BUREAU OF RECLAMATION

Hydrologic Variability Influences Steelhead Outmigration Patterns in California's Central Valley

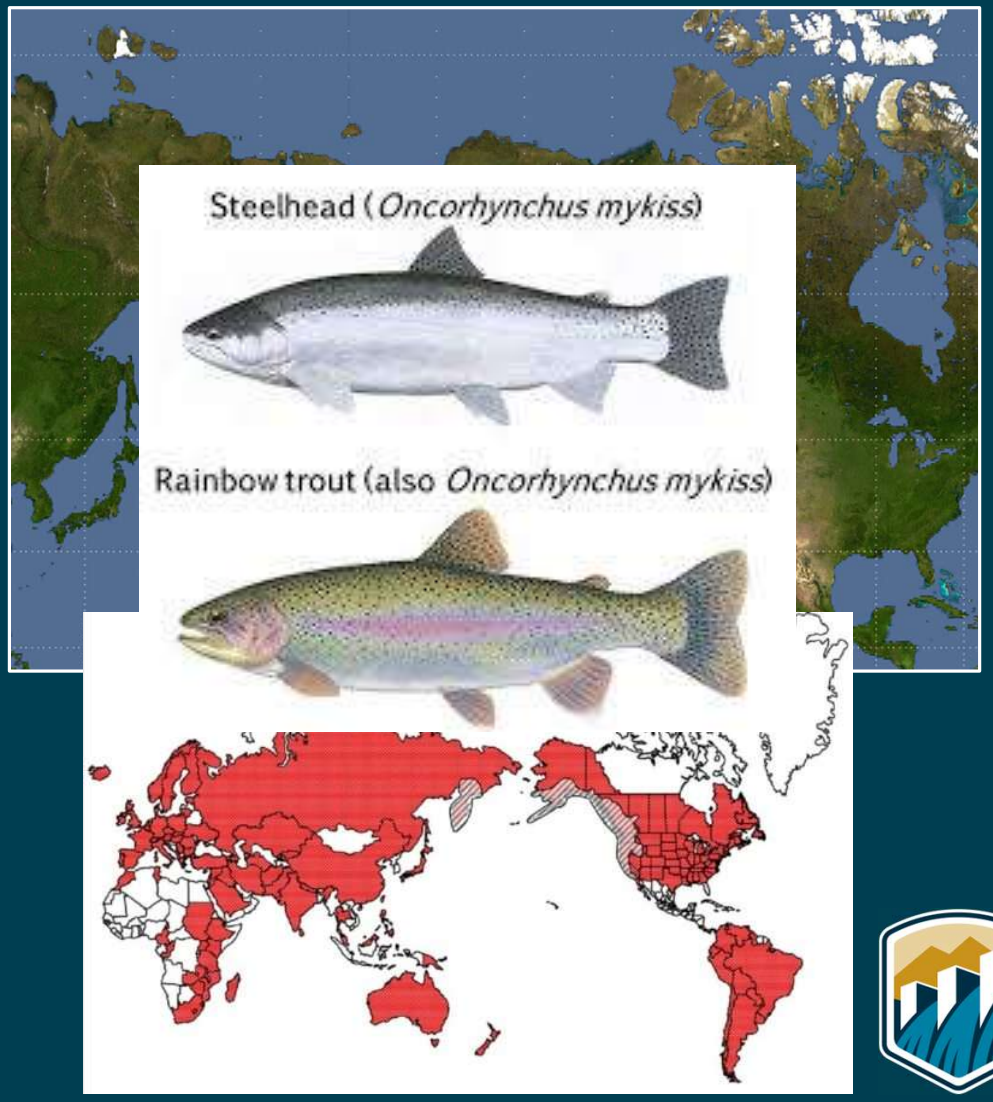
Chase Ehlo (USBR), Brian Mahardja (USBR), Josh Israel (USBR)

Acknowledgements

- Alex Vaisvil – USBR
- Mike Beakes – EPA
- Lauren Diaz – Oregon State University
- Tracy and Skinner Fish Collection Facilities (data collectors)
  - USBR
  - CDFW
  - DWR

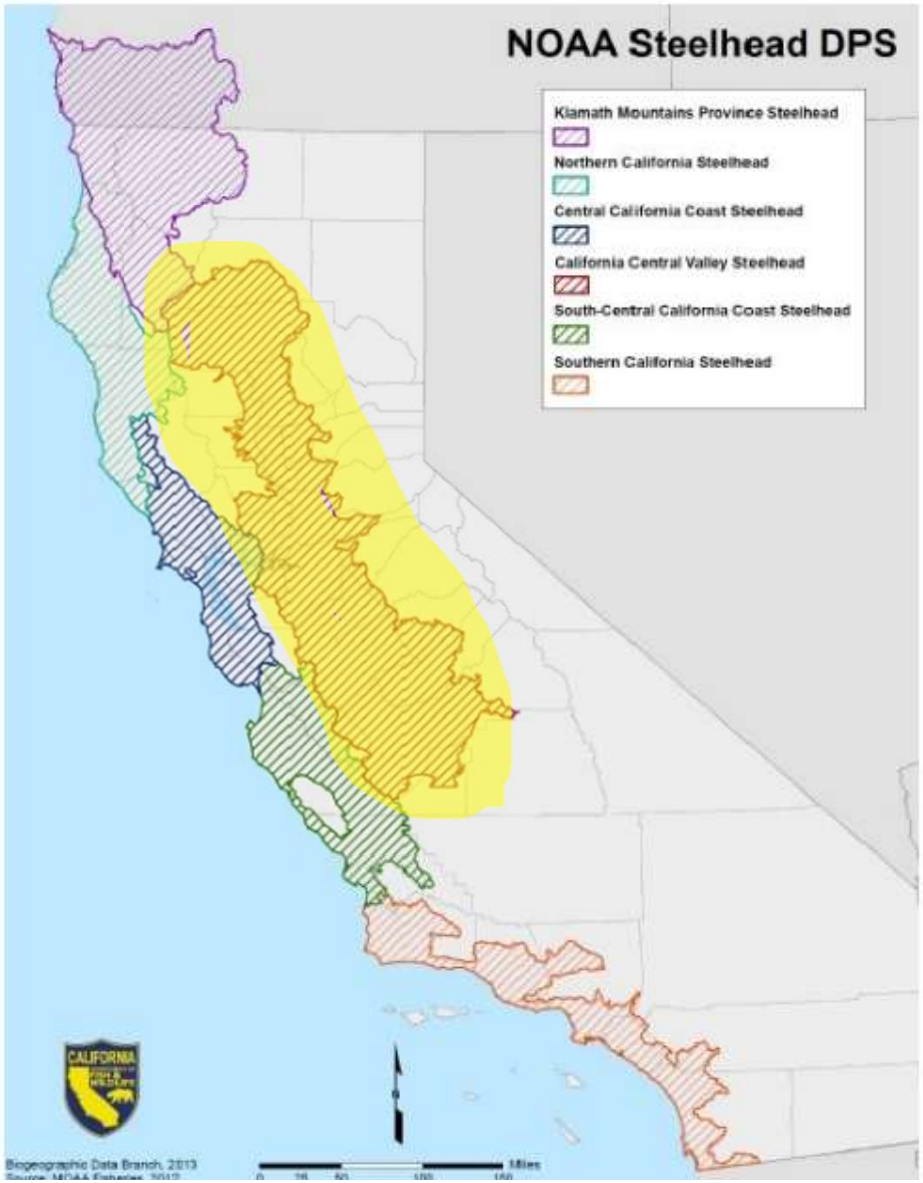
Oncorhynchus mykiss

- *O. mykiss* - native to western North America and parts of Russia
  - Introduced in streams worldwide
  - Residents (or Rainbow Trout)
  - Anadromous (or steelhead)



Central Valley Steelhead

- Six distinct population segments
- Central Valley Steelhead



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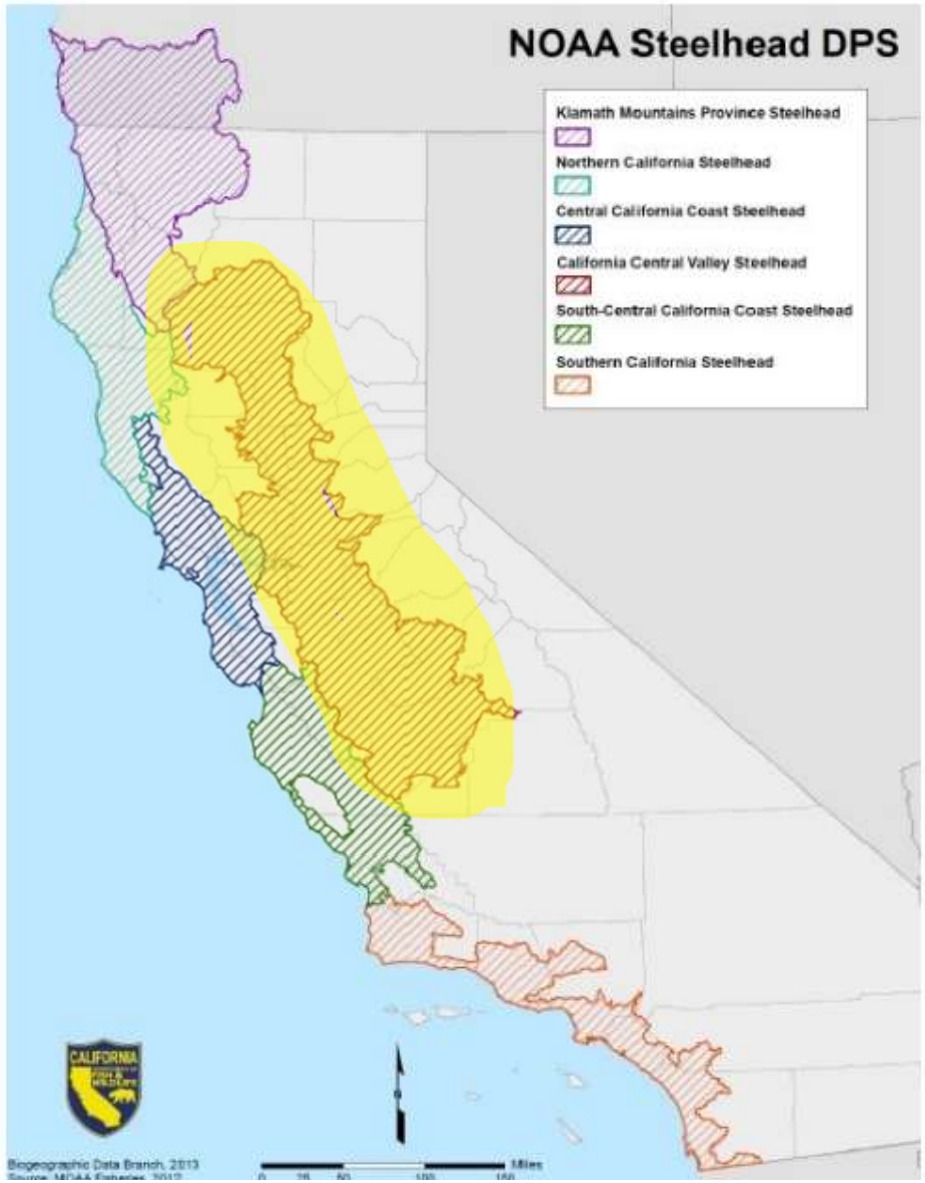

