

# Prospects for Recovery and Restoration of Coho Salmon in California



*C. Nicol*

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# Status of coho salmon in California, USA

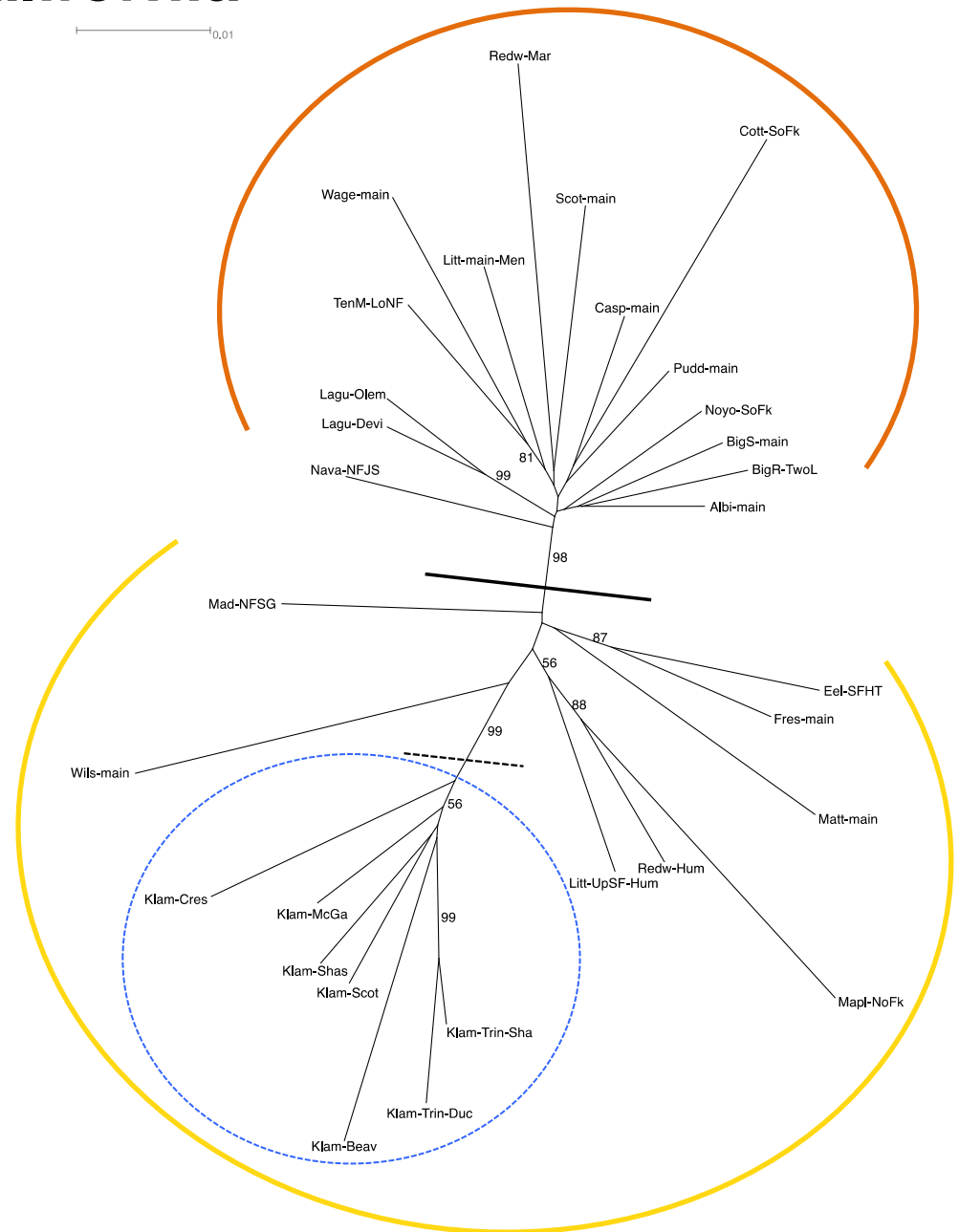
- Population declines, local extinctions
- Management units: Evolutionarily Significant Units (ESUs)
  - Southern Oregon/Northern California Coast Coho Salmon ESU (SONCC) – *Threatened*
  - Central California Coast Coho Salmon ESU (CCC) – *Endangered*
- All populations have protected status
- Life history
  - Anadromous, reproduce in natal streams, semelparous
  - 3-year life cycle; 3 brood years, little temporal gene flow



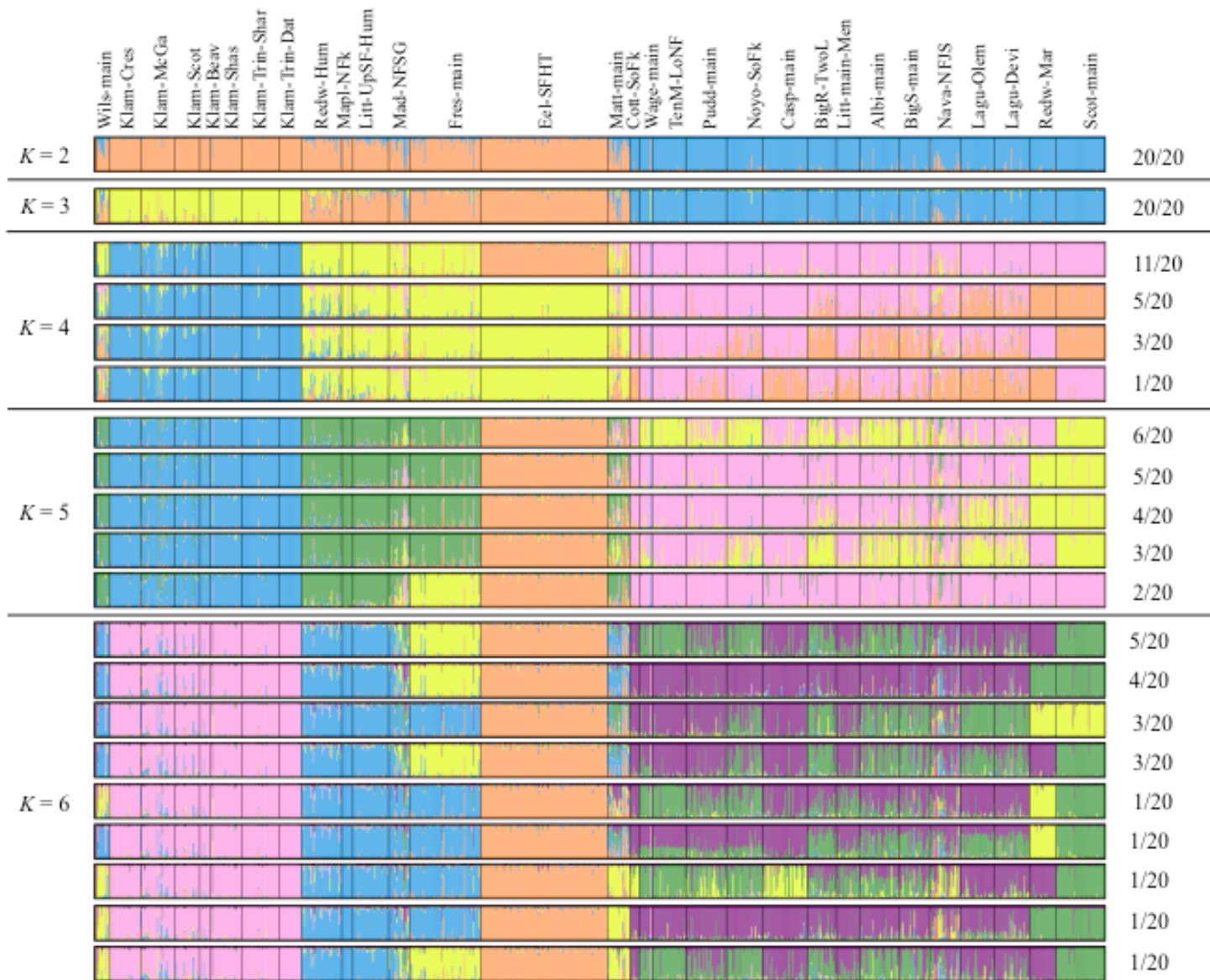
# Background: phylogeography of coho salmon in California

- 30 sites surveyed for young-of-year in 2003
- Significant hierarchical genetic structure
  - Greatest divergence at broadest geographic scale
- Klamath River basin distinct from other northern populations

Central California ESU ———  
Northern California ESU ———  
Klamath River basin - - - -



