Ecological Thresholds in Forecast Performance for Key U. S. West Coast Chinook Salmon Stocks

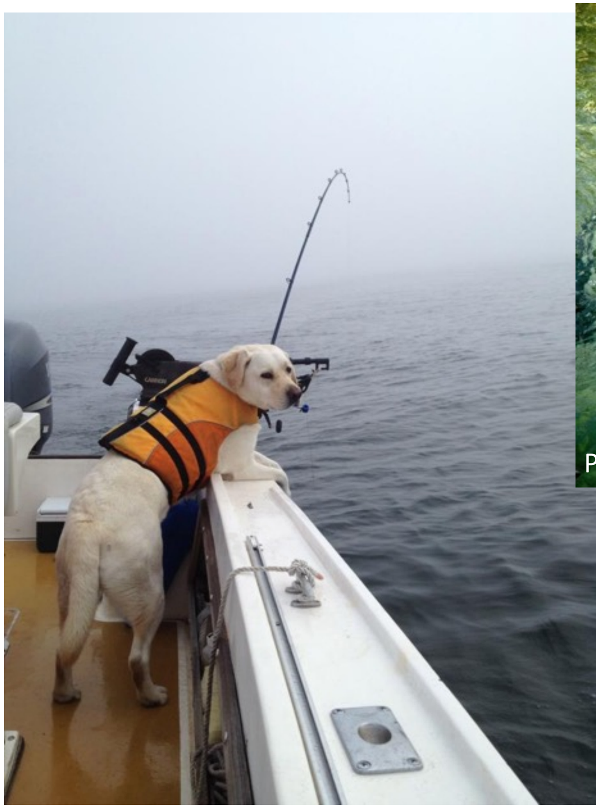

Photo credit: Zeke Lunder

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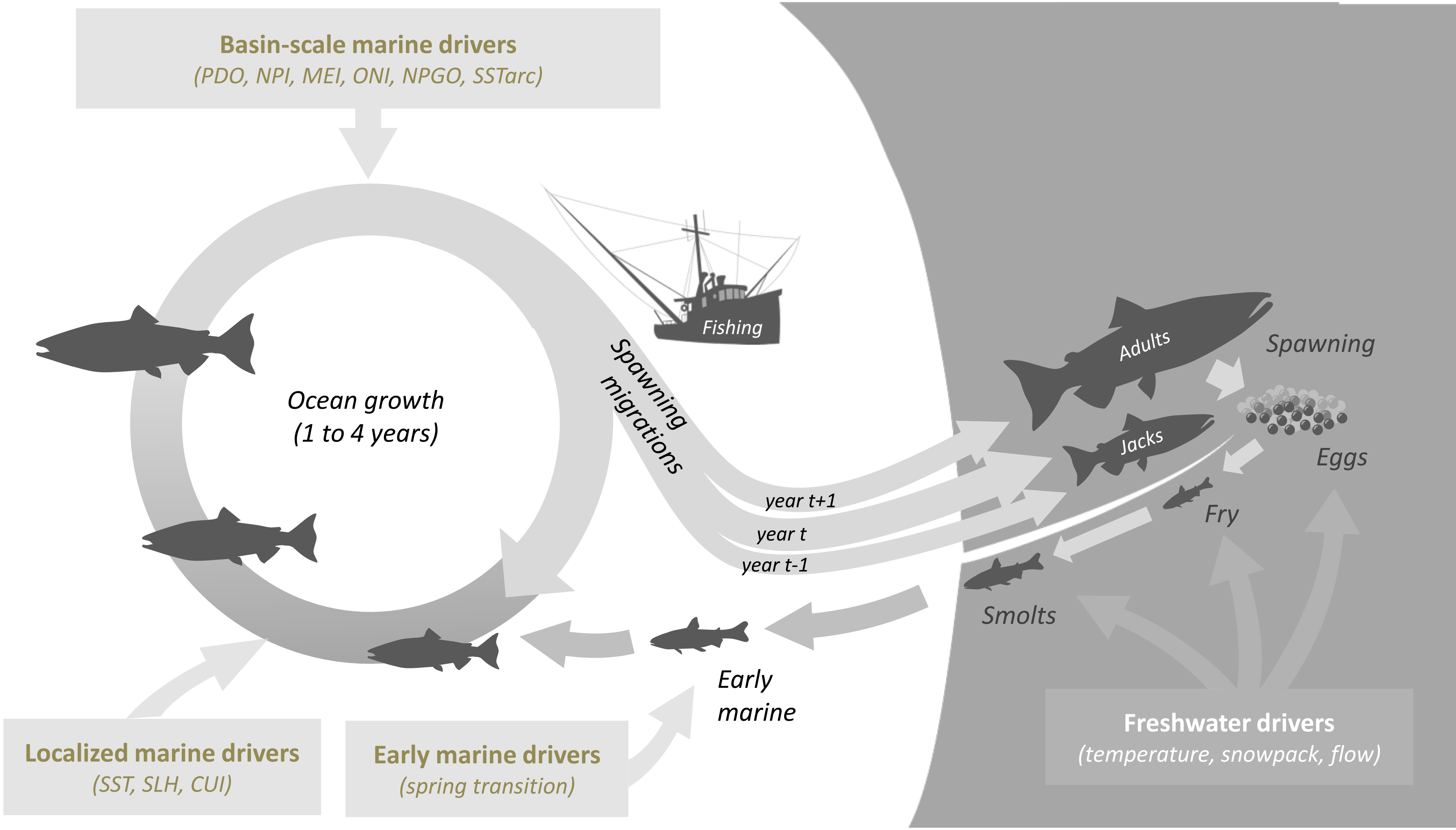
Salmon lifecycle and potential drivers



Ocean salmon fisheries on US West Coast

- Primarily time-area management
- Mixed stock fishery
  - Indicator stock approach
- Largely forecast-driven
  - Allowable harvest rates a function of expected abundance of key stocks

Motivation for this work

- Pacific Fisheries Management Council asks for research to identify “threshold” relationships with environmental indicators that could better inform salmon management
- Council recently noted increasingly variable salmon escapement and worsening forecast performance

