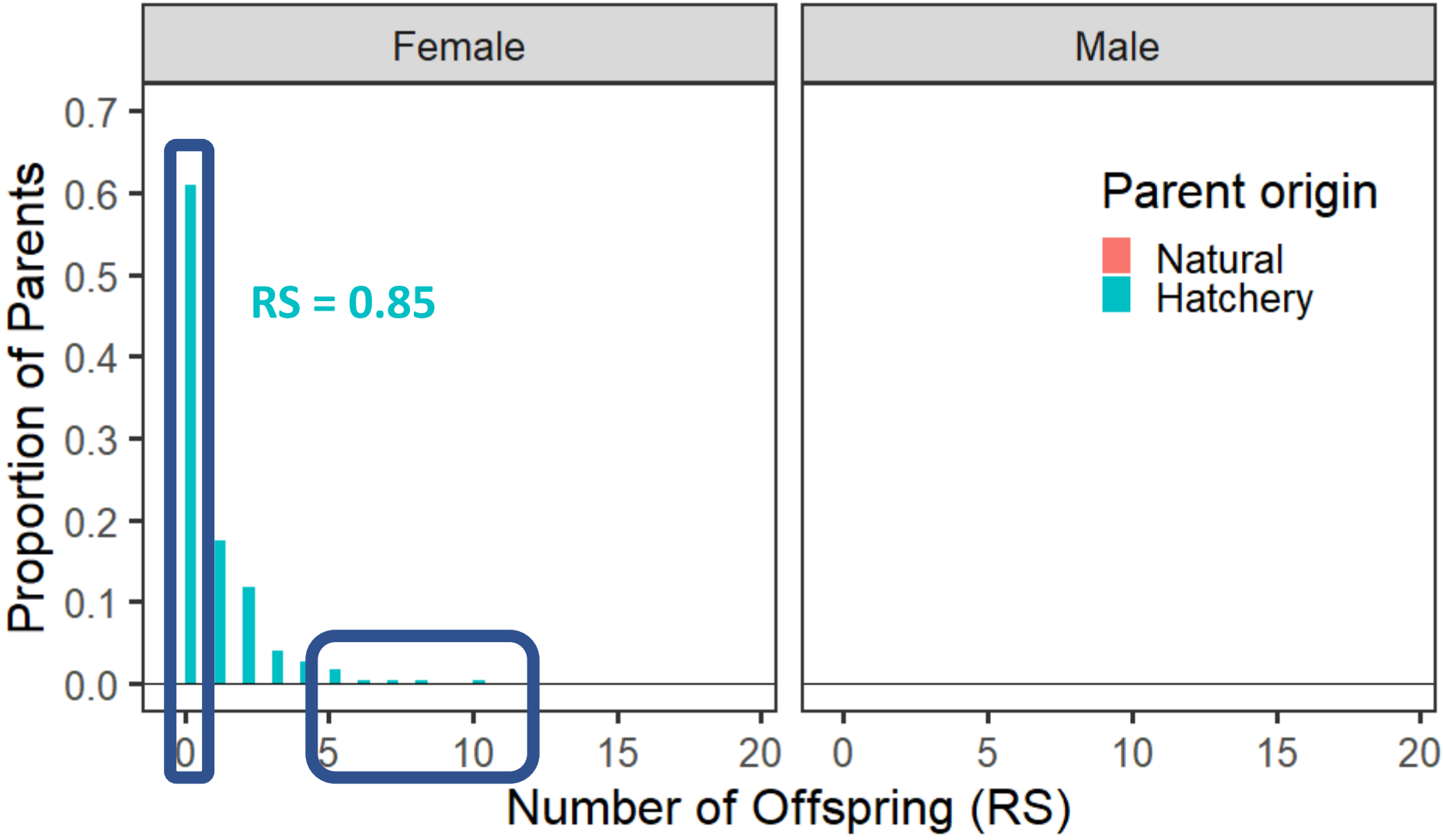
Male	2014 Parents	2016 Offspring	Average RS
Hatchery	**206**	**177**	**0.86**
Natural	**137**	**417**	**3.04**

