Approaches to accounting for pre-spawn mortality in evaluation of dam passage options for spring Chinook salmon (*Oncorhynchus tshawytscha*)

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UBC
Integrated Passage Assessment

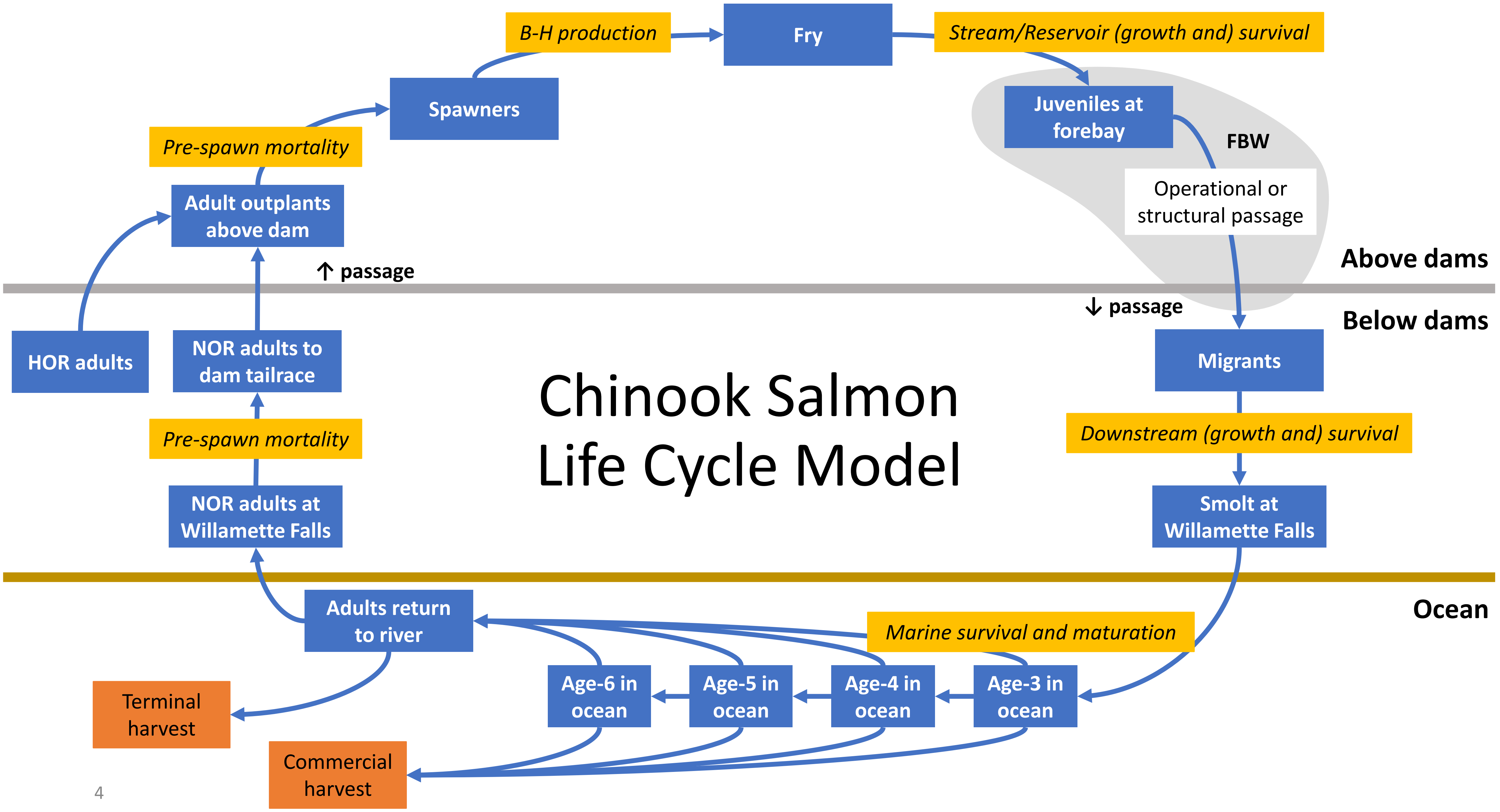
Overview

- What is pre-spawn mortality (PSM) and where does it fit into life cycle models of Chinook salmon in the Upper Willamette?
- Data and models available to parameterise life cycle models
- Effect of assumptions about PSM on performance metrics of dam passage options

Pre-spawn mortality (PSM)

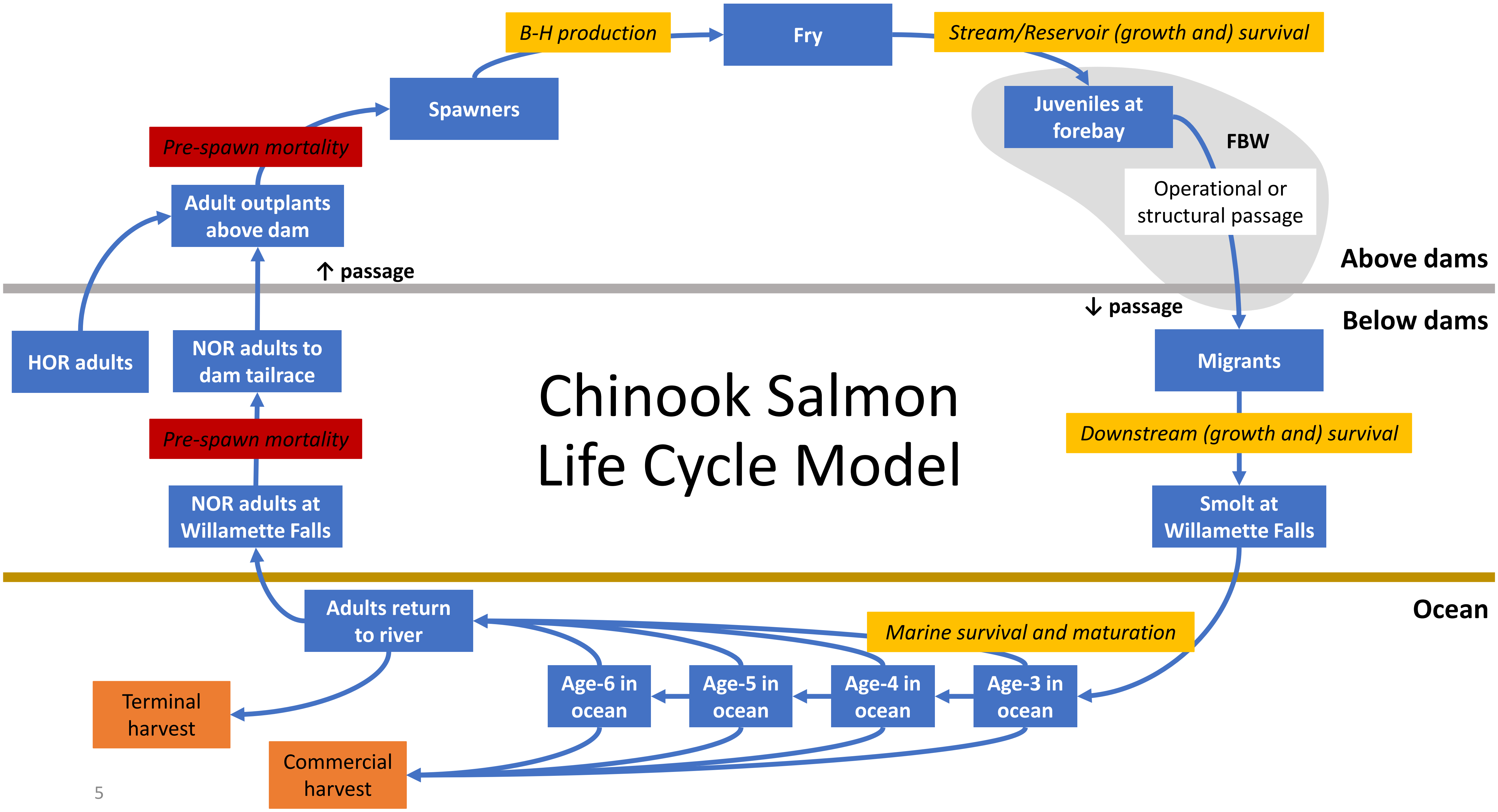
- Mortality of adults before they reproduce
- Important to population viability
- Factors include:
  - Elevated stream temperature
  - Injuries
  - Pathogens
  - Origin
  - Size