Management uses of abundance forecasts

1. Escapement goals
2. Exploitation rate caps
3. *Ecosystem considerations*

Sacramento Fall Chinook Harvest Control Rule

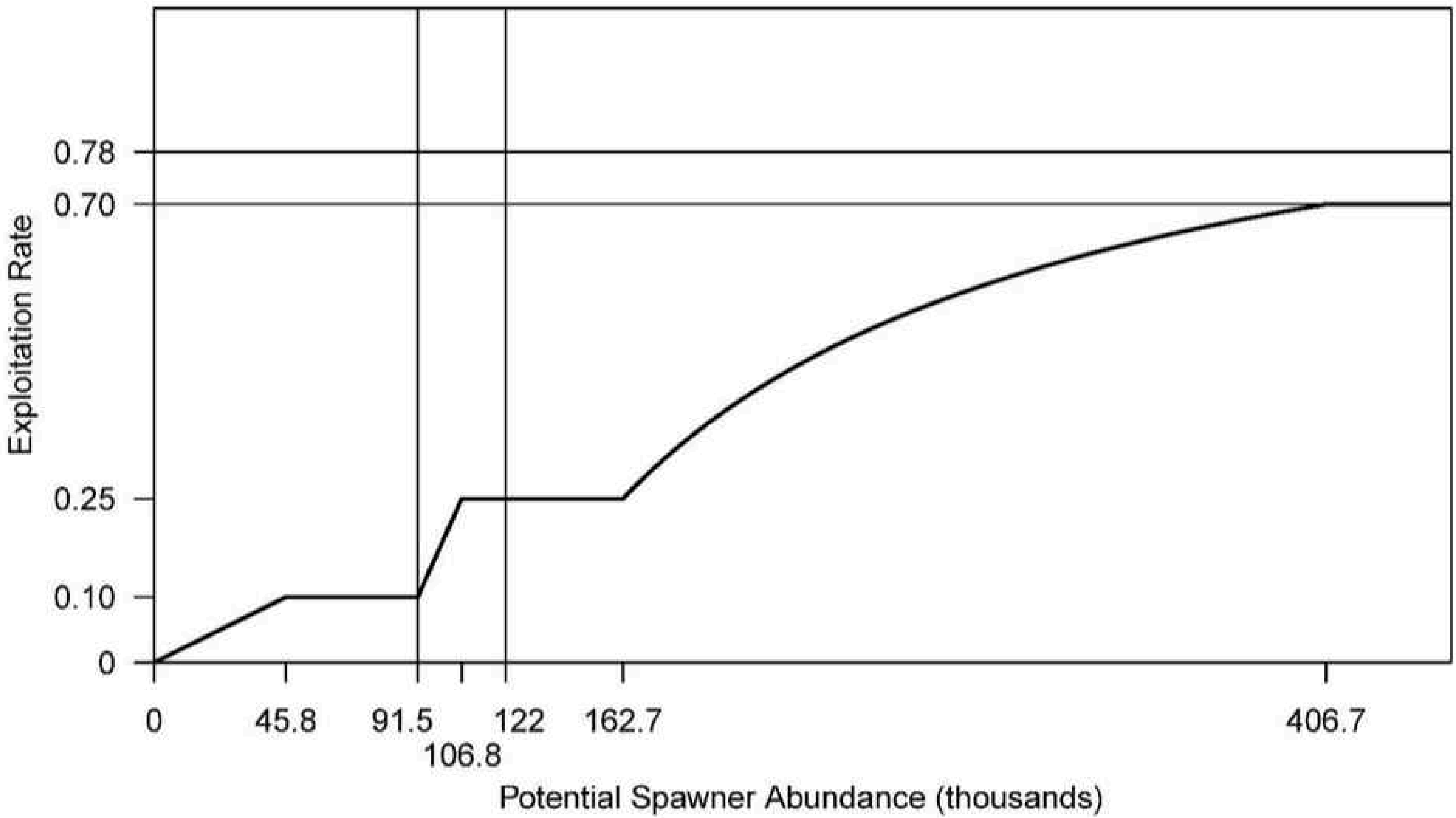


FIGURE A-1. Sacramento River fall Chinook control rule. Potential spawner abundance is the predicted hatchery and natural area adult spawners in the absence of fisheries, which is equivalent to the Sacramento Index. See the salmon FMP, Section 3.3.6, for control rule details.

Management uses of abundance forecasts

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Sacramento Winter Chinook Control Rule

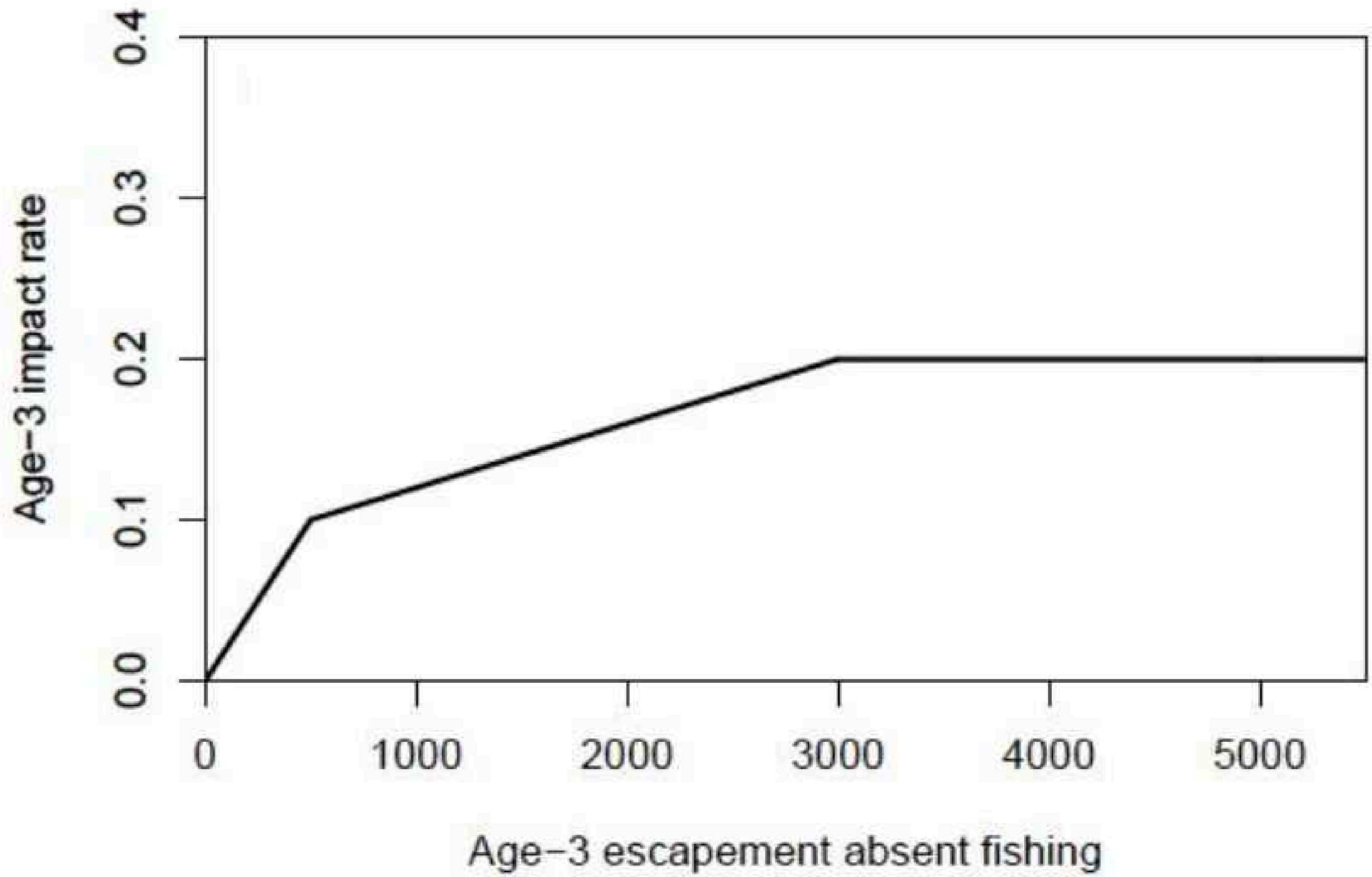

FIGURE A-3. Council Recommended Sacramento River winter Chinook impact rate control rule; which specifies the maximum forecast age-3 impact rate for the area south of Point Arena, California, as a function of forecasted age-3 escapement absent fishing.