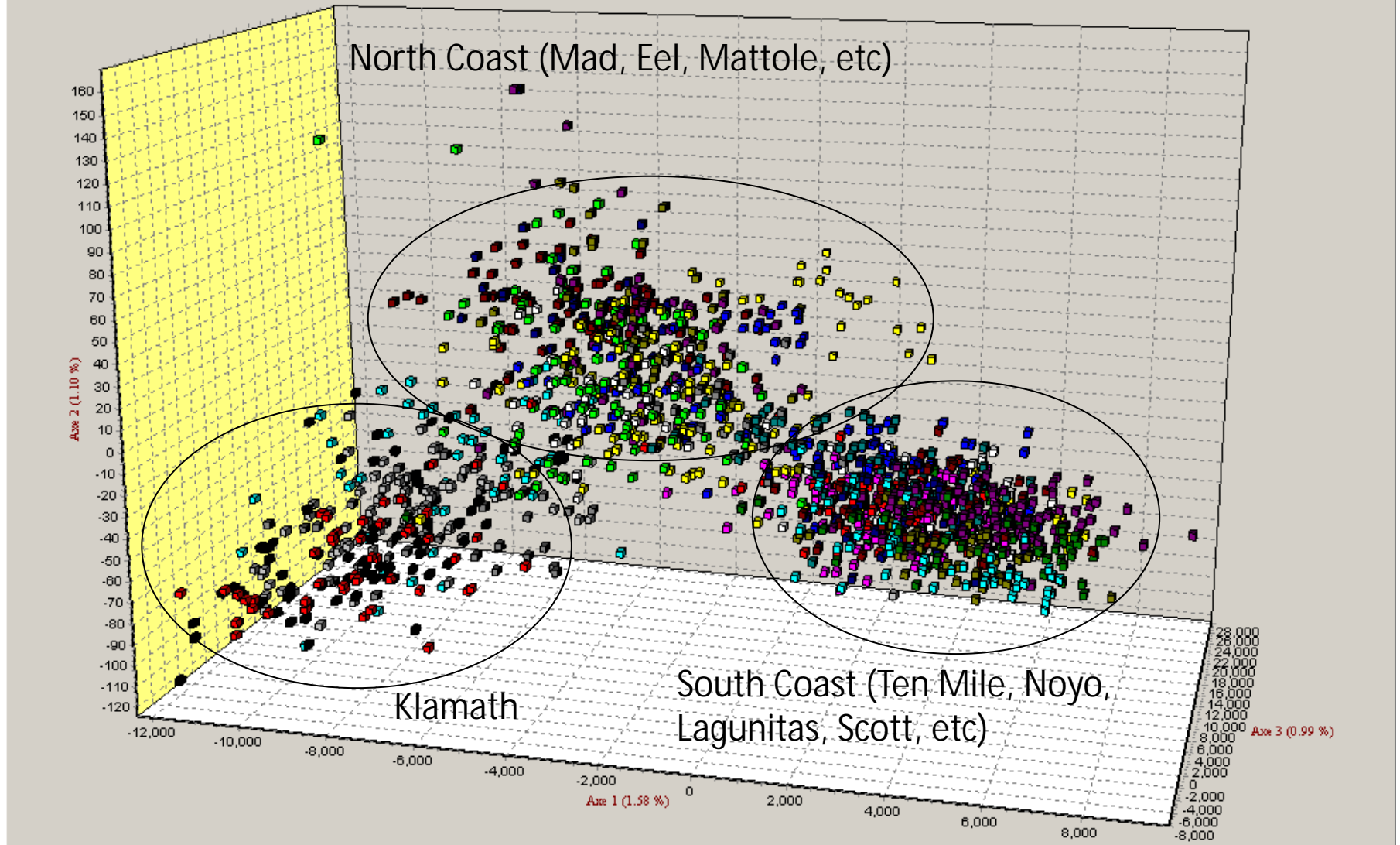
# Background: phylogeography of coho salmon in California



## Bayesian Clustering Analysis-Individual Genotypes

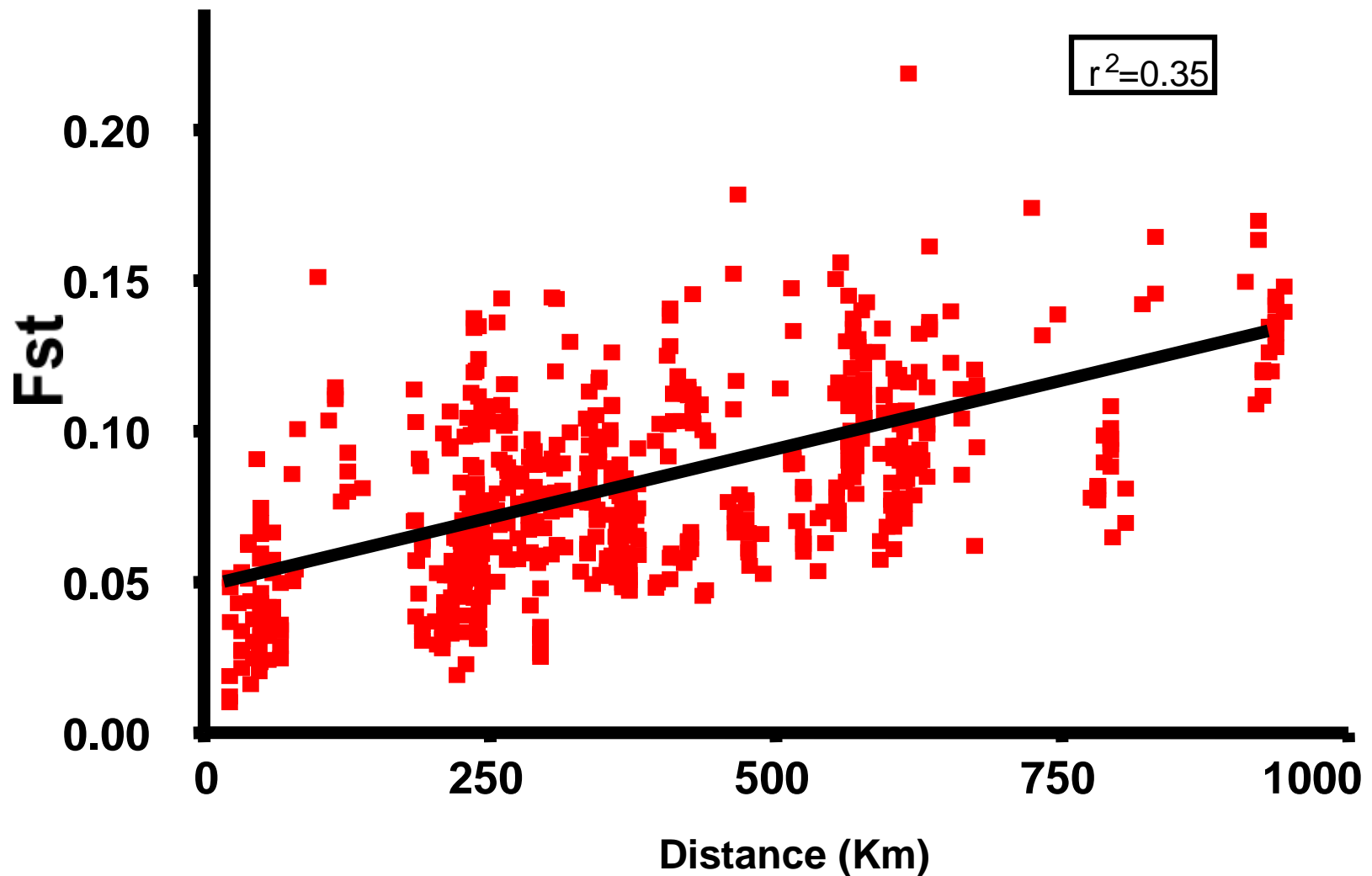
# Background: phylogeography of coho salmon in California

cohotr03finalgpp.gtx



## Factorial Correspondence Analysis-Individual Genotypes

# Isolation by distance-Coho Salmon



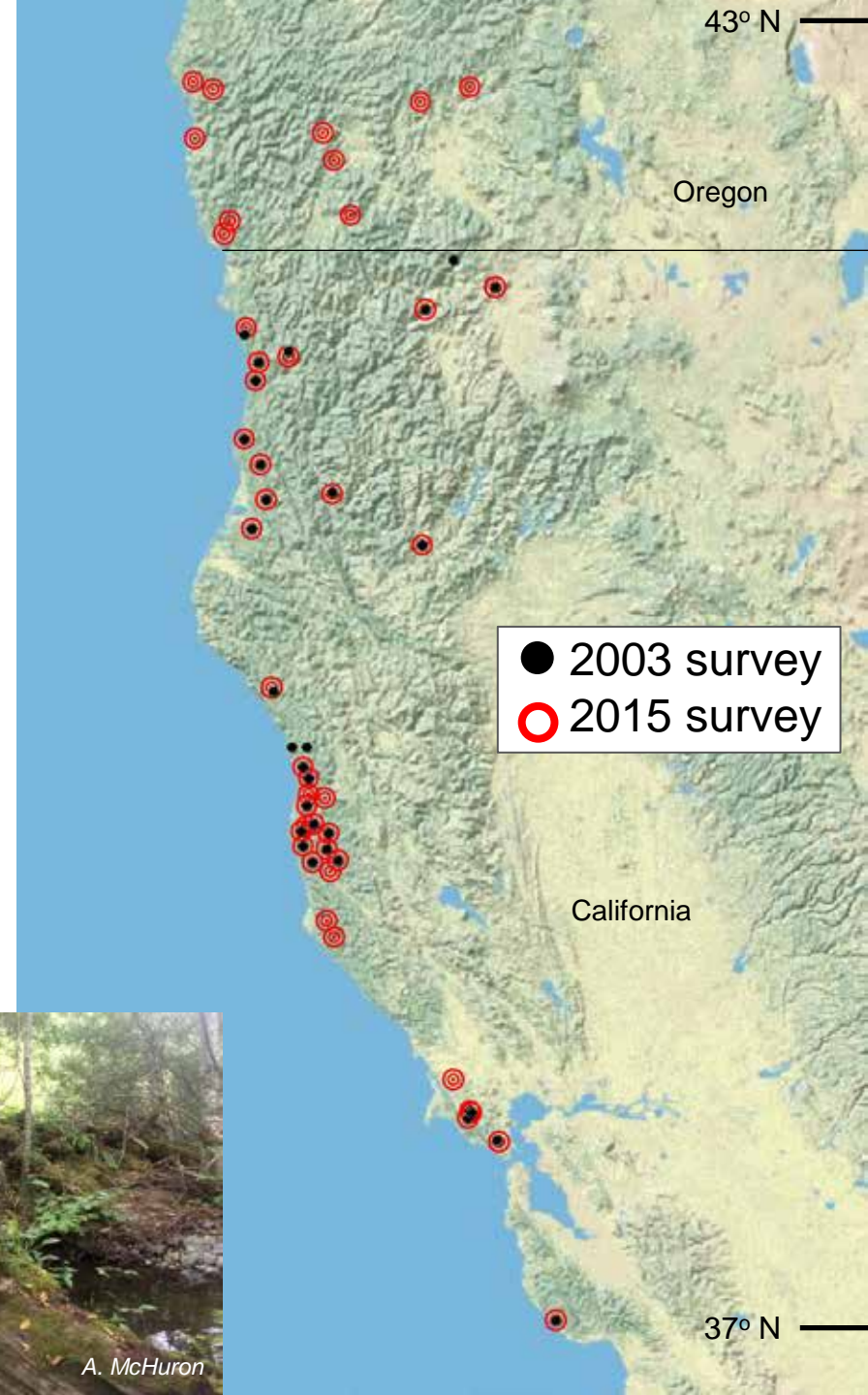
Strong relationship between genetic and geographic distance due to MIGRATION