RRS = 0.28

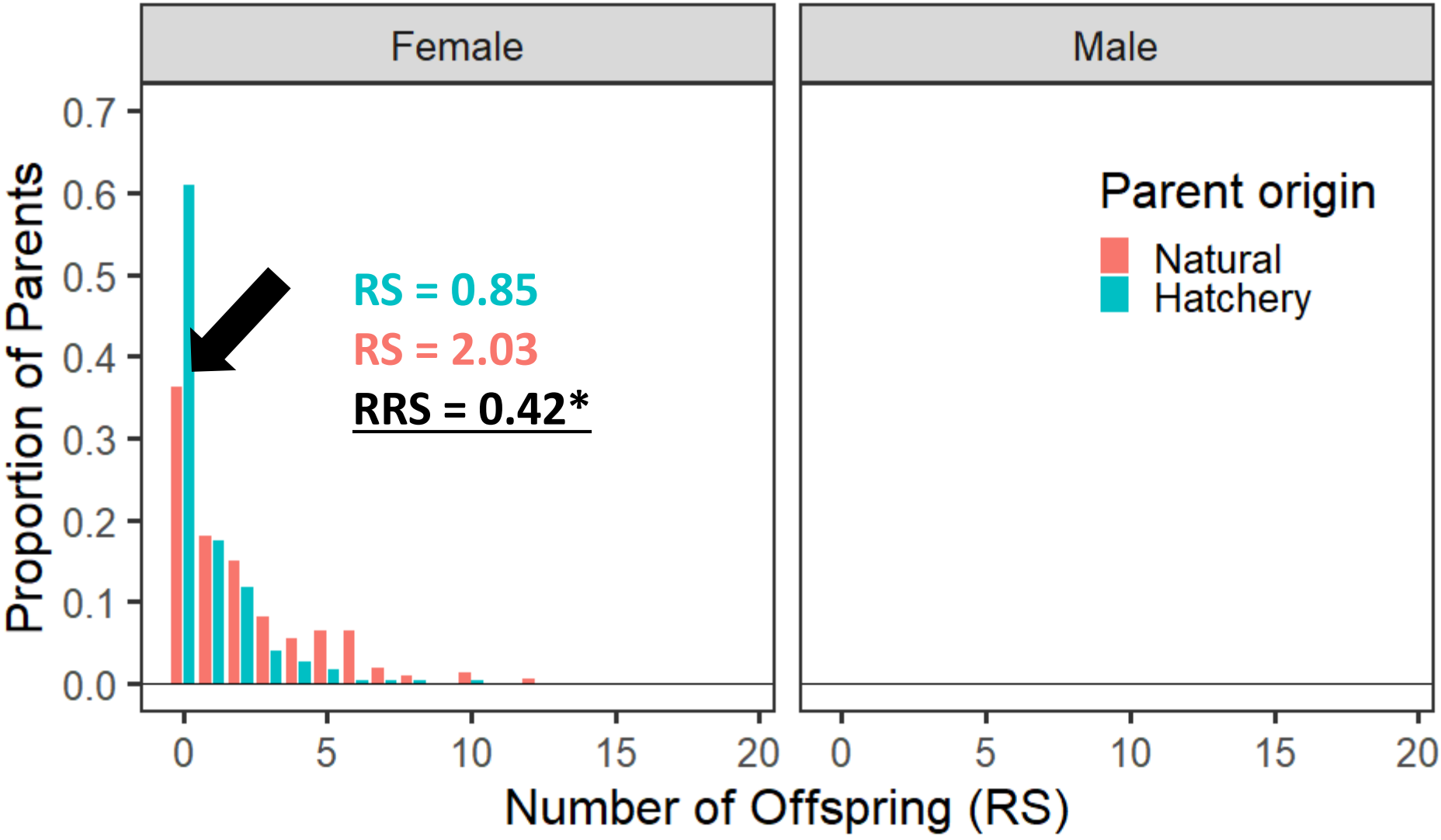
RS Distribution: Stockdale 2014/2016



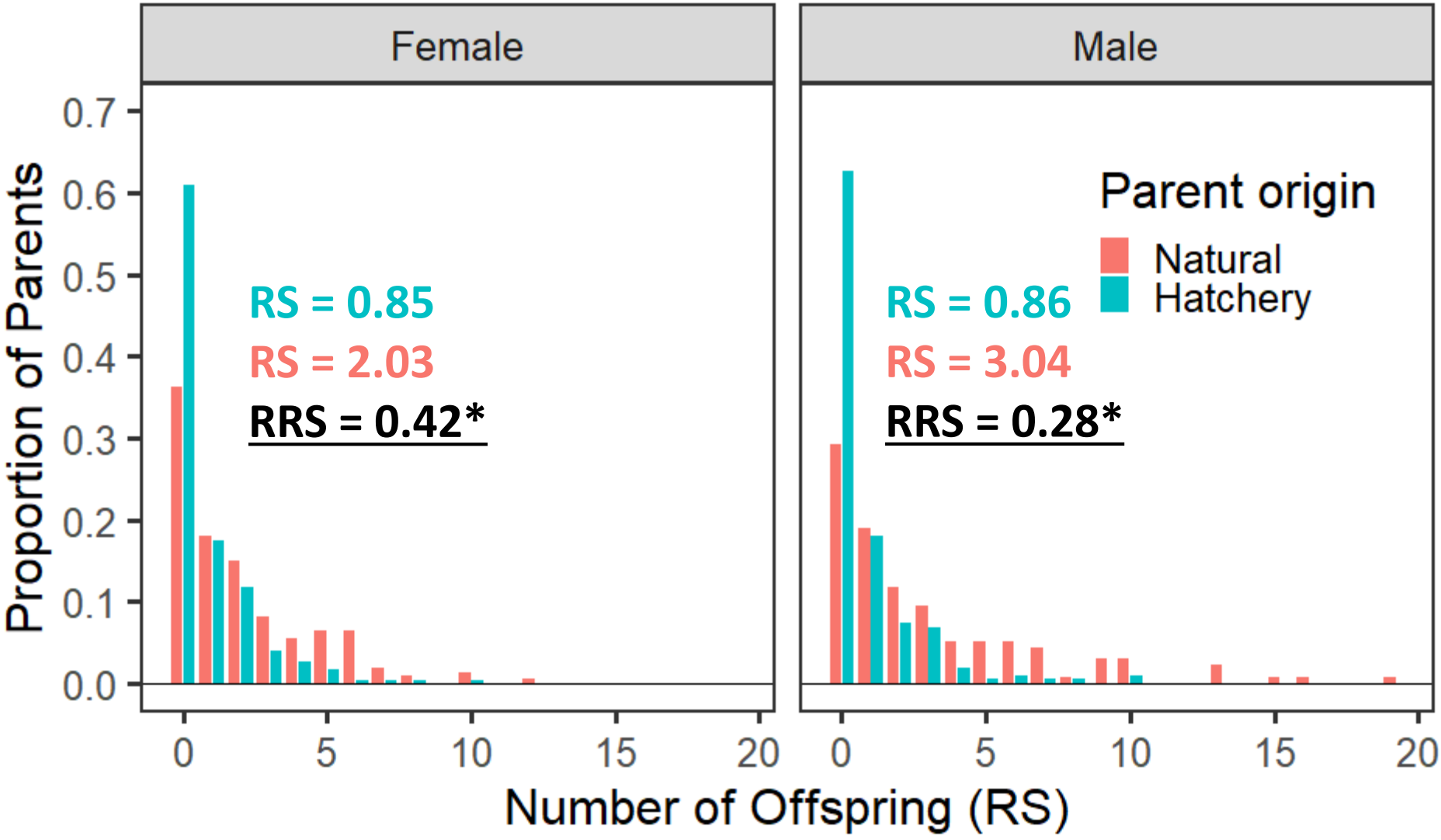
RS Distribution: Stockdale 2014/2016



RS Distribution: Stockdale 2014/2016



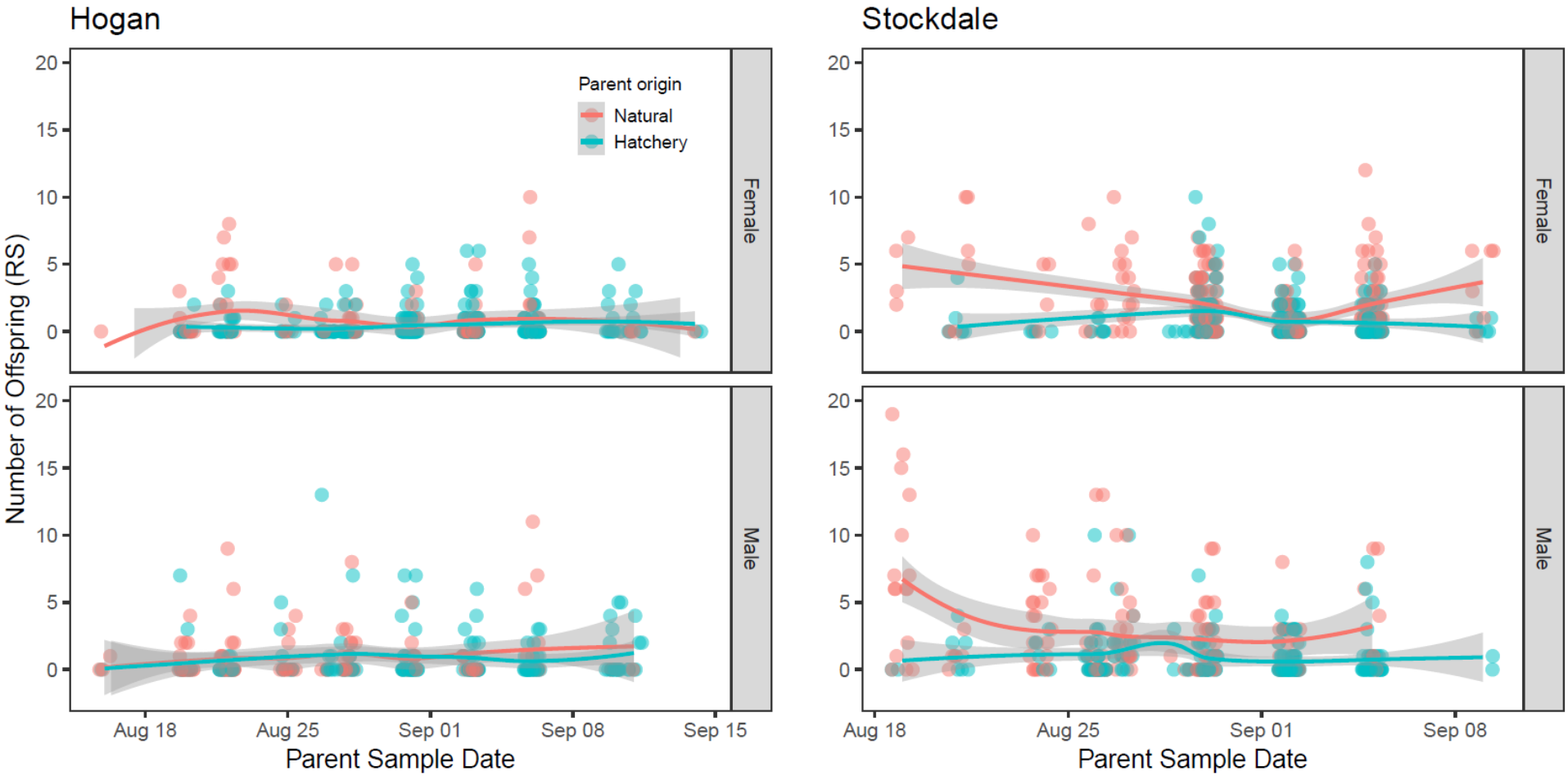
RS Distribution: Stockdale 2014/2016



Accounting for Phenotypic Differences

- Phenotypic differences between hatchery/natural
  - Body length
