Modeling Passage Options for Willamette Winter Steelhead

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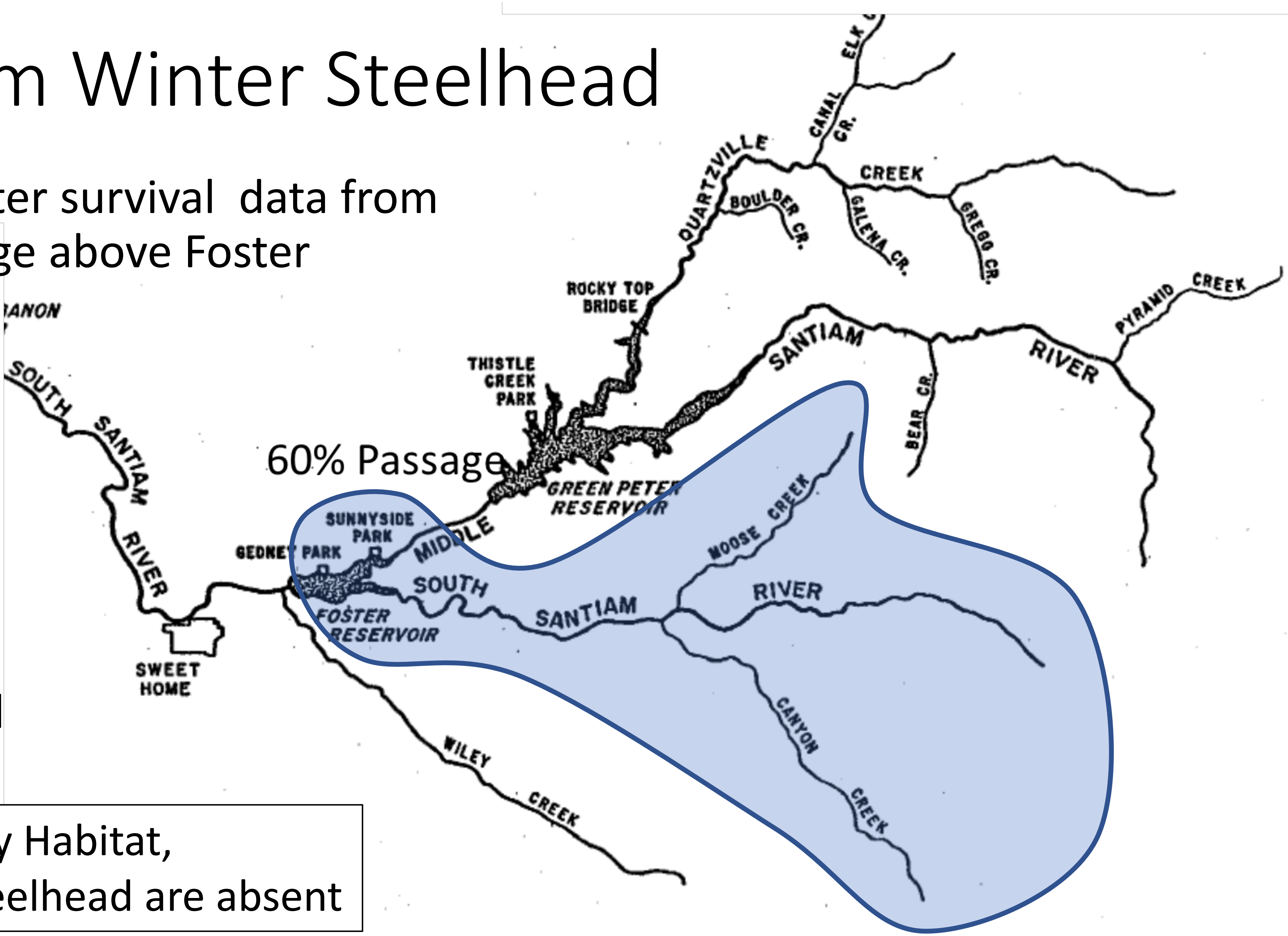
UBC
Integrated Passage Assessment

Outline

- Structure of the Demographic Model
  - e.g. Foster Winter Steelhead population
  - A three stage stock-recruit model
  - Data availability and inputs
  - Model fitting
- Incorporating Uncertainties
- Examples of Model Ouput
- Some Conclusions

South Santiam Winter Steelhead

- Estimates of Freshwater survival data from South Santiam Drainage above Foster
- Does not include
  - Above Green Peter
  - Mainstem and Tributaries below Foster
- 64% of Steelhead parr Capacity above Foster
- 15% of S Santiam total
  - Bond et al (2017)



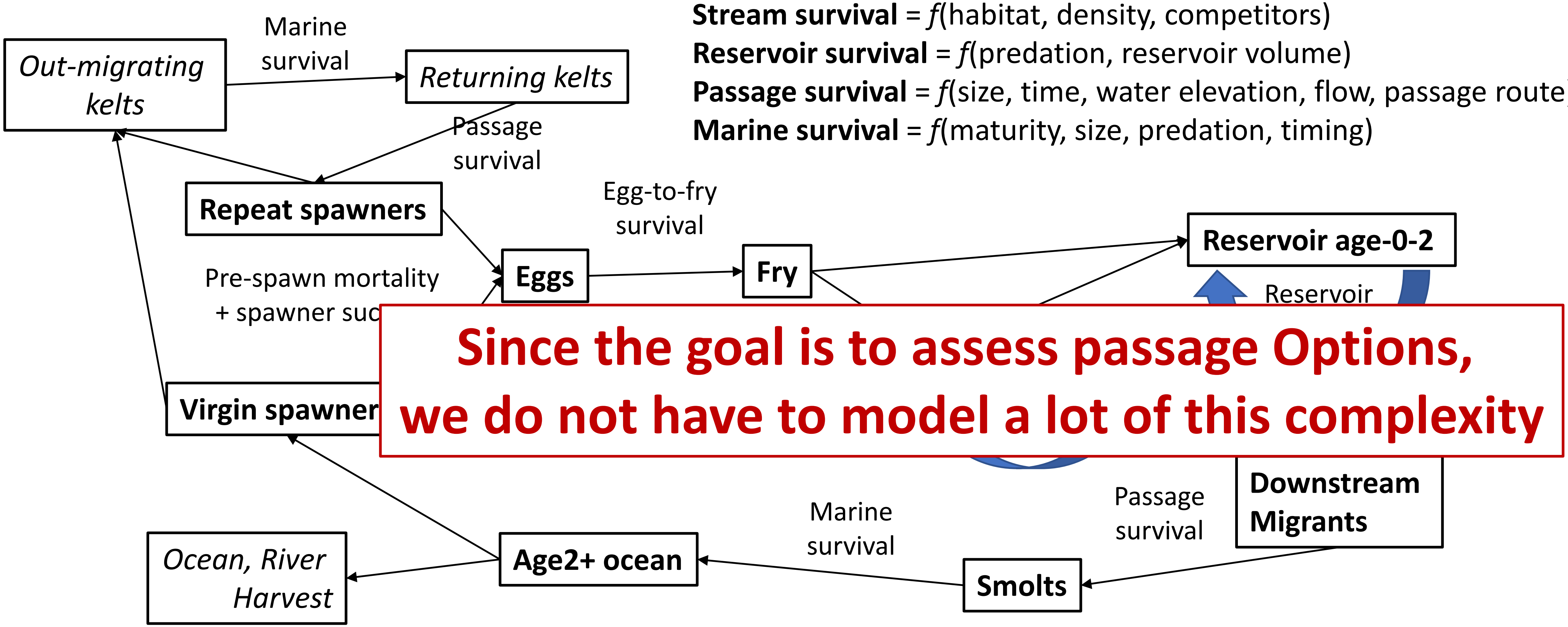
High Quality Habitat,
Summer steelhead are absent