Photo credits: Normandeau Associates/EAS



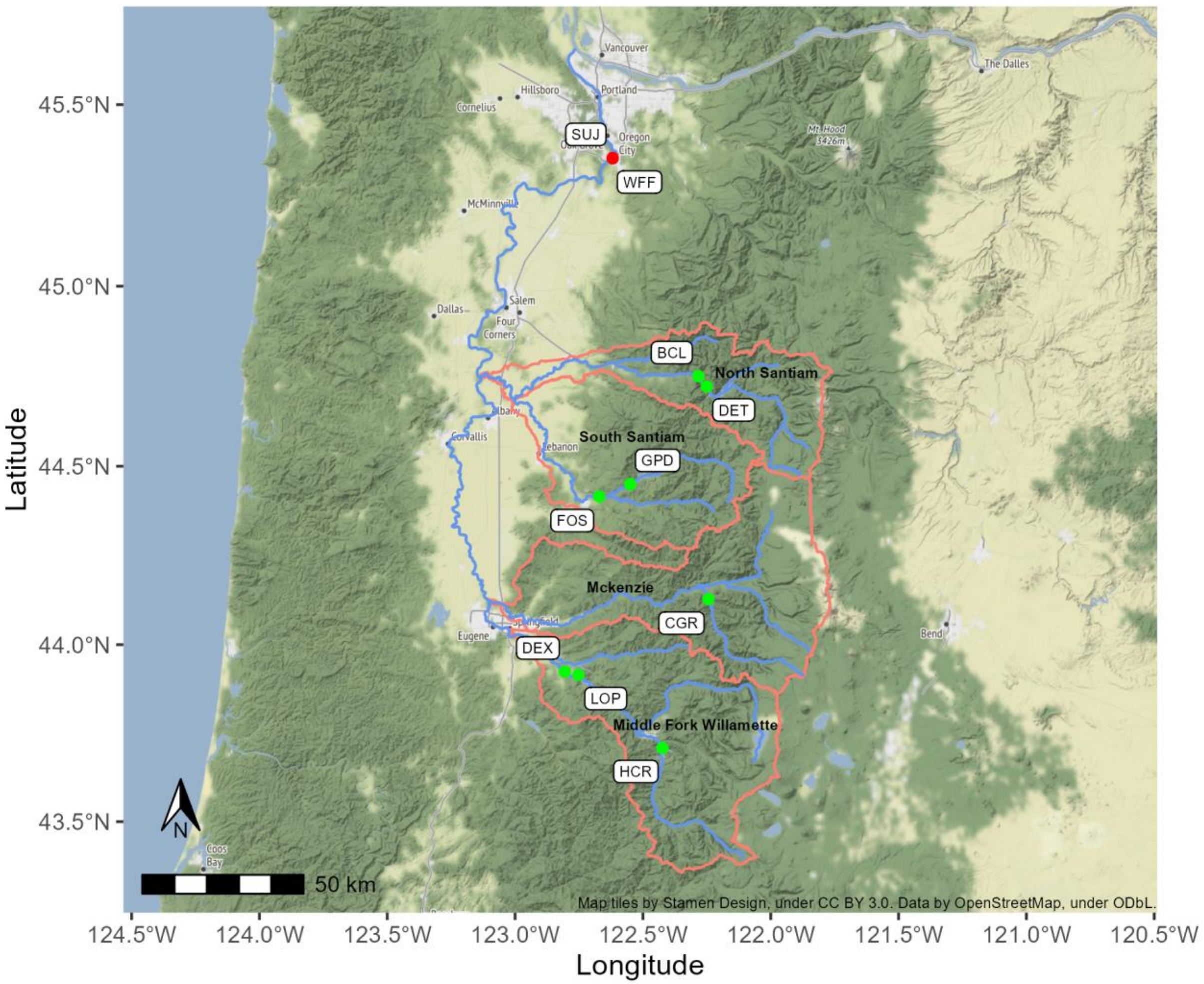
Chinook Salmon
Life Cycle Model
B-H production
Fry
Stream/Reservoir (growth and) survival
Spawners
Juveniles at forebay
FBW
Operational or structural passage
Pre-spawn mortality
Adult outplants above dam
↑ passage
Above dams
↓ passage
Below dams
HOR adults
NOR adults to dam tailrace
Migrants
Pre-spawn mortality
Downstream (growth and) survival
NOR adults at Willamette Falls
Smolt at Willamette Falls
Ocean
Adults return to river
Marine survival and maturation
Terminal harvest
Age-6 in ocean
Age-5 in ocean
Age-4 in ocean
Age-3 in ocean
Commercial harvest

Chinook Salmon Life Cycle Model



Where to account for PSM?

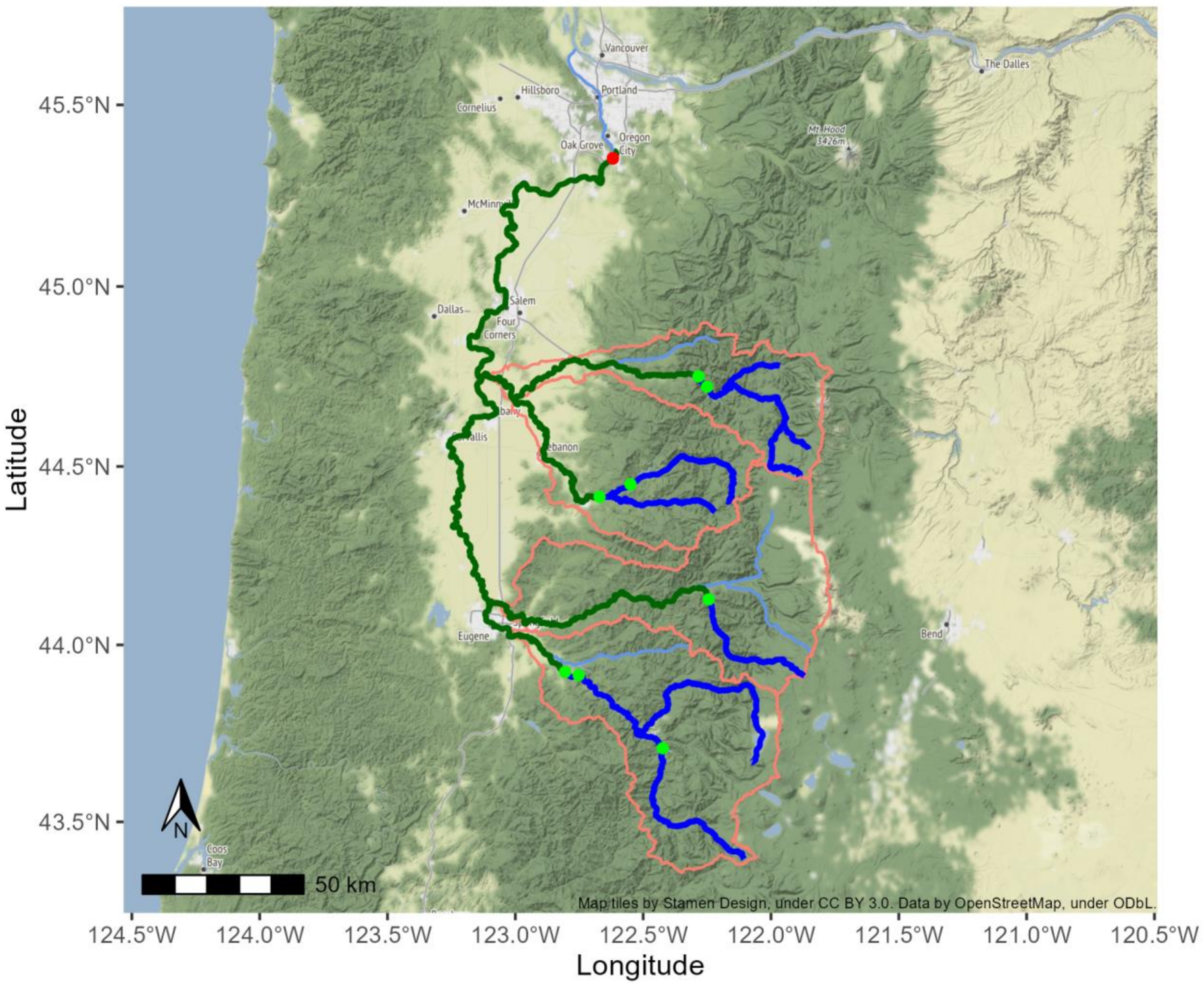
- Two sources of PSM:
  - En route mortality
  - Onsite mortality



Where to account for PSM?

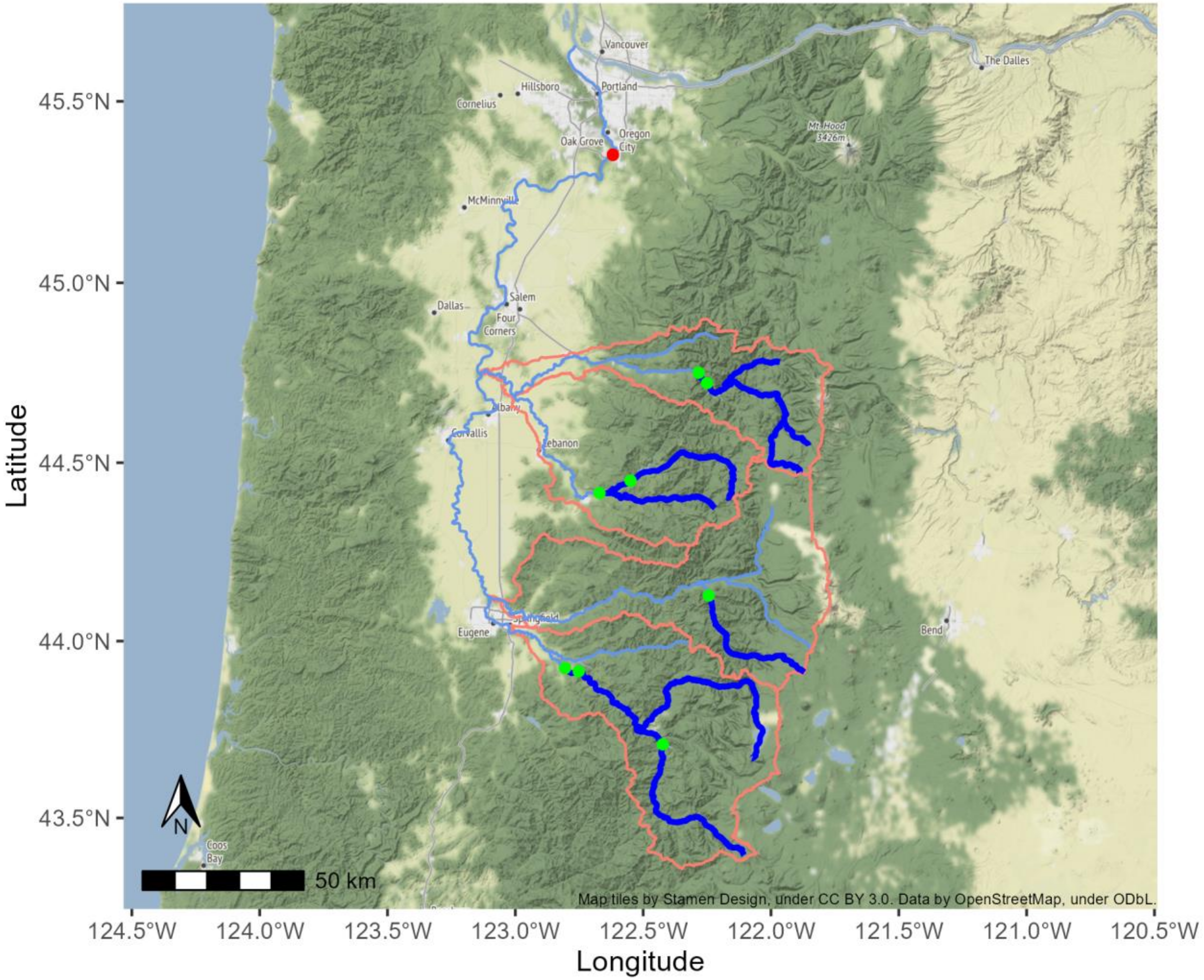
- Two sources of PSM:
  - En route mortality = below dam
  - Onsite mortality = above dam

- Lots of studies and data on PSM
- How to account for both mortality sources in life cycle models of the above dam population?