  - Sample date (run timing)
  - Sample location (within a stream)
    - Intertidal vs. freshwater spawners
- Correlated with number of offspring (RS)

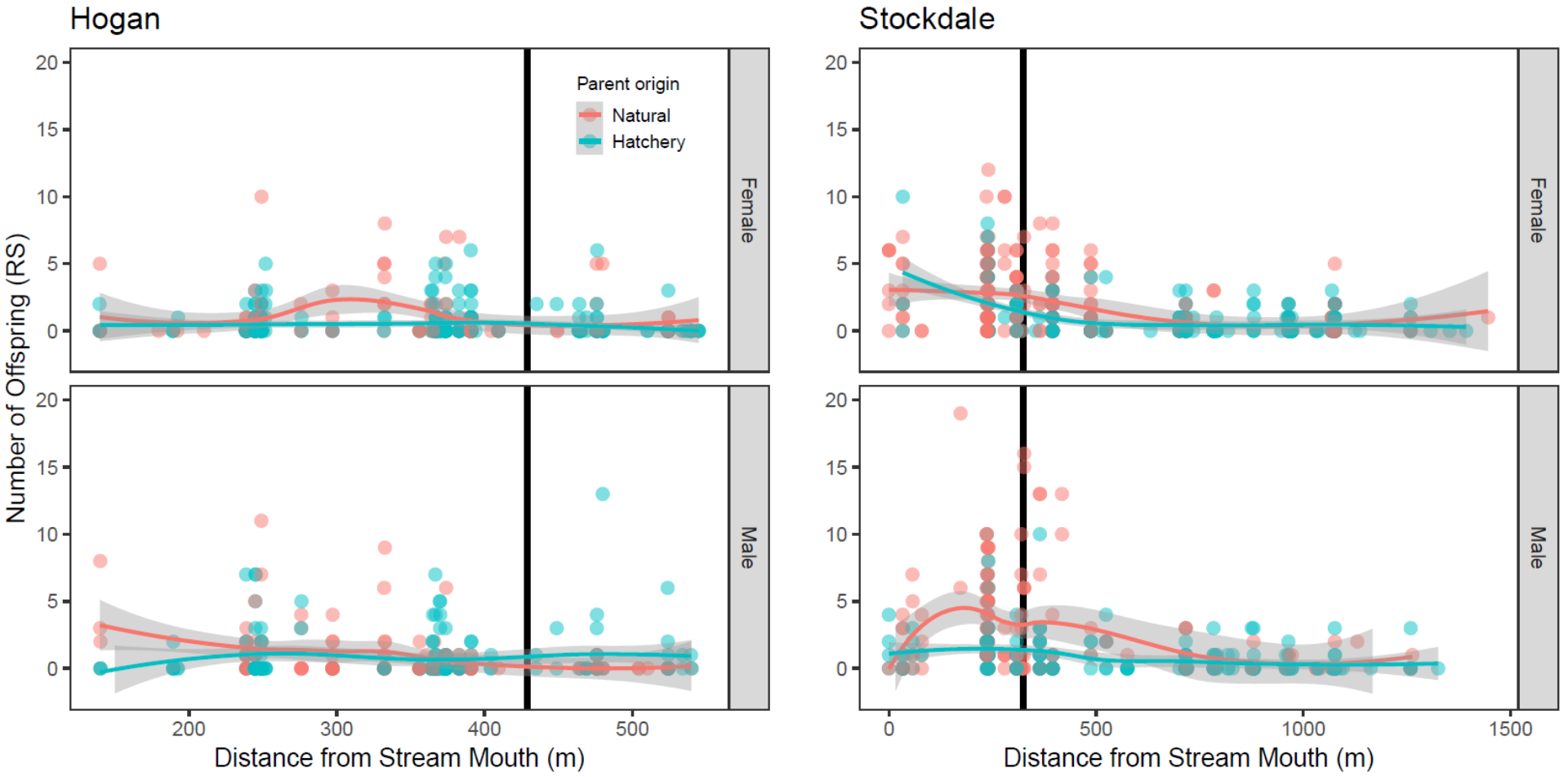
RS vs. Sample Date (2014/2016)



RS is higher early and late in the season for Stockdale…
but not for hatchery fish

Figure 4 – Shedd et al. 2022

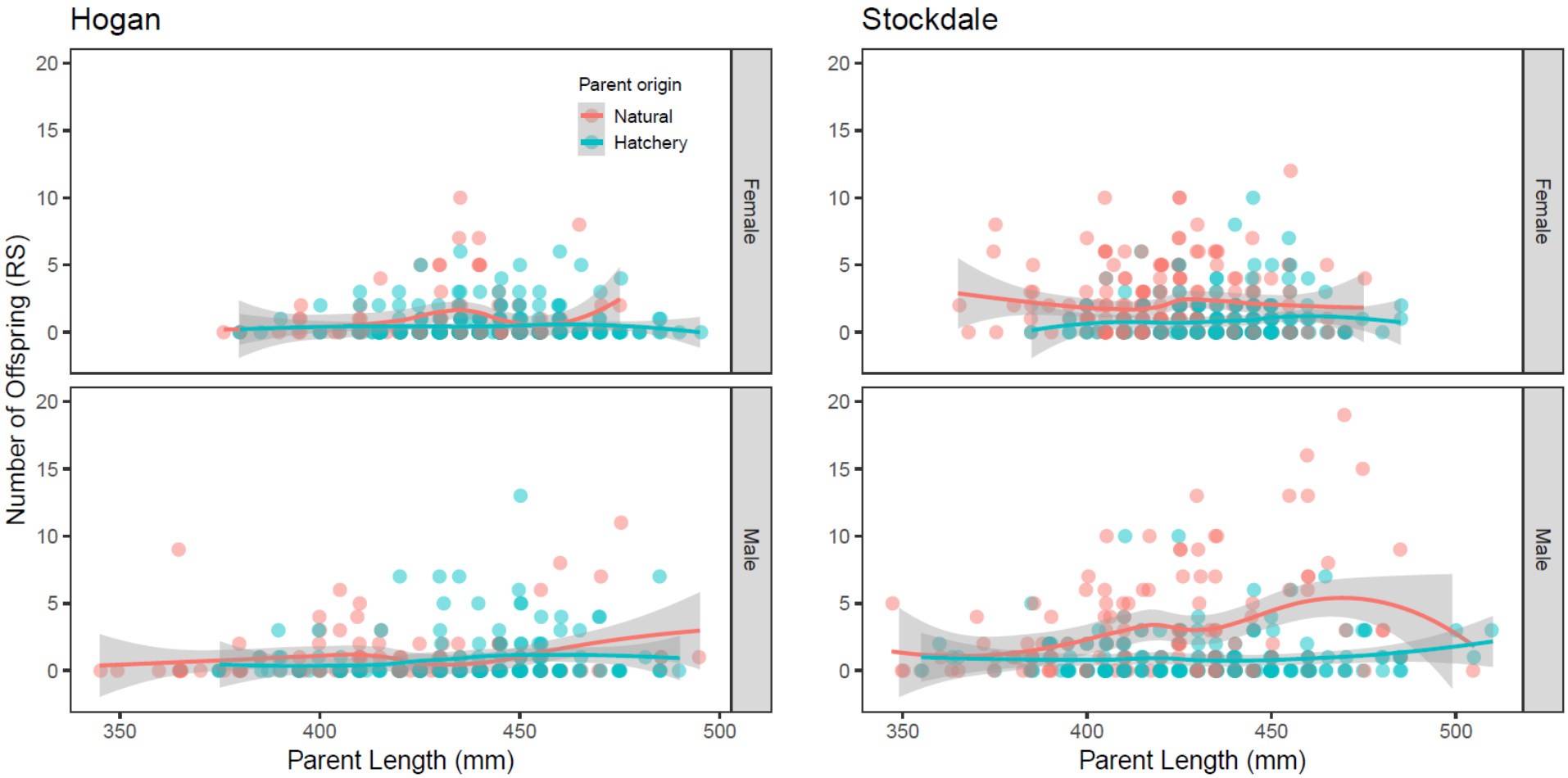
RS vs. Sample Location (2014/2016)