Winter Steelhead Life History:

- **Complex age structure**
- **A series of Stages and habitats**
- **Many factors affect survival x Stage**

A Lot of Information is available on Factors that Affect Stage Specific Survival/Growth

Pre-spawn mortality = *f*(temp, habitat, density, hatchery fish)
Spawner success = *f*(fecundity, %hatchery)
Egg-to-fry survival = *f*(density, temp, discharge, sediment)
Stream survival = *f*(habitat, density, competitors)
Reservoir survival = *f*(predation, reservoir volume)
Passage survival = *f*(size, time, water elevation, flow, passage route)
Marine survival = *f*(maturity, size, predation, timing)



Demography of Winter Steelhead

: $${N_1}/{N_0} = F S_F S_P \, S_M (1 + r)$$

- 3 phases: Before, During and After Passage
  - S_F - Potential egg deposition to the dam face **(Freshwater Survival)**
  - S_P - Dam face to Willamette Falls **(Passage Survival)**
  - S_M - Willamette Falls to adults prior to egg deposition **(Marine Survival)** [1]
- F is the number of female[2] eggs per spawner,
- r is the repeat spawning ratio and
- N_1 is the number of female spawners produced by N_0 female spawners.

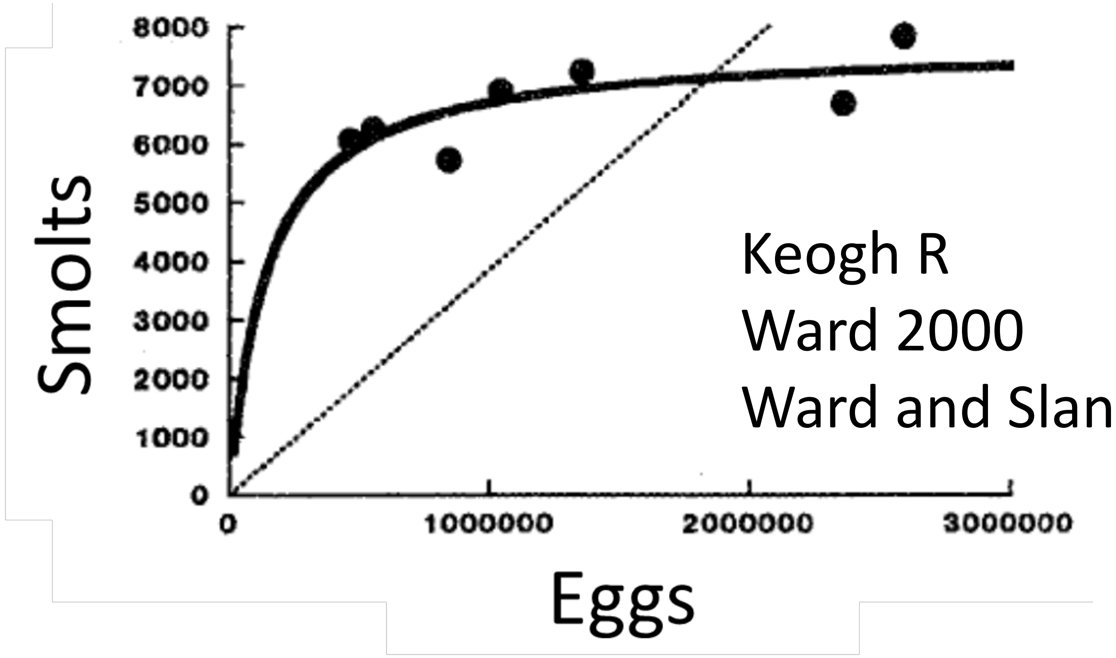
[1] S_M includes mortality Willamette Falls to Estuary, PSM, failure to enter fishway…

[2] Only female eggs (assumed to be half of the total) are tracked to simplify the demography.

More females than males are present in the returning adults (Mapes et al. 2017) and 80% of repeat spawners are female (Clemens 2015, Jepson et al. 2015). The sex ratio discrepancy is assumed to result from of higher non-anadromy rates in males and poor survival of male kelts.