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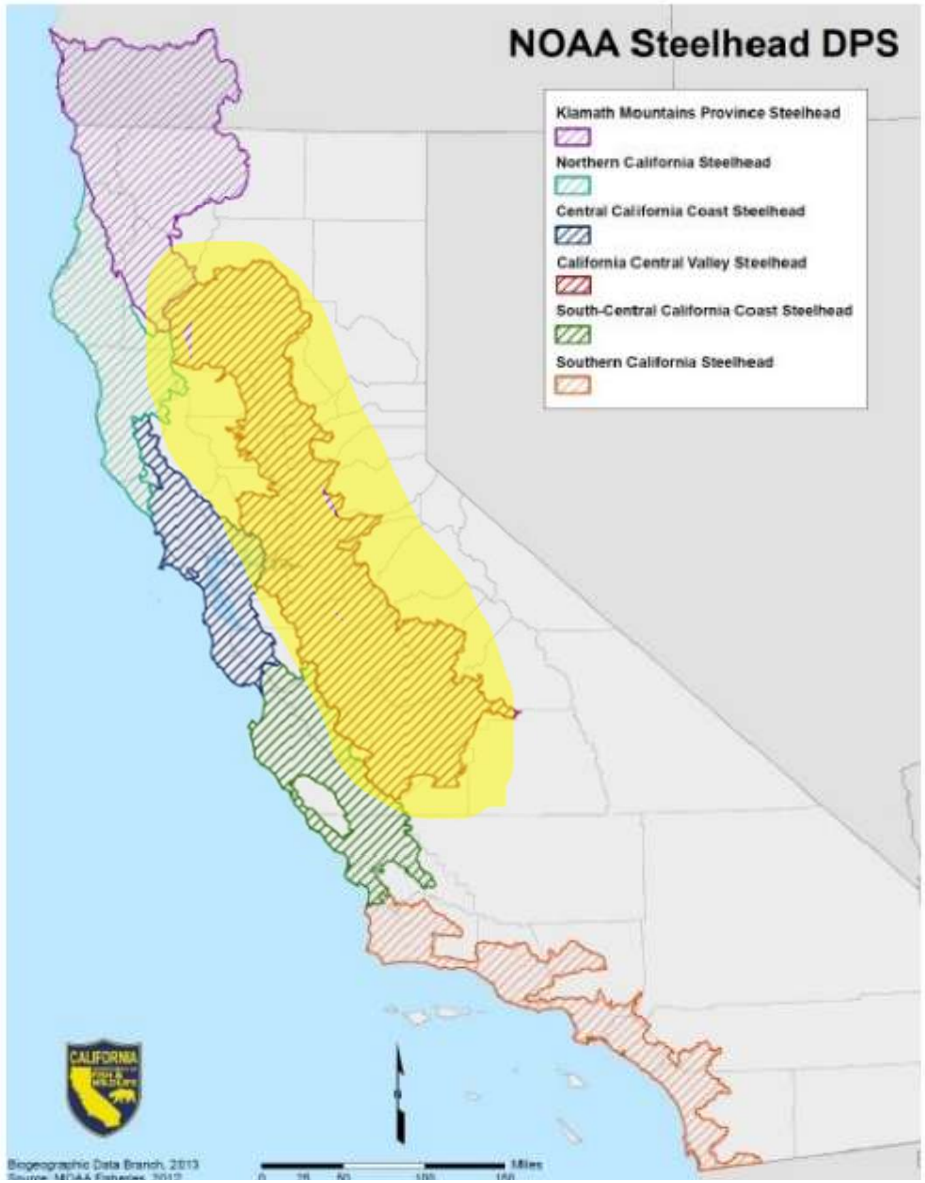

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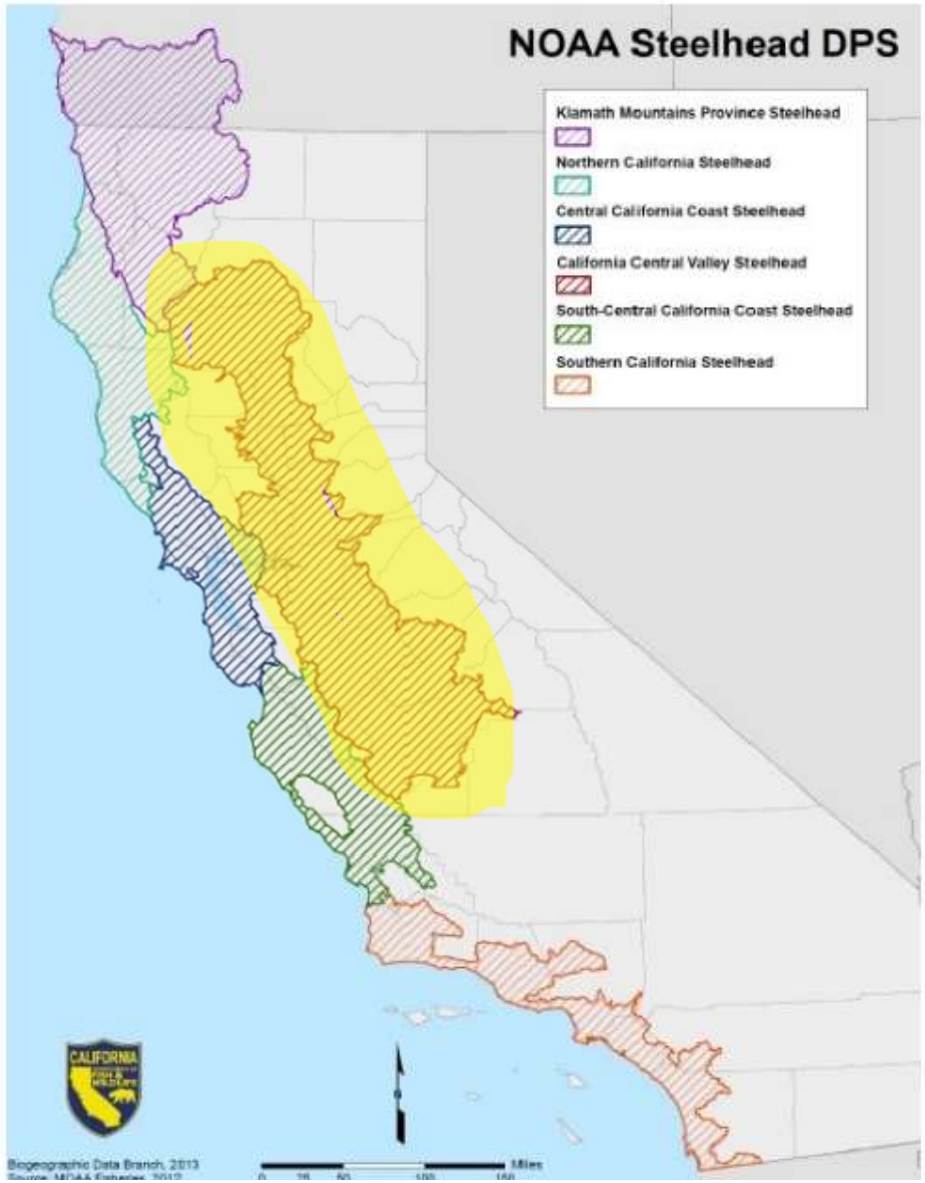

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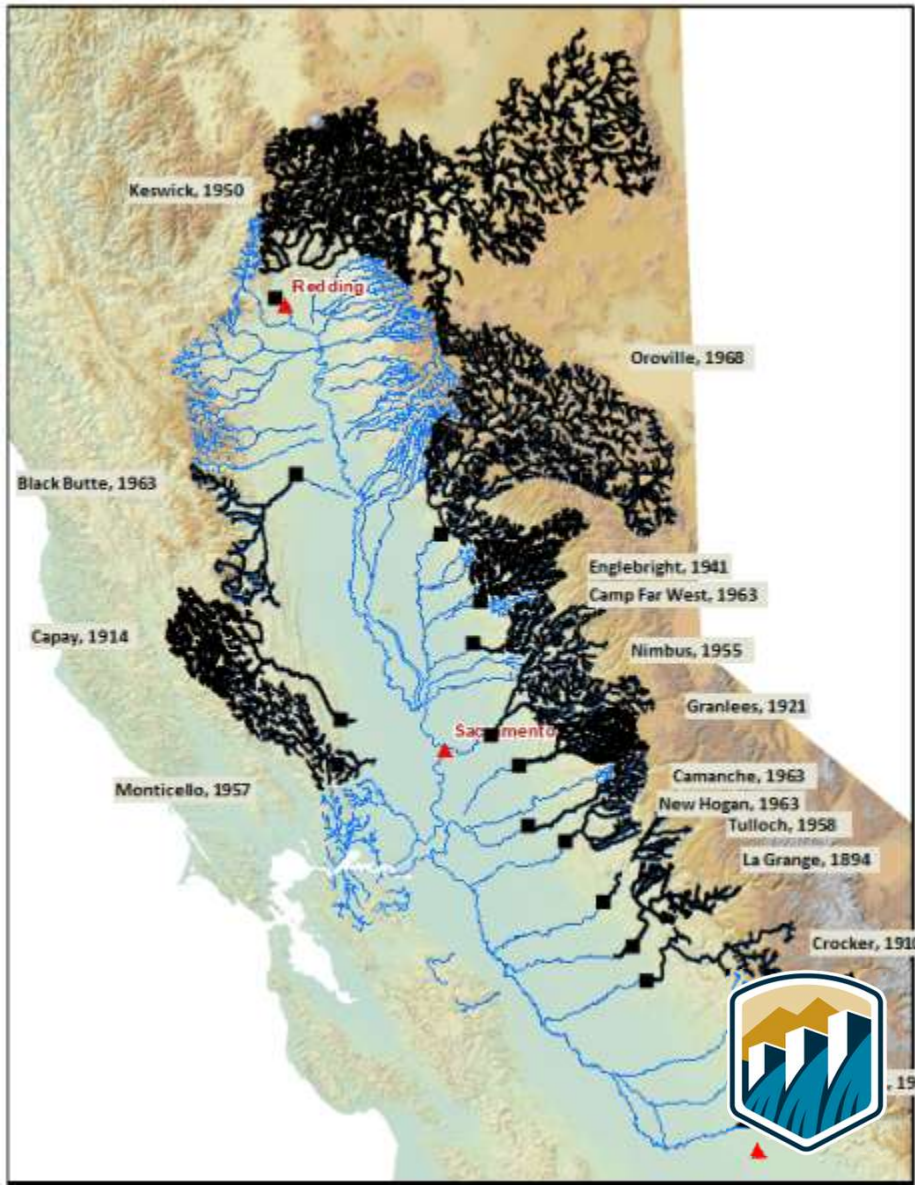