RS is higher near the intertidal in Stockdale

Figure 5 – Shedd et al. 2022

RS vs. Body Length (2014/2016)



RS is higher for larger males in Stockdale…
but not for hatchery fish

Figure 6 – Shedd et al. 2022

Accounting for Phenotypic Differences

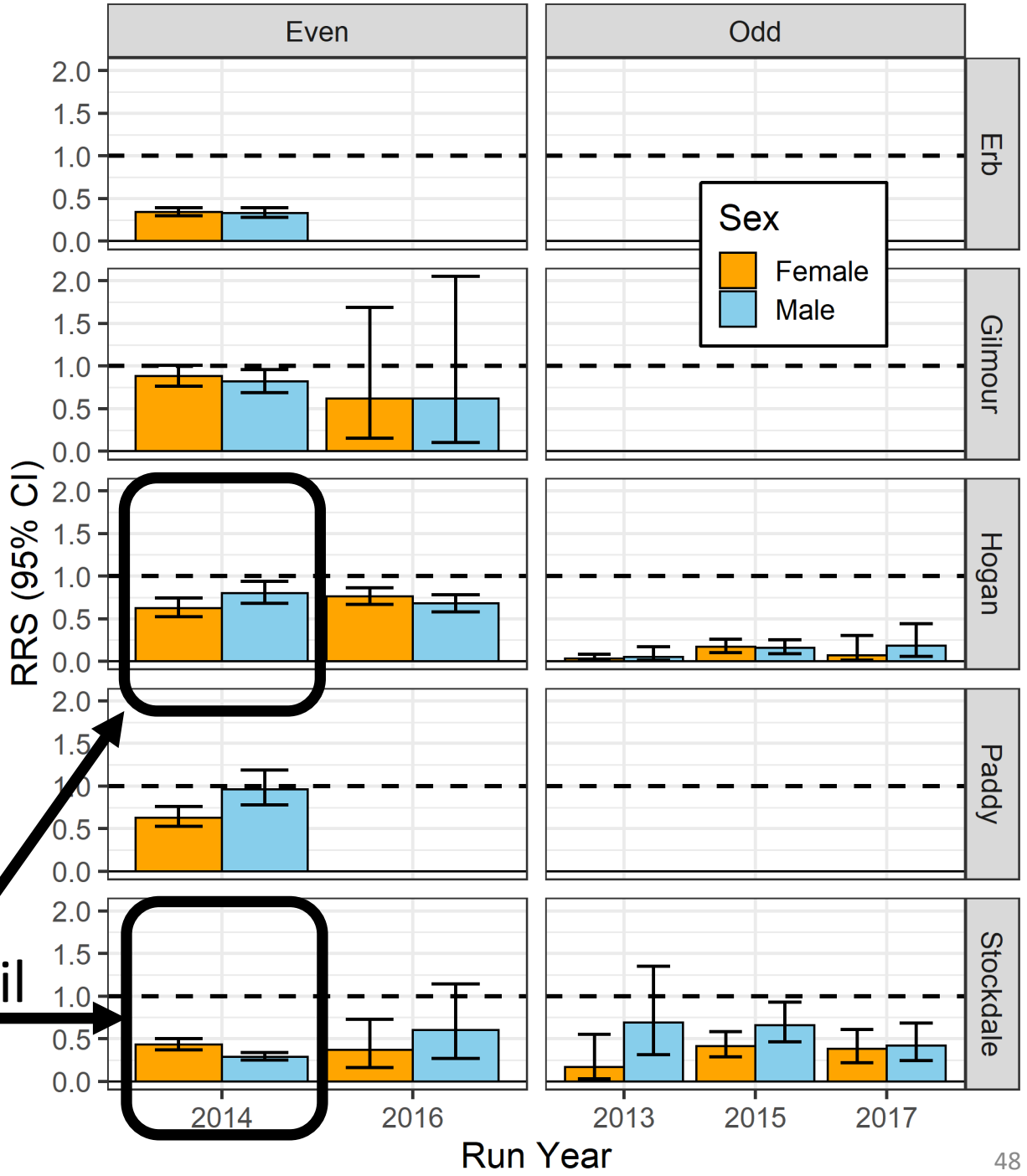
- Differences between hatchery/natural
  - Body length
  - Sample date (run timing)
  - Sample location (within a stream)
- Correlated with number of offspring (RS)
- Generalized linear models (GLM)
  - Origin - RRS ~ 42-60%