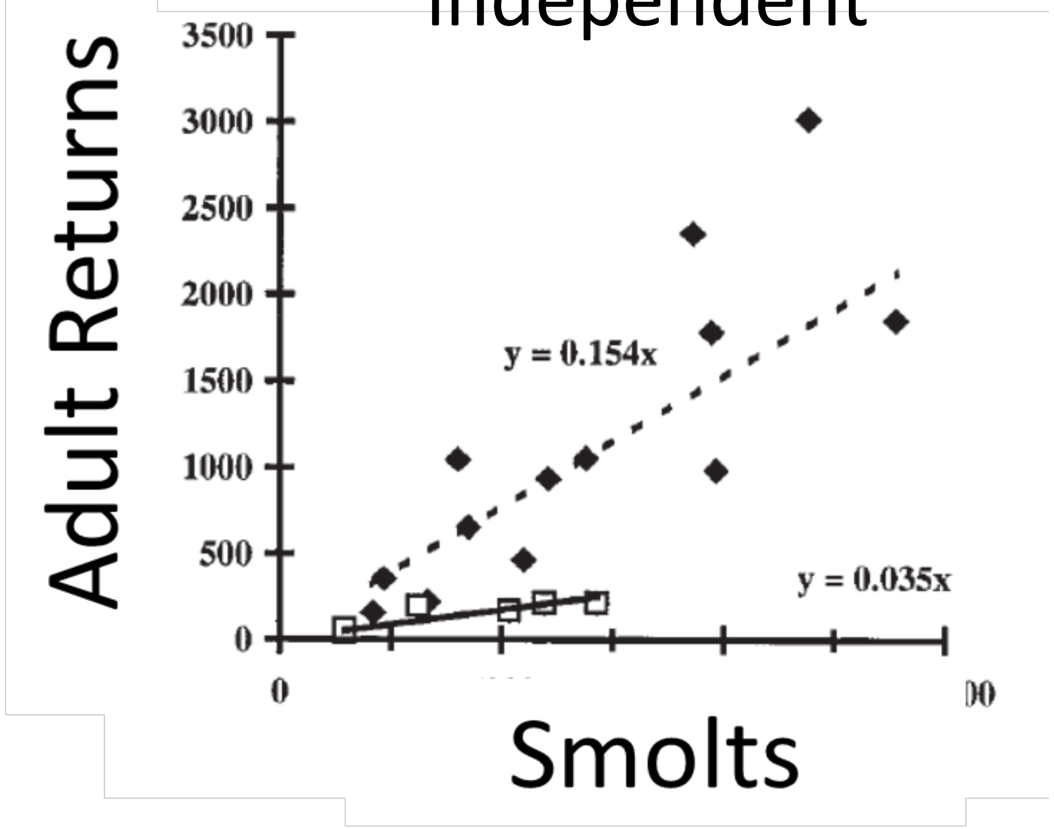
Model Structure for Winter Steelhead

Freshwater Survival (**S_F**) is strongly density dependent



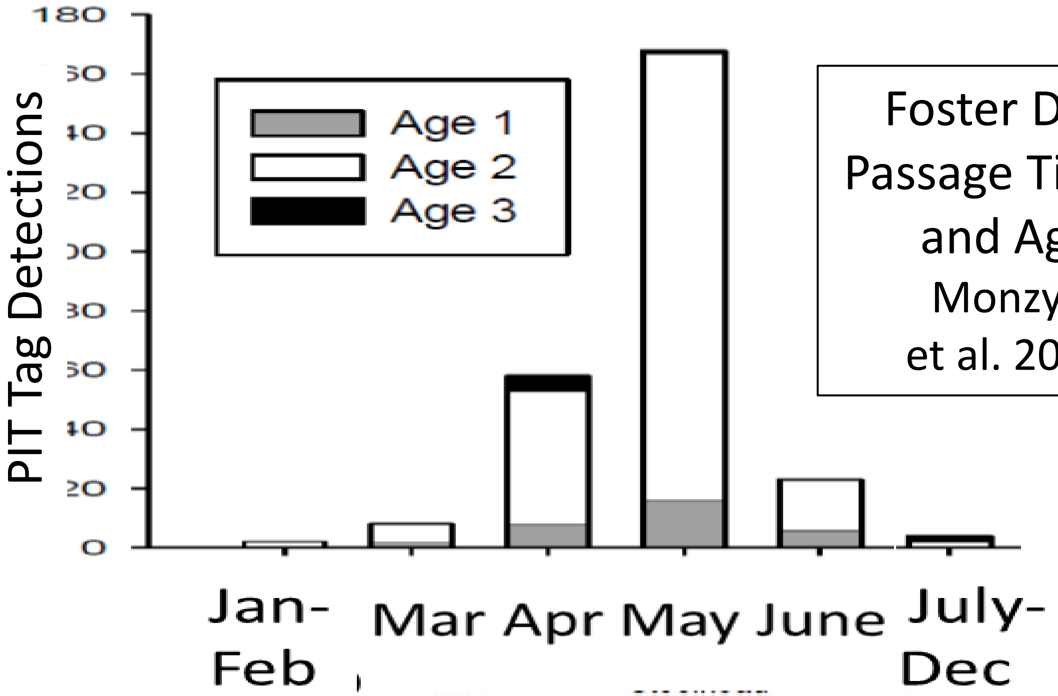
Keogh R
Ward 2000
Ward and Slaney 1993

Marine Survival (SM) is density independent

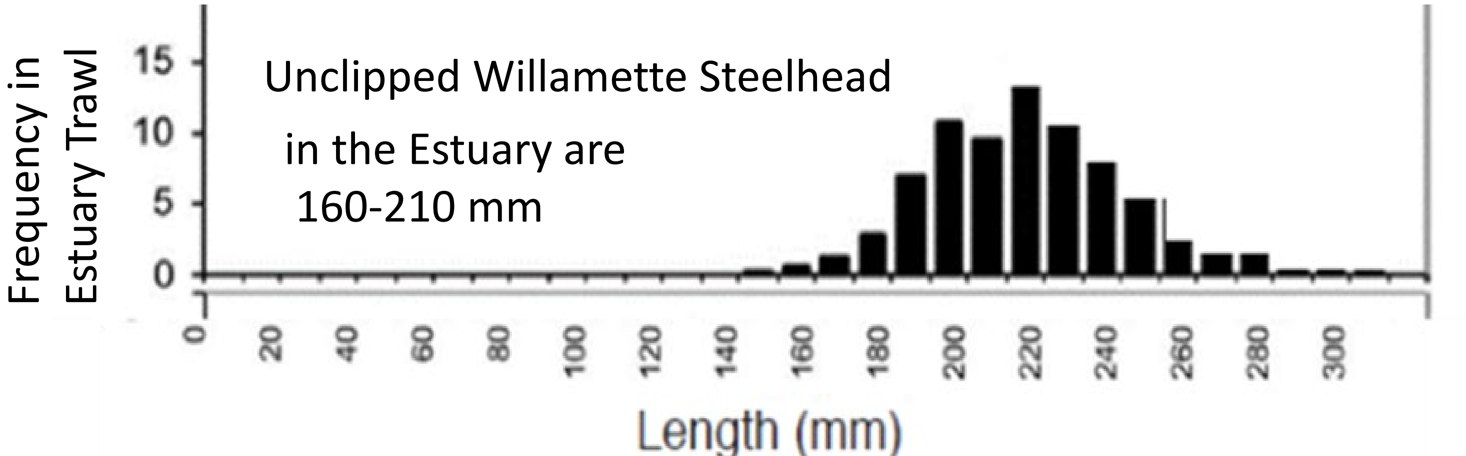


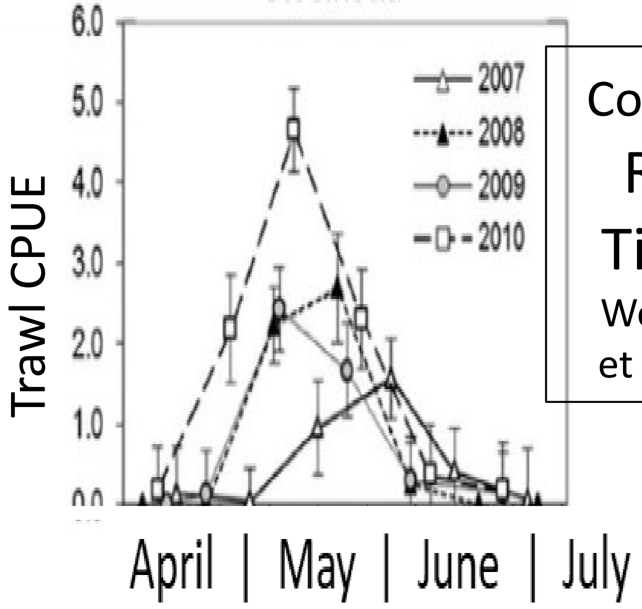
A Key Assumption: Rearing of Foster migrants in downstream areas is minimal

- Downstream migrants above Foster are PIT tagged as age-0, 1, 2
- Most are detected passing Foster as smolts in April-June, age-2
- Steelhead smolts migrate rapidly from Foster Dam to the Columbia River Estuary