Management uses of abundance forecasts

1. Escapement goals

2. Exploitation rate caps

3. *Ecosystem considerations*

Types of forecasts

1. Sibling relationships
2. Production multipliers
3. Environmental models
4. Ensembles

Klamath Fall Chinook forecast

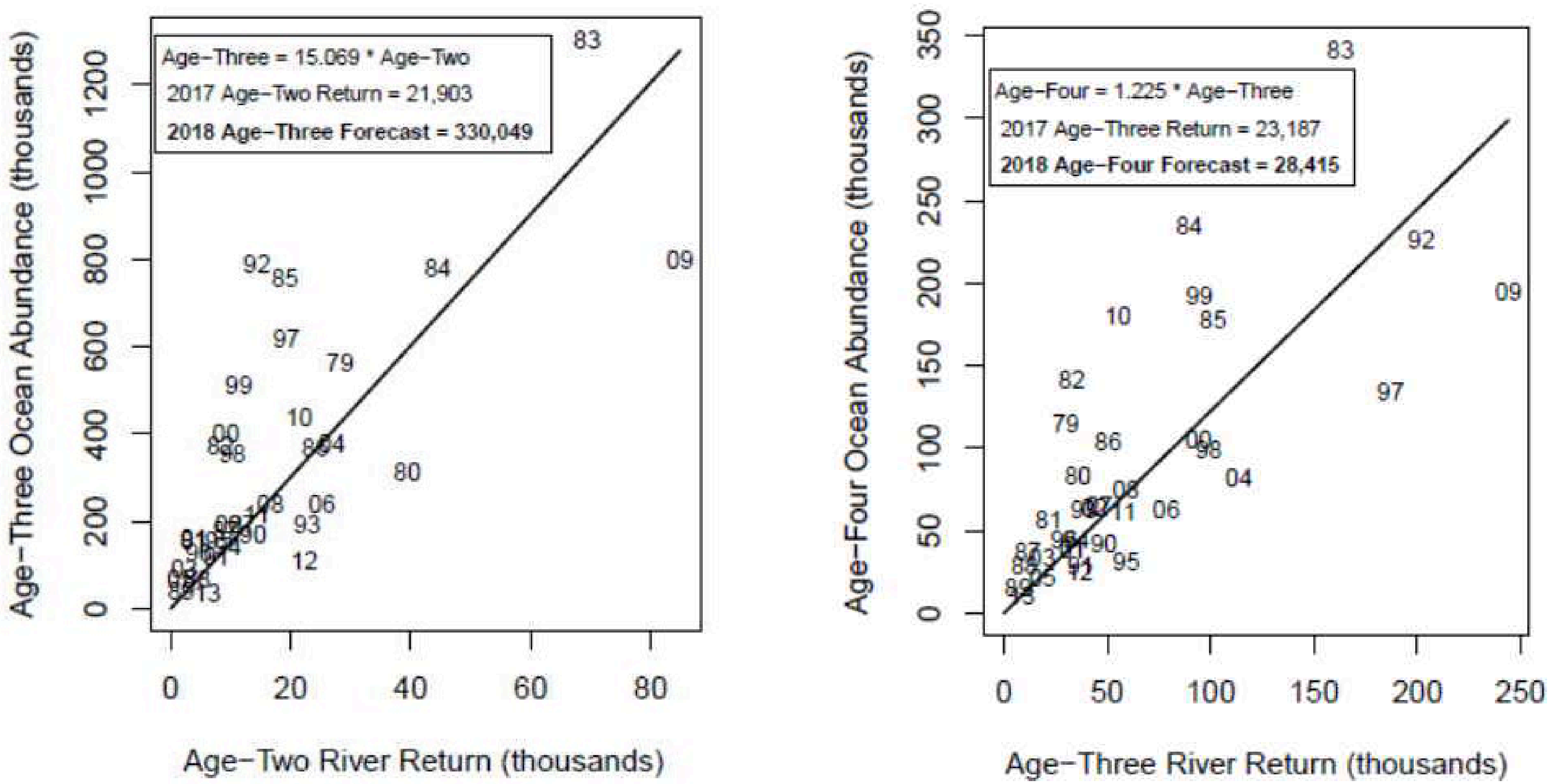

FIGURE II-3. Regression estimators for Klamath River fall Chinook ocean abundance (September 1) based on that year's river return of same cohort. Numbers in plots denote brood years.

Types of forecasts

1. Sibling relationships

2. Production multipliers
    1. Spawner counts
    2. Smolt outmigrant counts
    3. Hatchery release counts

3. Environmental models

4. Ensembles

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Forecast performance through time

TABLE II-9. Preseason forecasts and postseason estimates of Puget Sound run size for summer/fall Chinook in thousands of fish.[a/] (Page 1 of 4)

Year or Average	Preseason Forecast	Postseason Return	Pre/Post-season	Preseason Forecast	Postseason Return	Pre/Post-season	Preseason Forecast	Postseason Return	Pre/Post-season	Preseason Forecast	Postseason Return	Pre/Post-season
	Nooksack-Samish Hatchery and Natural			East Sound Bay Hatchery			Skagit Hatchery			Skagit Natural		
1993-95	45.2	27.6	1.65	3.3	1.6	9.41	1.3	3.4	0.47	9.1	7.3	1.33
1996-00	27.0	35.4	0.77	2.1	0.5	13.35	0.2	0.2	0.87	7.0	10.9	0.80
2001	34.9	65.6	0.53	1.6	0.9	1.85	0.0	0.0	-	9.1	14.1	0.64
2002	52.8	57.0	0.93	1.6	0.9	1.87	0.0	0.1	0.00	13.8	20.0	0.69
2003	45.8	30.0	1.53	1.6	0.2	7.51	0.0	0.3	0.00	13.7	10.3	1.33
2004	34.2	18.1	1.89	0.8	0.0	200.00	0.5	0.0	-	20.3	24.3	0.84
2005	19.5	16.5	1.18	0.4	0.0	13.33	0.7	0.4	1.88	23.4	23.4	1.00
2006	16.9	31.9	0.53	0.4	0.0	25.00	0.6	0.4	1.51	24.1	22.5	1.07
2007	18.8	26.5	0.71	0.4	0.0	66.67	1.1	0.4	2.75	15.0	13.0	1.15
2008	35.3	29.1	1.21	0.8	0.0	-	0.7	0.2	3.50	23.8	15.0	1.59
2009	23.0	20.9	1.10	0.1	0.0	25.00	0.6	0.1	6.00	23.4	12.5	1.87
2010	30.3	35.8	0.85	2.3	0.7	3.29	0.9	0.1	11.25	13.0	10.0	1.30
2011	37.5	33.3	1.13	0.4	0.7	0.57	1.5	0.1	15.00	14.3	9.2	1.55
2012	44.0	32.6	1.35	0.4	1.6	0.25	1.3	0.1	13.00	8.3	15.8	0.53
2013	47.2	31.4	1.50	2.0	1.1	1.82	0.3	0.1	3.00	12.9	13.0	0.99
2014	43.9	25.5	1.72	1.2	0.3	4.00	0.3	0.0	7.50	18.0	10.1	1.78
2015	38.6	18.1	2.13	1.2	0.9	1.33	0.6	0.0	-	11.8	14.8	0.80
2016	27.9	15.8	1.77	0.7	0.7	1.00	0.4	0.1	4.00	15.1	21.1	0.72
2017[b/]	21.2	17.2	1.23	0.8	0.5	1.70	0.4	0.1	4.08	15.8	13.6	1.16
2018	24.6	NA	-	0.7	NA	-	0.3	NA	-	13.3	NA	-
2019	21.3	-	-	0.3	-	-	0.3	-	-	13.6	-	-