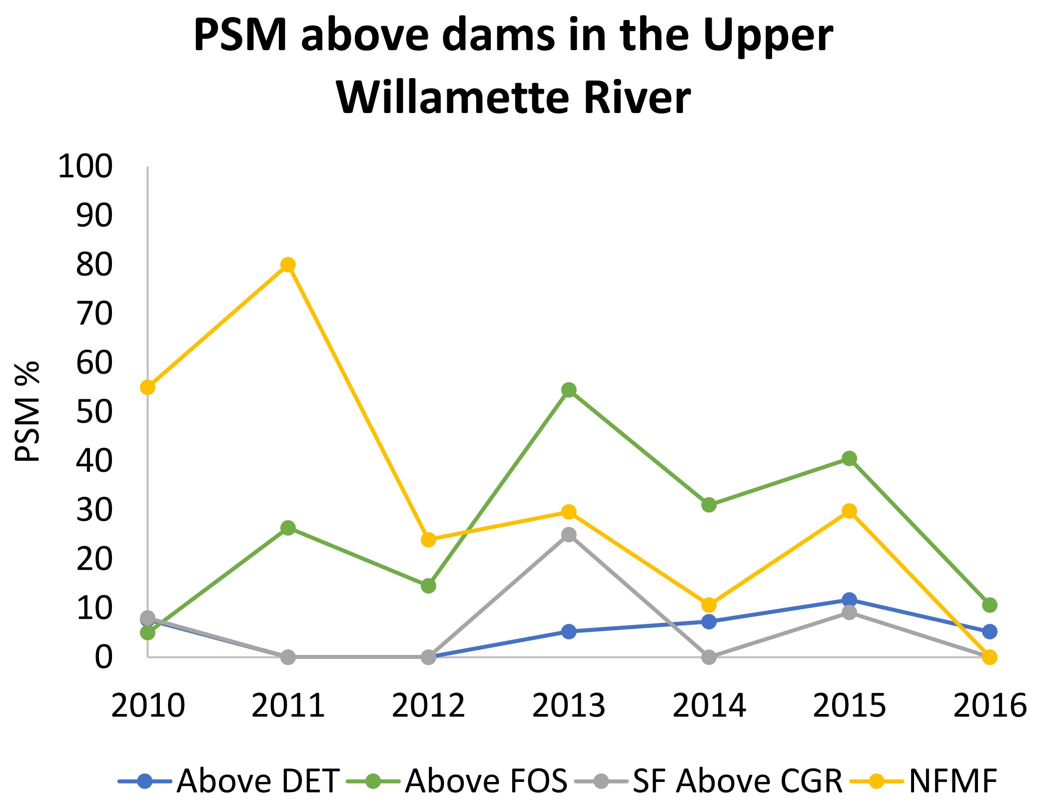
Onsite mortality

- Carcass recovery estimates:
    - ODFW (2010-2016)
    - Normandeau Associates/EAS (2018-2019)
- PSM if >50% egg retention



Onsite mortality estimates

- Carcass recovery estimates
  - ODFW (2010-2016)
  - Normandeau Associates/EAS (2018-2019)
- PSM if >50% egg retention
- Lots of interannual variation

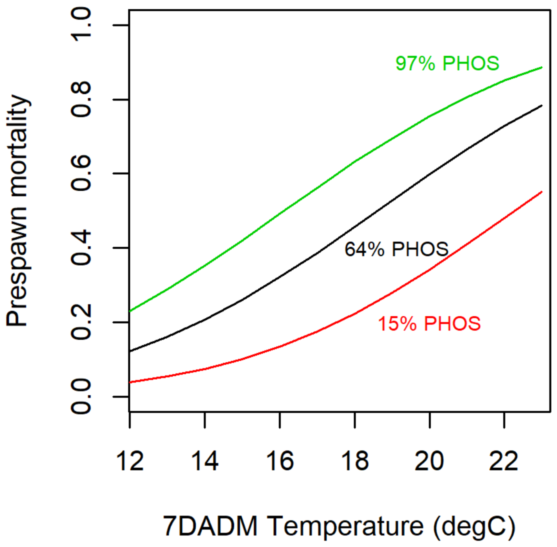


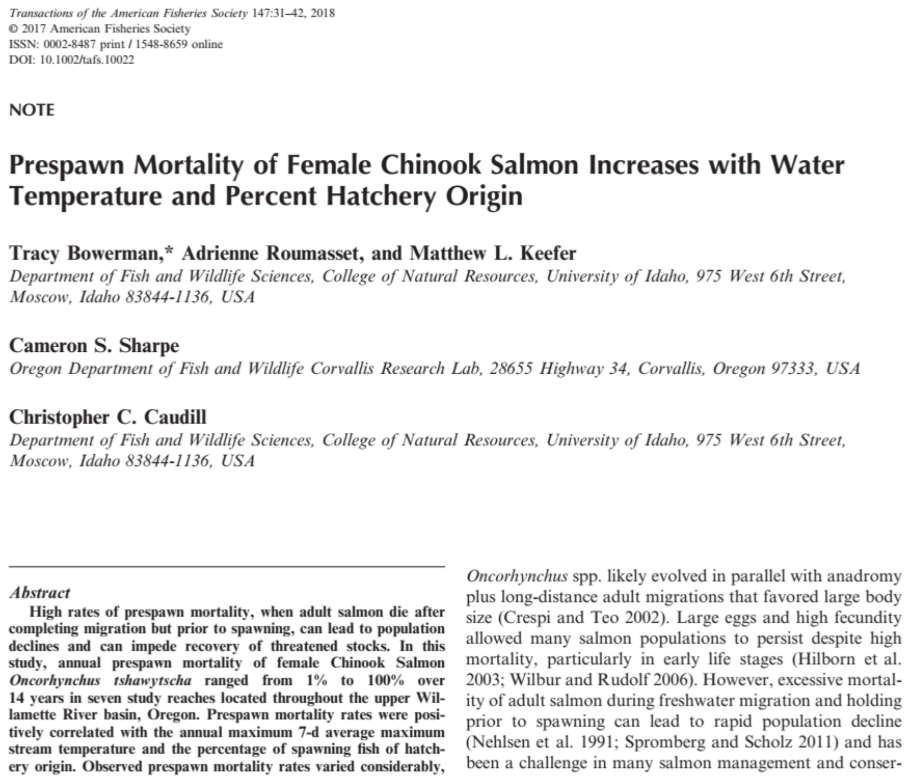
Mean: 5% 26% 6% 35%

Source: Cannon et al. 2011; Sharpe et al. 2013, 2014, 2015, 2016, 2017

Onsite mortality models

- Data modelled by Bowerman et al. (2018)
- Fit model to below dam data only
- 7-day average daily maximum (7DADM) temperature and proportion of hatchery-origin spawners (pHOS) significant





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NOTE

Prespawn Mortality of Female Chinook Salmon Increases with Water Temperature and Percent Hatchery Origin

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Abstract
High rates of prespawn mortality, when adult salmon die after completing migration but prior to spawning, can lead to population declines and can impede recovery of threatened stocks. In this study, annual prespawn mortality of female Chinook Salmon *Oncorhynchus tshawytscha* ranged from 1% to 100% over 14 years in seven study reaches located throughout the upper Willamette River basin, Oregon. Prespawn mortality rates were positively correlated with the annual maximum 7-d average maximum stream temperature and the percentage of spawning fish of hatchery origin. Observed prespawn mortality rates varied considerably,

Oncorhynchus spp. likely evolved in parallel with anadromy plus long-distance adult migrations that favored large body size (Crespi and Teo 2002). Large eggs and high fecundity allowed many salmon populations to persist despite high mortality, particularly in early life stages (Hilborn et al. 2003; Wilbur and Rudolf 2006). However, excessive mortality of adult salmon during freshwater migration and holding prior to spawning can lead to rapid population decline (Nehlsen et al. 1991; Spromberg and Scholz 2011) and has been a challenge in many salmon management and conser-

Accounting for onsite mortality above dams

- Life cycle model included above dam PSM using Bowerman et al. (2018) model
  - Bootstrapped 7DADM temperature from USGS gages above dams
  - pHOS determined from outplant ratio HOR:NOR
  - Random effects of year and site
- Initial runs showed PSM overestimated compared to observed data from 2010-2016