Foster Dam Passage Timing and Age
Monzyk et al. 2017





Columbia River Timing
Weitkamp et al. 2012

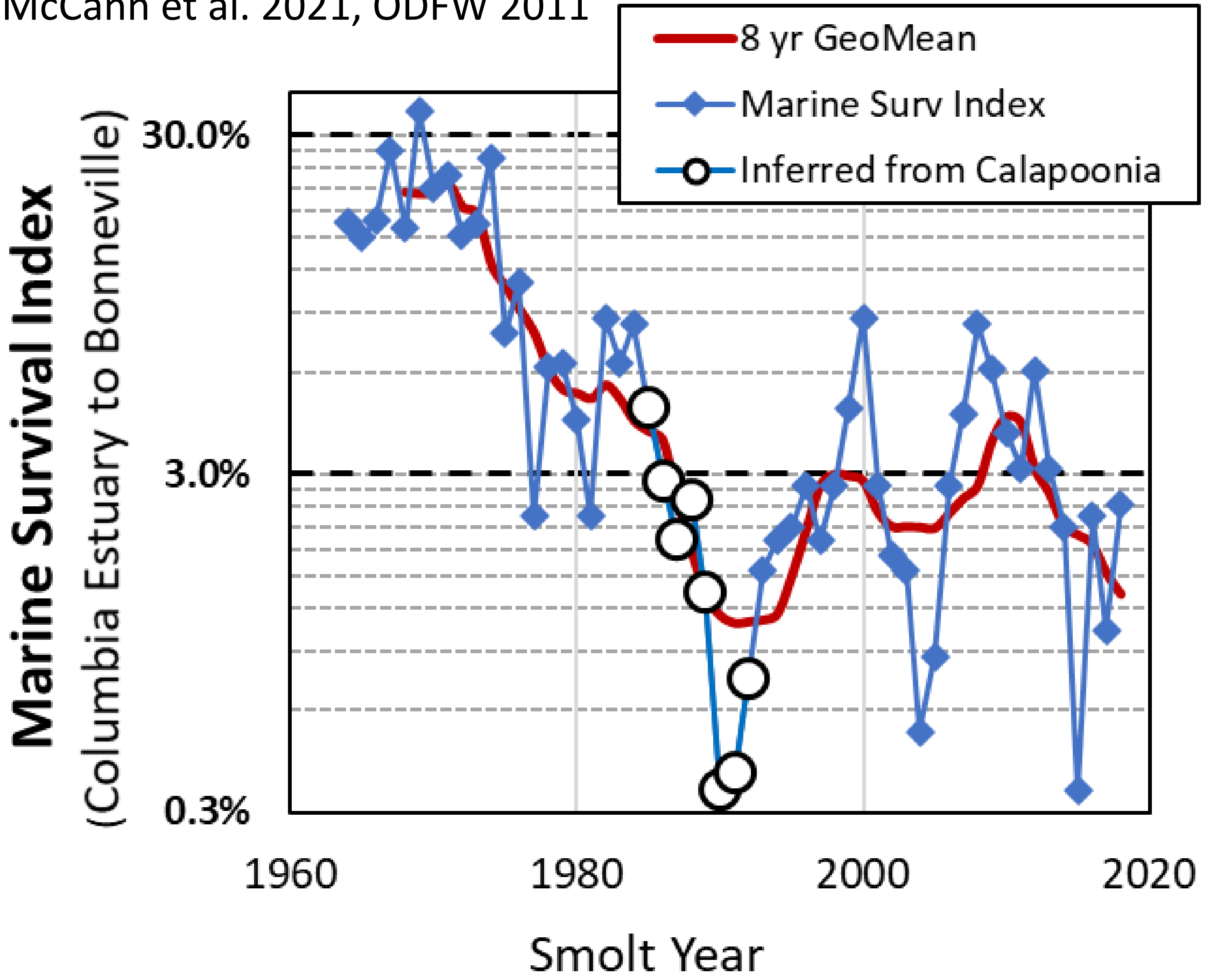
Data Availability

- South Santiam River
  - Adults x sex at Foster (Mapes et al. 2017)
  - Redd distribution (Mapes et al. 2017)
  - Downstream passage at Foster
  - Downstream migrant age, size, timing
- Willamette River
  - Winter steelhead counts at Willamette Falls
  - Distribution of adults tagged at Willamette Falls (Jepson et al. 2015)
  - Age composition 1981-94 (Clemens 2015)
  - Repeat spawner proportion (Jepson et al. 2015)
- Ocean survival data from a variety of Columbia River stocks

An Index of Marine Survival for Columbia R Steelhead

- Historical Marine Survival has spanned a 20-fold range (8 yr geometric mean)
- More recently (1999-2018) the 8 yr mean has varied by 4-fold (1.1%-4.4%) but annual variations are much larger (0.3% - 8.7%)
- Historic Time series includes large annual variations as well as 5-10 year trends
- Adult Steelhead abundance is directly proportional to marine survival

McCann et al. 2021, ODFW 2011



Demography of Winter Steelhead

- Given these assumptions, a multistage Beverton-Holt stock recruit model can be fitted to a time series

$$R = {}^{aS}/_{(1+\ aS/B)} \text{ where } a = FS_F S_P\, S_M (1+r)$$

- ***S_M*** - **Marine Survival:** Annual estimate for Columbia R stocks
- ***S_P*** – **Passage Survival:** Defined by the **F**ish **B**enefits **W**orkbook
- **B - density compensation factor** (maximum abundance)
  - where ***B_F*** is smolt habitat capacity (Bond et al. 2017

$$B = B_F S_P S_M (1+r)$$

- <u>**S_F** is the only unknown parameter</u>
  - Fitting the model generates a probability density function for **S_F** ; given the observed abundances

Generating Spawners, Recruits from the South Santiam Data

Counts of Female Recruits: Foster Dam

Spawner Year	Female Count
2006	226
2007	111
2008	127
2009	106
2010	271
2011	198
2012	179
2013	168
2014	128
2015	81
2016	133
2017	10
2018	16
2019	42
2020	66
2021	7

Ocean age of Spawners

Ocean Survival by Smolt Year

Back Calculate: timing and **number of Smolts** leaving each year

Dam Passage proportions X Year Fish Benefits Workbook

Back Calculate: number of Smolts arriving at Foster Dam x Year

Counts of Spawners X Brood year

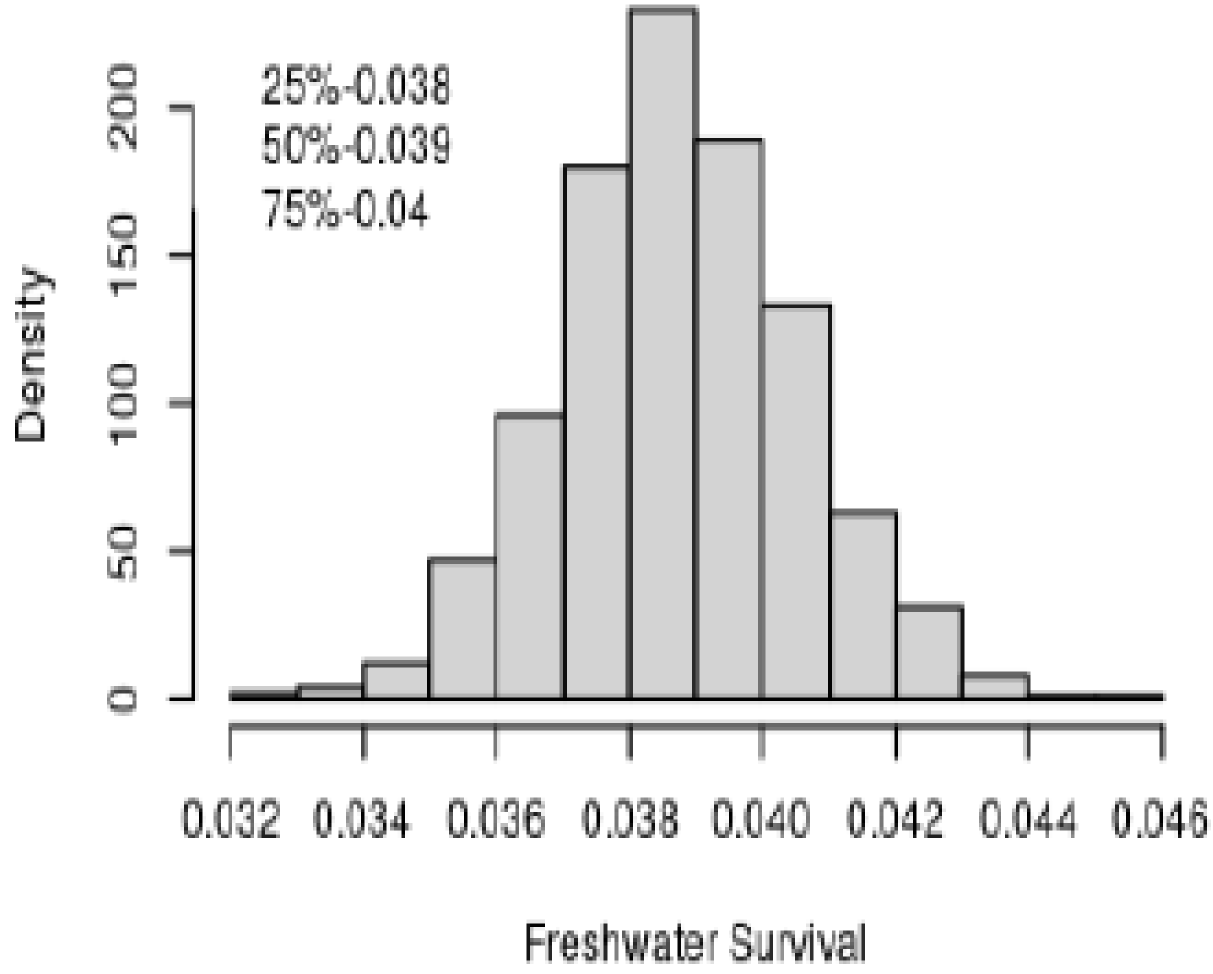
Back Calculate: Number of Smolts for each Cohort of Spawners