Forecast estimate

Observed returns

https://www.pcouncil.org/wp-content/uploads/2019/02/2019_Pre-I_master_Final_022819.pdf

Forecast performance metric
(response variable)

$$P_y = \frac{\frac{f_y - o_y}{o_y}}{\frac{1}{N}\sum_{i=ymin}^{i=ymax}\left|\frac{f_i - o_i}{o_i}\right|}$$

P – performance
y – year
f – forecast
o – observation/postseason estimate

> 0 means overforecast
< 0 means underforecast

Do thresholds exist?

- Looked at forecast performance of priority stocks
  - Ocean fishery: Sacramento and Klamath fall Chinook
    - PFMC indicators, often largest contributors to ocean fisheries
  - SKRW prey: Puget Sound summer-fall Chinook
- Environmental indicators considered
  - Freshwater: flow, temperature, snowpack
  - Local ocean: upwelling, spring transition, SLH, SST
  - Basin/oceanographic: PDO, NPI, MEI, ONI, NPGO, SSTarc
  - Lags scaled to habitat use over lifecycle
- Full disclosure: this resulted in multiple tests!
  - Null model, Bonferroni considerations

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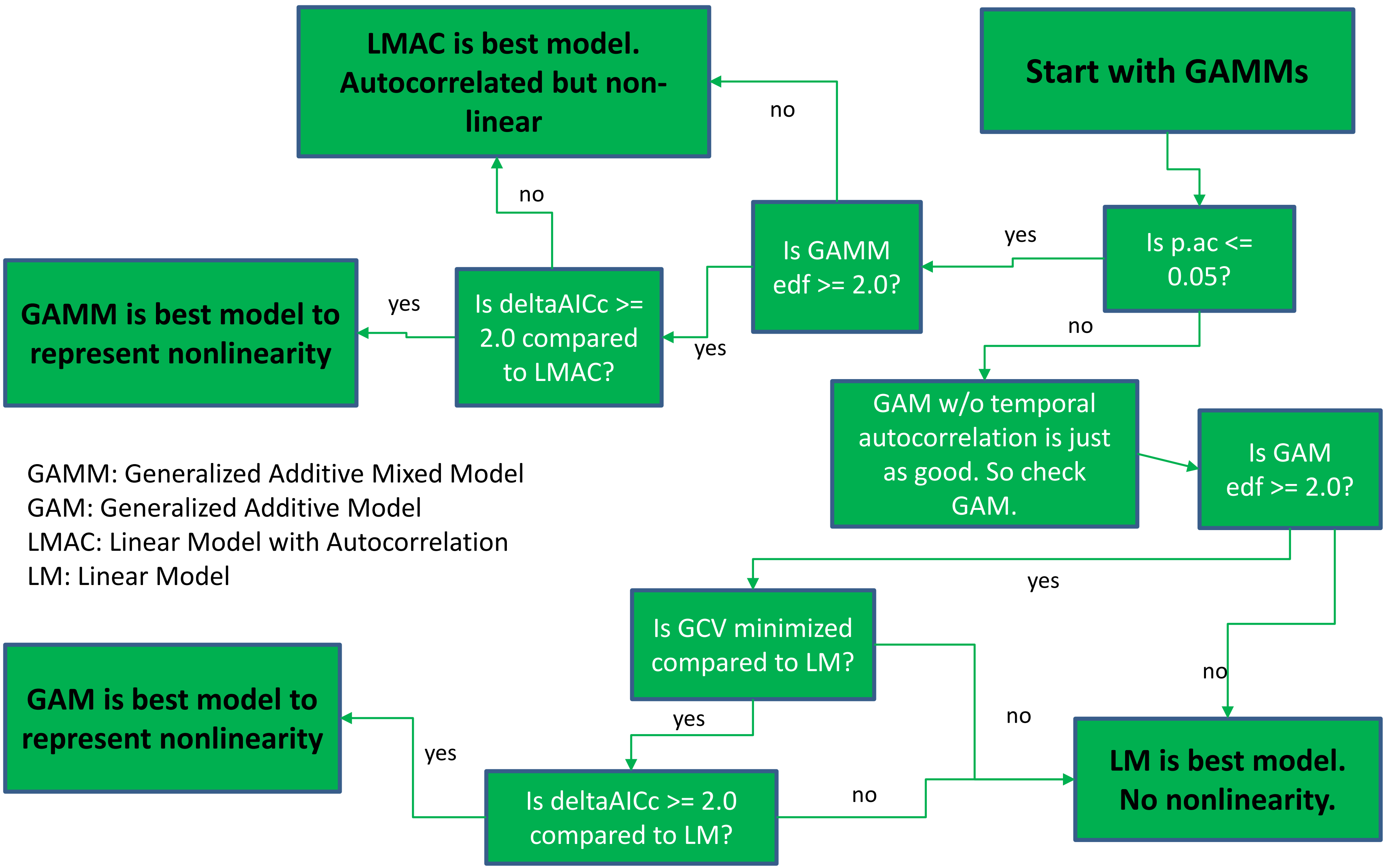
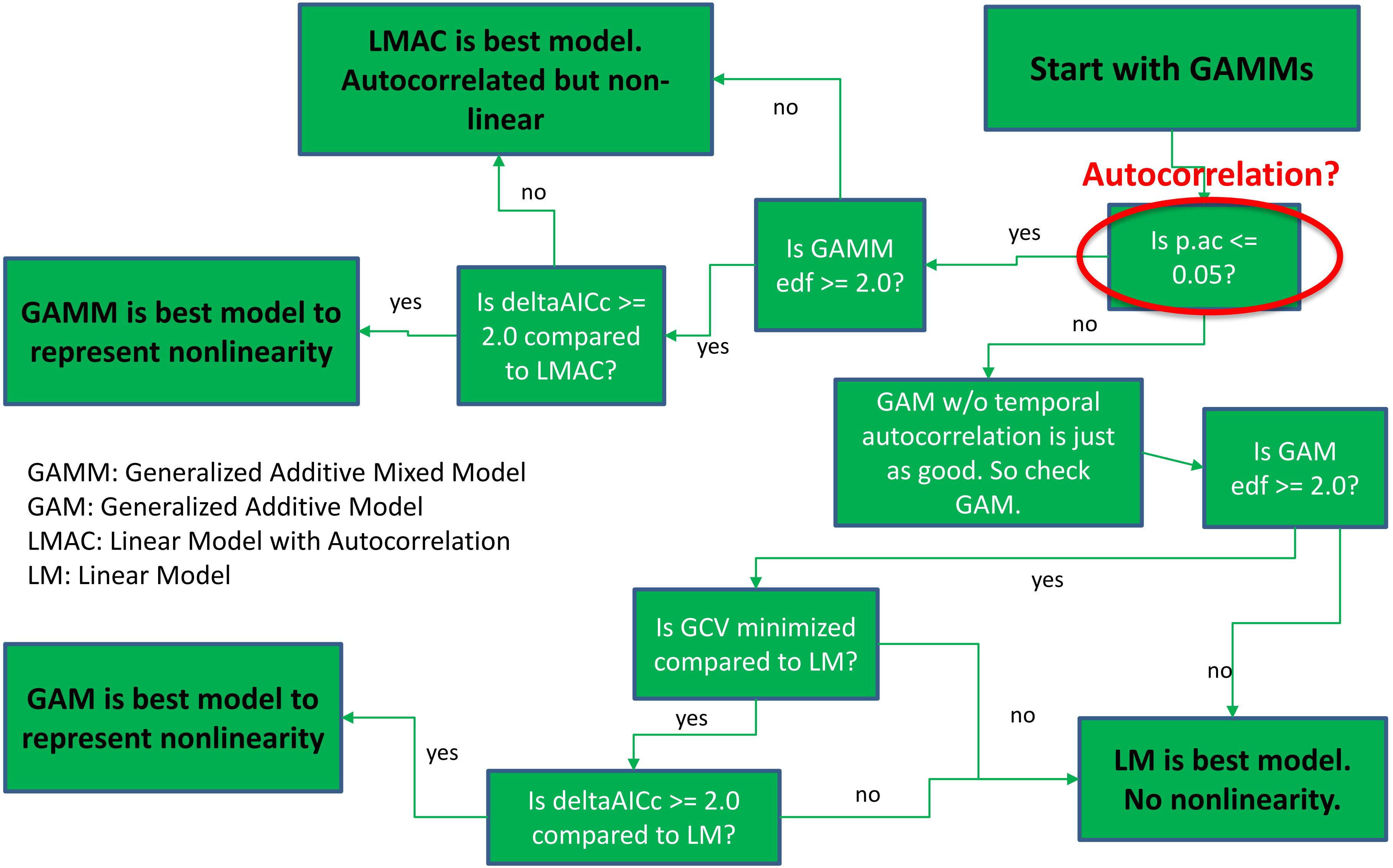
Distinguishing nonlinear relationships