# Temporal Monitoring of Coho Salmon

- Survey populations at two time points
  - Time series data at a regional scale
  - Examine allele frequency change over time
- Timepoint 1: baseline sampling in rivers throughout California in 2003 (n=1,976)
- Timepoint 2: revisited same sites in 2015 (n=2,223)
  - Expanded to include Oregon sites
- Four generations between surveys
  - Sampled two cohorts of the same brood cycle

# Sampling locations

- Sampled juveniles in natal streams
- Spatially stratified electrofishing protocol
- 46 sites yielded coho salmon in 2015
- n=75 maximum per site





# Analytical objectives

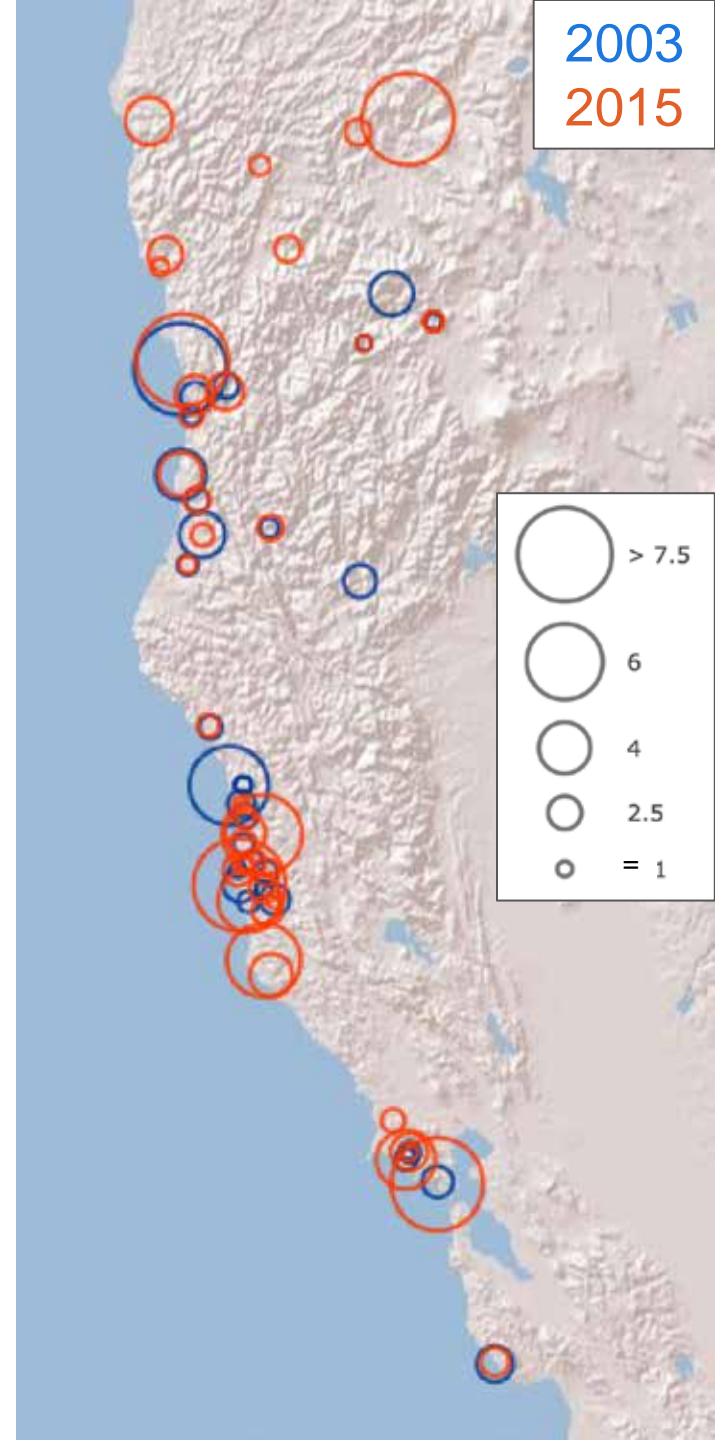
- Analysis of family structure
- Examine patterns of population structure at multiple spatial scales
- Assess temporal stability of genetic composition of populations
- Estimate effective population size ( $N_e$ )

Genotype data: 95 SNP loci  
n=4,199 individuals

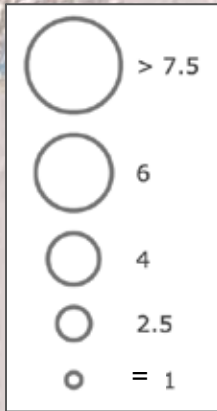


# Results

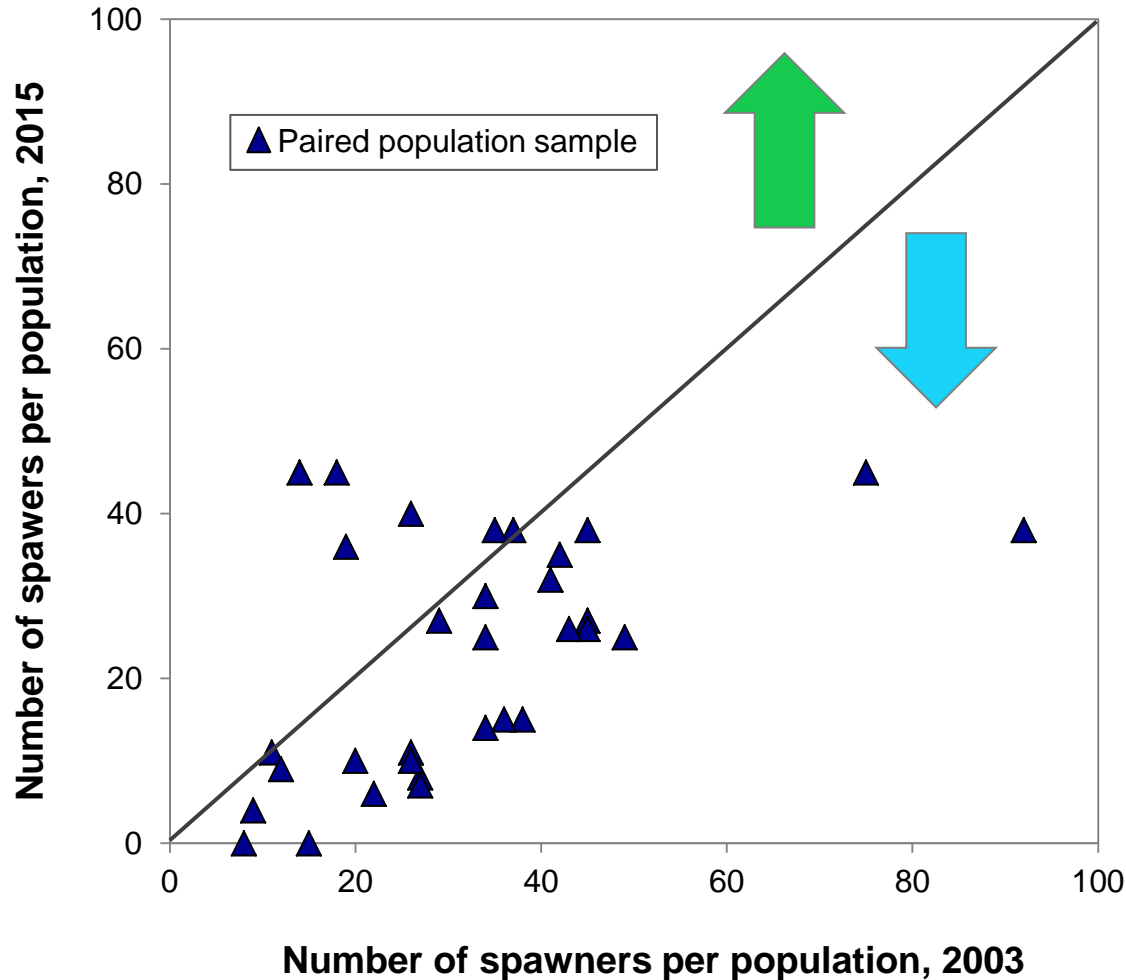
- Sibship reconstruction: full siblings detected in almost all populations
- Mean sibship size by site ->
- Mean sibship size by year
  - **2003 = 2.2**
  - **2015 = 3.3**
- Family structure may obscure or distort population structure
  - Omit full sibs from population analyses (revised n=2,460)