Model Fit:

Freshwater Survival= Smolts/Spawners

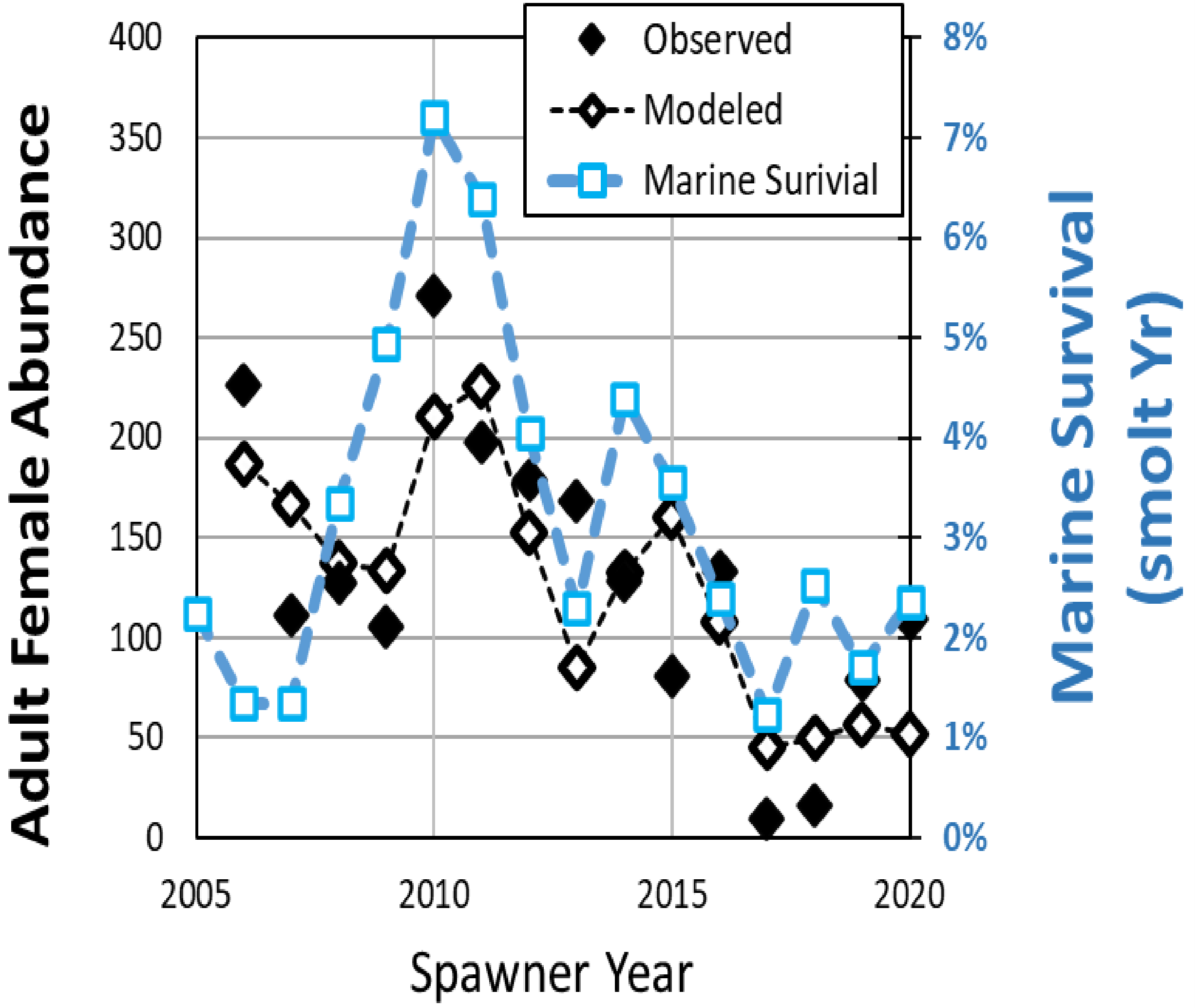
Model Estimate of Freshwater Survival

- Estimated as a single parameter for the entire time series
- This structure assumes that Freshwater survival does not vary:
  - randomly among years or
  - in trends across several years
- Uncertainty represents the range of probable values, given the data and model structure
- Range is small (3.4-4.4%)



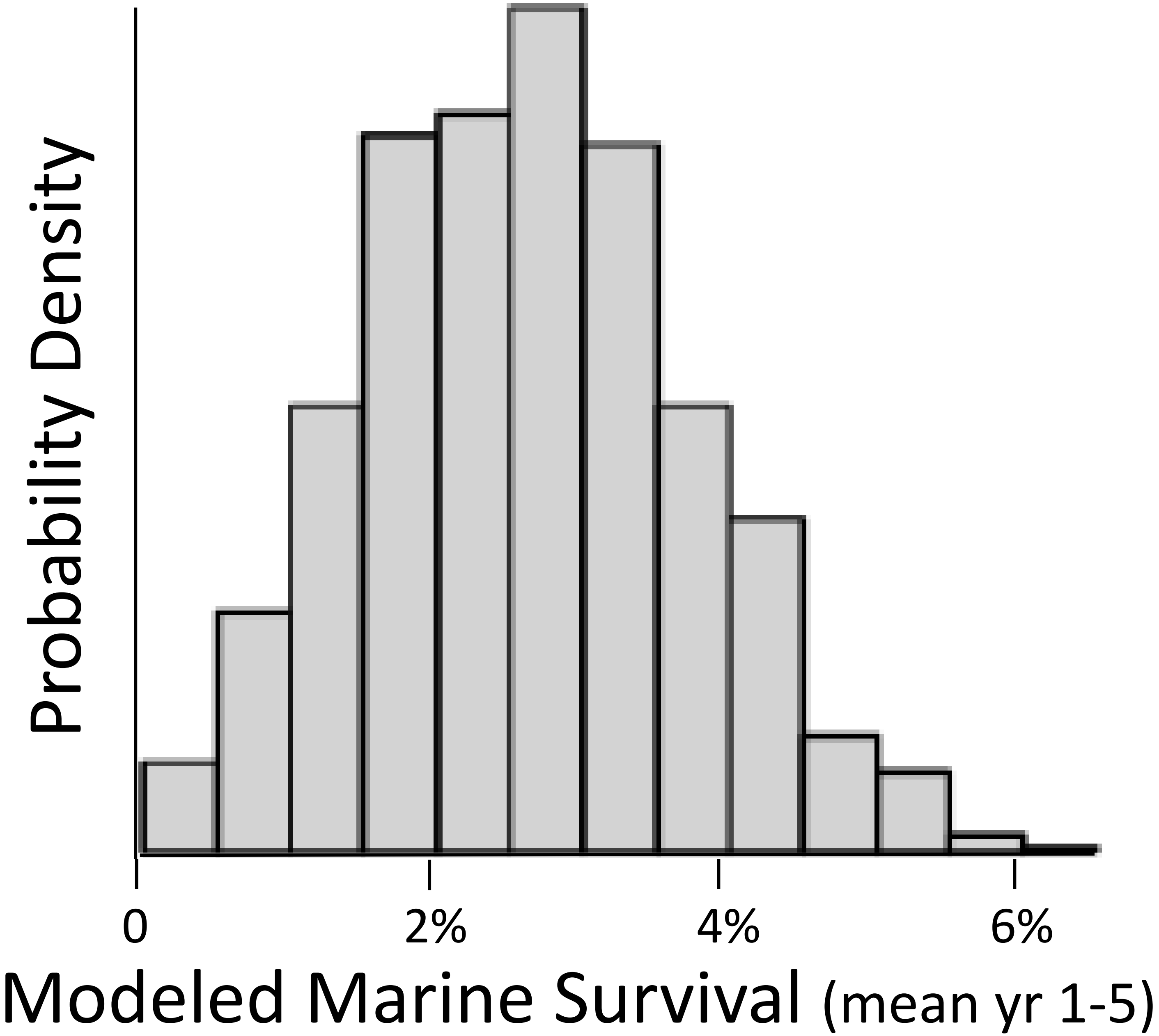
Observed and Modelled Abundance

- Model fits the observed quite well r^2=0.58
- Most of the variation abundance is associated with variation in Marine Survival
  - Serial Correlation: High Marine Survival followed by low Marine Survival
  - Modeled Repeats are up to 30% of the female run (buffers population against year class failure