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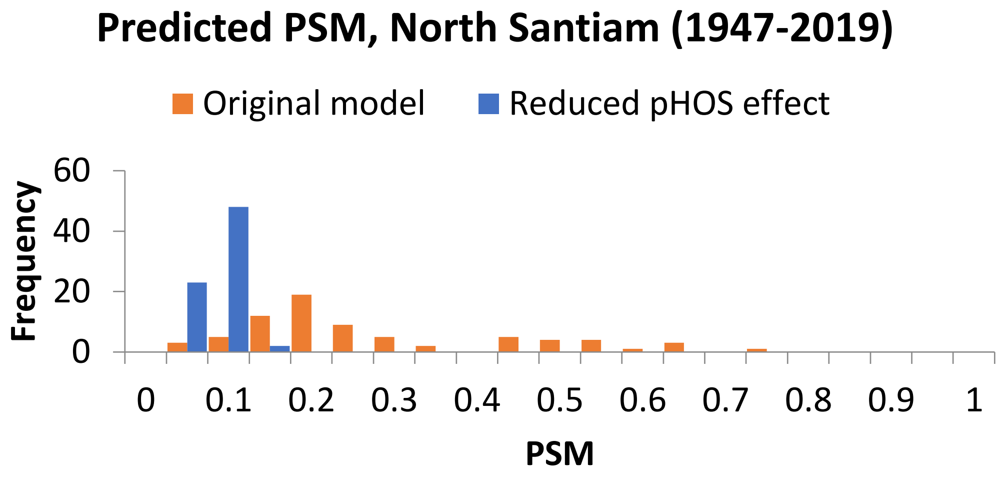
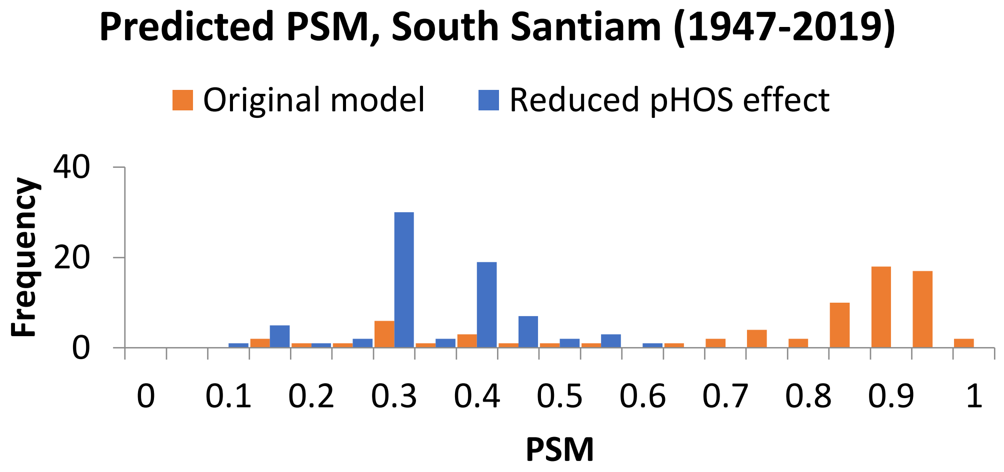
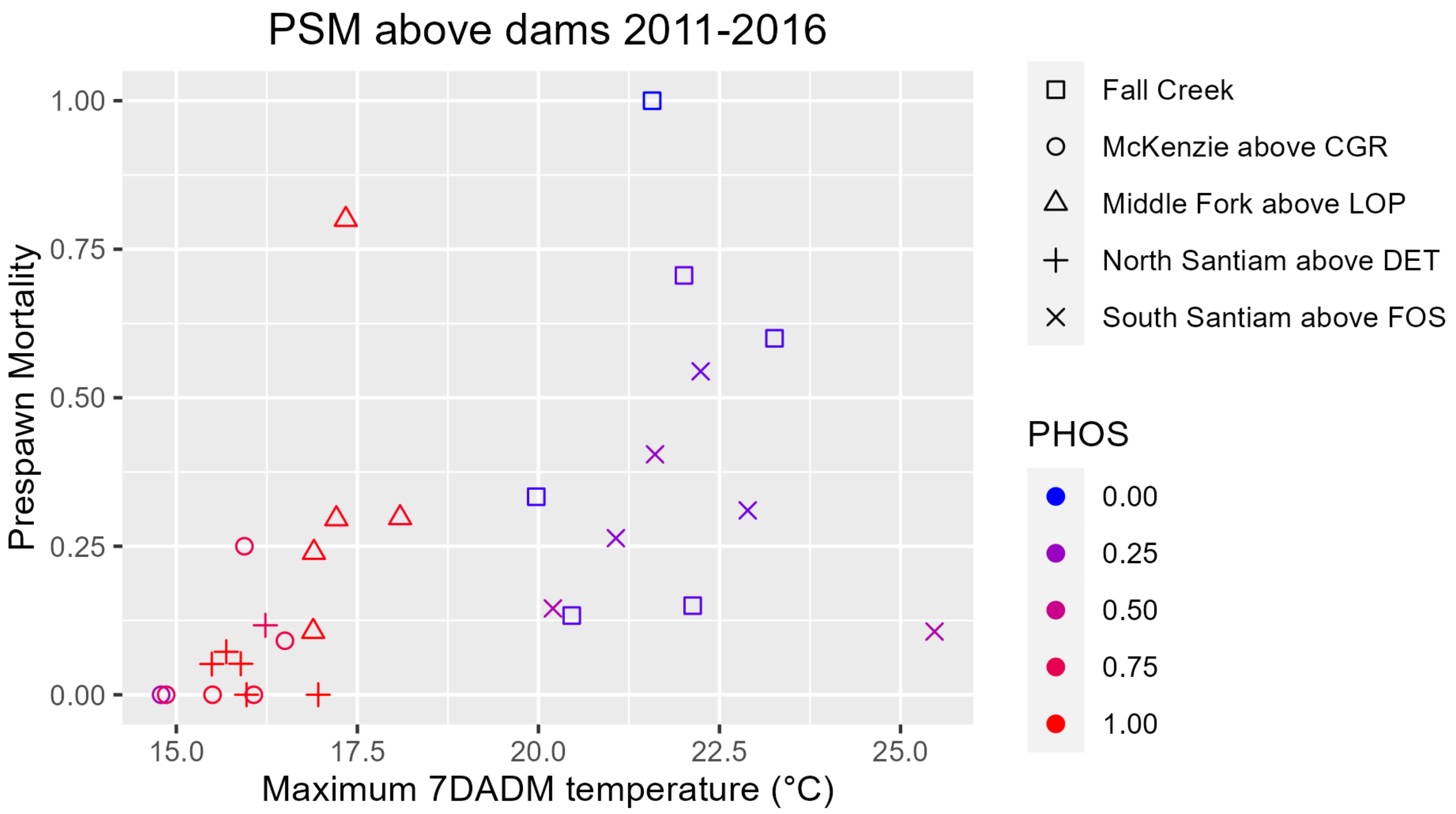
  - Bootstrapped 7DADM temperature from USGS gages above dams
  - pHOS determined from outplant ratio HOR:NOR
  - Random effects of year and site
- Initial runs showed PSM overestimated compared to observed data from 2010-2016
- Modified model with reduced size of pHOS effect led to more consistent PSM predictions
  - Mortality driven mainly by temperature





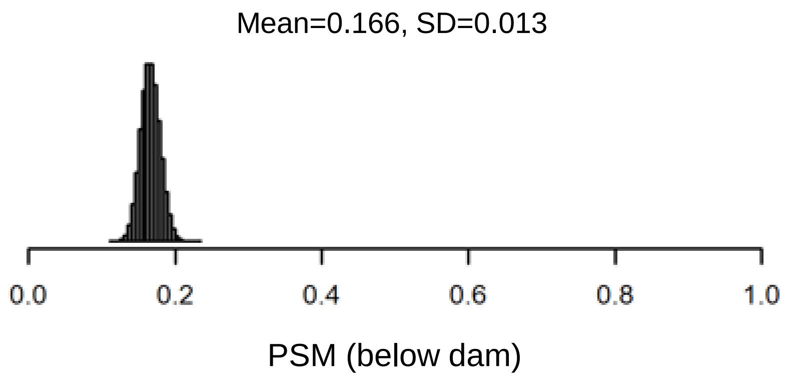
Different effect of origin above dams?

- Data show PSM reduced where pHOS high
- Confounding as sub-basins with warmer temperatures also those with only natural-origin return (NOR) outplanting
- Prevents further modelling of these data so more data needed



En route mortality

- Radio-telemetry study by Keefer et al. (2017) tagged adults at Willamette Falls and monitored survival to each sub-basin
- Body condition and injuries sustained during upstream migration were better predictors of mortality than temperature
- Results used to specify a distribution for en route mortality



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MANAGEMENT BRIEF

Condition-Dependent En Route Migration Mortality of Adult Chinook Salmon in the Willamette River Main Stem