2003  
2015



# Temporal trends in reproduction

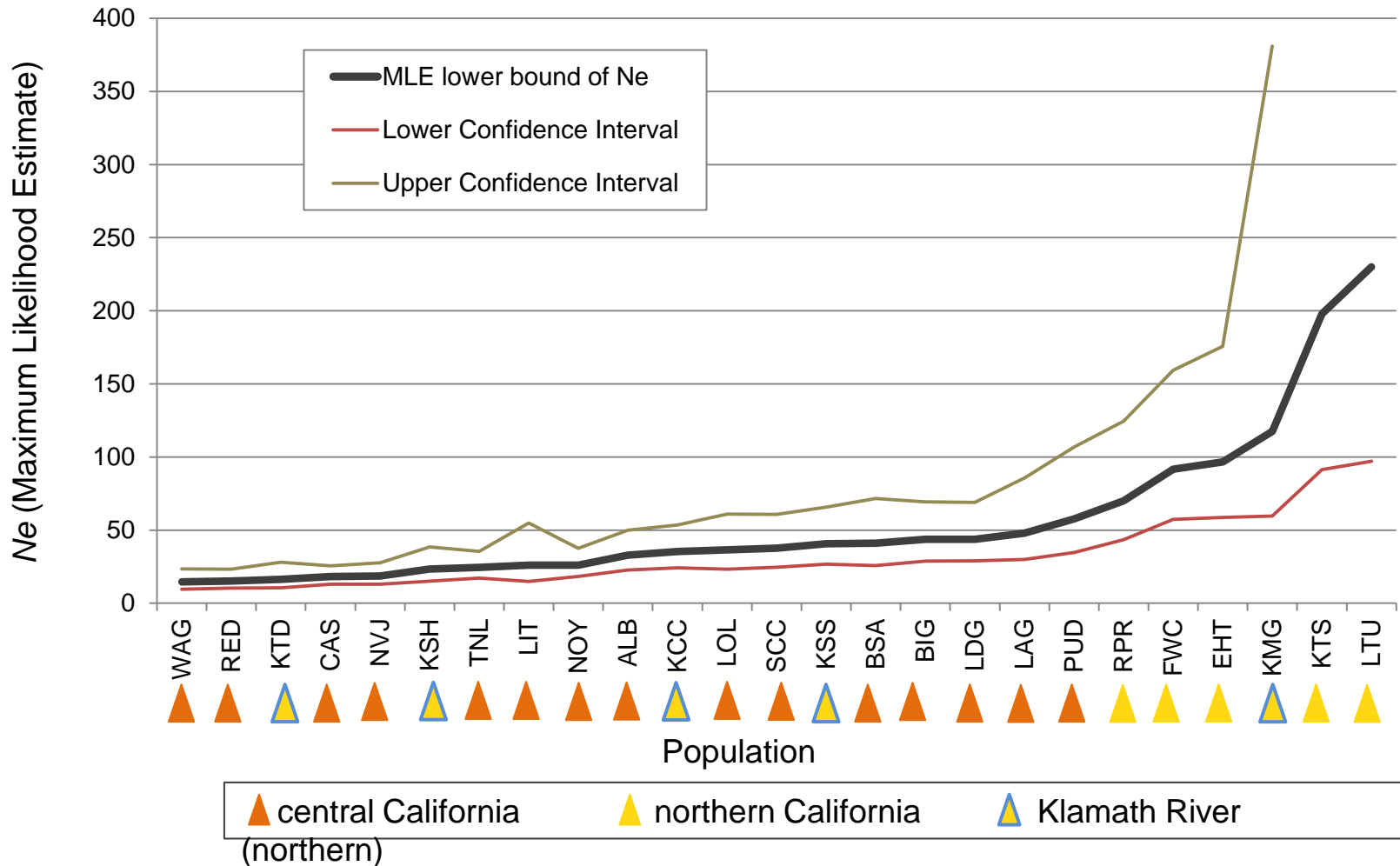


- 32 paired temporal population samples
- Estimated number of spawning adults that produced each sample of juveniles
- Net decrease in number of spawners between 2003 and 2015

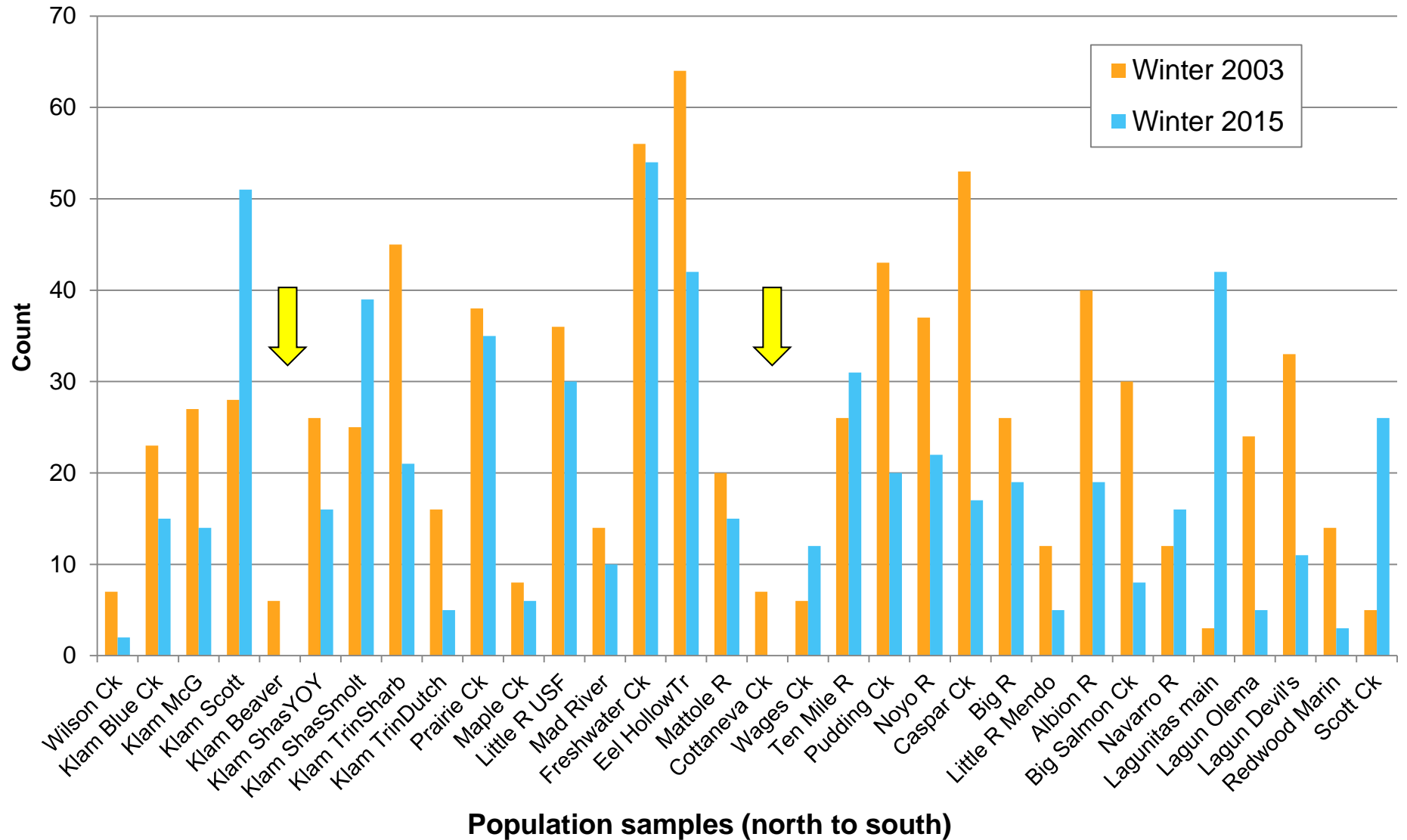
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# Effective population size