Modeling Marine Survival

- Future projections are modeled using the historic time series
- Random effect parameters describe interannual variation
- Trends modeled by varying correlations among consecutive years
  - Fitted to the historic time series



Incorporating Uncertainties

- Survivals are all ratios, so are directly comparable
  - relative uncertainty expressed as ratio upper:lower bound+1SD/-1SD
- Marine Survival: 4.9-fold variation
  - Mean=2.46% ±1 SD= 1.12%-5.45%, annual geometric 1999-2018
- Freshwater Survival: 1.1-fold variation
  - Fit of observed Spawners-Recruits, Mean=3.88% ±1 SD= 3.70%-4.06%,
    - Smolts/female at low density
- Uncertainty in passage parameters:

	Passage Efficiency			
	mean	-1 SD	+1 SD	Ratio
Low Pool	48%	43%	52%	**1.19**
High Pool	60%	48%	72%	**1.49**
	Passage Survival			
Low Pool	62%	59%	65%	**1.10**
High Pool	75%	68%	82%	**1.19**

Other Uncertainties with less direct effects on Outcomes
- Maximum number of smolts
- Age Structure
- Repeat Spawner fraction

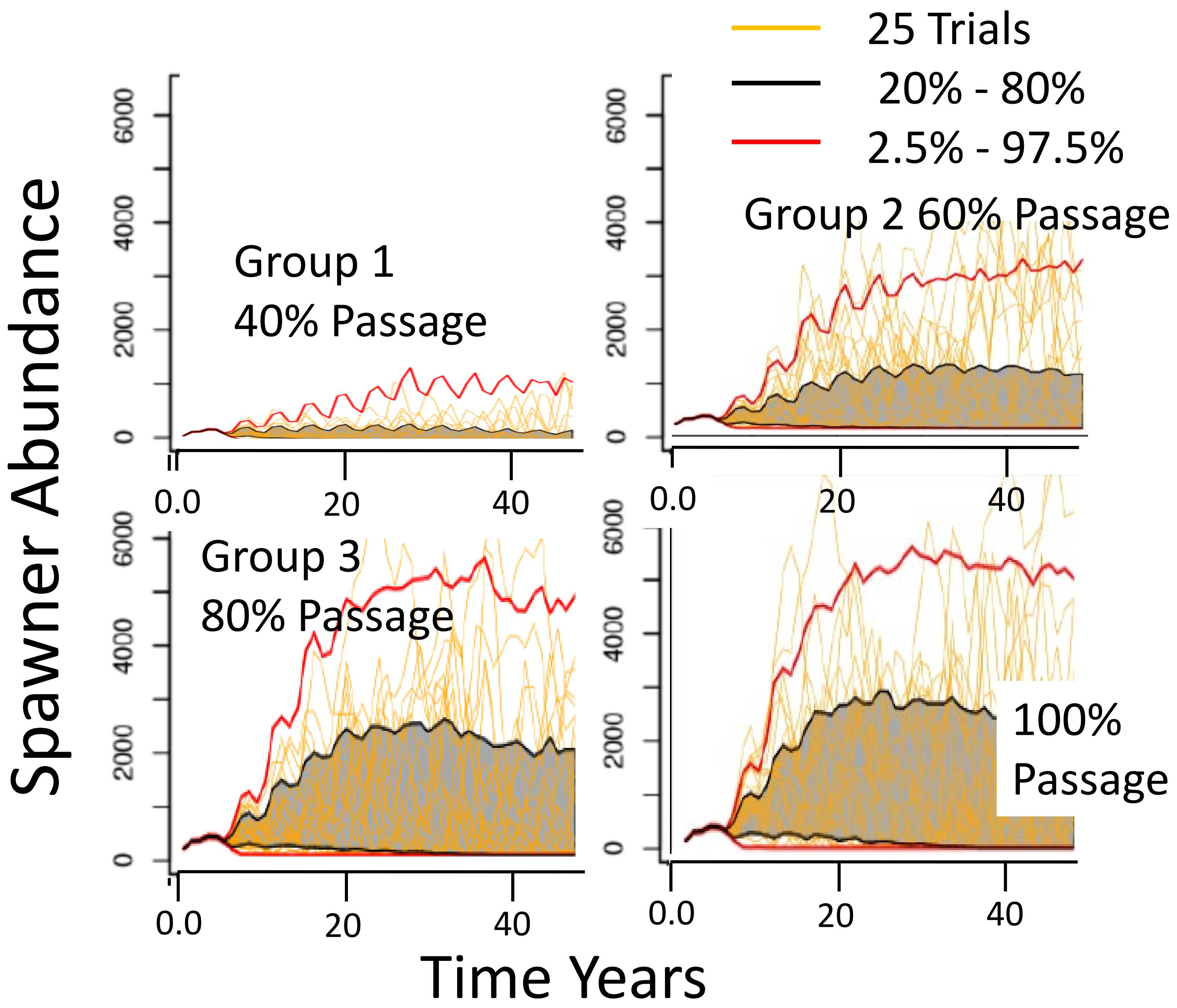
Liss et al. 2020, Hughes et al. 2019, 2021

Model Application: Management Agencies choose Lever settings
Options can be grouped by Passage Parameters

Dummy Levers	Group 1		Group 2	Group 3	
	Opt. 1	Opt.t 2	Opt. 3	Opt. 4	Opt. 5
Water Quality Levers					
e.g. TDG			X		
e.g. Temperature Downstream				X	X
e.g. Spring Reservoir Elevation	X				
Discharge Levers					
e.g. Adjust Flows	X	X	X		X
Passage Levers					
e.g. Downstream Passage Structure			X	X	X
Attraction Efficiency	50%	67%	80%	89%	89%
Passage Survival	80%	60%	75%	90%	90%
% that approach and pass the dam	40%	40%	60%	80%	80%

Model Projections
(e.g. Spawner abundance)

- **<u>One Trial:</u>** Population model predicts future population X time
- **<u>Repeated Trials:</u>** Quantify uncertainty by using with randomly chosen parameter sets