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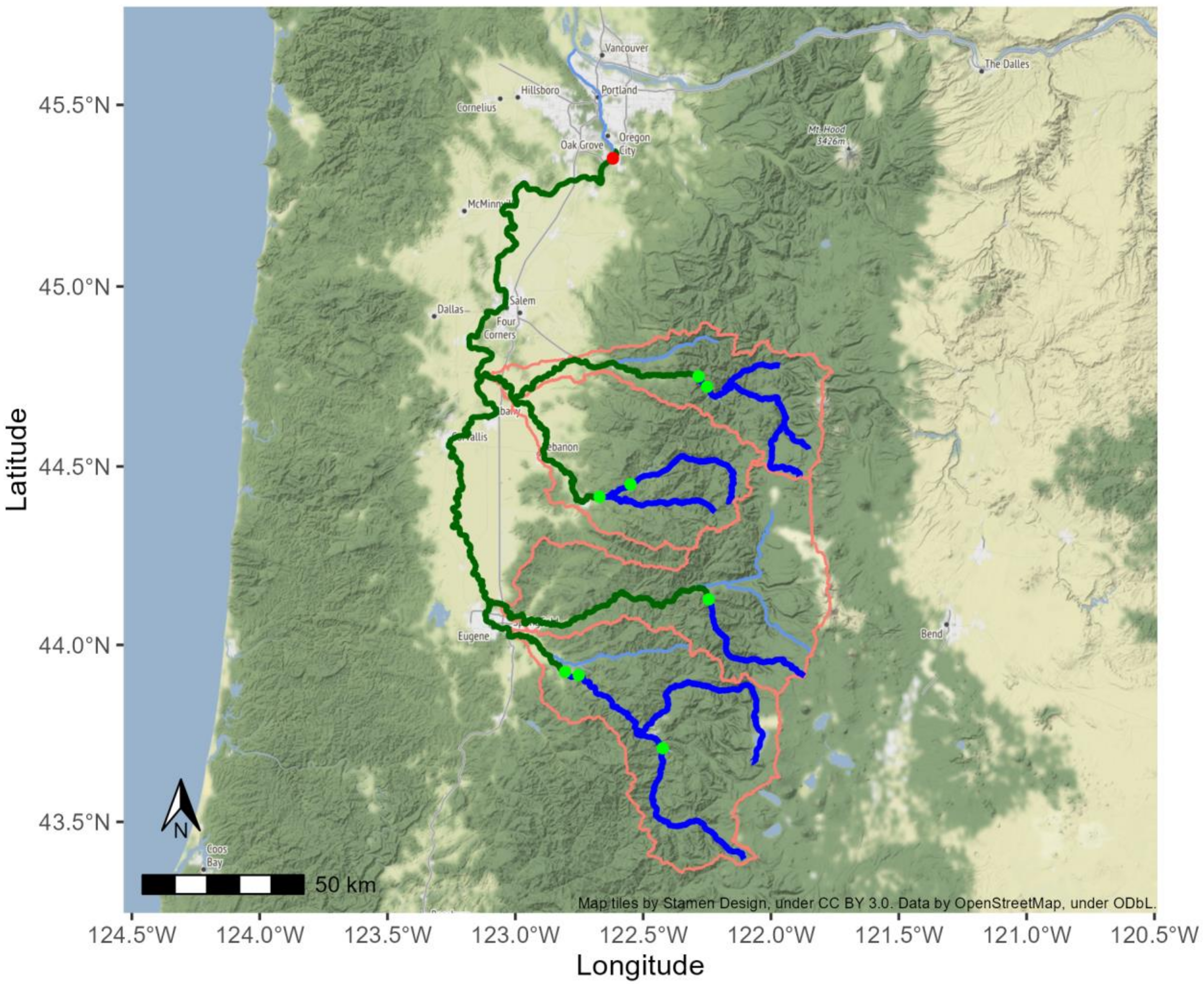
Abstract
Episodically high adult mortality during migration and near spawning sites has hindered the recovery of threatened spring-run Chinook Salmon *Oncorhynchus tshawytscha* in Oregon's Willamette River basin. In 2011–2014, we assessed migration mortality for 762 radio-tagged adults along a ~260-km reach of the main stem of the Willamette River. Annual survival of salmon to spawning tributaries ranged from 0.791 (95% CI = 0.741–0.833) to 0.896 (0.856–0.926), confirming concerns about mortality in the migration corridor. In a series of general linear models, descaling, marine mammal injuries, and head injuries to adult Chinook Salmon were linked to reduced survival during migration to tributaries. Many injuries were minor (i.e., epidermal

et al. 2000; Cooke et al. 2008; Lundqvist et al. 2008). In-river fisheries typically account for the largest proportion of adult salmon mortality in freshwater, but a variety of other sources can be important. Episodic or chronic adult mortality has been associated with physical and environmental migration barriers (e.g., Caudill et al. 2007; Hinch et al. 2012; Sigourney et al. 2015), physiological limitations (e.g., Cooke et al. 2012; Eliason and Farrell 2016), predation (Quinn et al. 2003; Keefer et al. 2012), and a variety of pathogens and parasites (e.g., Bakke and Harris 1998; Wagner et al. 2005; Benda et al. 2015).

Adult salmon mortality in freshwater is often partitioned

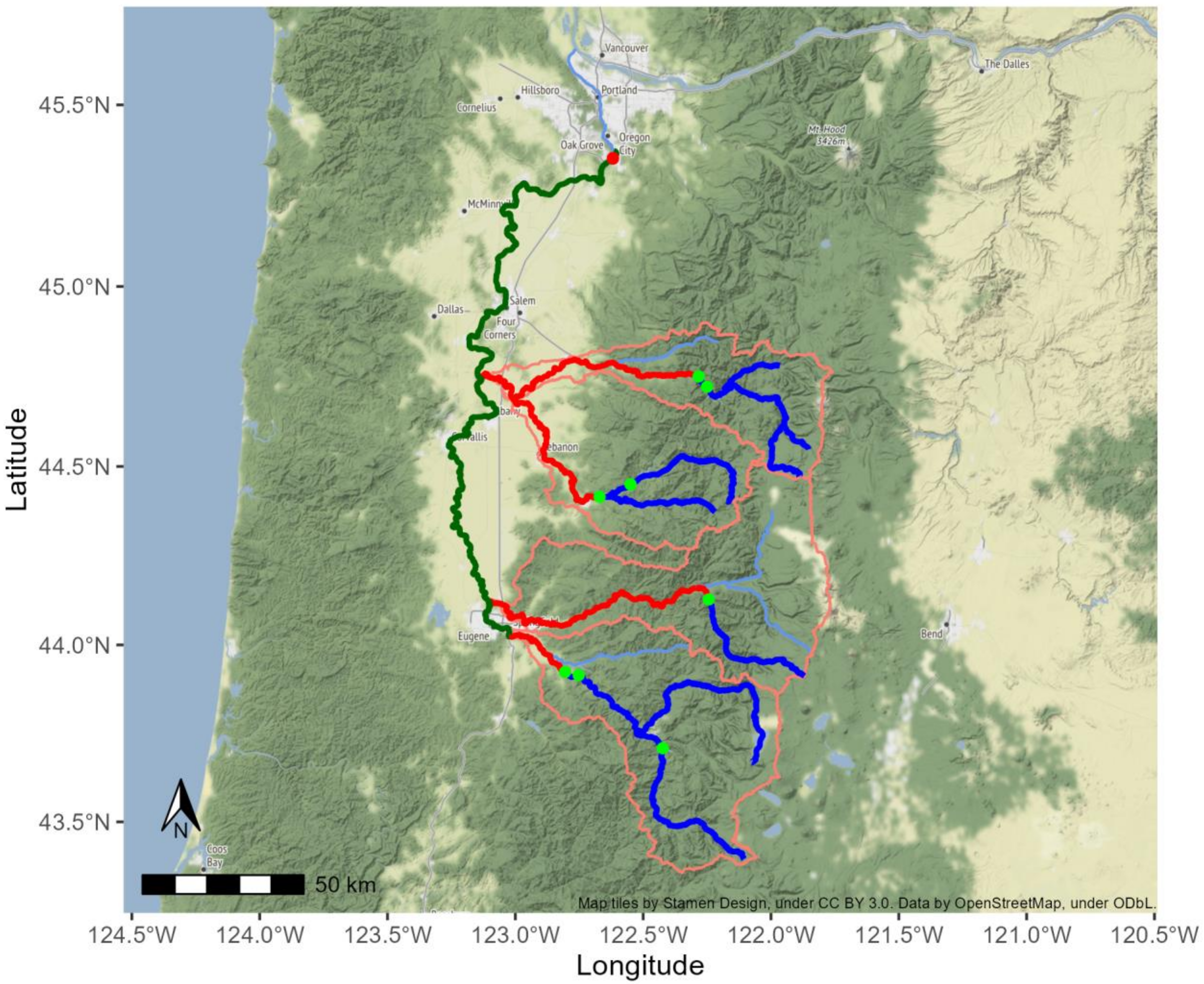
Life cycle modelling to evaluate dam passage

- Onsite and en route PSM components built into life cycle model
- Dam passage rates under different options determined by Fish Benefits Workbook (FBW)
- Model calibrated to NOR and age composition in each sub-basin
- LCM used to compute performance metrics under dam passage measures from 10,000 simulations



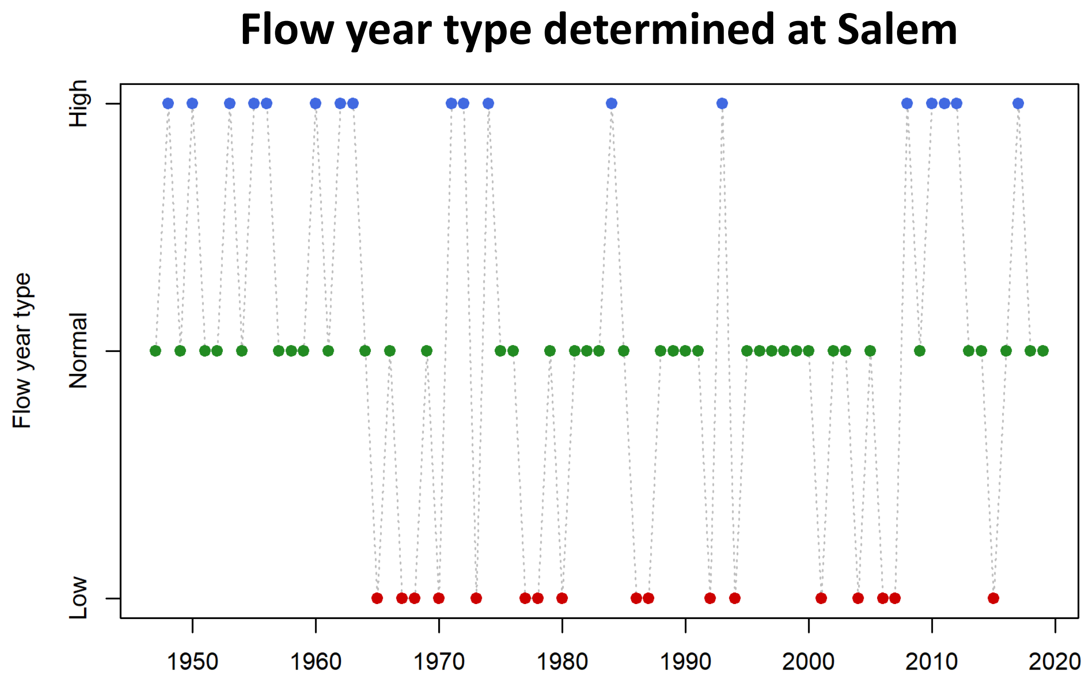
Accounting for downstream temperature

- Temperature regime downstream of dams may vary under different dam passage options.
- May have variable effect on mortality
  - Not accounting for it may misrepresent en route mortality risk
- Further developed life cycle model to account for additional component of below dam PSM