GAMM: Generalized Additive Mixed Model
GAM: Generalized Additive Model
LMAC: Linear Model with Autocorrelation
LM: Linear Model

Distinguishing nonlinear relationships



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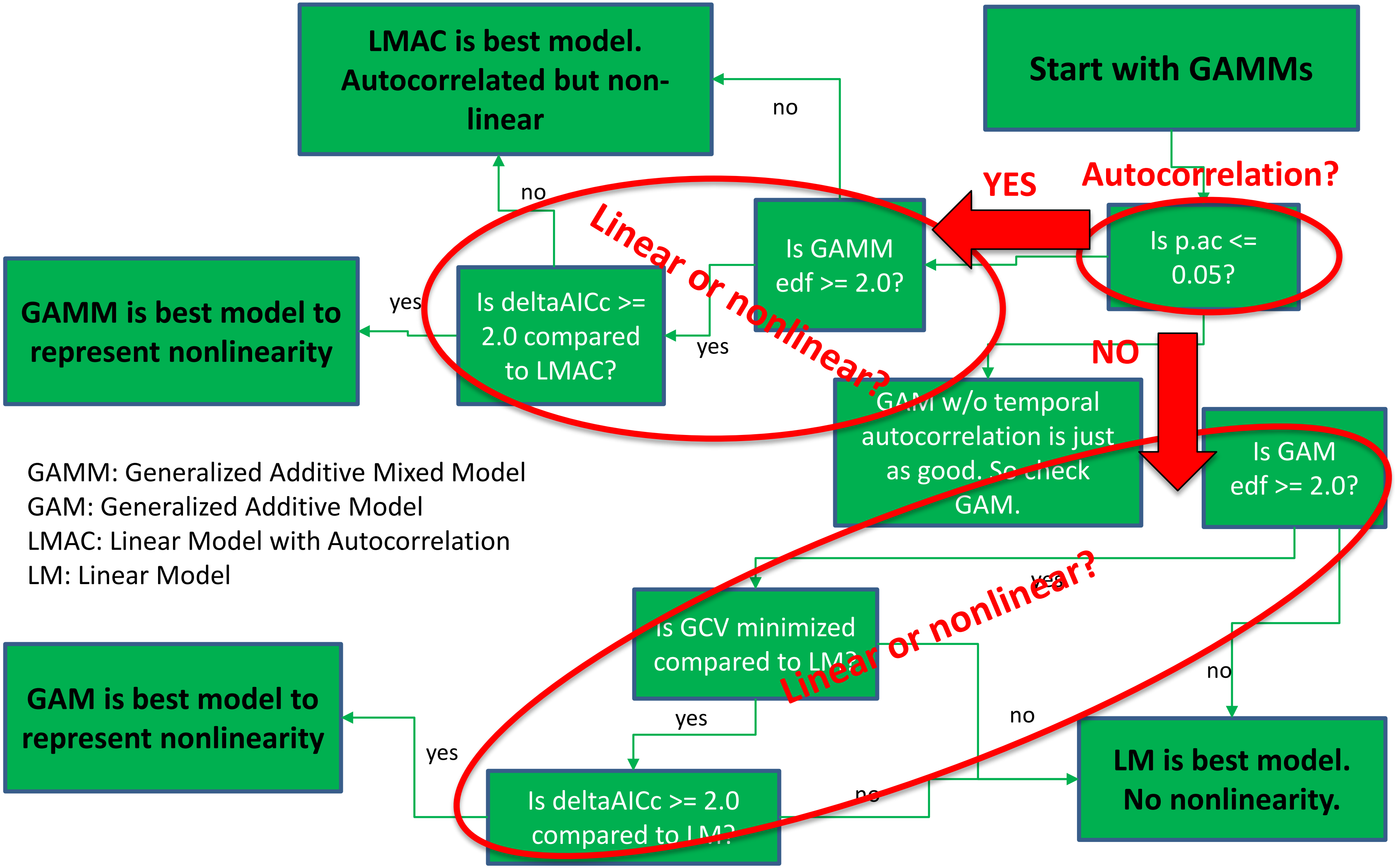