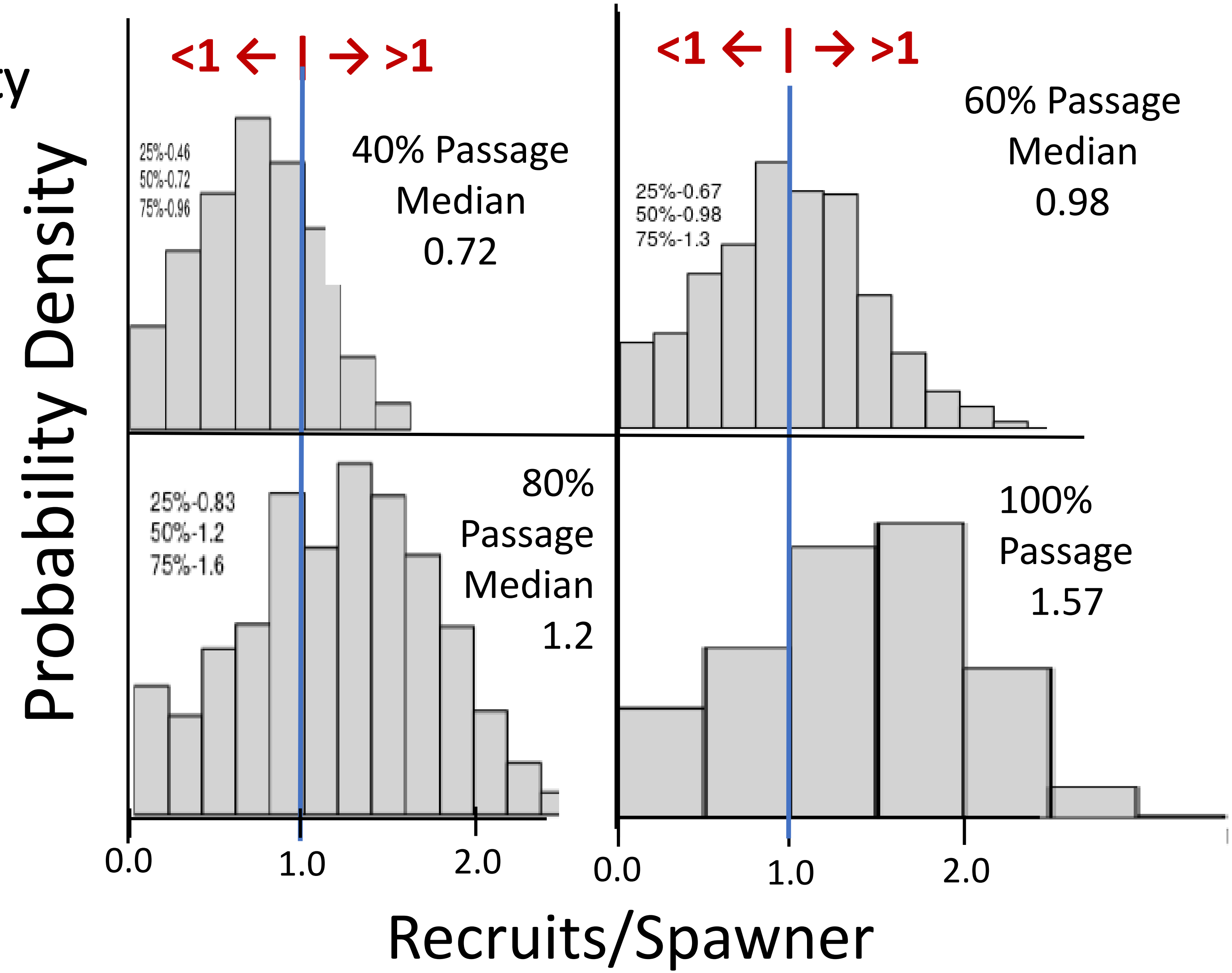


Model generates Performance Metrics (PMs)

e.g. <u>Population resilience</u>

Recruits/Spawner at low density

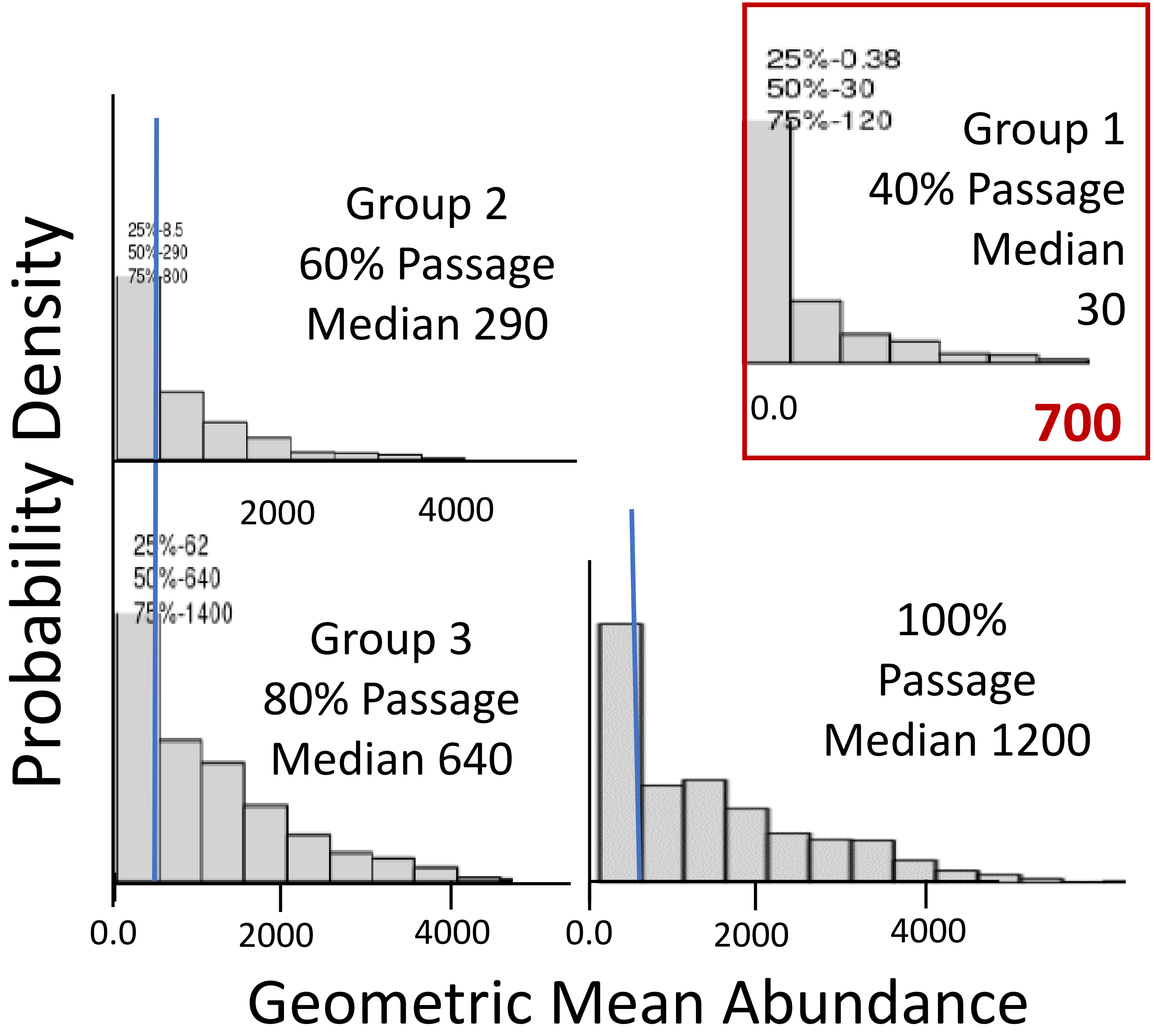
- Outcomes are probability densities, not single numbers
- Metrics are expressed as medians and ranges
- Often a PM will have a "critical" or "target" value
  - e.g. Recruits/Spawner should be > 1