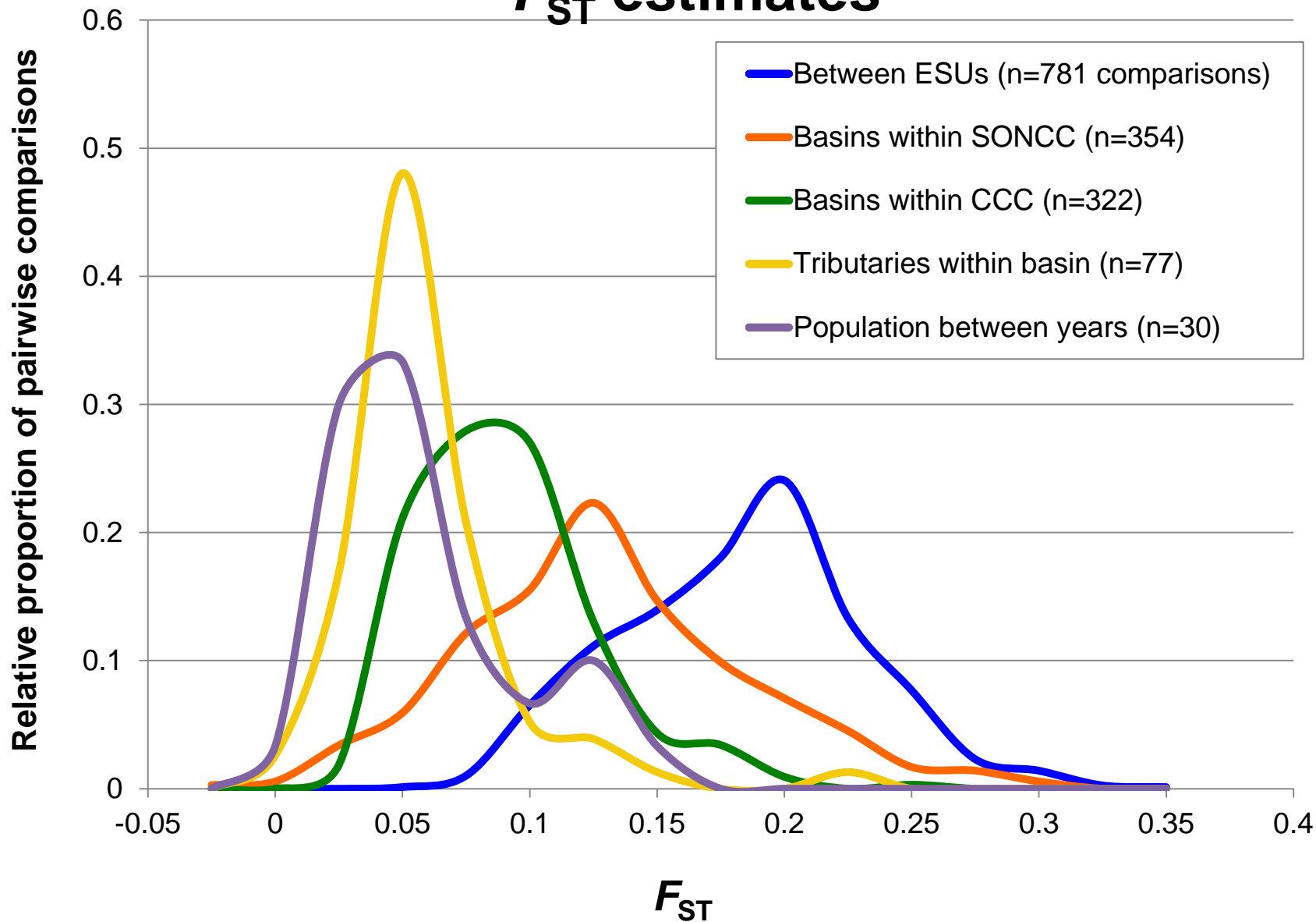
- Method in development: estimating  $N_e$  using the temporal method, accounting for family structure using Colony output
- Upper bound of  $N_e$  difficult to estimate due to small sample sizes



# Temporal trends in reproduction, by population: estimated number of spawning adults in 2003 and 2015



# Relative divergence between populations: distributions of pairwise $F_{ST}$ estimates



# Mendocino Coast-CA Coho Salmon Stronghold

Population	Coho Salmon Escapement 2009 to 2015						
	2009	2010	2011	2012	2013	2014	2015
Mendocino Coast	887	898	1427	2848	3365	869	8577
Lost Coast Diversity Strata	672	1059	1212	2756	4646	869	7991
Navarro Point Diversity Strata	158	513	542	250	578	2	586
Albion River	8	0	162	66	894	0	467
Big River	80	134	160	269	519	155	1344
Big Salmon Creek	0	NS	NS	19	0	NS	NS
Brush Creek	0	0	0	0	0	0	0
Caspar Creek <sup>1</sup>	6	5	27	20	10	0	40
Cottenteva Creek	0	0	NS	0	NS	0	NS
Elk Creek	NS	NS	0	NS	NS	0	NS
Garcia River	69	9	90	0	211	3	469
Greenwood Creek	9	0	NS	NS	0	NS	2
Hare Creek	NS	0	0	NS	0	0	NS
Juan Creek	NS	NS	NS	0	NS	NS	25
Little River	4	2	8	2	2	2	65
Navarro River	70	452	420	244	354	0	423
North Fork Navarro River <sup>2</sup>	ND	ND	ND	ND	140	0	199
Noyo River	294	286	411	228	784	723	3468
South Fork Noyo River <sup>1</sup>	19	63	39	38	398	305	616
Pudding Creek <sup>1</sup>	50	9	199	415	283	0	539
Ten Mile River	0	190	395	1127	440	3	1654
Usal Creek	10	2	0	10	13	0	0
Wages Creek	0	0	0	NS	NS	0	NS

<sup>1</sup> Life Cycle Monitoring stream mark-recapture estimates

<sup>2</sup> Life Cycle Monitoring stream using area under the curve estimates since 2013

Source: Gallagher et al. 2015

# Coho Salmon Conservation Efforts

Coho smolts

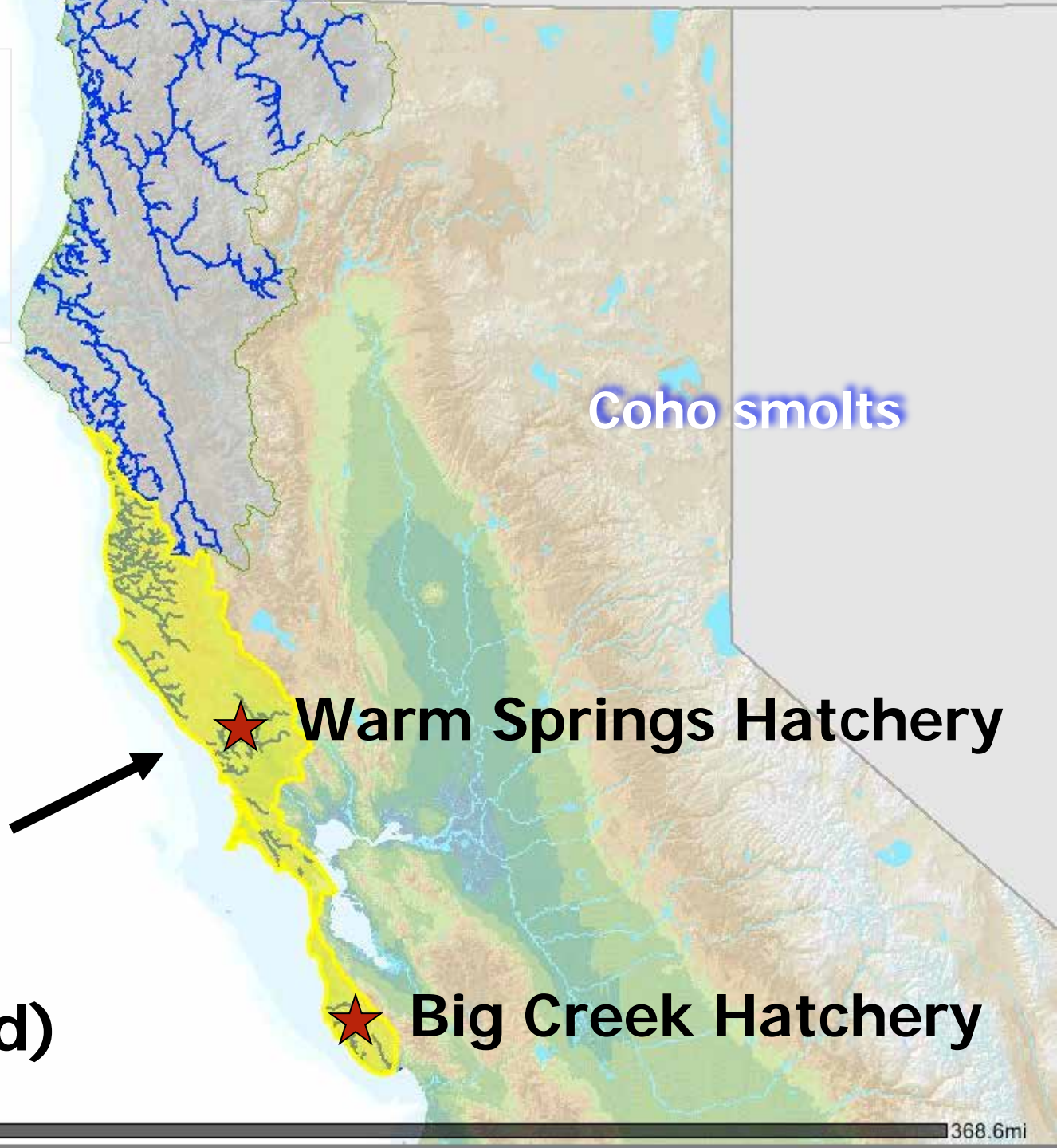
Central California Coast Coho Salmon ESU (Endangered)

★ Warm Springs Hatchery

★ Big Creek Hatchery

0

368.6mi





# Central California Coho Salmon Captive Broodstock Programs

- Two captive rearing programs initiated because of steep declines in mean abundance and widespread disappearance in the southern part of the ESU
- Goals are to hold individuals from small, remnant populations through high mortality life stages to ensure persistence of populations and reintroduce recently extirpated populations
- One in Sonoma County at the Warm Springs Hatchery: focused on Russian River recovery
- One in Santa Cruz County at Big Creek Hatchery (Scott Ck): focused on South of Golden Gate recovery.