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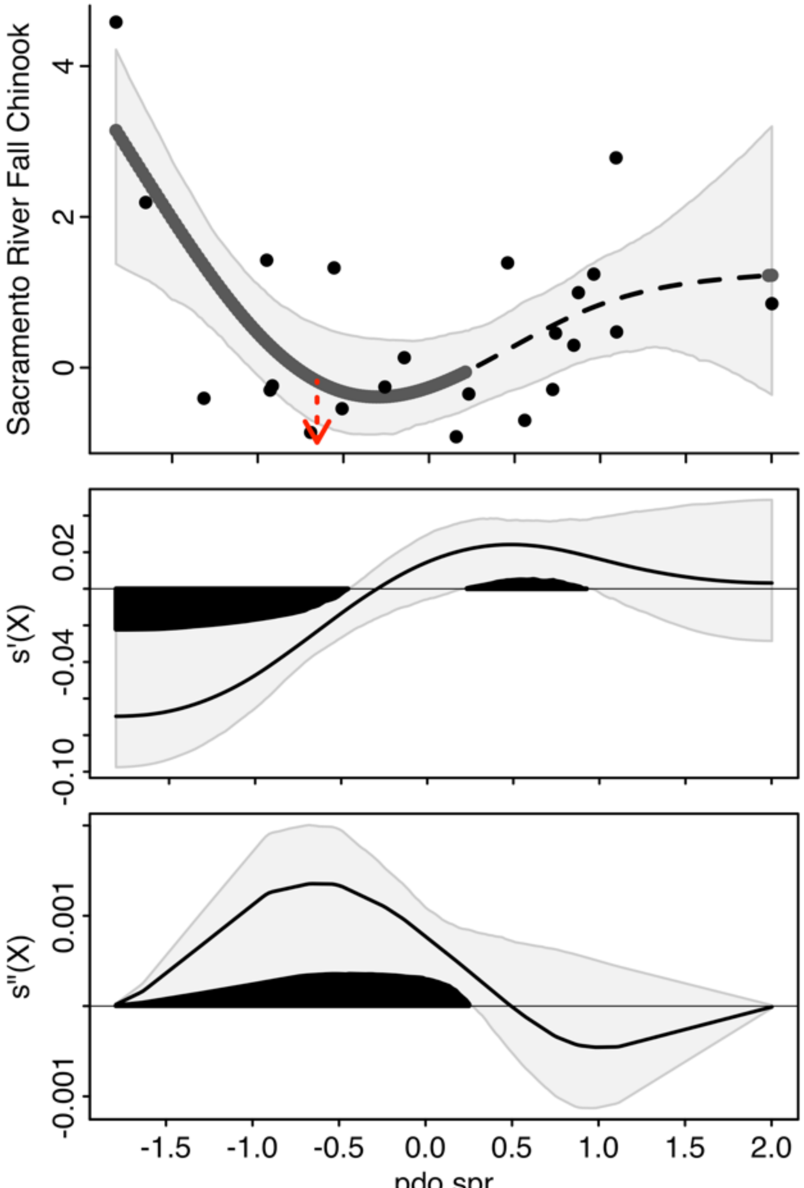
If nonlinear response, is there a threshold?



Fitted relationship

First derivative

Second derivative

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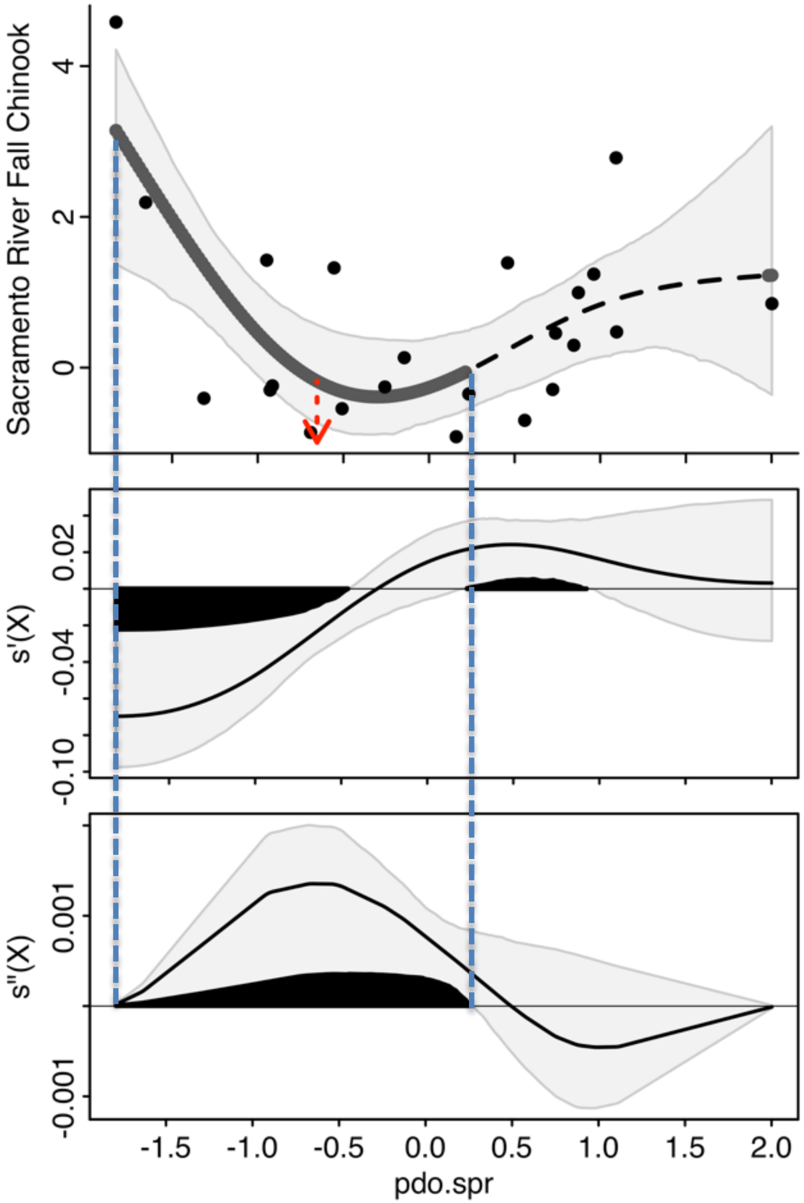