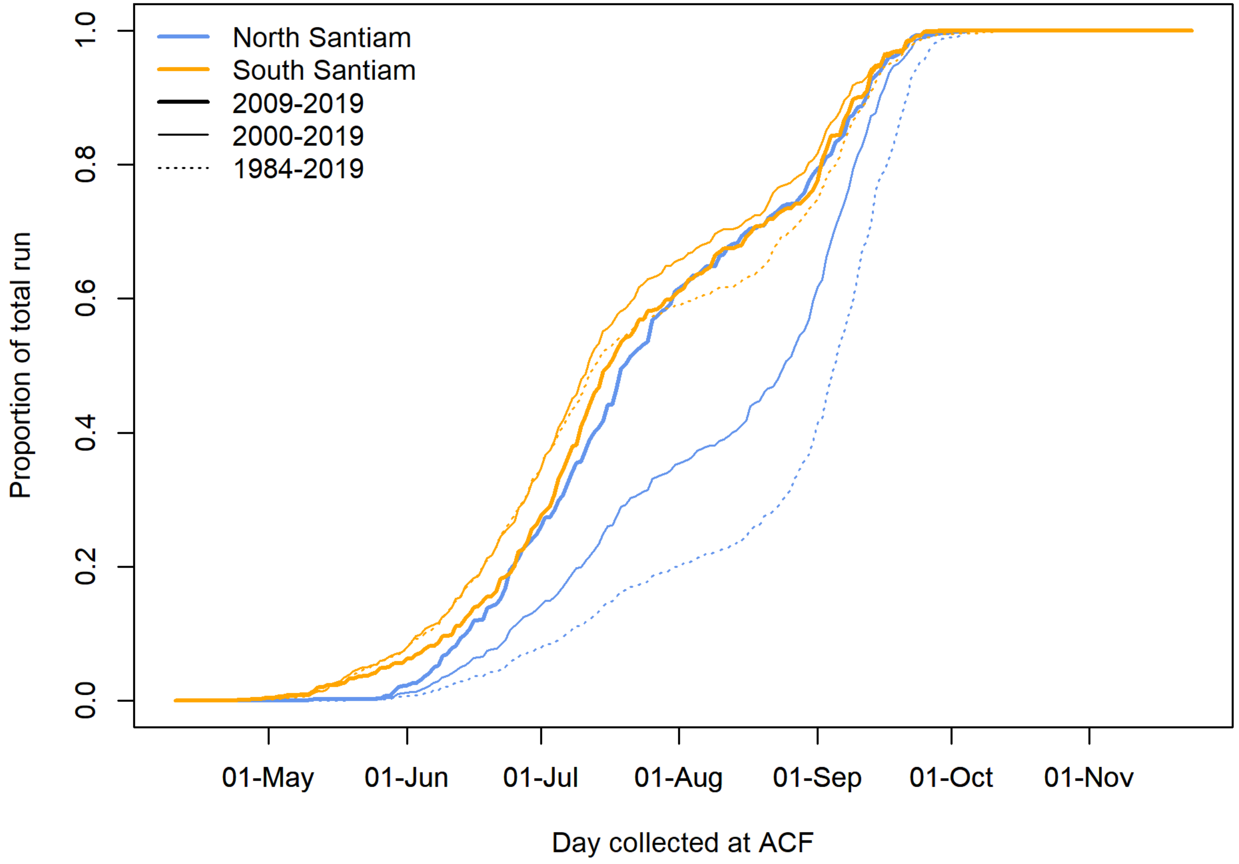
Accounting for downstream temperature

- Temperature predicted below dams under different passage measures by flow year (USGS CE-QUALW2 output)
  - 2011 (high flow = cool/wet)
  - 2015 (low flow = hot/dry)
  - 2016 (normal flow = warm/normal)
- Daily maximum temperatures in *c*.250m segments downstream of dams
- Used to calculate 7DADM across segments in mainstem to tailrace reach



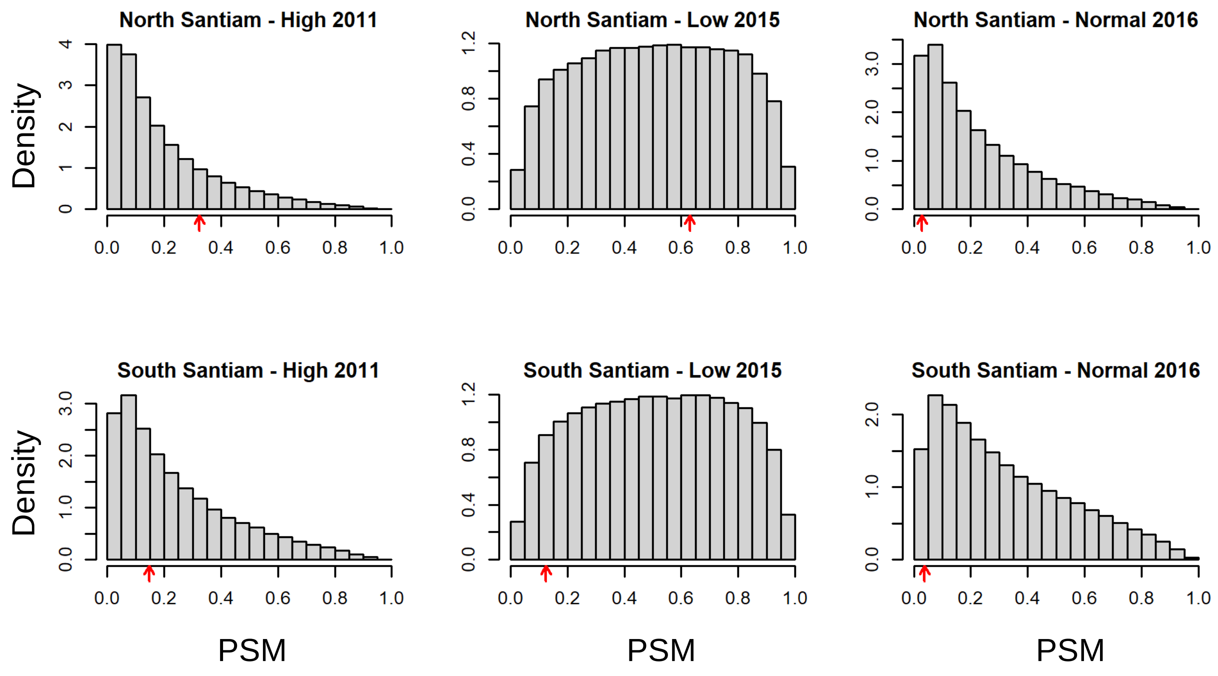
Temperature experienced depends on timing

- Adults return to dam tailrace and are potentially outplanted above dam before experience highest temperatures
- Used data on daily returns to determine maximum date to use in calculating 7DADM temperature
- Recent mean run timing similar among sub-basins



Temperature experienced depends on timing

- Differences between observed PSM and PSM predicted using 7DADM given upper date at each 1% of run minimised using date when 62% of run had returned
- Predicted PSM distributions using August 2nd contained observed values for each sub-basin and flow year



Below dam measure and flow year effects

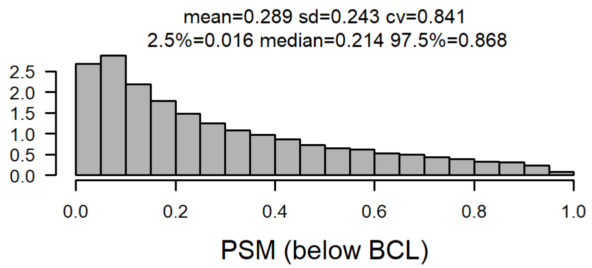
- Measures with spring drawdown result in highest temperatures
  - Limited availability of cooler reservoir water for summer release
- Bowerman et al. (2018) used to incorporate 7DADM in life cycle model
- Model recalibrated with additional PSM component
  - Marine survival increased to compensate for reduced freshwater survival

		Maximum 7DADM temperature (°C): 1 May - 2 Aug	
Measure	**Flow year**	**North Santiam (below Big Cliff)**	**South Santiam (below Foster)**
No Action	High	18.7	19.5
	Normal	19.3	20.8
	Low	23.5	23.5
Structural	High	19.9	21.3
	Normal	22.1	23.5
	Low	22.5	24
Spring Spill + Fall Drawdown	High	19.2	19.7
	Normal	21.4	22.9
	Low	21	22.3
Spring Drawdown + Fall Drawdown	High	18.6	17.8
	Normal	24.5	24
	Low	25.8	25.3

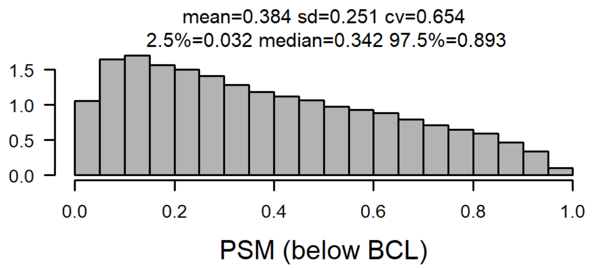
Mainstem to tailrace mortality

- Across flow year types an additional below dam mortality of >50% depending on the sub-basin and dam passage measure