Model predictions can include a variety of PMs

e.g. Adult numbers years 21-36

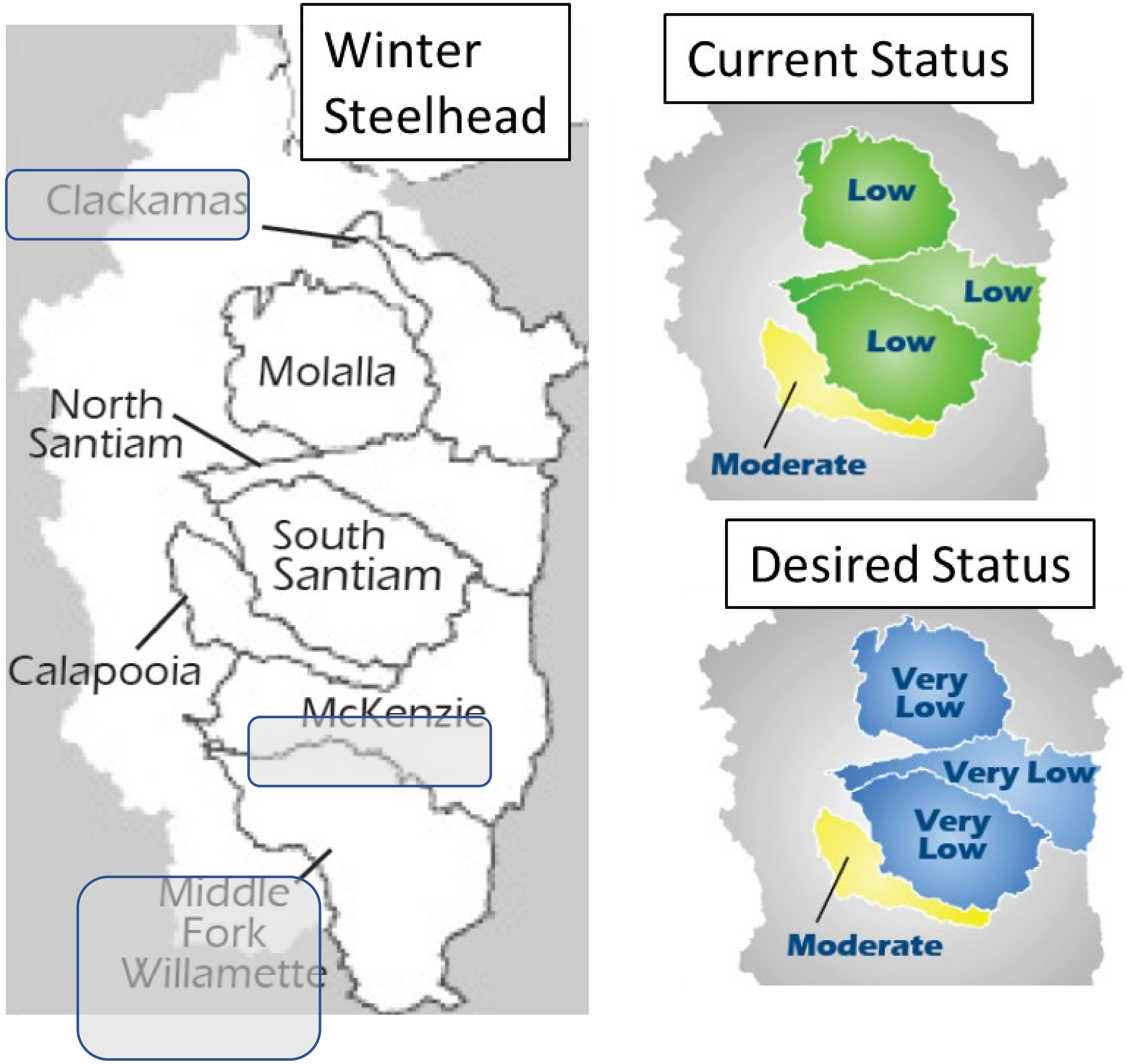
- The spread among trials within a group is very large because of high uncertainty in Marine Survival
- The spread among groups is much greater than in the resilience PM



Priorities and Goals –ODFW, NOAA 2011

Upper Willamette River Conservation & Recovery Plan for Winter Steelhead

- Passage mitigation provides limited opportunities to help recover steelhead populations in 2 of 4 drainages
- Future marine survival trends are the largest source of uncertainty
- Only 21% of the habitat in the Santiam drainage is above Foster, Green Peter and Detroit dams
- The value of higher elevation habitat is likely to increase with Climate change



Conclusions

- Management Actions are urgently required
  - Spawner abundance has been below 20 adults in 2 of the last 5 years
    - Estimated 8 and 6 virgin females in 2017 and 2021, respectively
- The effectiveness of passage lever is limited by other survival stressors on the population
  - Low marine survival is the biggest factor in recent abundance trends
  - Even with 100% passage mitigation, the probability of dropping below the target abundance of 100 spawners is still 10%-20%
- Additional management levers are available
  - e.g. predator control, attractiveness of the fishway entrance, summer steelhead management below the dam, rainbow trout management above the dam

Acknowledgments

- Oregon State Fish and Wildlife Department for its implementation of the paired release experiments and Beach Seine study and making the PIT tag data from them available for this study
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Demography of Winter Steelhead : $N_1/N_0 = F S_F S_P S_M (1+r)$

- **Observations:**
  - N_1 is the number of female spawners produced by N_0 female spawners.
    - Foster fishway counts
  - F is the number of female[2] eggs per spawner,
  - r is the repeat spawning ratio and
  - S_M - **Marine Survival** from Willamette Falls to adults prior to egg deposition [1]
- S_P – **Passage Survival** from Dam face to Willamette Falls
  - Defined by the **F**ish **B**enefits **W**orkbook
- S_F is estimated by fitting Predicted to Observed N_1 *vs.* N_0
  - **Freshwater Survival** from potential egg deposition to the dam face

Model demography using Age, Survival data

- 81% of smolts are age-2, rest age-3
- 68% of virgin spawners are 2-ocean, rest are 3-ocean
- r=13.8% of females are repeat spawners

$$N_1 = {aN_0}/{(1 + \ aN_0/B)} \text{ where}$$

$$a = FS_F S_P \, S_M (1 + r) \qquad B = B_F S_P S_M (1 + r)$$

- S_M = marine survival (McCann et al. 2021)
- S_P = passage probability (Hughes et al, 2021, Liss et al. 2020)
  - S_P by Option is been estimated for each Option, age and species
- B_F defined by historic maximum number of adults at Willamette Falls and proportion of South Santiam adults at Falls (Jepson et al. 2015)

South Santiam Population above Foster

Data Observations

- Observed abundance of unclipped, female winter steelhead passed since 2006

  Proportion of females varies but not as much as abundance

- Similar abundance pattern at Willamette Falls

Year	Foster Adults	% female	Female	Will F. Winter Sthd
2006	419	54%	226	6404
2007	209	53%	111	5474
2008	256	50%	127	4915
2009	192	55%	106	2813
2010	426	64%	271	7337
2011	315	63%	198	7441
2012	317	56%	179	7616
2013	283	59%	168	4944
2014	214	60%	128	5349
2015	127	64%	81	4508
2016	206	65%	133	5778
2017	18	56%	10	822
2018	29	55%	16	1829
2019	79	53%	42	3202
2020	109	61%	66	5510

An Example Three Groups of Options

- 3 Groups that share passage probability
- Distinct differences but high variation in adult abundance is driven by fluctuations in marine survival
- Numbers prior to 2009 are driven by initialization numbers
- Perfect Passage produces a slow rebuild

	Dummy Options				
	Historic Baseline	**Group 1 40%**	**Group 2 60%**	**Group 3 80%**	**100% Passage**
DPE		50%	80%	89%	
DPS		80%	75%	90%	
DPE*DPS	**45%**	**40%**	**60%**	**80%**	**100%**
Ave. N	**116**	**99**	**176**	**271**	**382**