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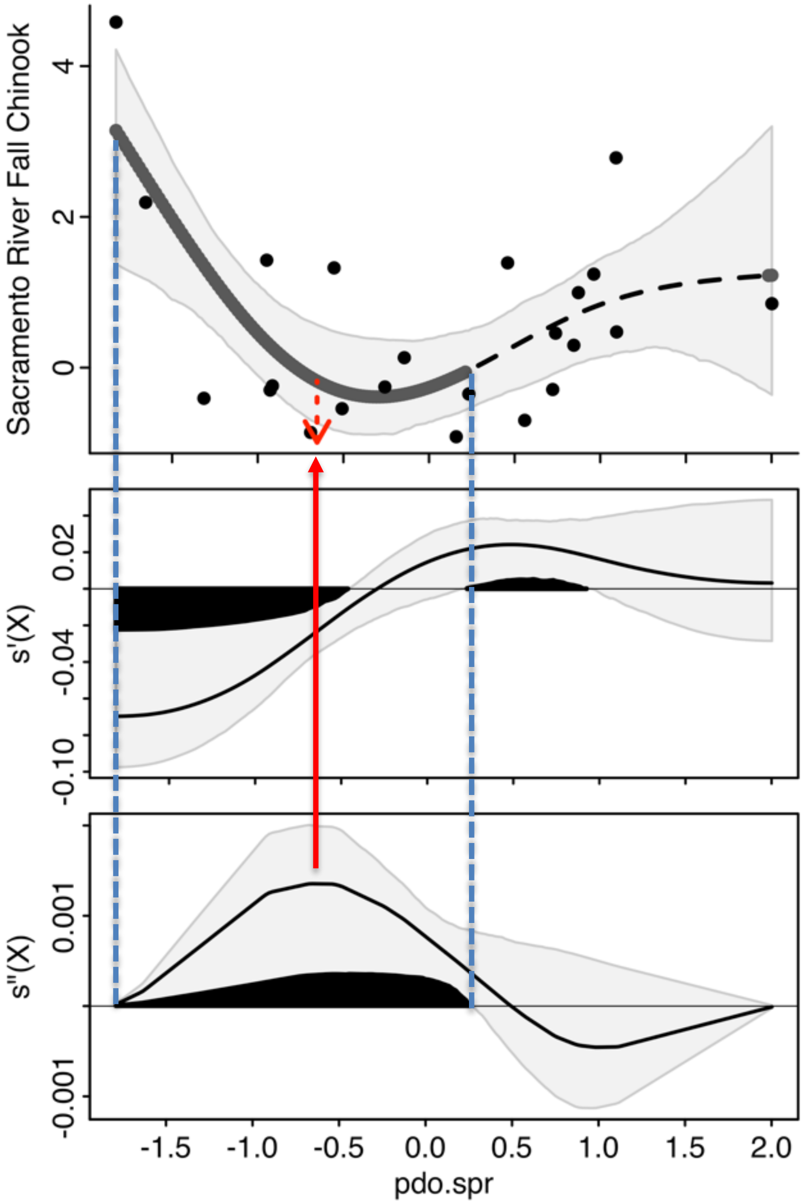

Fitted relationship

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Results – key fishery stocks

- Klamath fall Chinook: top model (linear) had $R^2=0.16$, top nonlinear model $R^2=0.13$, $p_{null}=0.81$
- Sacramento fall Chinook: two models with $R^2>0.40$ both nonlinear with thresholds ($p_{null}=0.46$ or 0.17)

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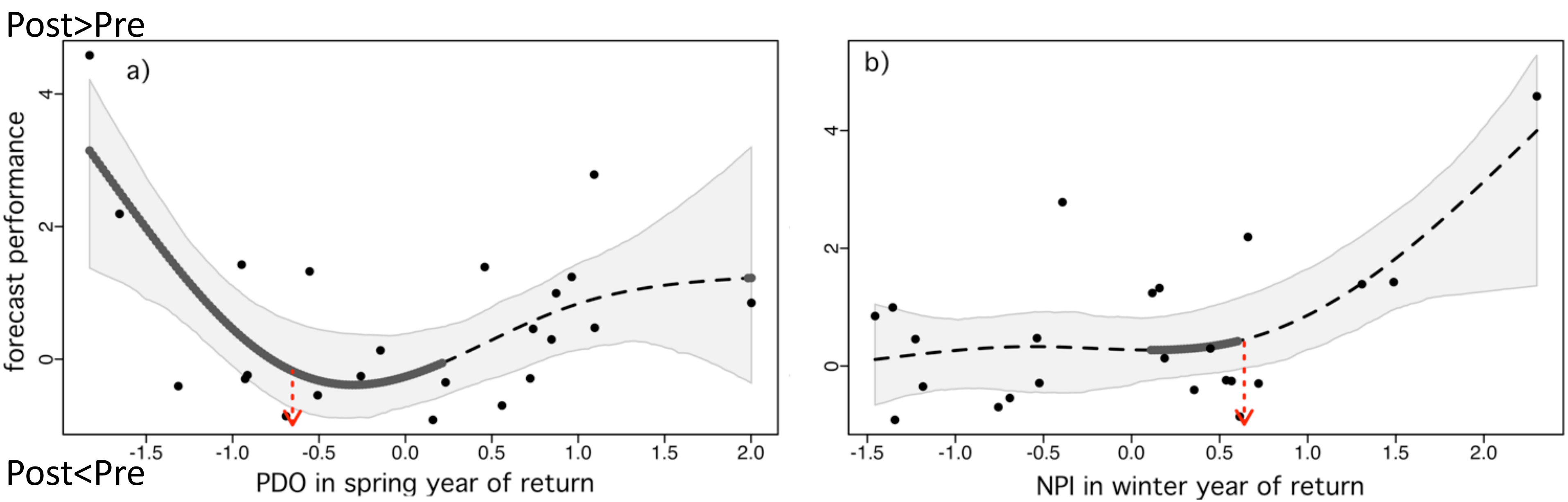
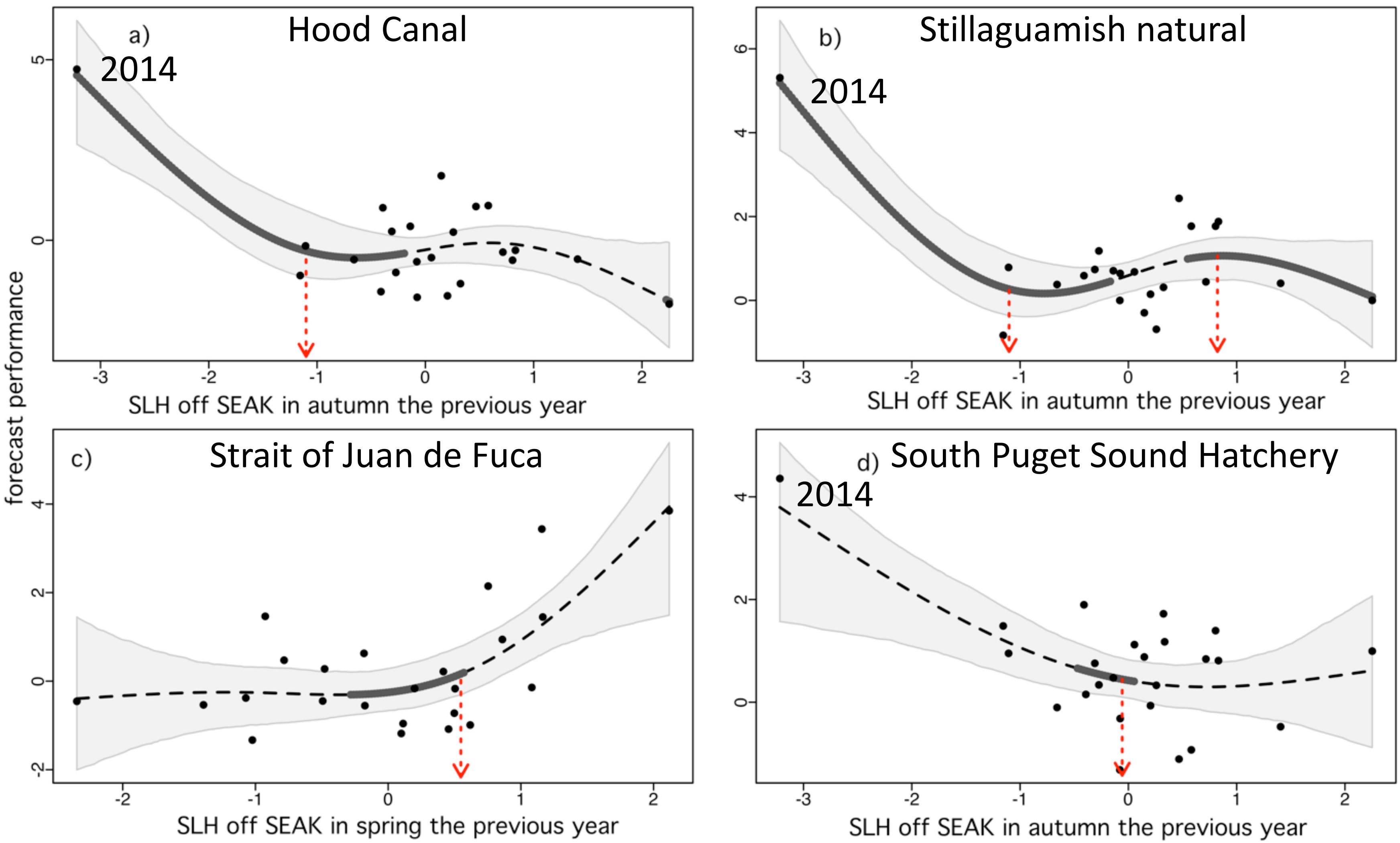