Variable	Estimate ± SE	p-value
Female Stream Origin [DBC]	0.022 ± 0.015	0.128
Male Stream Origin [DBC]	0.005 ± 0.011	0.612
Female Ovulation Rate	0.02 ± 0.031	0.516
<b>Relatedness Coefficient <math>R_{xy}</math></b>	<b>0.162 ± 0.057</b>	<b>0.004</b>
Female Internal Hz	0.021 ± 0.07	0.760
Male Internal Hz	0.056 ± 0.059	0.345

A generalized linear model analyzing the effects of six potential predictor variables on deformity rate reveals a significant relationship between relatedness ( $R_{xy}$ ) of parent pairs and alevin deformity rate in juvenile coho salmon at Warm Springs Hatchery.

Conrad JL, Gilbert-Horvath E, Garza JC (2013) Genetic and phenotypic effects on reproductive outcomes for captively-reared coho salmon. *Aquaculture* 404:95-104



# A gallery of deformities in age 1 coho salmon



# Coho Salmon are Ocean Fish

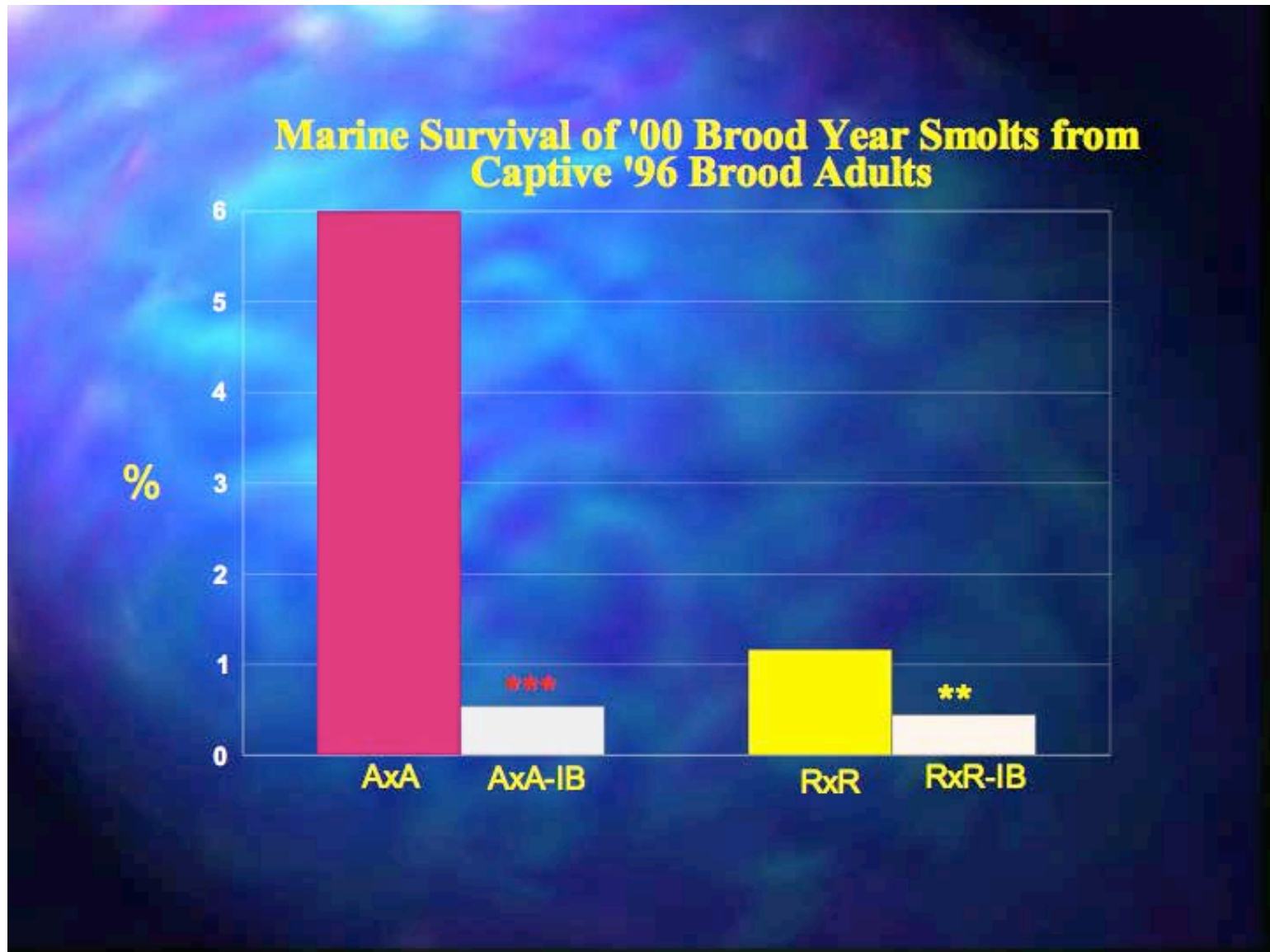


-Coho salmon (*O. kisutch*) are born in freshwater but, in California, most migrate to the sea one year after emergence and spend two years in the ocean

-Much more difficult to study them in the ocean, both because of spatial scale, but also because of lack of ability to discriminate fish from different populations

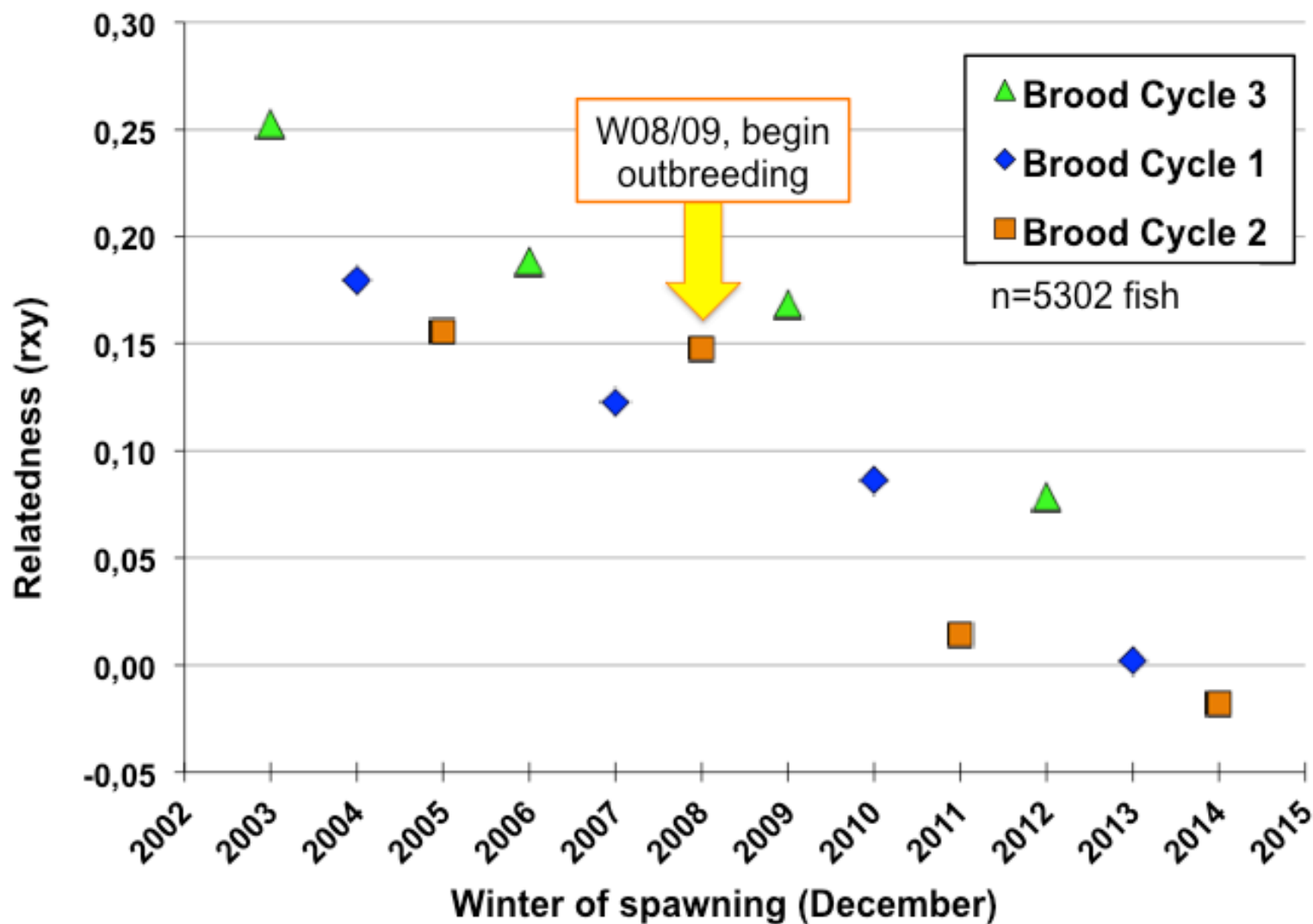
**A major driver of recovery is something that we barely understand and directly influence.**