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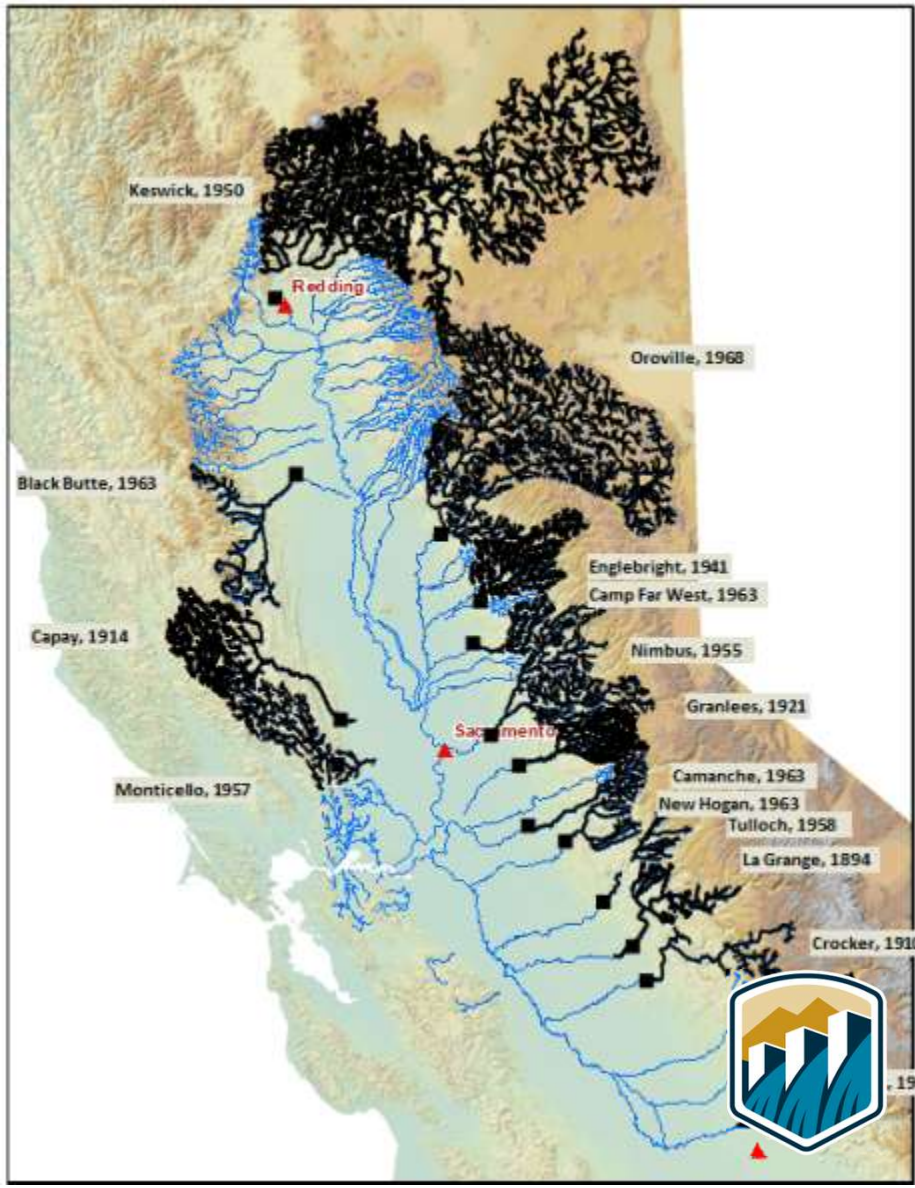
  - BUT water conveyance comes with his own set of threats



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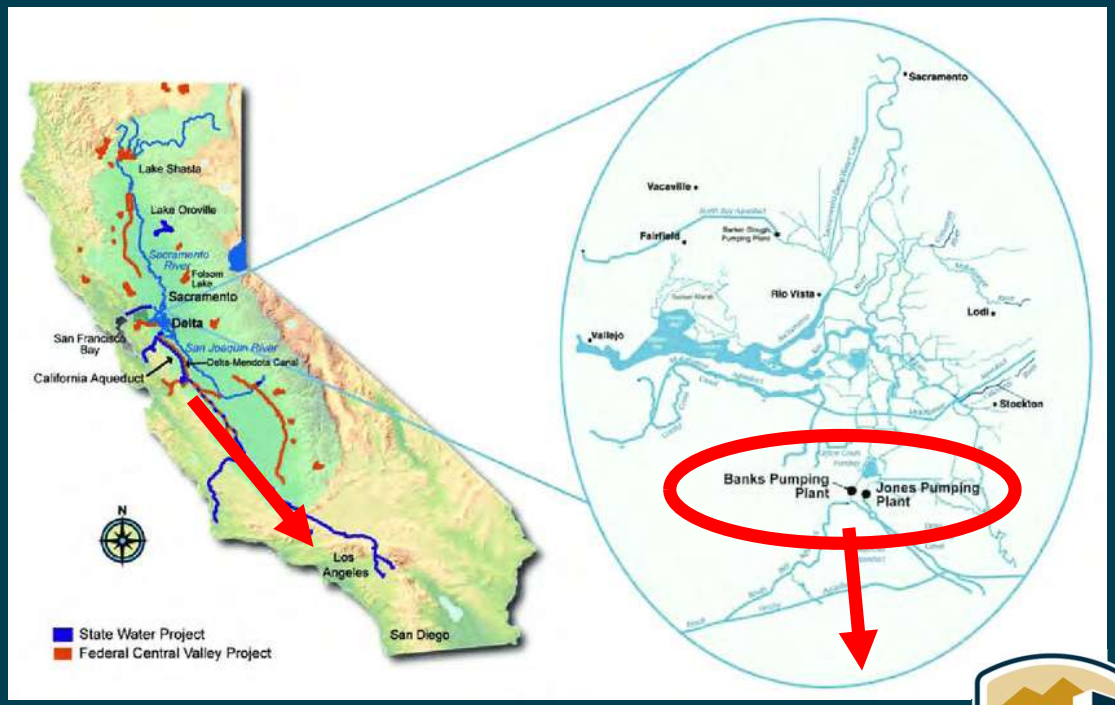

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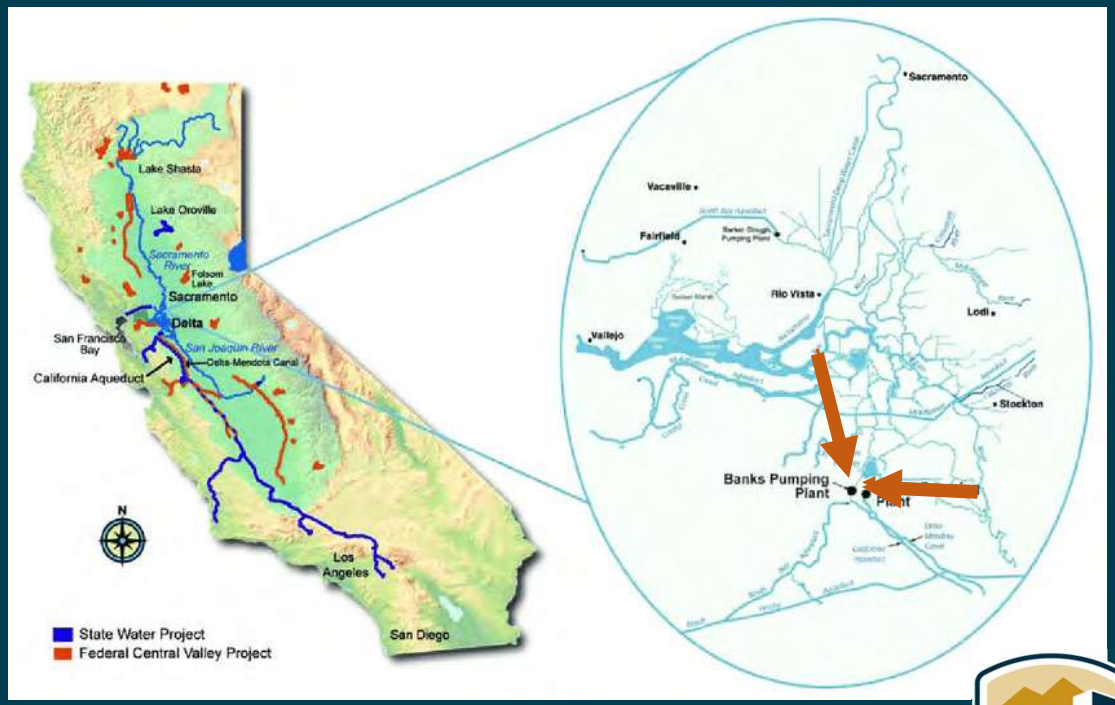
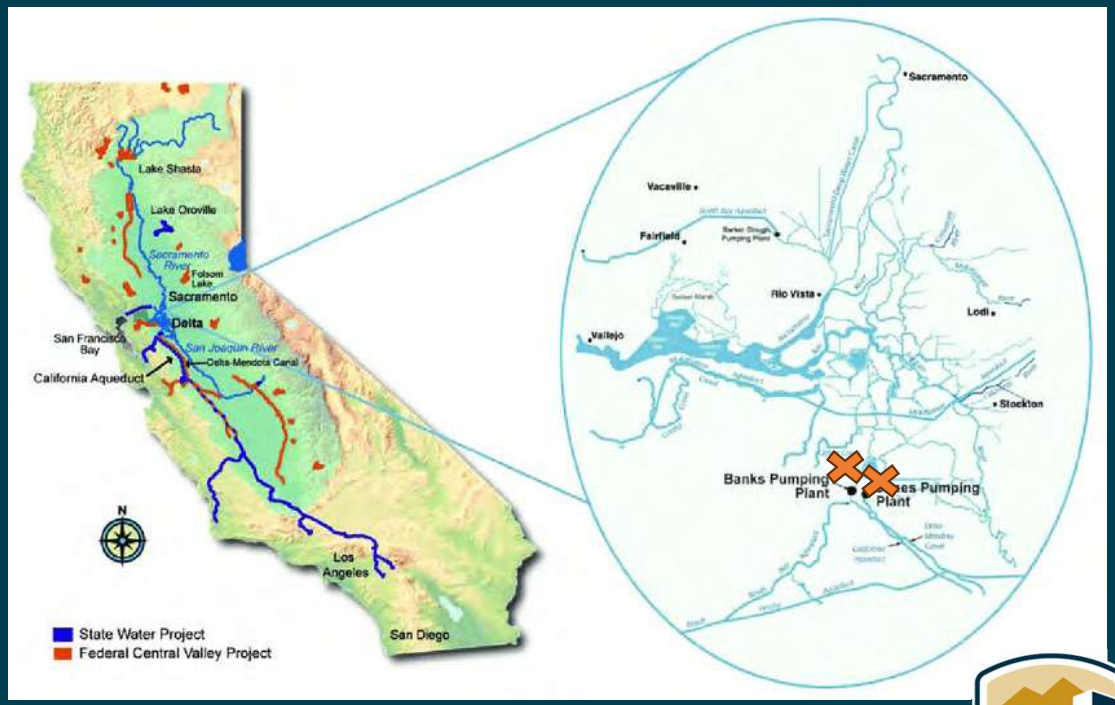
- Pumps can create net negative flow in the delta
  - More negative flow = more fish at pumps



