How important is the use of prior information for the estimation of freshwater and smolt-adult survival rates using data from PIT tag studies?

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Integrated Passage Assessment

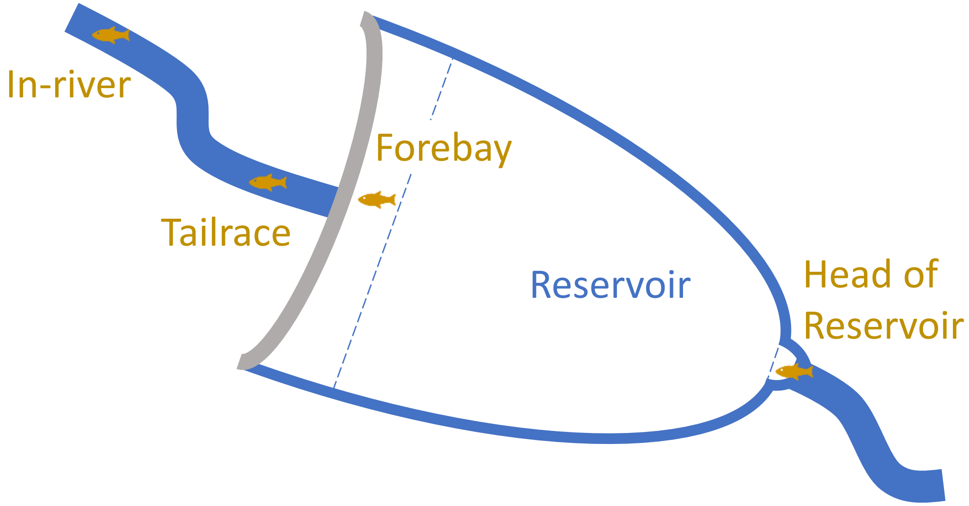
Willamette PIT tag studies

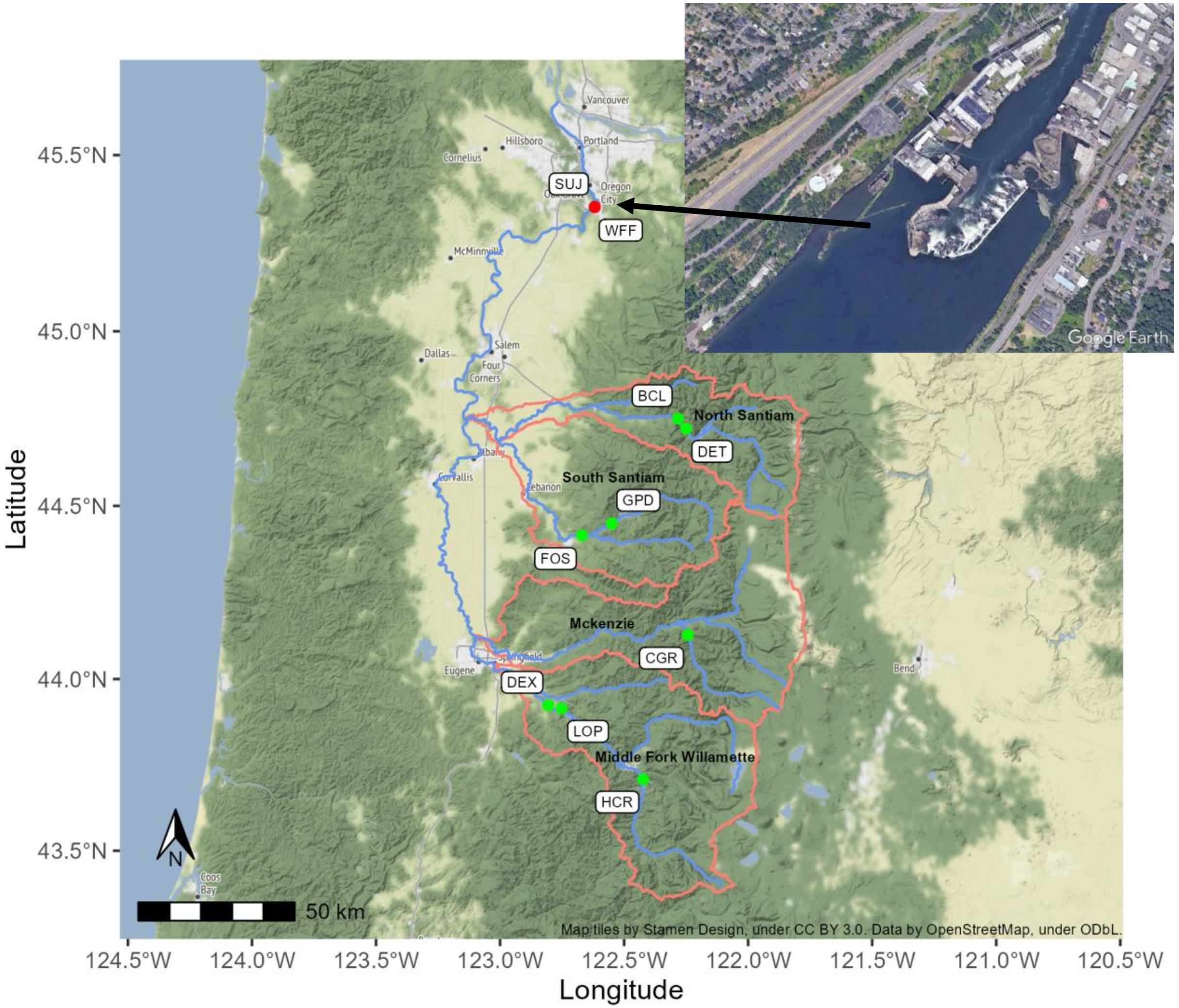
- PIT tag studies performed in all Willamette sub-basins
  - Chinook salmon (*Oncorhynchus tshawytscha*)
  - Steelhead (*O. mykiss*)
  - Hatchery-origin (HOR) above/below dam paired releases (>>10k fish)
  - Natural-origin (NOR) captured releases (<1k fish)
  - All data available via PTAGIS repository
- Most studies interested in dam passage survival and migration timing
- Further modelling can provide estimates of freshwater and marine survival rate for input to life cycle models