## Inbreeding and Marine Survival

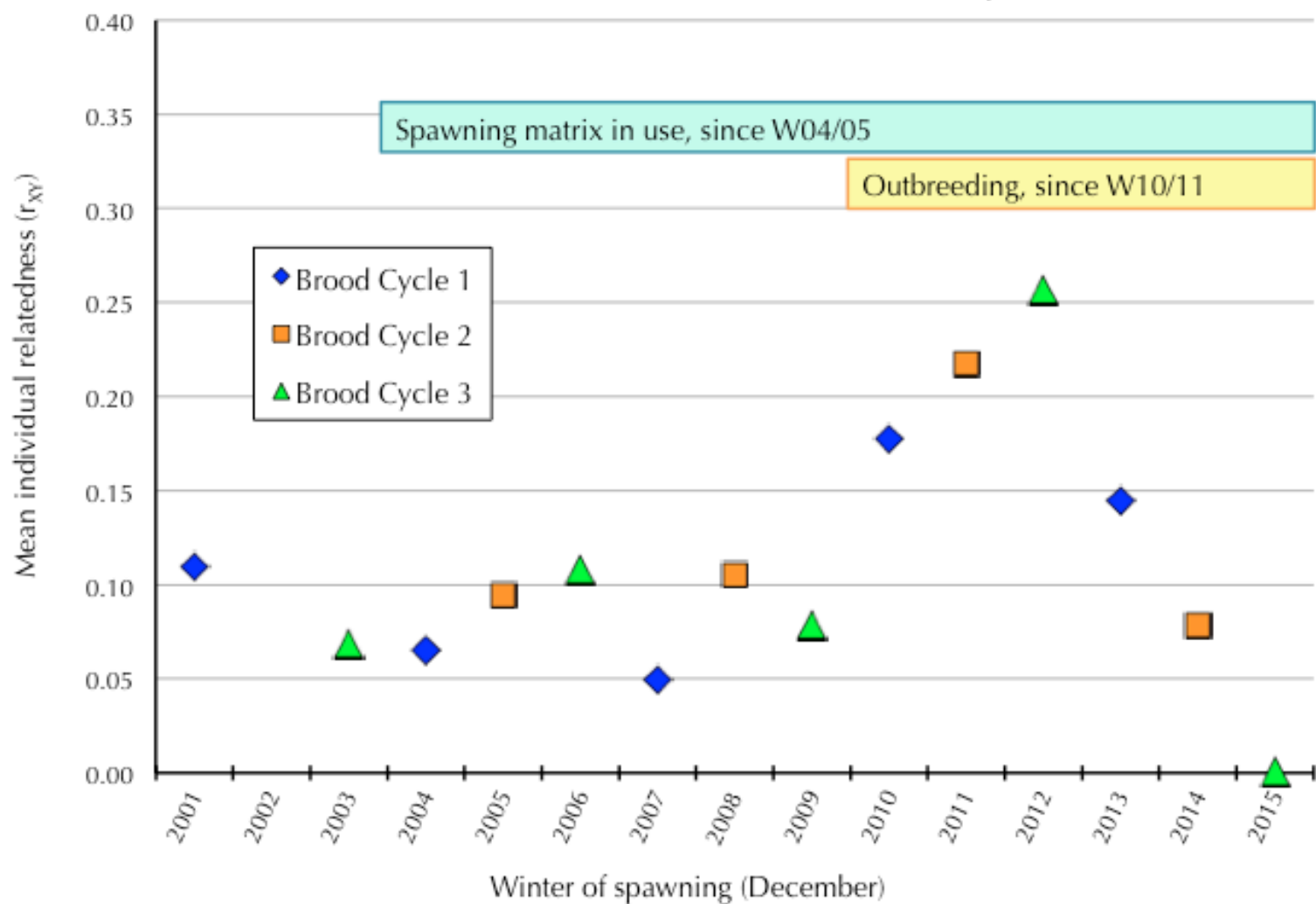


Steelhead, Sashin Ck. Alaska; Thrower and Hard, unpublished data

## Mean relatedness of Russian River broodstock



## Mean relatedness of Scott Creek coho salmon captive broodstock



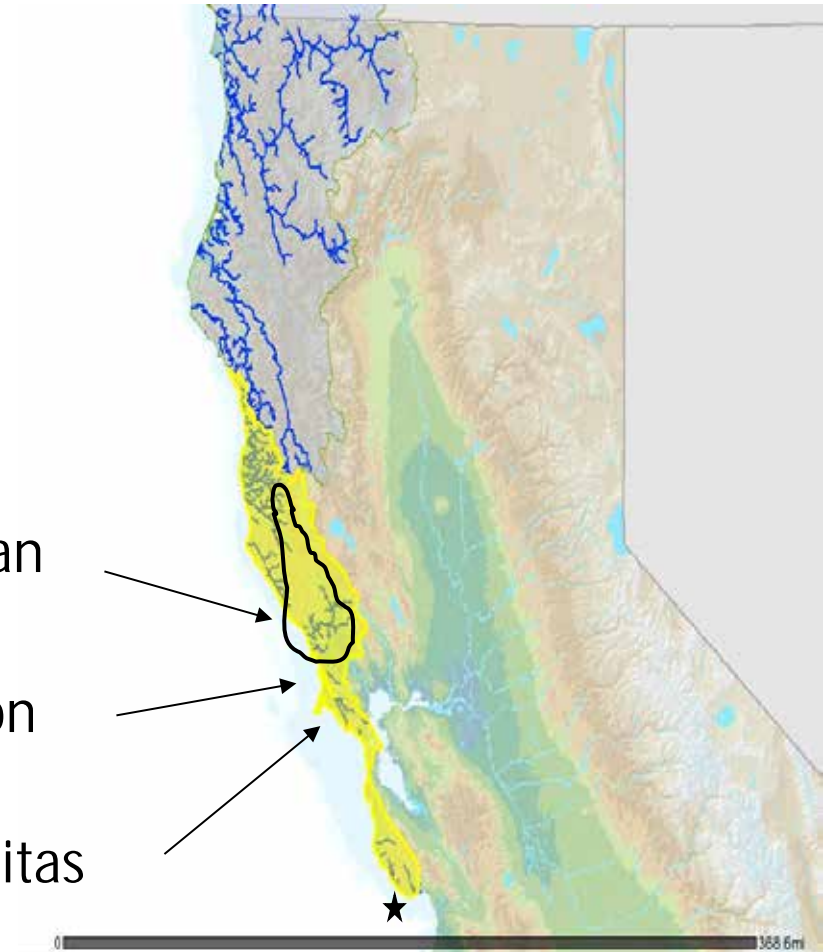


# Coho Salmon Conservation Efforts

Experimental  
reintroduction into Salmon  
Creek started in 2008



Russian  
River  
Salmon  
Creek  
Lagunitas  
Creek



# Release of captively raised maturing adult coho salmon as a novel strategy for restoration and recovery

- Salmon Ck.- no coho salmon since ~1980
- Adults from Lagunitas Creek (N=152) and from the Russian River (N=158) released in December 2008
- Juveniles confirmed and sampled in two creeks, Fay Creek (N=105) and Finley Creek (N=105) in July 2009.
- Genotyped with 18 microsatellites. Data analyzed with NewHybrids. Sibship reconstruction with Almudevar & Field (1999).



# Origin of coho salmon in Salmon Creek

	<b>No. of individuals</b>		
	Russian x Russian	Lagunitas x Lagunitas	Hybrid
Fay Ck	8	35	62
Finley Ck	0	14	90

	<b>No. of Matings</b>		
	Russian x Russian	Lagunitas x Lagunitas	Hybrid
Fay Ck	1	2	5 or 6
Finley Ck	0	1	2

NewHybrids posterior probabilities had mean of 0.99 to assigned genealogical class.



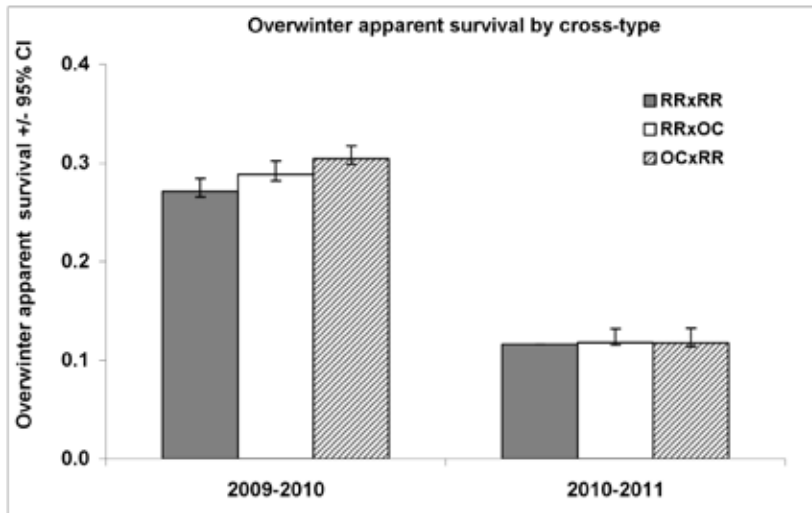
# Adult Release Conclusions

- Endangered coho salmon reproduce when released as mature adults raised entirely in freshwater
- Coho salmon in Salmon Ck do not avoid hybridization and may prefer it
- Hybrids have higher no. of offspring/ family
- NewHybrids accuracy confirmed with parentage.