Central Valley Water Operations

- Adjacent Salvage Facilities



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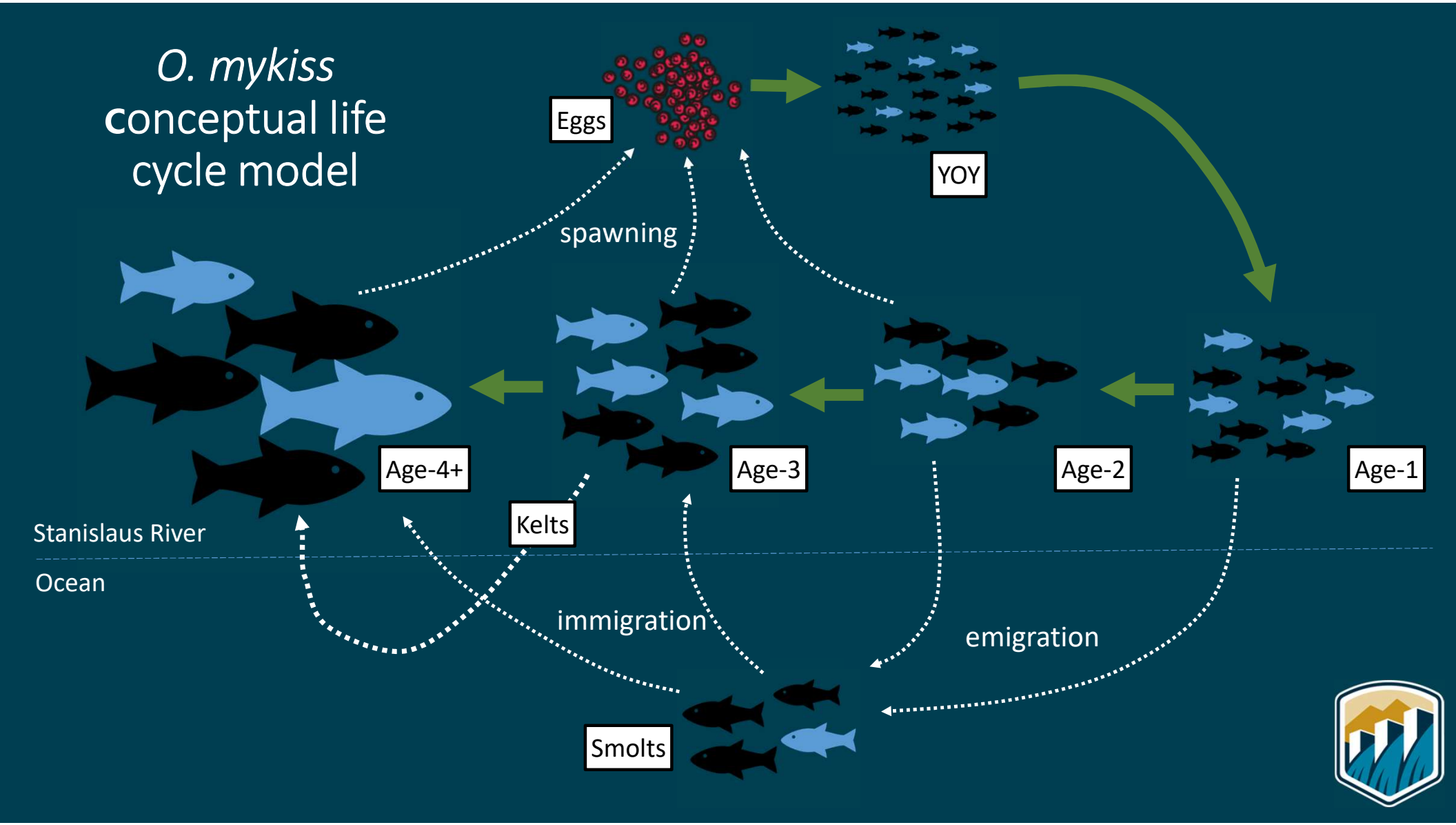
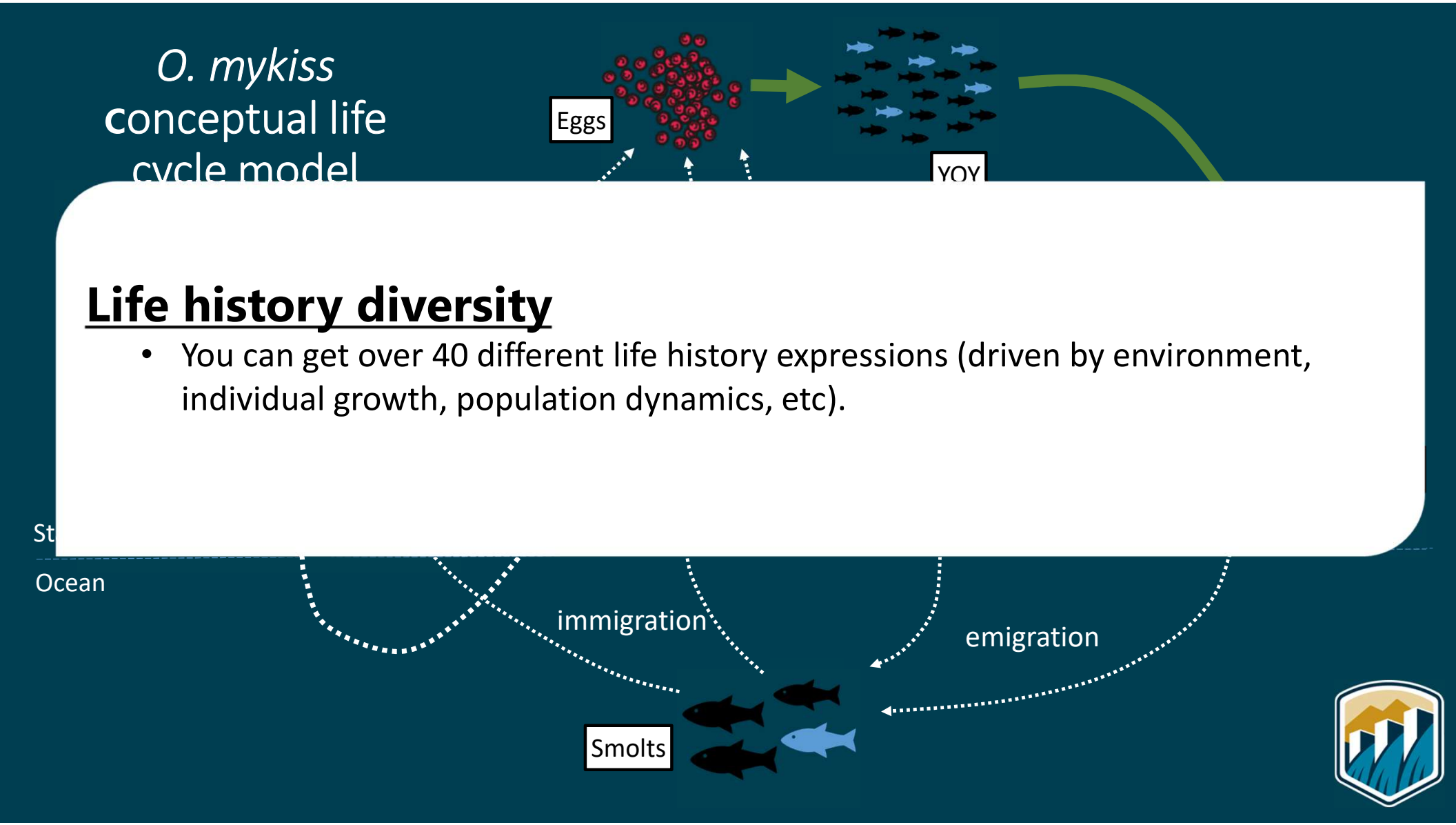
  - 3000 steelhead/year
  - Exceedance = Operational Adjustments
  - This is not based on any kind of abundance


O. mykiss
conceptual life
cycle model
Eggs
YOY
spawning
Age-4+
Age-3
Age-2
Age-1
Kelts
Stanislaus River
Ocean
immigration
emigration
Smolts

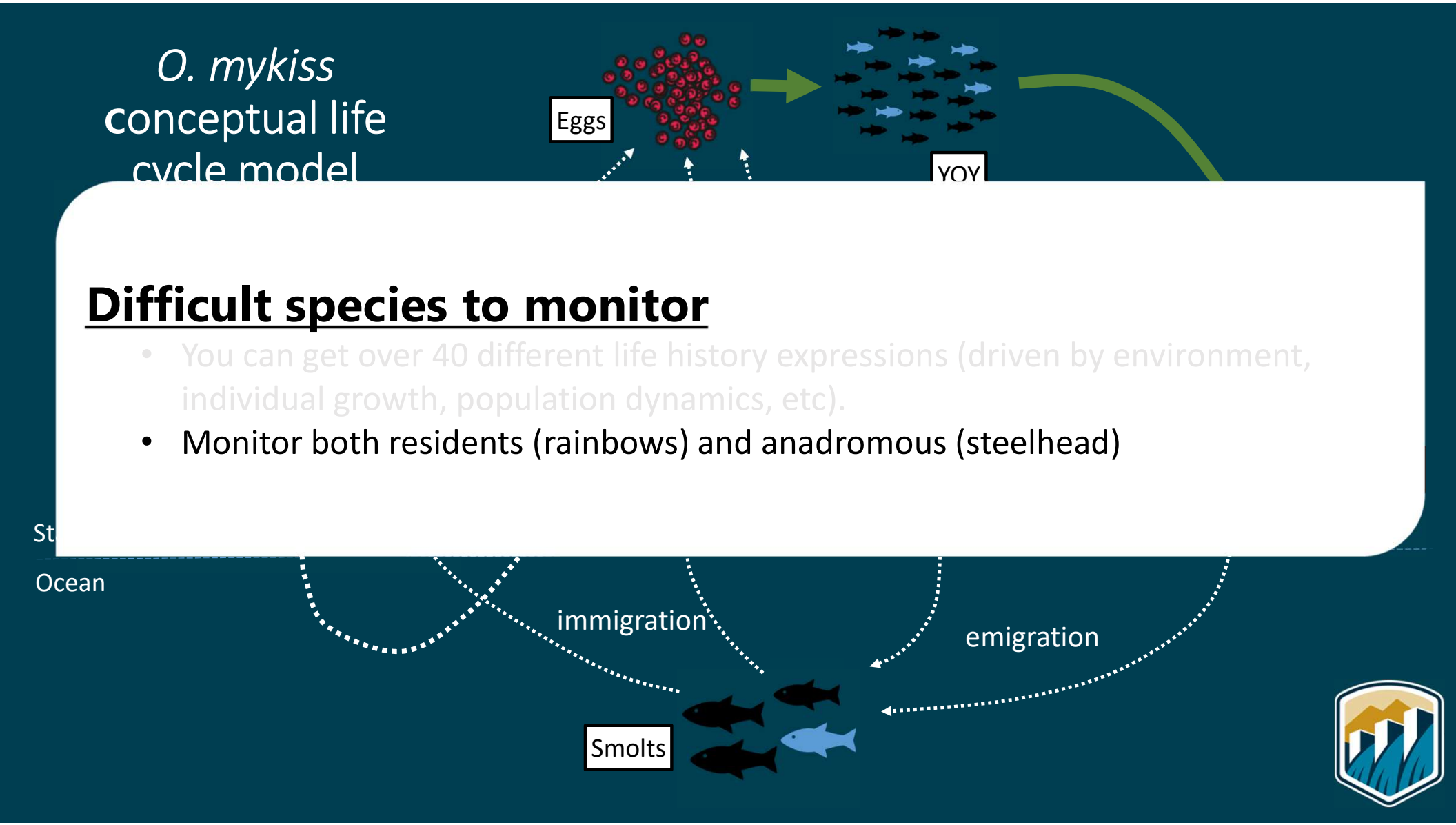
O. mykiss conceptual life cycle model



Life history diversity

- You can get over 40 different life history expressions (driven by environment, individual growth, population dynamics, etc).