Results – Puget Sound stocks

Stock	obs. R^2>0.5	p_{null}	obs. R^2>0.33	p_{null}
South Puget Sound natural summer-fall Chinook	4	0.15	14	0.0012
Tulalip Hatchery summer-fall Chinook	2	0.91	8	0.55
South Puget Sound hatchery summer-fall Chinook	1	0.55	6	0.20
Hood Canal combined summer-fall Chinook	4	0.31	7	0.51
Stillaguamish natural summer-fall Chinook	2	0.80	6	0.67
Snohomish hatchery summer-fall Chinook	0	1.00	0	1.00
Snohomish natural summer-fall Chinook	0	1.00	6	0.15
Strait of Juan de Fuca combined summer-fall Chinook	0	1.00	3	0.66
Nooksack-Samish combined summer-fall Chinook	0	1.00	1	0.71
Skagit natural summer-fall Chinook	0	1.00	0	1.00

SLH off Alaska the previous year?



Specifically, Sea Level Height in 2013.

Multiple Puget Sound stocks came in well below their forecasts in 2014.

Considerations on thresholds

- $R^2>0.50$ rare, seen at rates expected by chance
- Rate of $R^2>0.33$ seen is unlikely by chance alone
- Null model may be too conservative
  - (Not all stock-index-lag combinations equally plausible a priori)
- Mechanistic explanations for many relationships
- Important drivers/lags for different forecast types make sense
- Outliers have a lot of leverage, but this is what you'd expect in a threshold scenario

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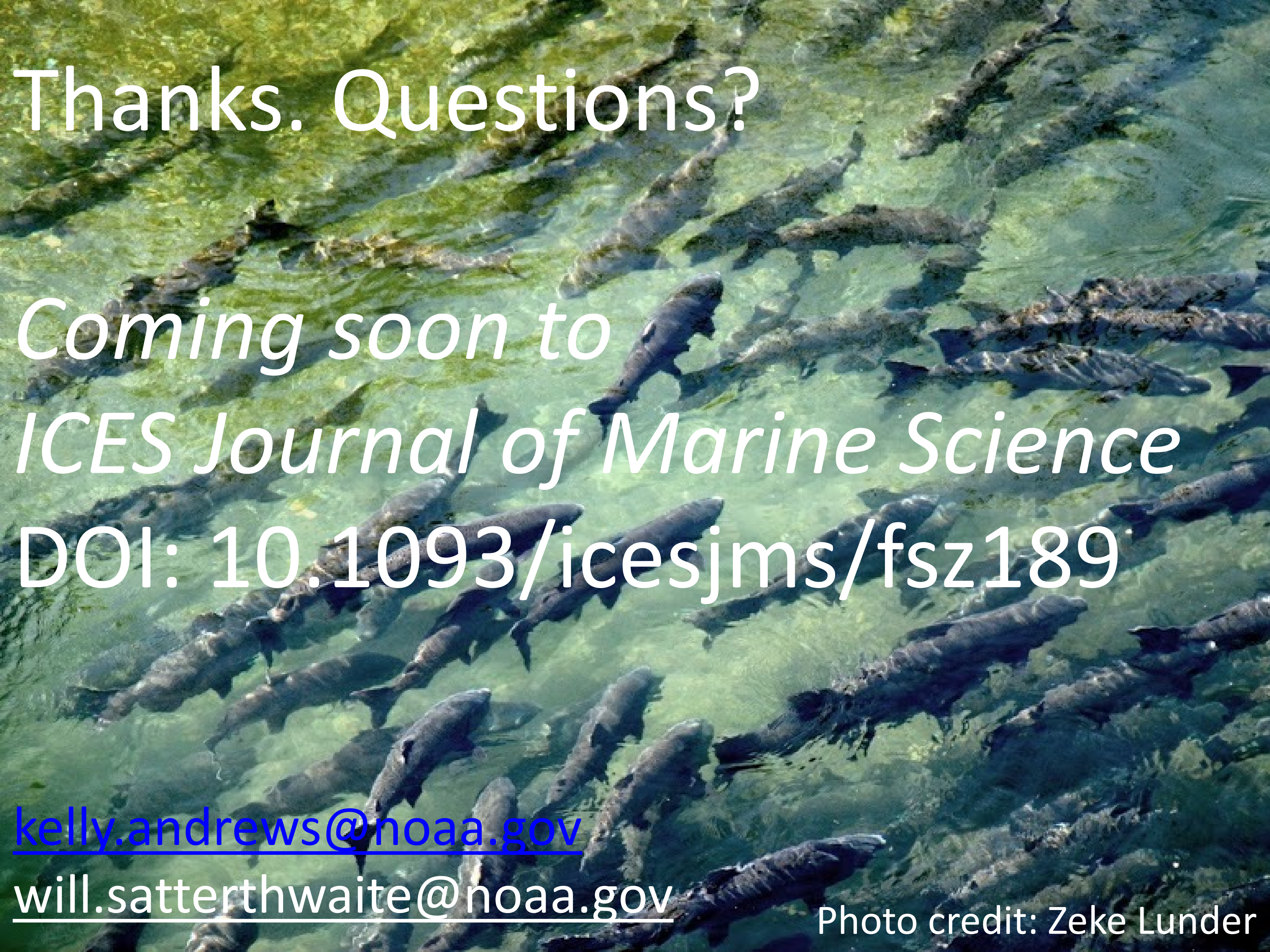
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