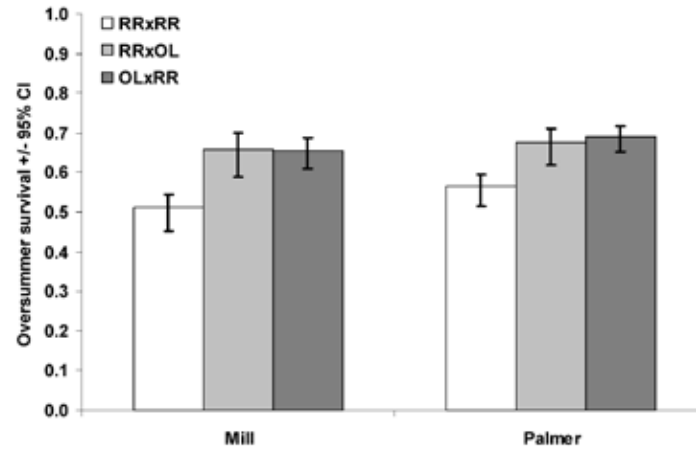


# Coho salmon Outcrossing Experiment

## Instream Survival Results



Overwinter survival rate of F1 of Russian River broodstock (RR) outcrossed with Lagunitas/Olema Creek (OL) coho

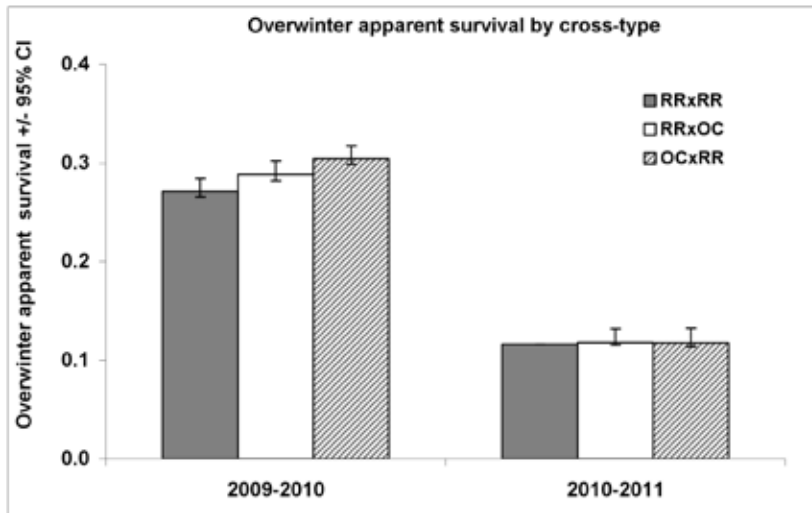


Oversummer survival rate of F1 of Russian River broodstock (RR) outcrossed with Lagunitas/Olema Creek (OL) coho

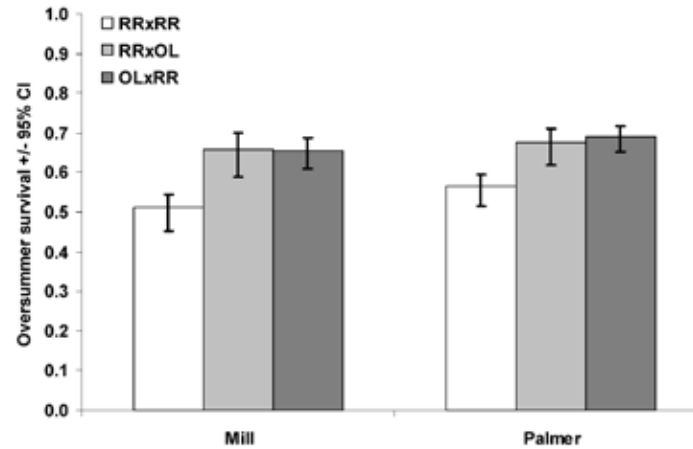


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Oversummer survival rate of F1 of Russian River broodstock (RR) outcrossed with Lagunitas/Olema Creek (OL) coho

Outcrossed coho salmon survive better at all juvenile life stages

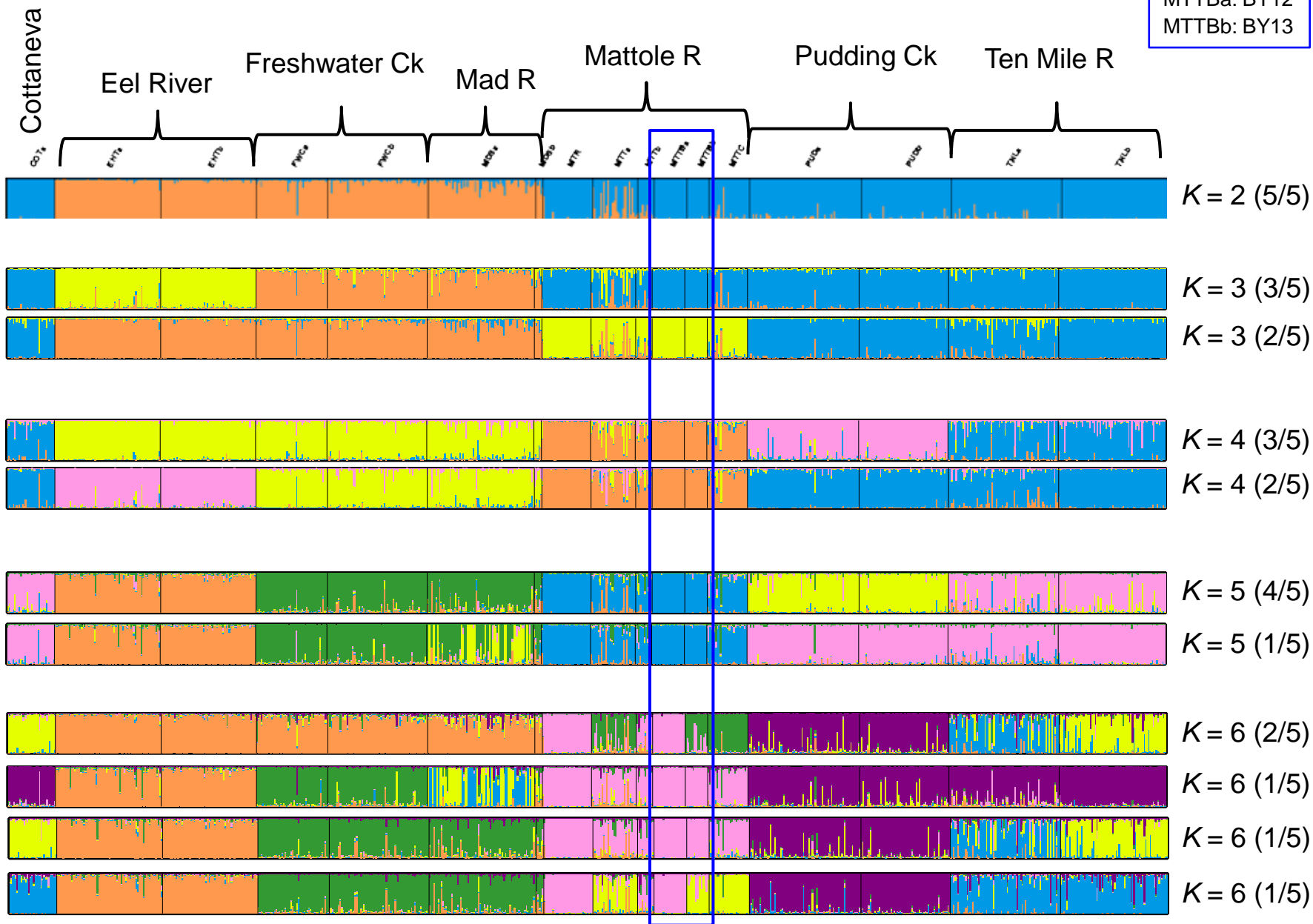


# Genetic analysis of Mattole River coho salmon young-of-year

- Baker Creek tributary, Mattole River, California
- YOY (young-of-year) were sampled
  - August 2013 (Brood year 12/13)
  - August 2014 (Brood year 13/14)
- Genetic analyses – 90 SNP loci
  - Colony v2 to resolve familial relationships
  - Population assignment test using nearby reference populations
  - Ancestry analysis

# Ancestry analysis (Structure v2.3.4)

MTTBa: BY12  
MTTBb: BY13





# Conclusions

- Regional-scale geographic structure is concordant with management unit boundary
- Statewide decrease in number of spawning adults that produced the sampled juveniles
  - Impact of 5-year drought on habitat
- Connectivity between proximate basins
- Minimal temporal structure: within-population genetic composition relatively consistent over time
- Ancestry and affiliation of small populations influenced by migrants from nearby basins

# Conservation Priorities

- Habitat restoration!!!!!!
- Connectivity of populations
- Maintain remaining genetic variation
- Evaluation of strategies
  - Where are recovery efforts having a positive impact?



A. McHuron

# California Salmon: the Future

Opportunities abound



# Conservation Priorities

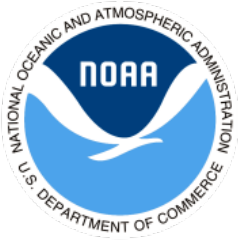
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# Acknowledgements

- Southwest Fisheries Science Center-NOAA/UCSC
  - Molecular Ecology Team: Eric Anderson, Ellen Campbell, Anthony Clemento, Cassie Columbus, Laney Correa
  - Landscape Ecology Team: Heidi Fish, Alex McHuron, Casey Sheridan, Emily Tucker
- California Department of Fish & Wildlife
- Tons of partners statewide



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*M. Bond*

Thank you!