O. mykiss conceptual life cycle model



Difficult species to monitor

- You can get over 40 different life history expressions (driven by environment, individual growth, population dynamics, etc).
- Monitor both residents (rainbows) and anadromous (steelhead)

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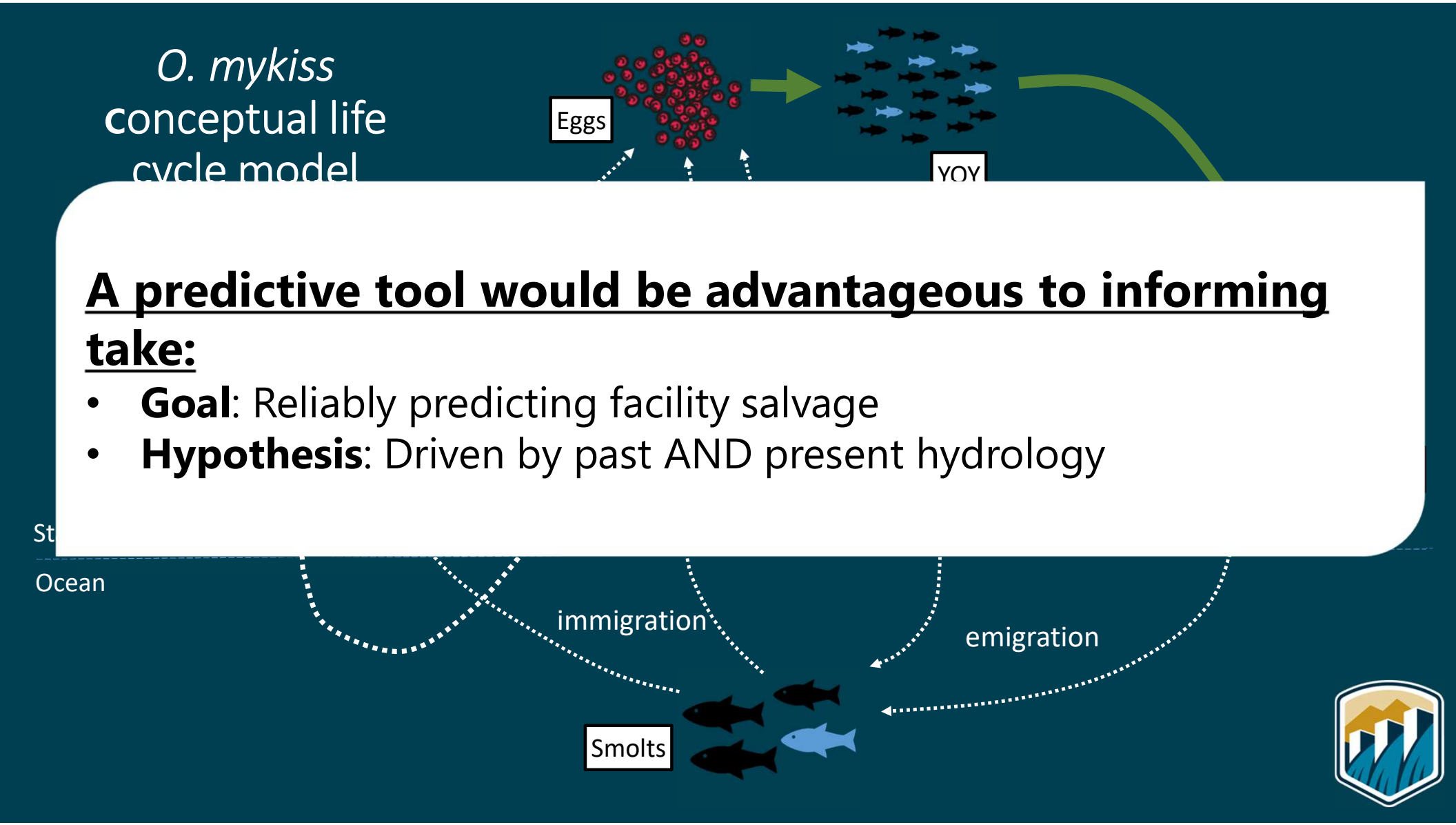

A predictive tool would be advantageous to informing take:

- **Goal**: Reliably predicting facility salvage
- **Hypothesis**: Driven by past AND present hydrology

Modeling Process

- Negative Binomial model
  - Total Annual salvage
- Initially a total of 11 covariates
- Model selection process
  - Removed collinearity -> Top 5 models (AICc) -> Cross Validation -> residual testing

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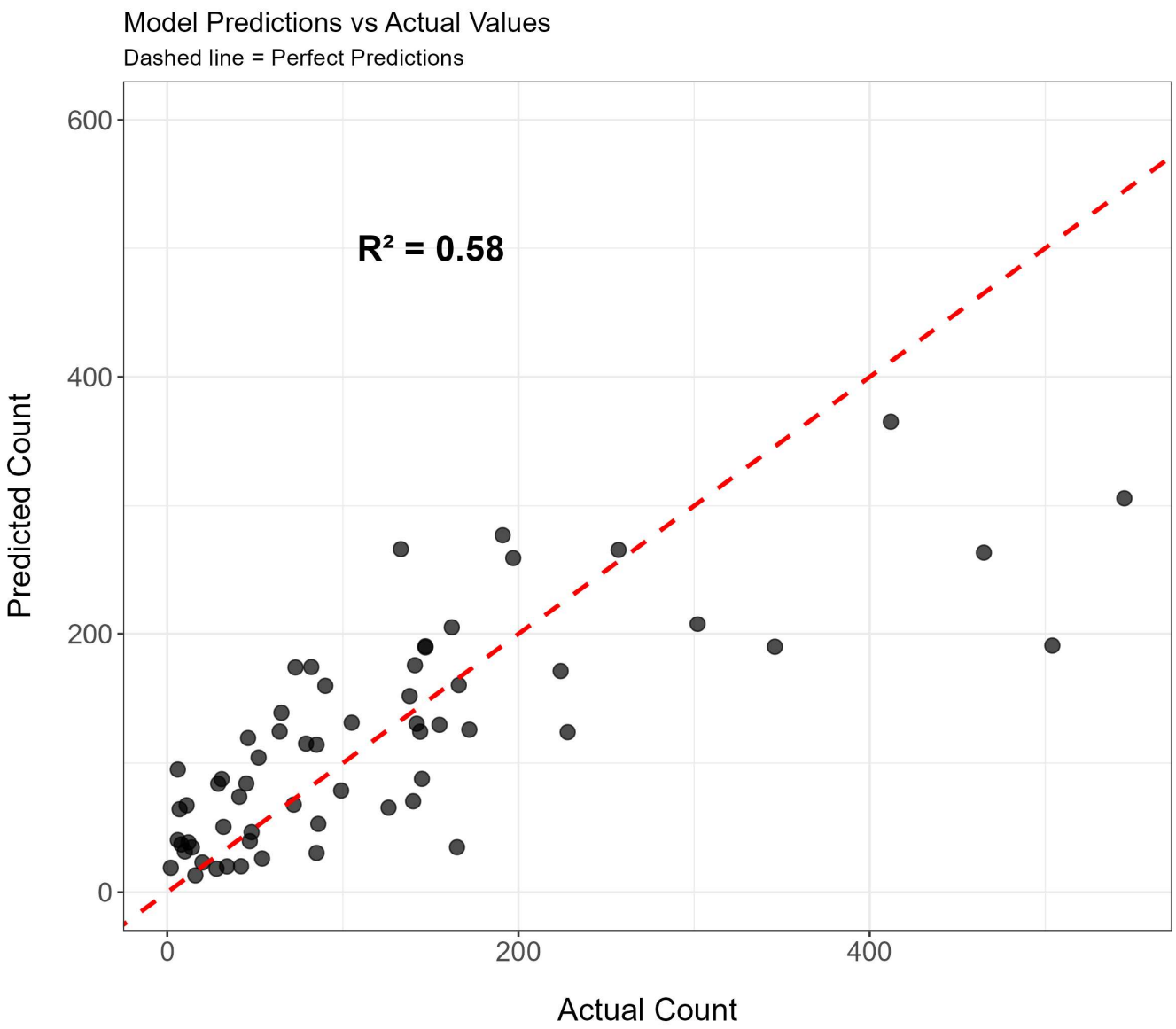
- **Final Model Included**
  - **Real-time components: OMR and Exports**
  - **Categorical variables: era and facility**
  - **Historical component: San Joaquin Index from Last Year and Two Years Ago**
    - *With an interaction*

How well does the model predict?

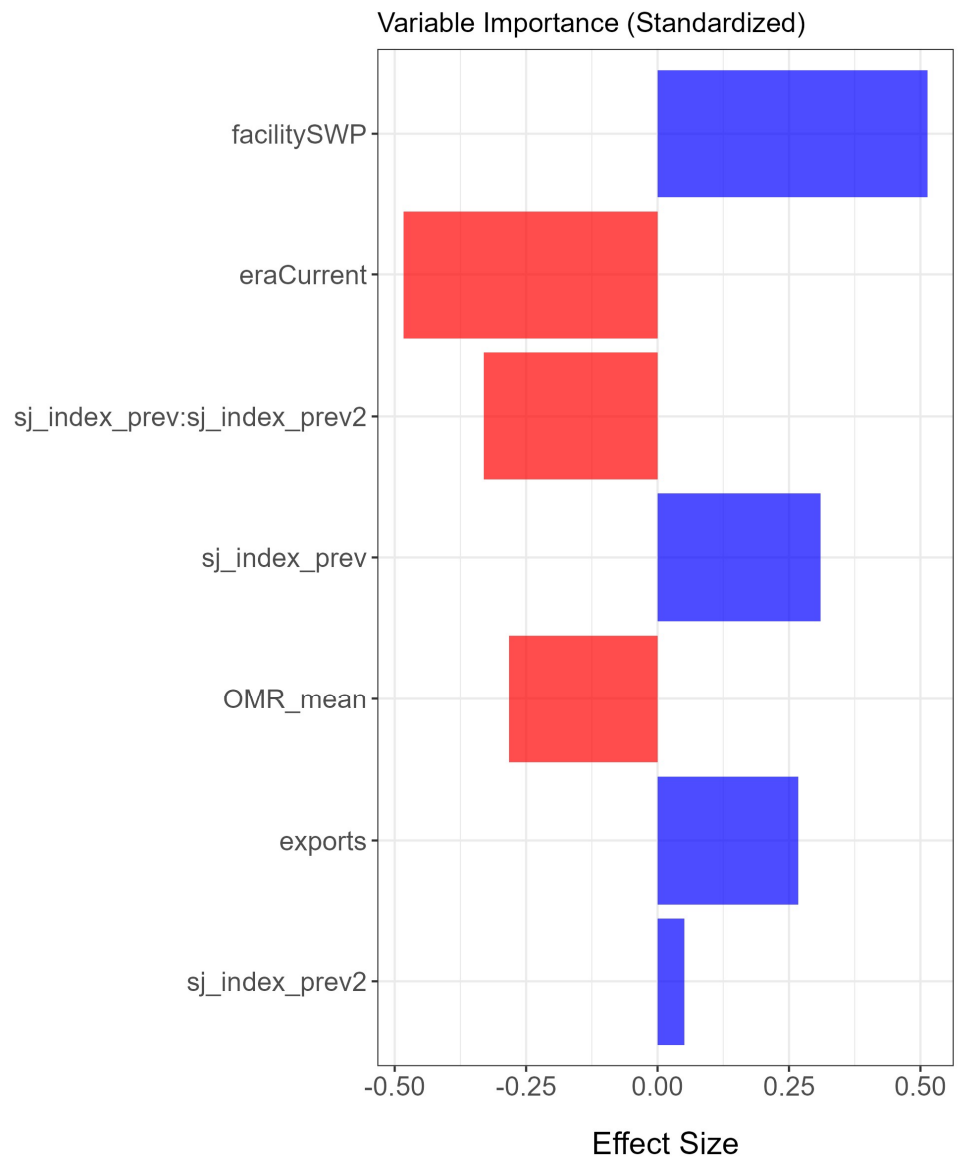
- Model explains a little more than half of the variance
- Mean absolute error = 56
  - Expect predictions to be roughly within this range
  - Dependent on magnitude
- Overall
  - Pretty good



What matters the most?