Summary of RRS to Date

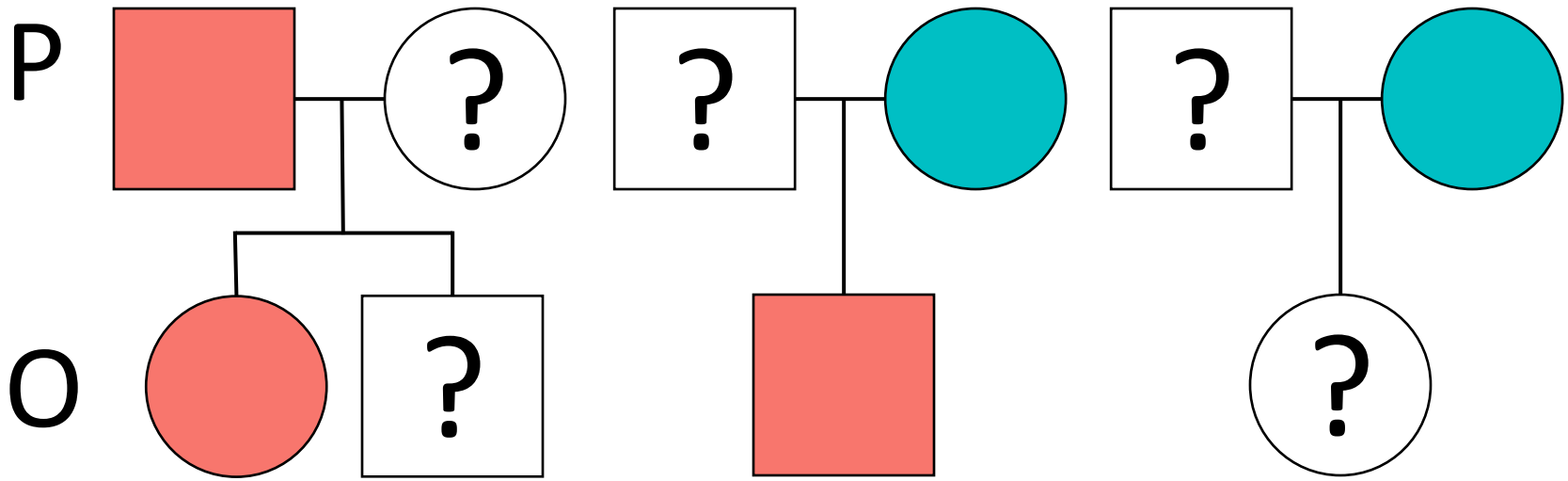
<u>128K</u> samples analyzed

$$RRS = \frac{\overline{RS}_{Hatchery}}{\overline{RS}_{Natural}}$$

Results shown in detail on previous slides



Parent-Offspring Duos

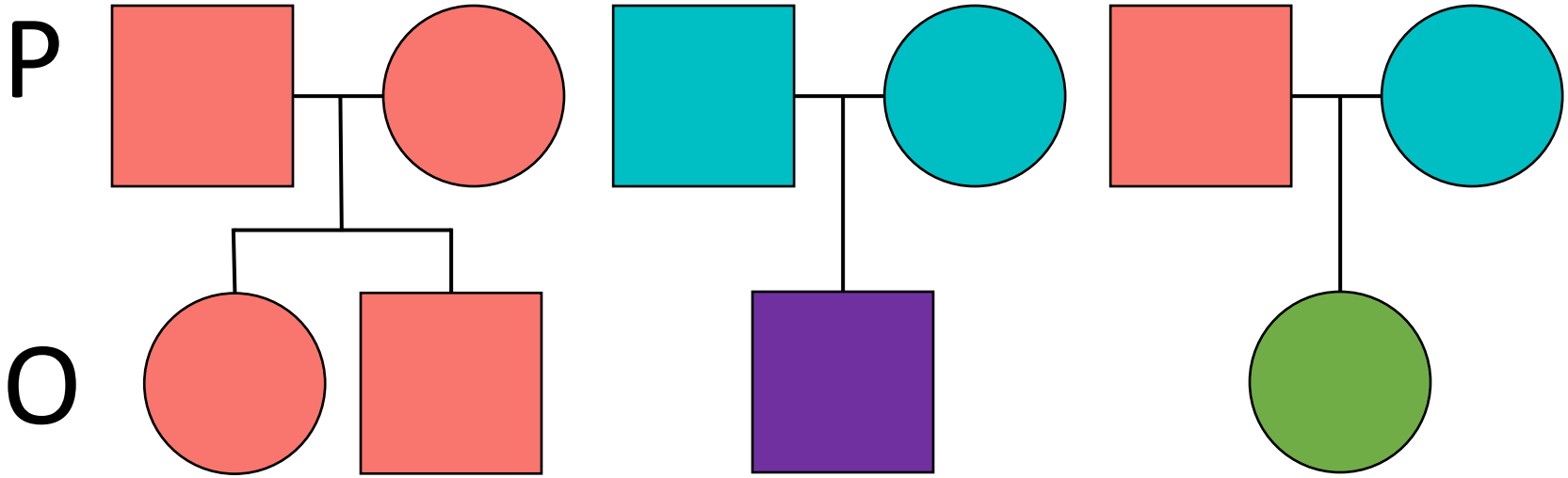


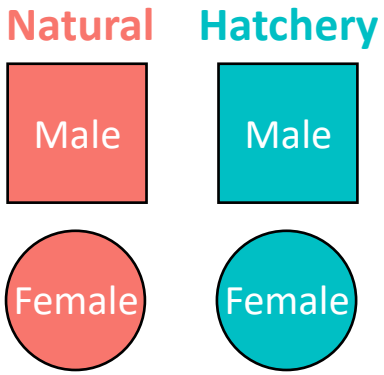
Natural **Hatchery**

Male Male

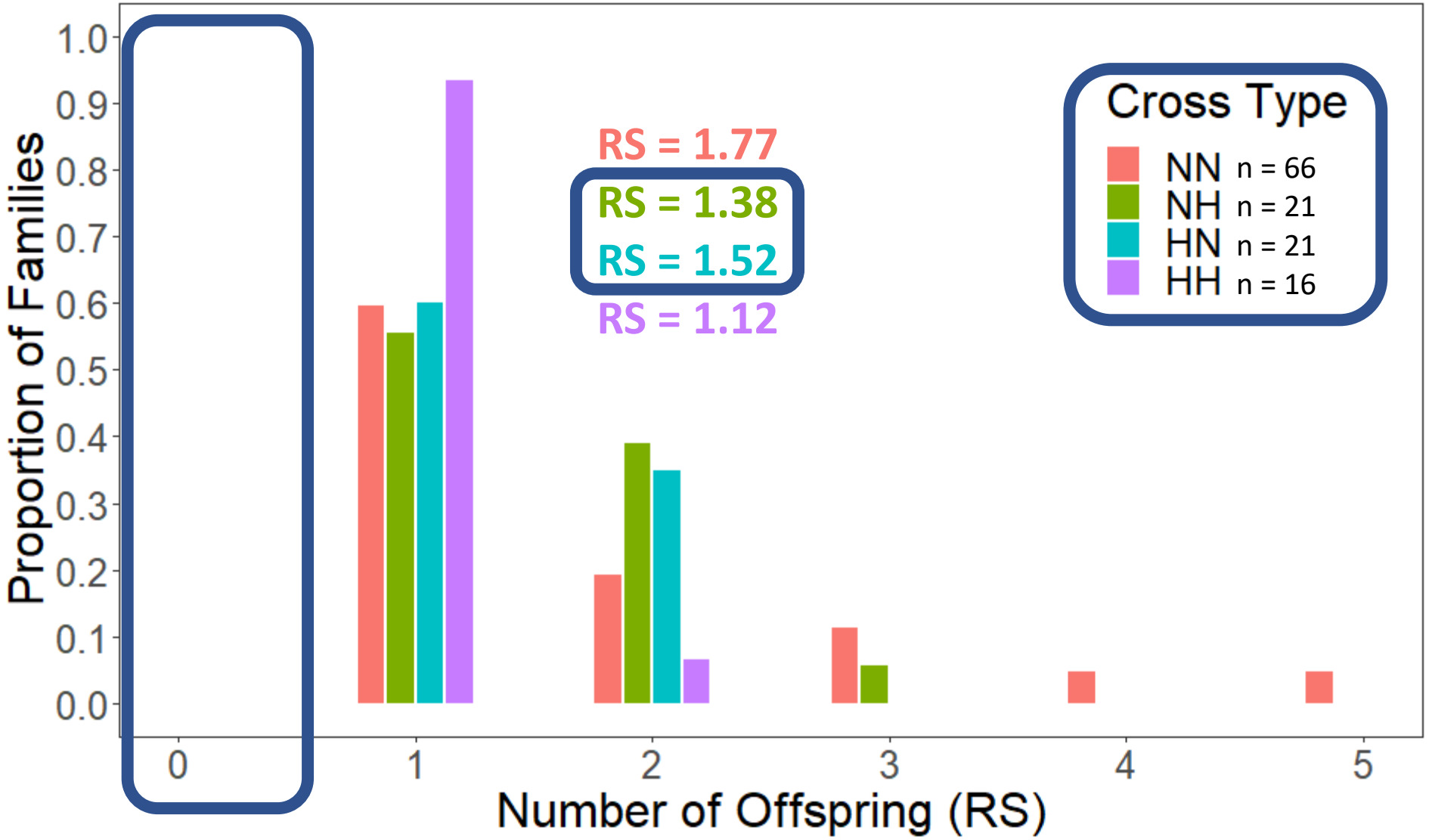
Female Female

Parent-Pair-Offspring Trios





RS Distribution: Stockdale 2014/2016

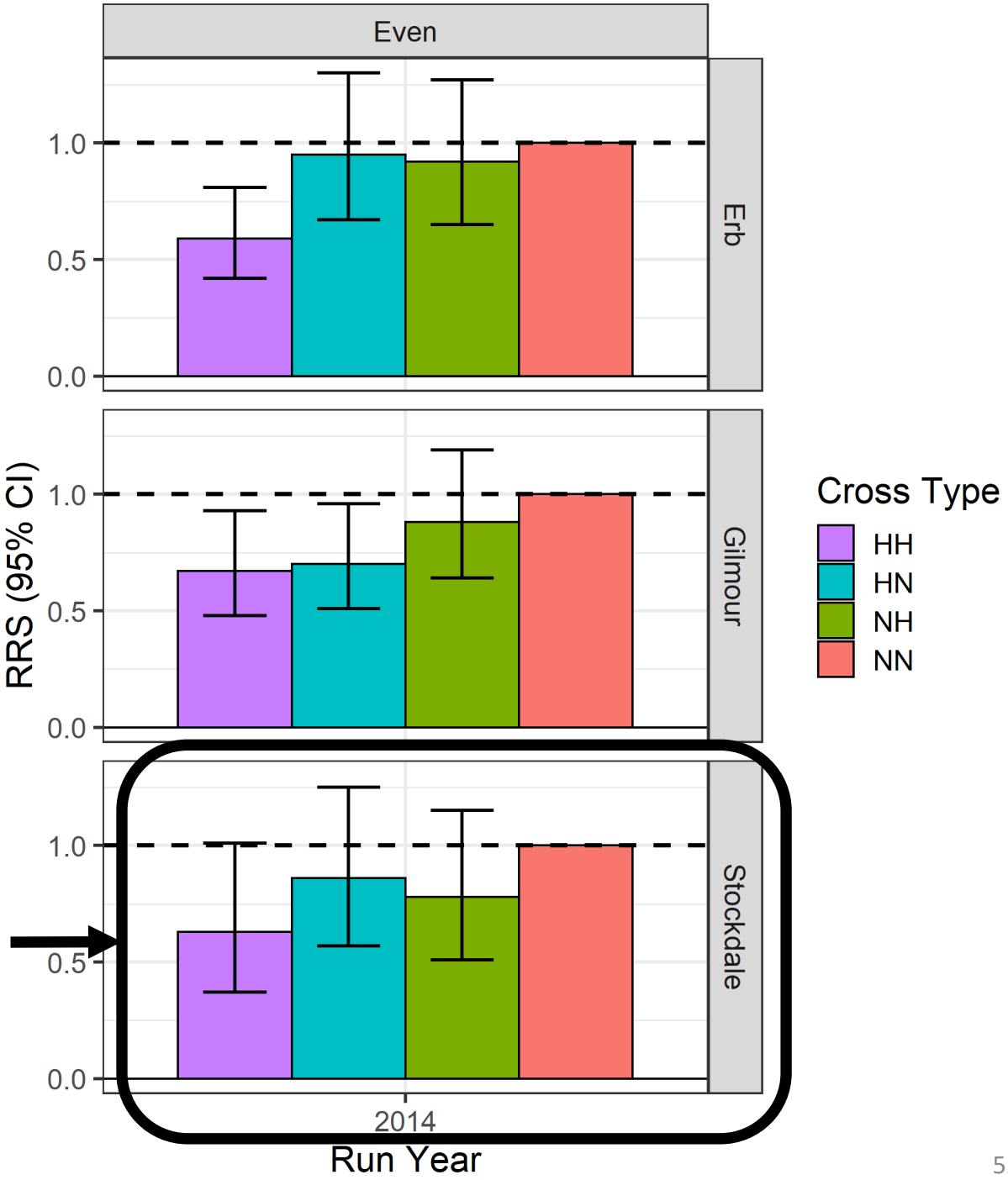


Summary of RRS to Date

Limited to $n_{family} > 15$

$$RRS = \frac{RS_{XX}}{RS_{NN}}$$

Results show in detail on previous slides



Conclusions

- Hatchery-origin strays spawn in streams
- Stray hatchery-origin RRS < 1
- Variability in RRS (streams, years, sexes)
- Body size, sample date, sample location matter…
- But stray hatchery-origin RRS still < 1
- Hybrids had intermediate RRS

Remaining Questions

- Are observed reductions in hatchery-origin RRS an artifact of the study design?
  - Returning adults that are harvested?
  - Returning adults that stray to other streams?
  - Sampling proportion through time?
  - Both possible, but unlikely to fully explain our results
- Are results consistent in other streams and years?
  - Yes, RRS consistently < 1, but lots of variation
- Do hatchery/natural hybrids consistently produce fewer offspring than two natural-origin pink salmon?
  - Yes, on average
- Are reductions in fitness persistent across generations (grand-offspring and beyond)?
  - We do not know yet