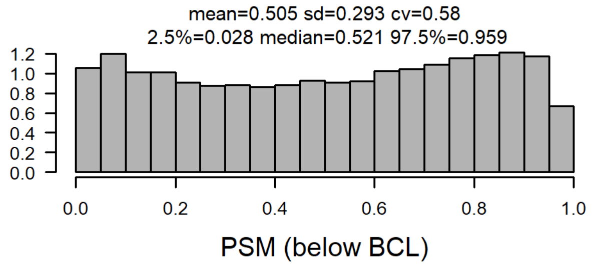
No Action



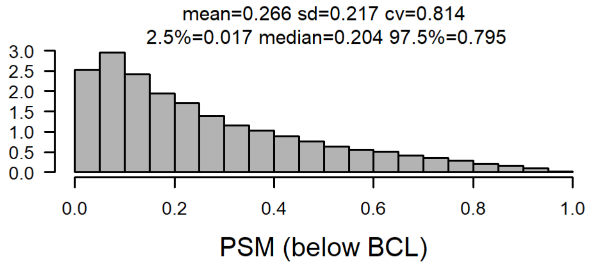
Structural



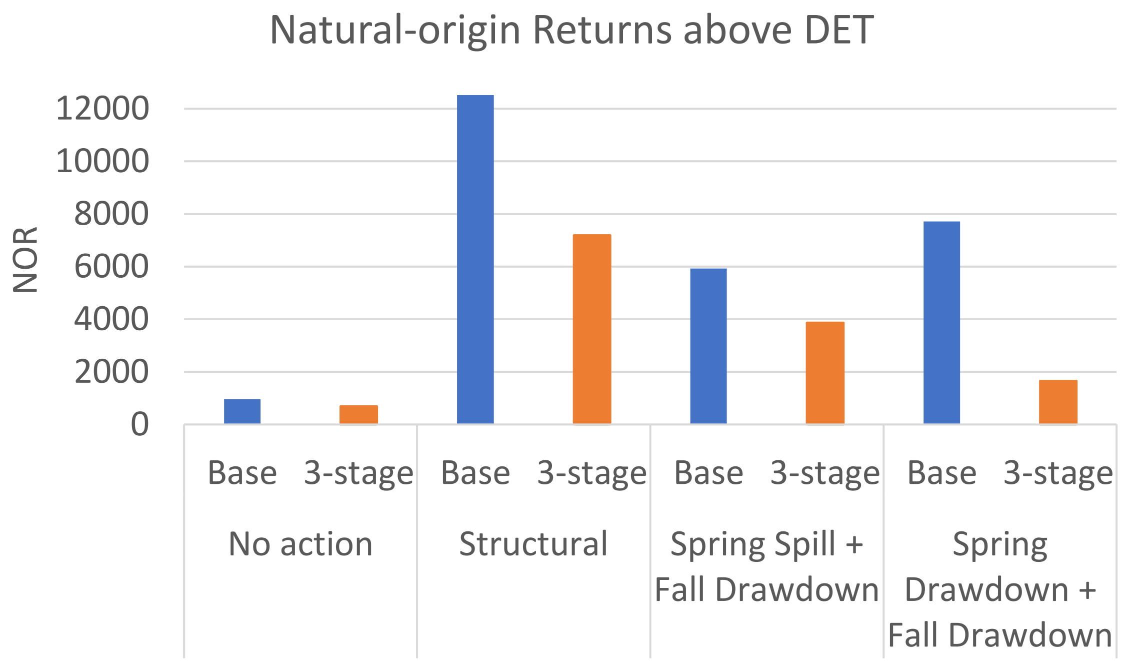
Spring Drawdown + Fall Drawdown

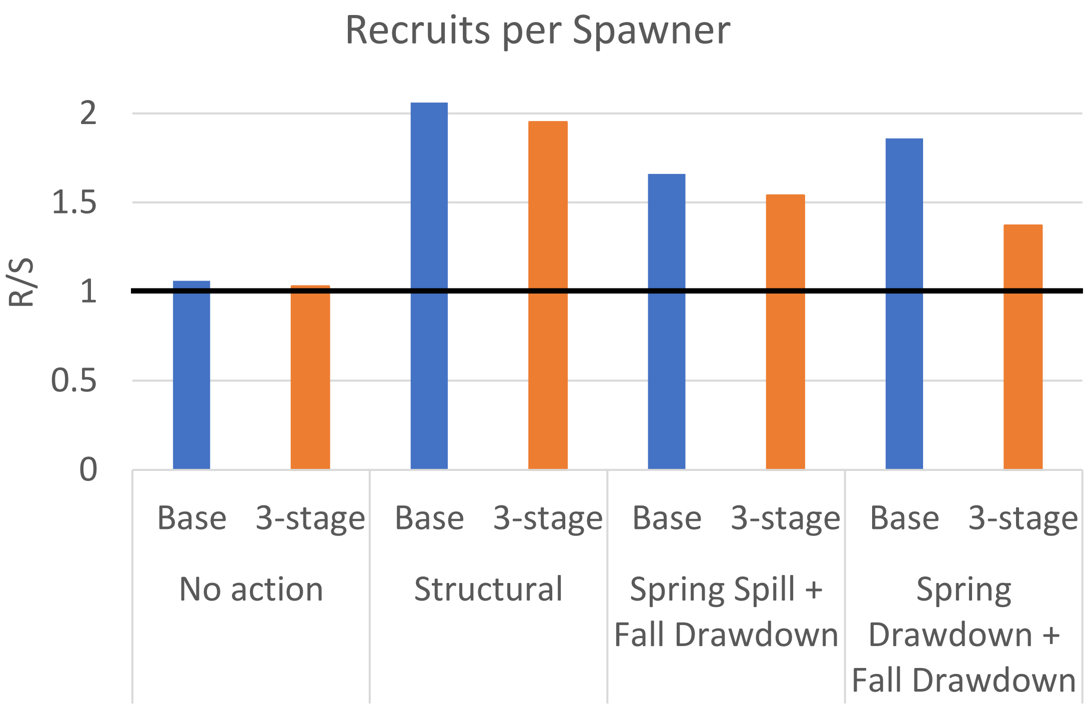


Spring Spill + Fall Drawdown



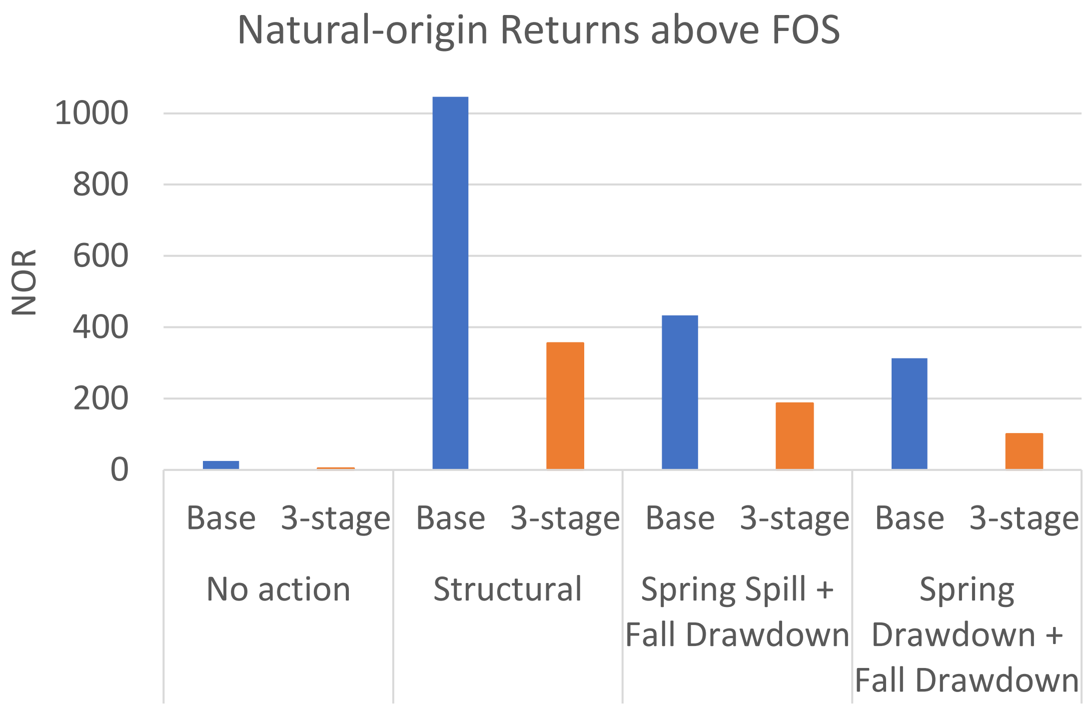
Sensitivity analysis: North Santiam

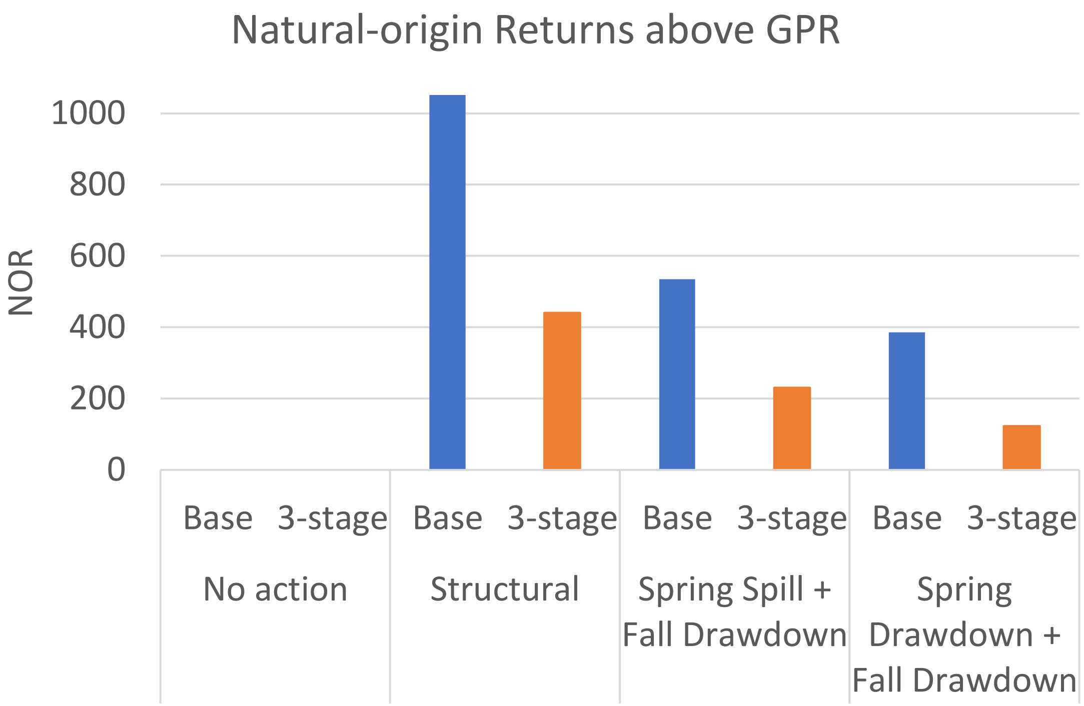




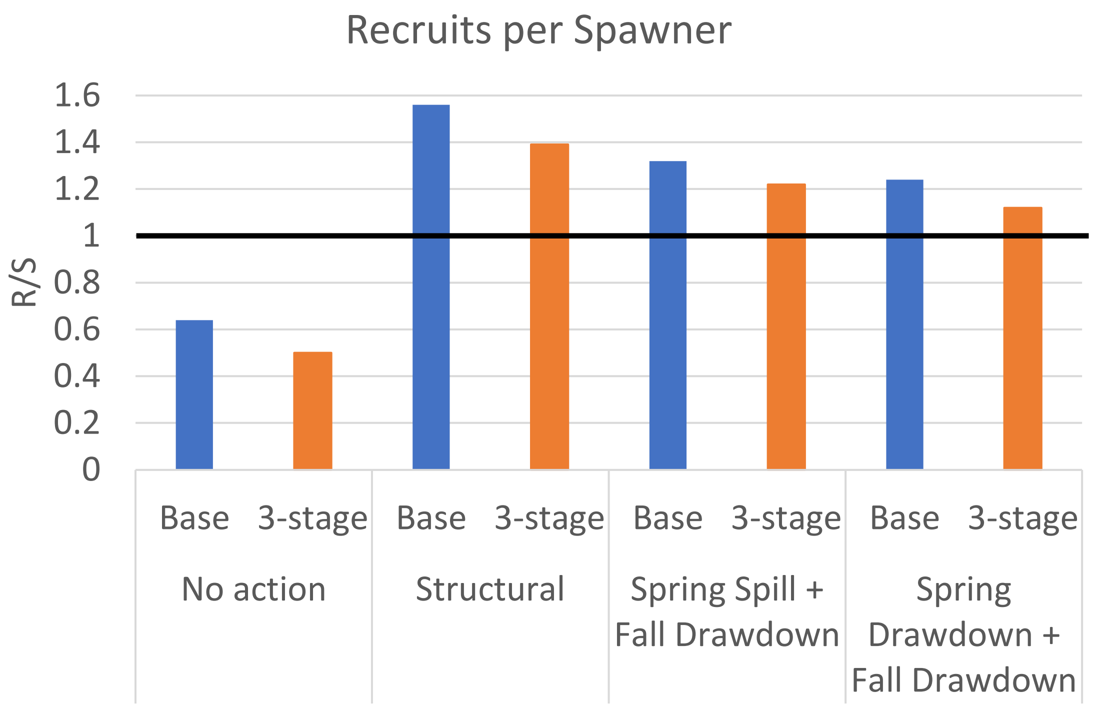
Additional PSM component below dams resulted in reduced numbers of predicted NORs and R/S relative to base case life cycle model predictions.

Sensitivity analysis: South Santiam



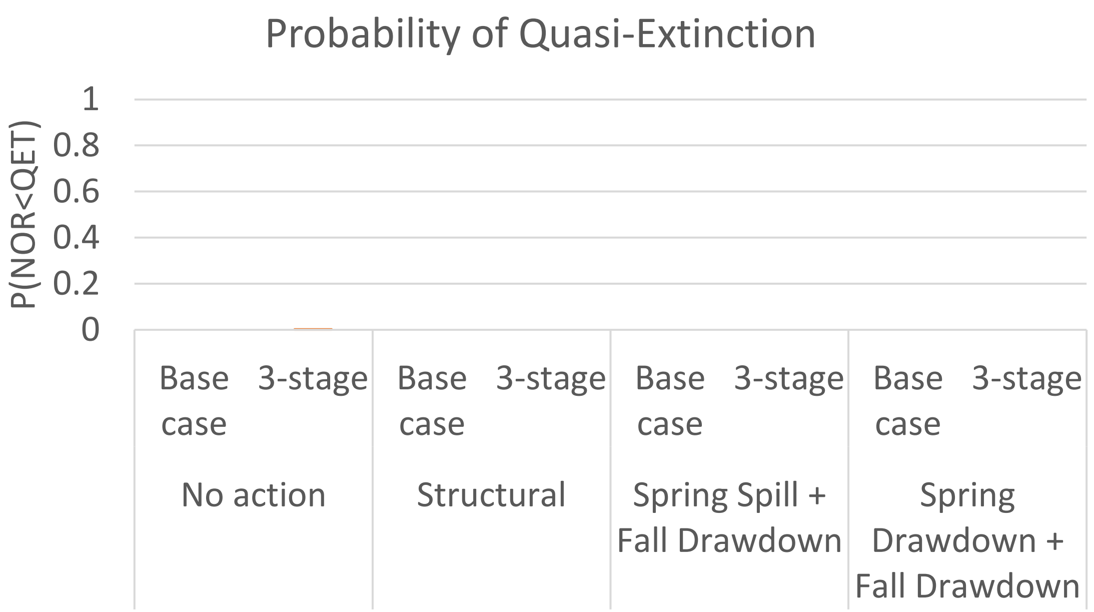


Sensitivity analysis: South Santiam

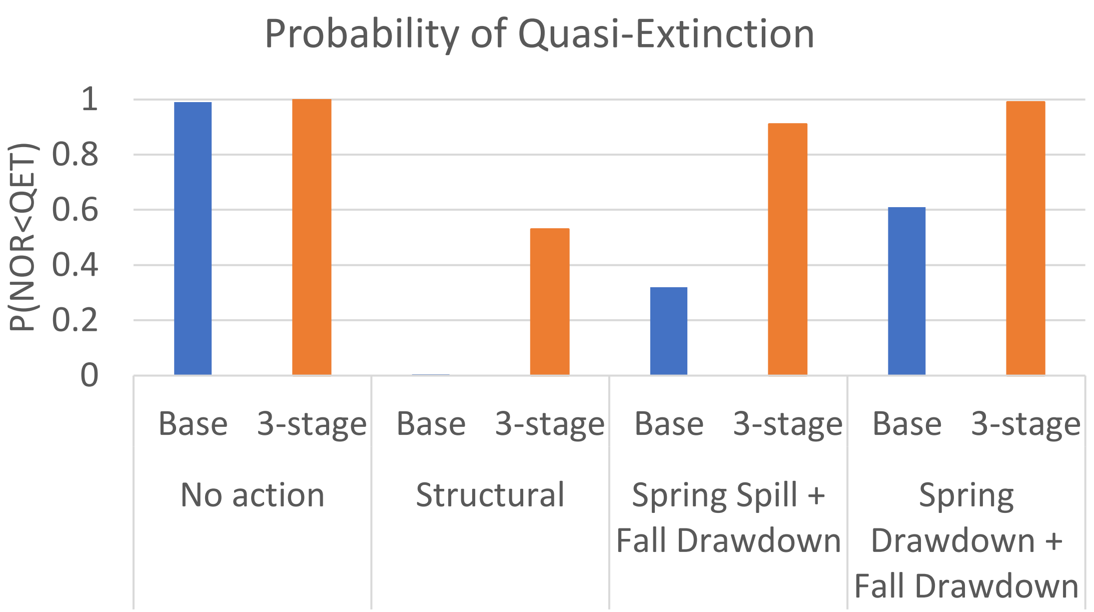


Sensitivity analysis: Extinction risk

North Santiam



South Santiam



Effects on extinction risk vary by sub-basin

Considerations in modelling PSM

- Important to account for all sources of en route and onsite PSM into life cycle models as above dam population outcomes in response to dam passage measures affected
- Effect of pHOS on PSM above dams less important than below dams
- Base case likely underestimates en route mortality, but additional temperature-based component may be too large due to use of an onsite PSM model to predict en route PSM
  - Above dam population migrating through below dam reaches, rather than remaining in them for a prolonged period to spawn.
  - Adults may not be as susceptible to increased temperature as predicted by onsite model
- Unknown sub-lethal effects from below dam migration that affect PSM above dams
- Further field studies needed to better inform a model of en route mortality
  - e.g., radio-telemetry monitoring of returning adult Chinook salmon above dams until reach spawning grounds

Acknowledgements

- Rachel Laird and Rich Piaskowski (USACE)
- USGS for CE-QUALW2 temperature outputs