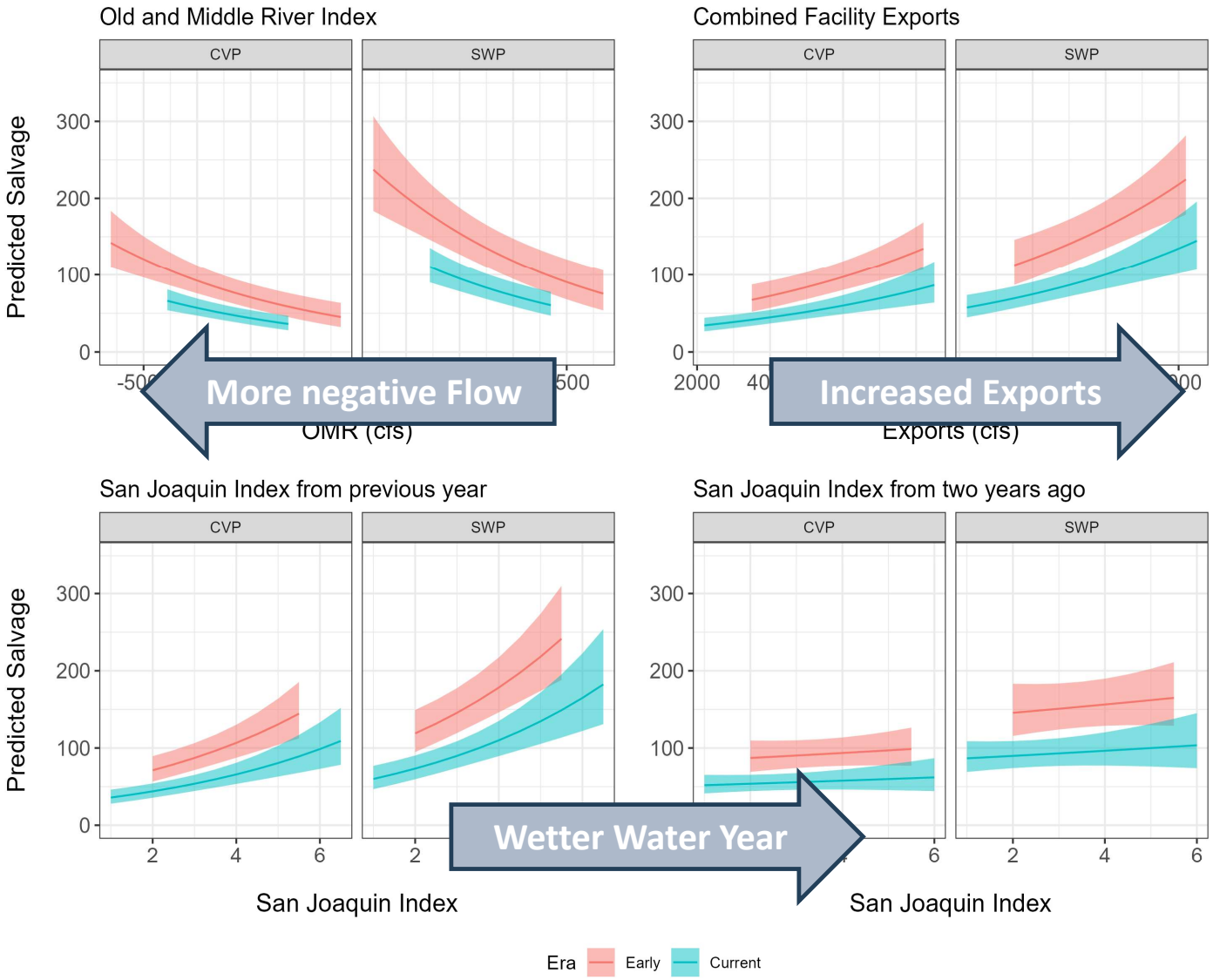
- Slope Coefficents
- Water year indexes and real-time flows are on two different scales.
  - Scale everything between 0 and 1
- Facility > Era > water year index interaction > real-time covariates and individual water year types

Interaction



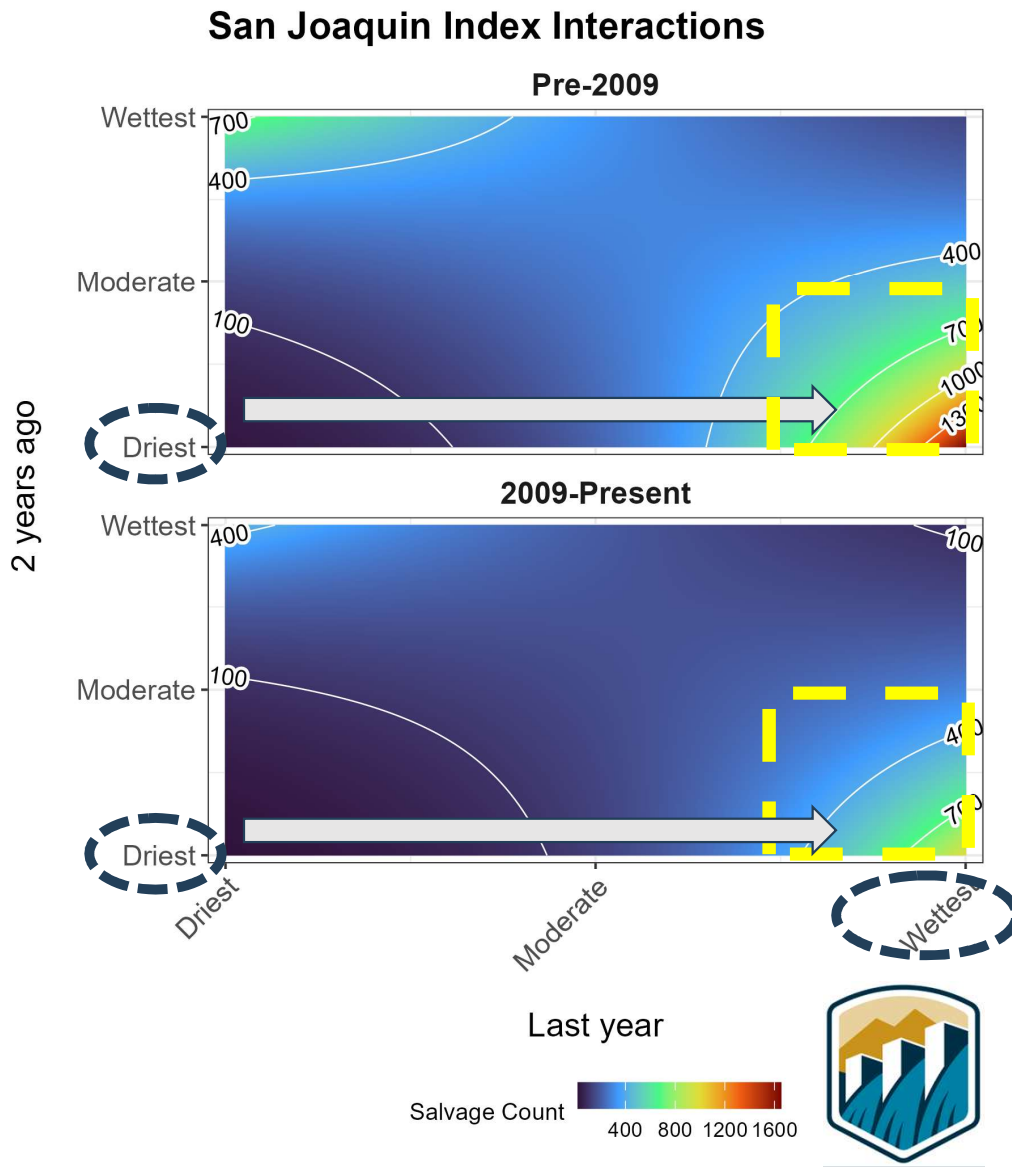
Smoothed Results

- Current and historic hydrology determines loss
- BUT the water year indices interact