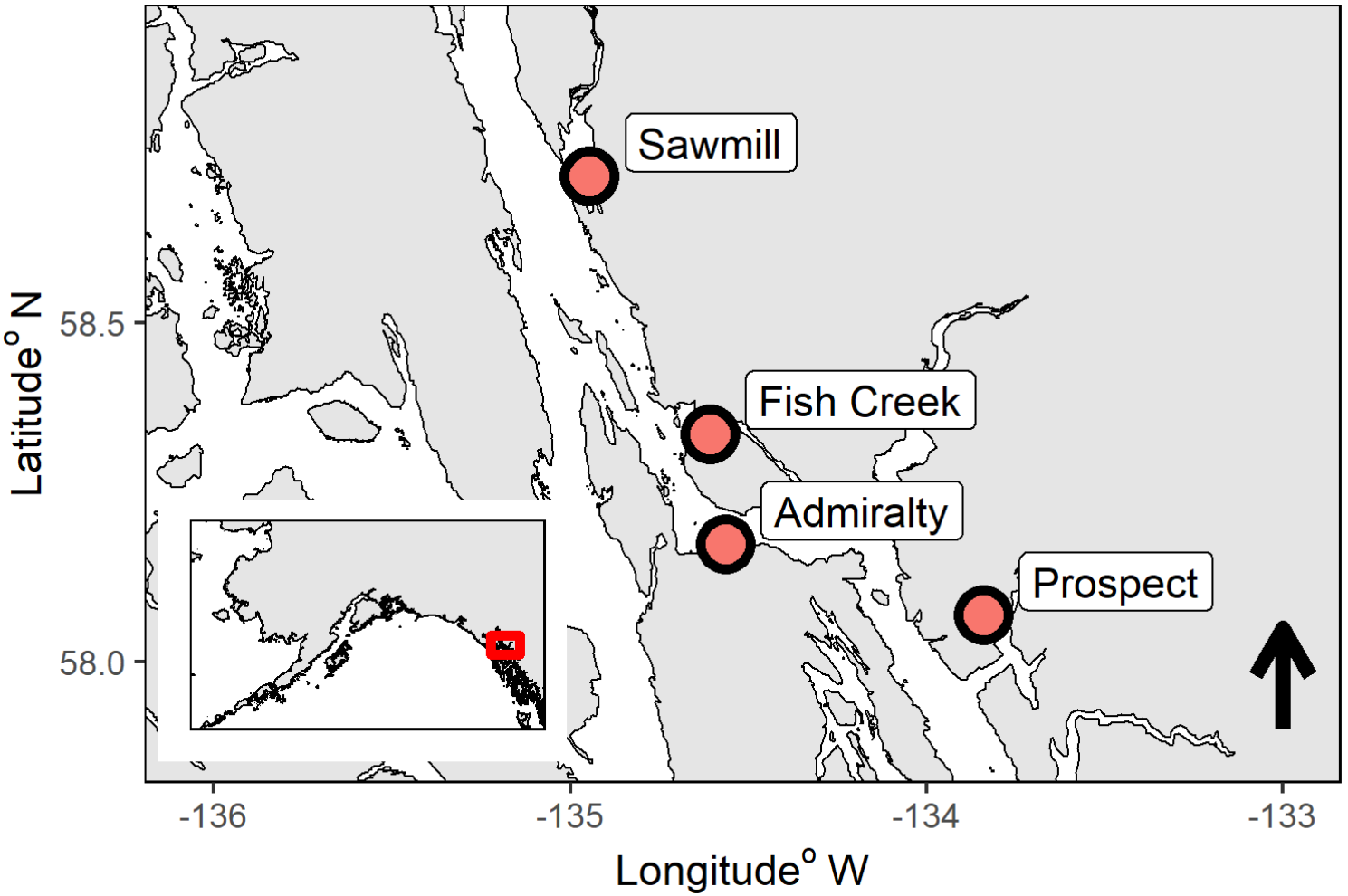
Acknowledgements

- Alaska Hatchery Research Program
  - State of Alaska
  - Seafood industry
  - Private non-profit hatcheries
- North Pacific Research Board (Project #1619)
  - Funding for Hogan Bay analyses (2013-2016)
- Saltonstall-Kennedy (NA16NMF4270251)
  - Funding for Stockdale analyses (2014/2016)
- Prince William Sound Science Center
  - Field collection
- ADF&G Cordova Otolith Lab
- University of Washington - Seeb Lab
- ADF&G Gene Conservation Laboratory

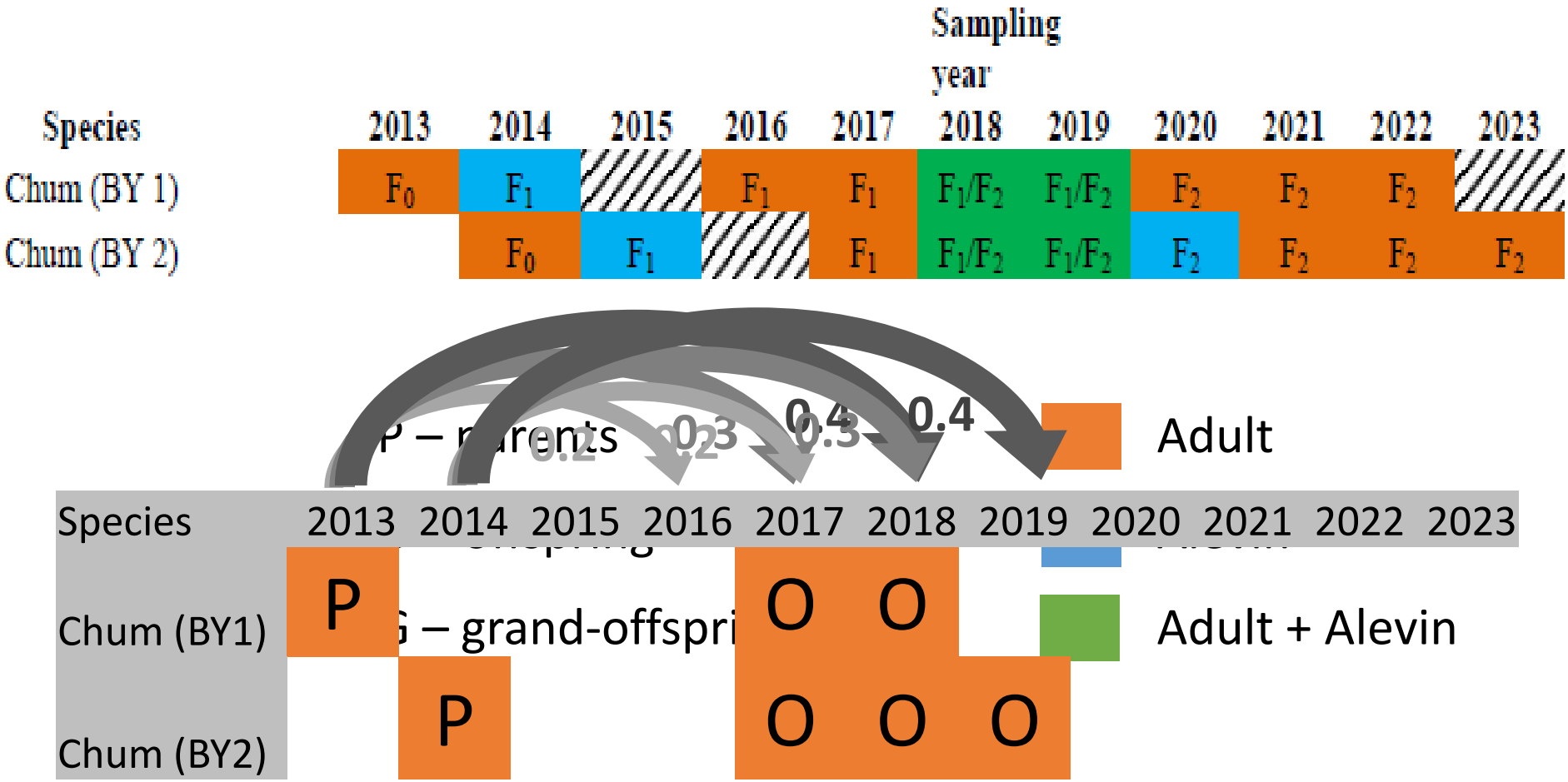

Questions?
© Thomas C. Kline, Jr.