Water Year Index Interaction

- A dry year followed by a wet year is associated with high loss



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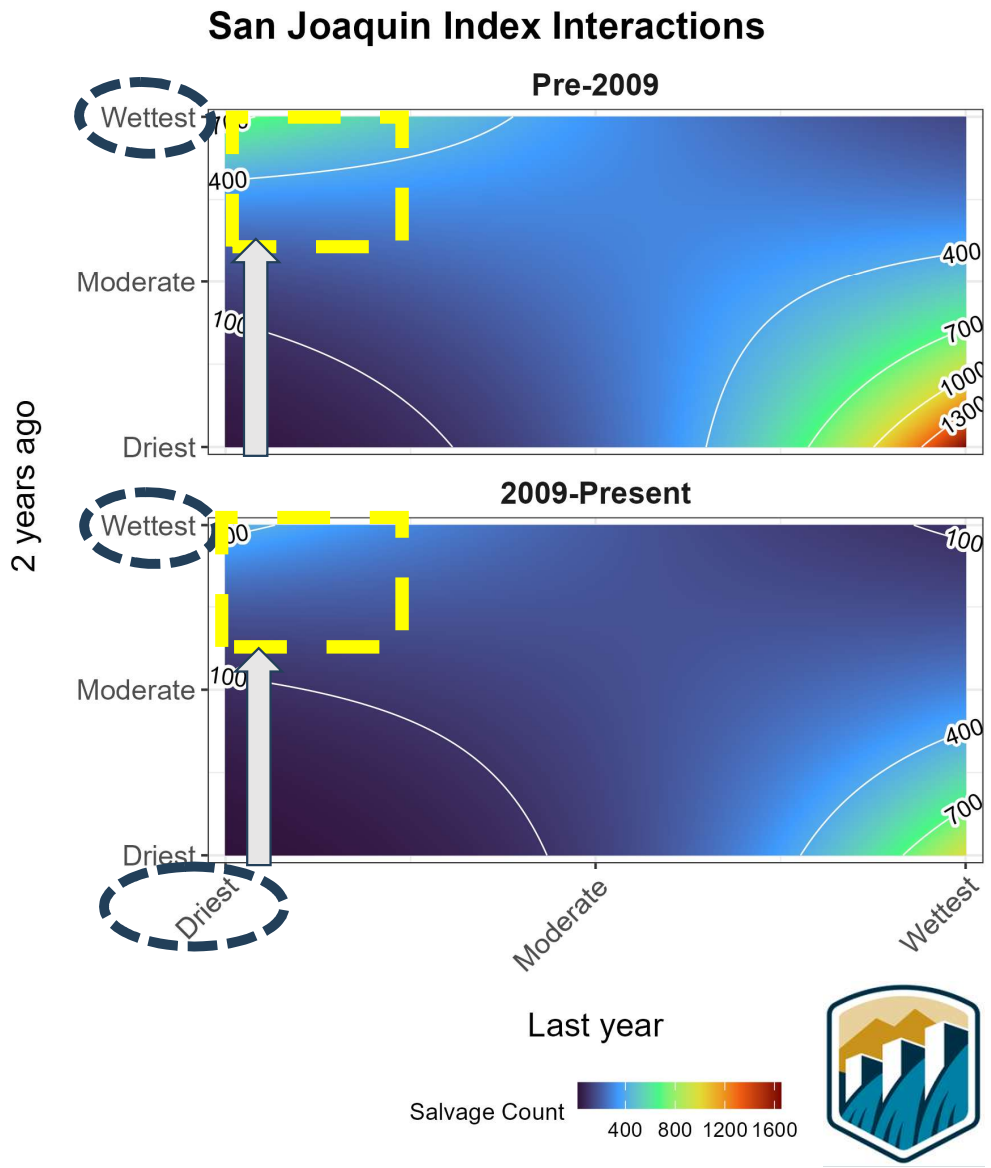
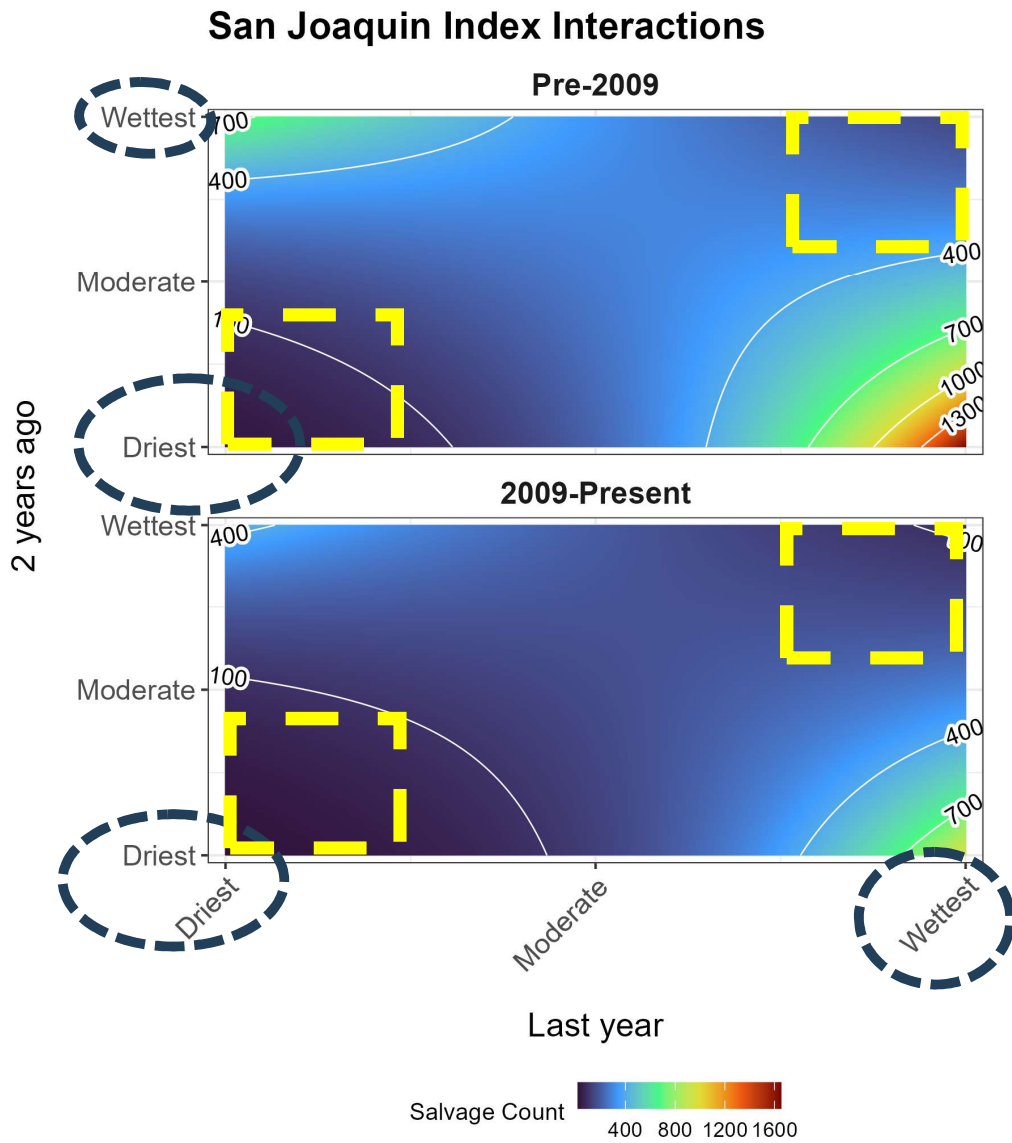


Water Year Index Interaction

- A dry year followed by a wet year is associated with high loss
- Inverse is also true
- Less loss with less disparity in water year types



What is driving all of this?

- Delta hydrology and effects on salvage are pretty well known
  - Maybe not good for predicting outmigration abundance
- The historic hydrolo : uncertainty
  - Is it an estimate of
  - Why San Joaquin Ir
- But what explains t

Why?

Dam Operations are cueing outmigration?

- D…ell known
  - Maybe not good for predicting outmigration abundance
- The historic hydrology may help explain some of that uncertainty
  - Is it an estimate of abundance? Or magnitude?
  - Why San Joaquin Index and not Sacramento?
- But what explains this phenomenon?

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Population level effects (density-dependence)

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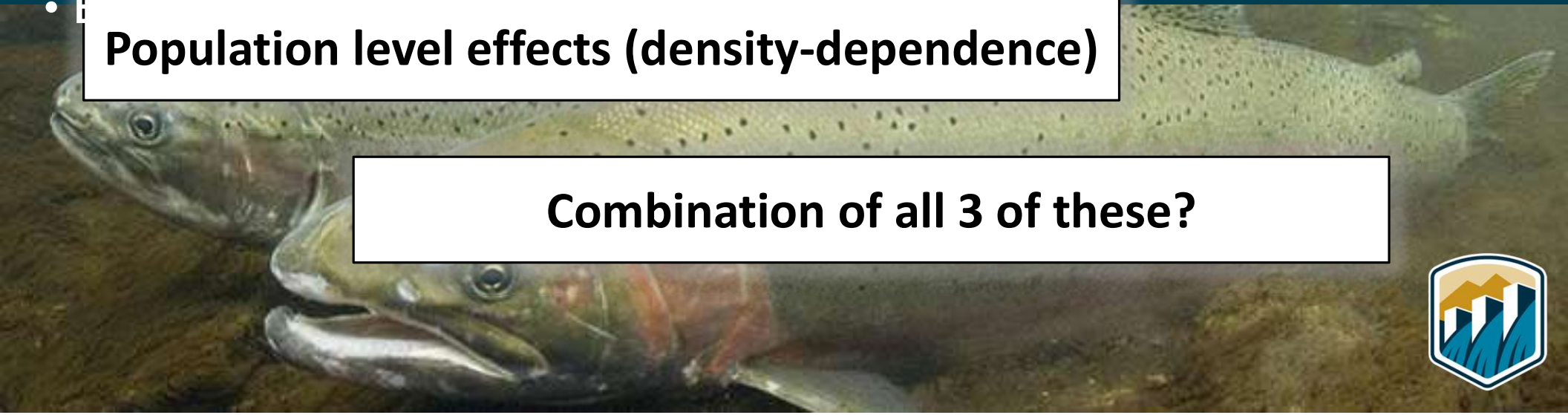
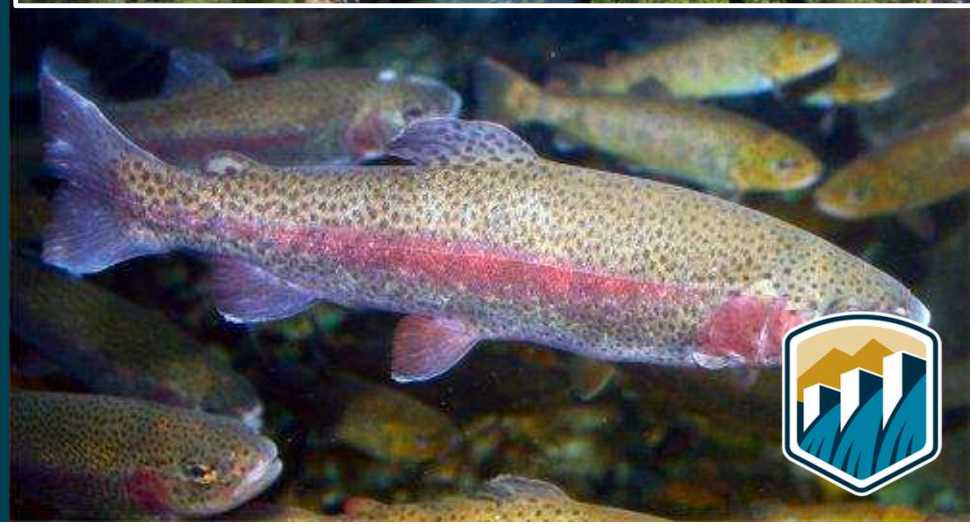
Population level effects (density-dependence)

Combination of all 3 of these?



Management Implications

- Move from reactive to proactive management
- Useful tool for real-time management
  - Forecast salvage at different operational outlooks
- Help narrow down (or think differently) about environmental variables
  - Water year index = unimpaired flow
  - Pressure, Productivity, etc?



In Summary

- Annual salvage predicted with real-time and historic metrics
  - Historic metrics have larger effects on the outcome
  - Real-time components are still important
- Next steps
  - Model refinement
  - Publish
  - See if it holds true for other steelhead populations (i.e. Columbia River)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QUESTIONS??
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Covariates

Description	Parameter	Type	Notes
San Joaquin Index from Previous Year	sj_index_prev	Continuous	Based on annual runoff
San Joaquin Index from 2 years ago	sj_index_prev2	Continuous	Based on annual runoff
Sacramento Index from Previous Year	sac_index_prev	Continuous	Based on annual runoff
Sacramento Index from 2 years ago	sac_index_prev2	Continuous	Based on annual runoff
Era	era	Categorical	Pre-2009 & Post-2008
Sacramento Flow	sac	Continuous	Averaged annually for Jan-Jun
Vernalis Flow	sjr	Continuous	Averaged annually for Jan-Jun
OMRI	OMR_mean	Continuous	Averaged annually for Jan-Jun
Exports	exports	Continuous	Averaged annually for Jan-Jun

Water year indices

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San Joaquin Index from Previous Year	sj_index_prev	Continuous	Based on annual runoff
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Sacramento Index			runoff
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Era			2008
Sacramento Flow			y for Jan-Jun
Vernalis Flow			y for Jan-Jun
OMRI	OMR_mean	Continuous	Averaged annually for Jan-Jun
Exports	exports	Continuous	Averaged annually for Jan-Jun

- **Essentially a measure of the annual runoff in each basin**
- **Continuous variable between 0 - 10 binned into 5 water year types:**
  Critical, Dry, Below Normal, Above Normal, and Wet
- **Assume most steelhead are outmigrating at age 1 and age 2**