AHRP Fitness Study: SEAK Chum Salmon

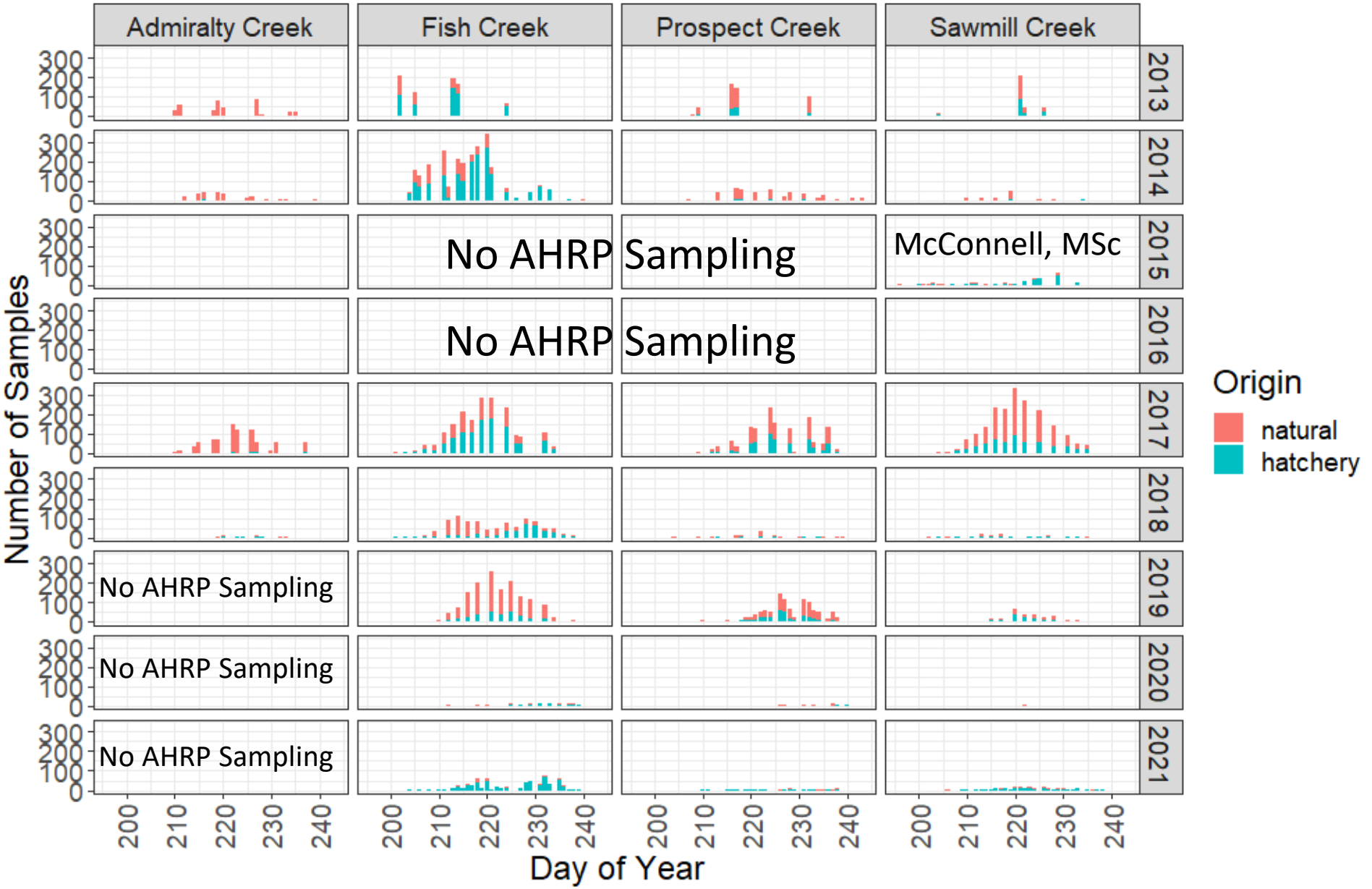
AHRP Streams in SEAK



Study Design: Original

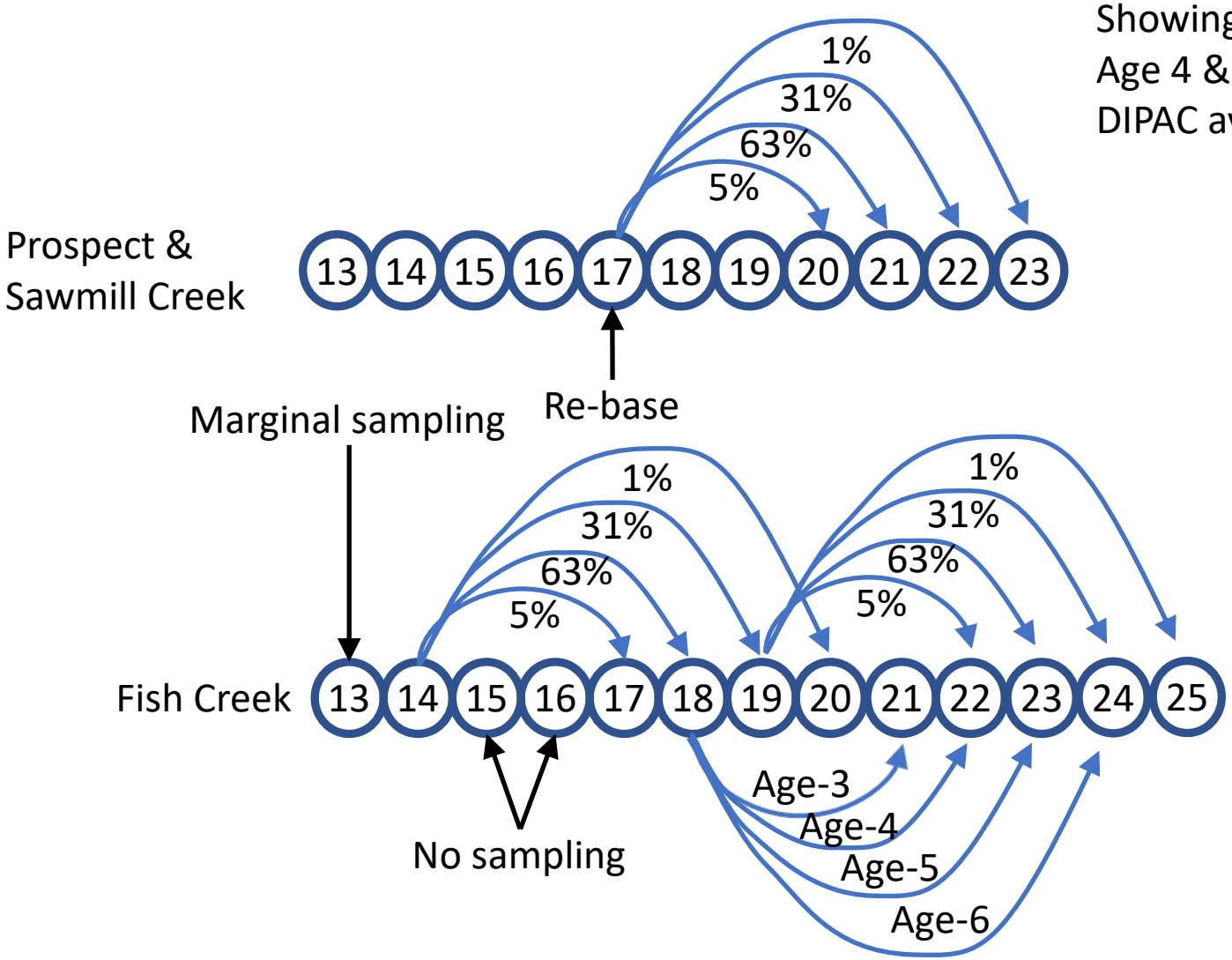


Samples Collected to Date



Study Design: Revised

Showing returns age 3 to 6
Age 4 & 5 are most common
DIPAC average 1989-2020



Remaining Work

- Field sampling in 2022 & 2023
- Design genetic markers for parentage
- Genotype samples
- Parentage analysis
- Calculate RRS
- GLM to account for length, date, and location

Acknowledgements

- Alaska Hatchery Research Program
  - State of Alaska
  - Seafood industry
  - Private non-profit hatcheries
- Pacific Salmon Commission
  - Northern Endowment Fund
- Sitka Sound Science Center
  - Field collection
- ADF&G Mark, Tag and Age Lab
- ADF&G Gene Conservation Laboratory

Questions?