‘Real-time’ covariates

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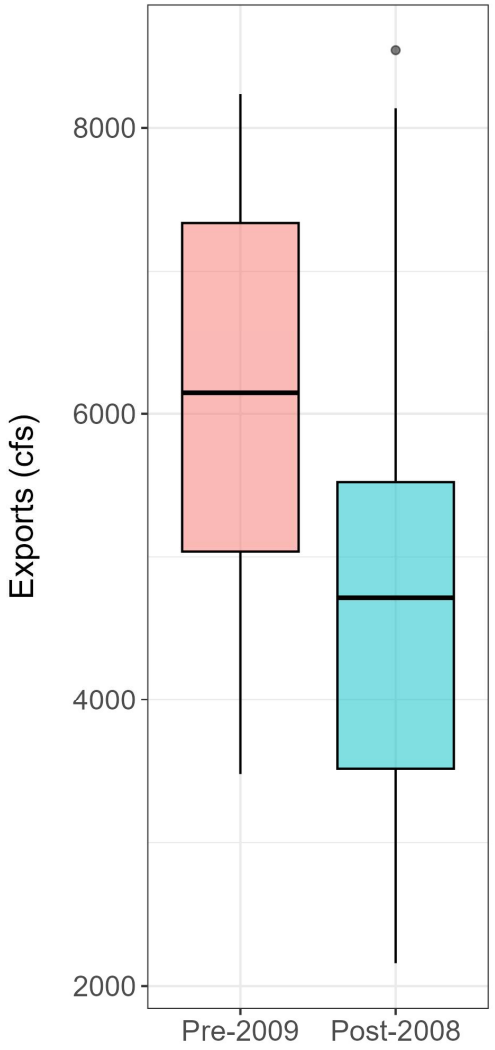
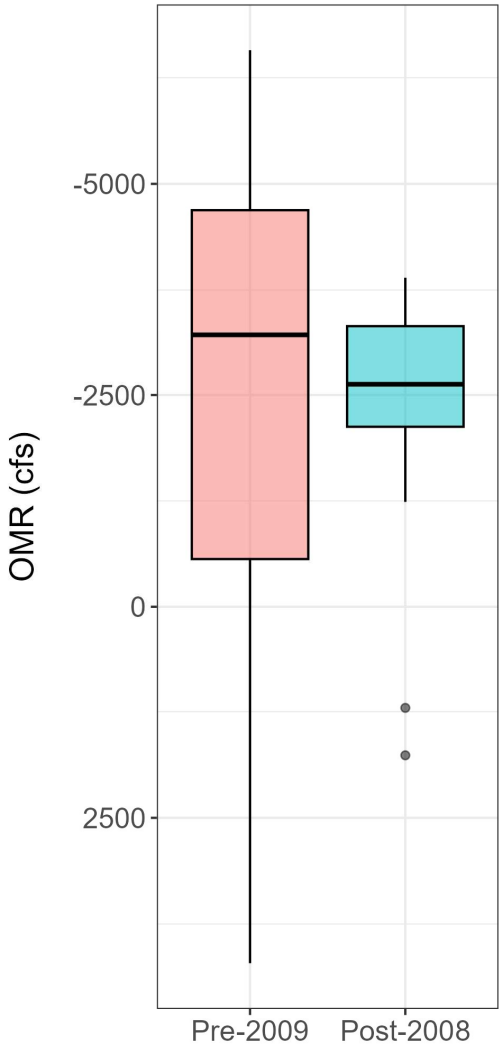
OMRI	**OMR_mean**	**Continuous**	**Averaged annually for Jan-Jun**
Exports	**exports**	**Continuous**	**Averaged annually for Jan-Jun**

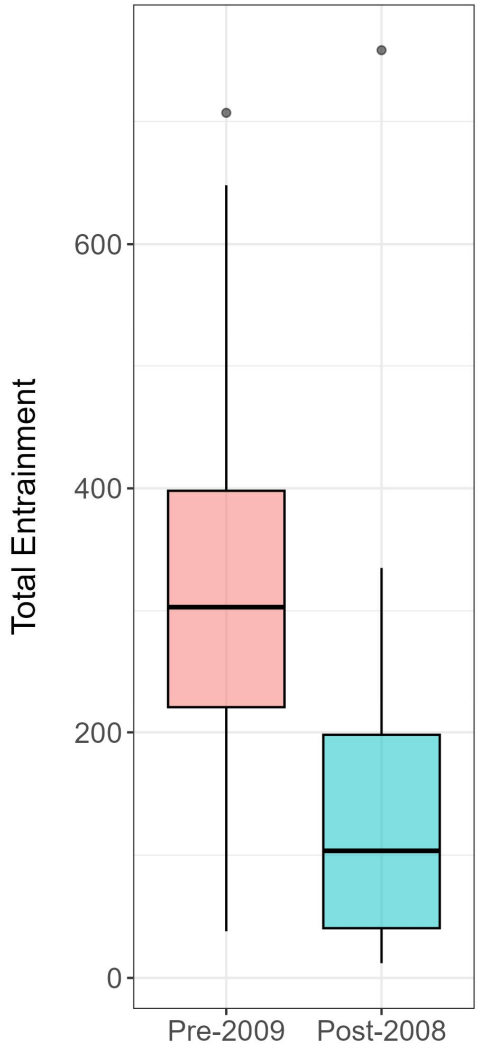
- **OMRI – Old and Middle River Index** *(net negative flow towards facility)*

Era

Description
San Joaquin Ind
San Joaquin Ind
Sacramento Ind
Sacramento Ind
Era
Sacramento Flo
Vernalis Flow
OMRI
Exports







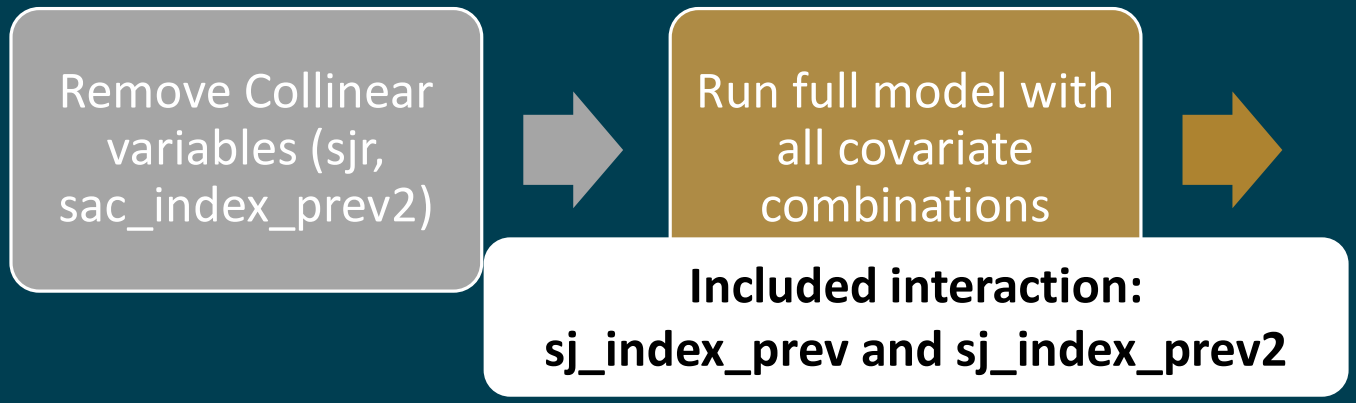
Slide 40

IJ1 These era seem to overlap 1 year?
Israel, Joshua A, 2025-09-03T05:14:41.564

Modeling Process

Remove Collinear variables (sjr, sac_index_prev2)

Modeling Process



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Remove Collinear variables (sjr, sac_index_prev2)

Run full model with for all covariate combinations

Subset Top 5 models based on AICc

Model Combination	AICc	ΔAICc
era + exports + OMR_mean + sj_index_prev*sj_index_prev2	**391.4**	-
exports + OMR_mean + sj_index_prev*sj_index_prev2	391.6	0.19
era + exports + OMR_mean + sj_index_prev	392.3	0.91
era + OMR_mean + sj_index_prev	392.4	0.96
era + exports + sac+ sj_index_prev*sj_index_prev2	392.8	1.38

Modeling Process

Remove Collinear variables (sjr, sac_index_prev2)

Run full model with all covariate combinations

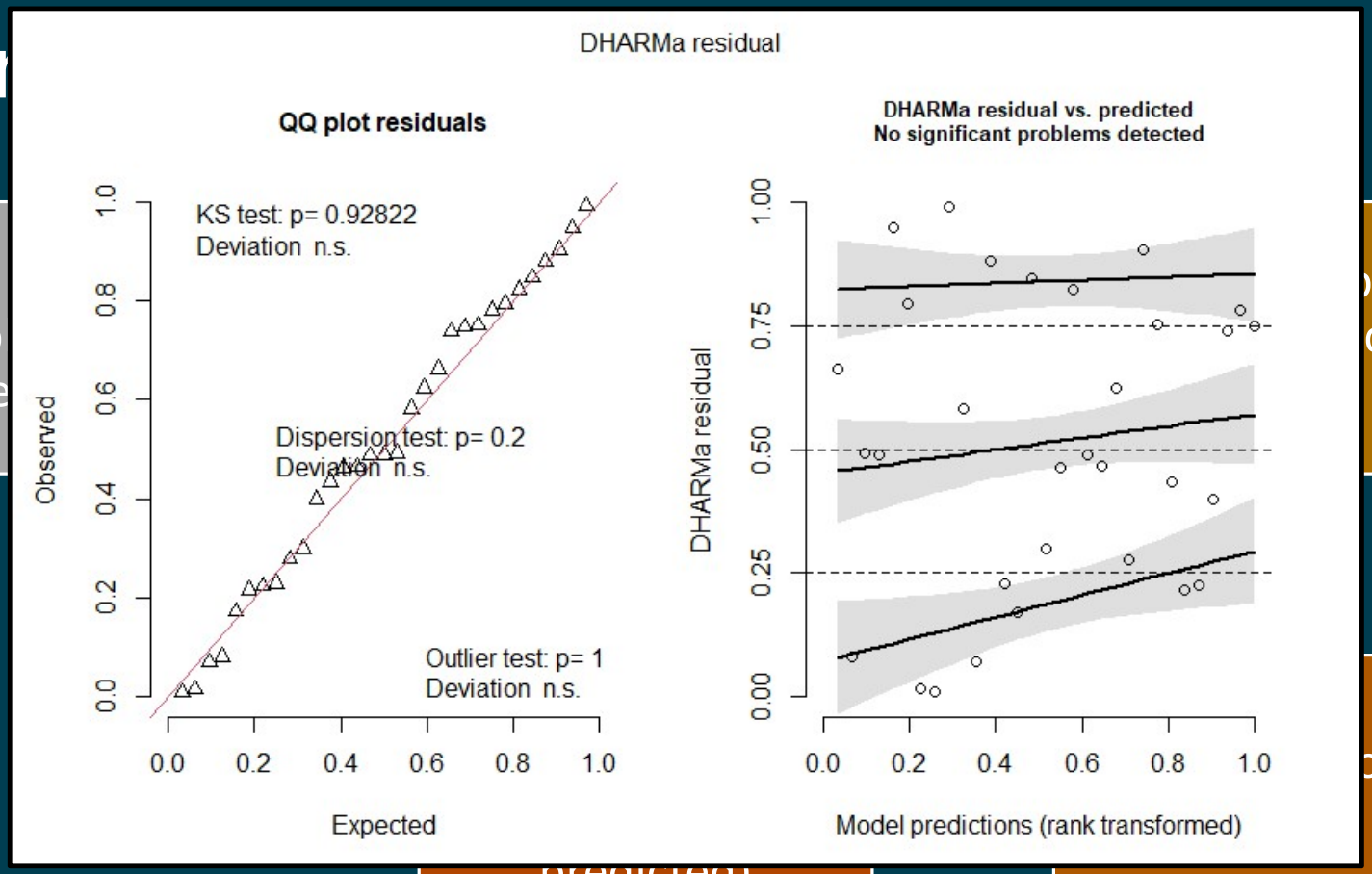
Subset Top 5 models based on AICc

Leave one out analysis

Model Combination	RMSE
era + exports + OMR_mean + sj_index_prev*sj_index_prev2	**145**
exports + OMR_mean + sj_index_prev*sj_index_prev2	153
era + exports + OMR_mean + sj_index_prev	176
era + OMR_mean + sj_index_prev	164
era + exports + sac+ sj_index_prev*sj_index_prev2	155

Modelir

Remove
variab
sac_inde



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predicted)

out

Modeling Process