PTAGIS

Willamette PIT tag studies

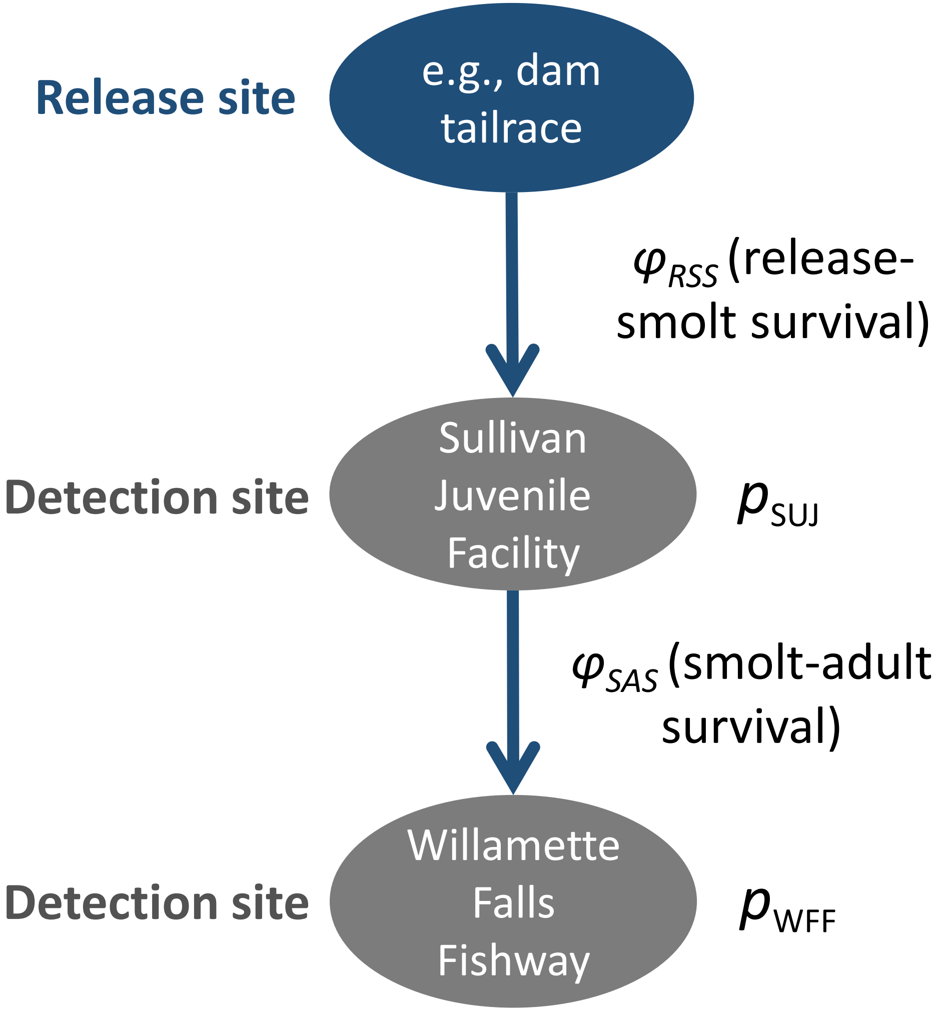
- Release sites above and below dams
  - Head of reservoir, Reservoir forebay, Dam tailrace, In-river
- Interrogation sites at Willamette Falls
  - SUJ (09/2018) & WFF (04/2019) detection arrays currently not operating





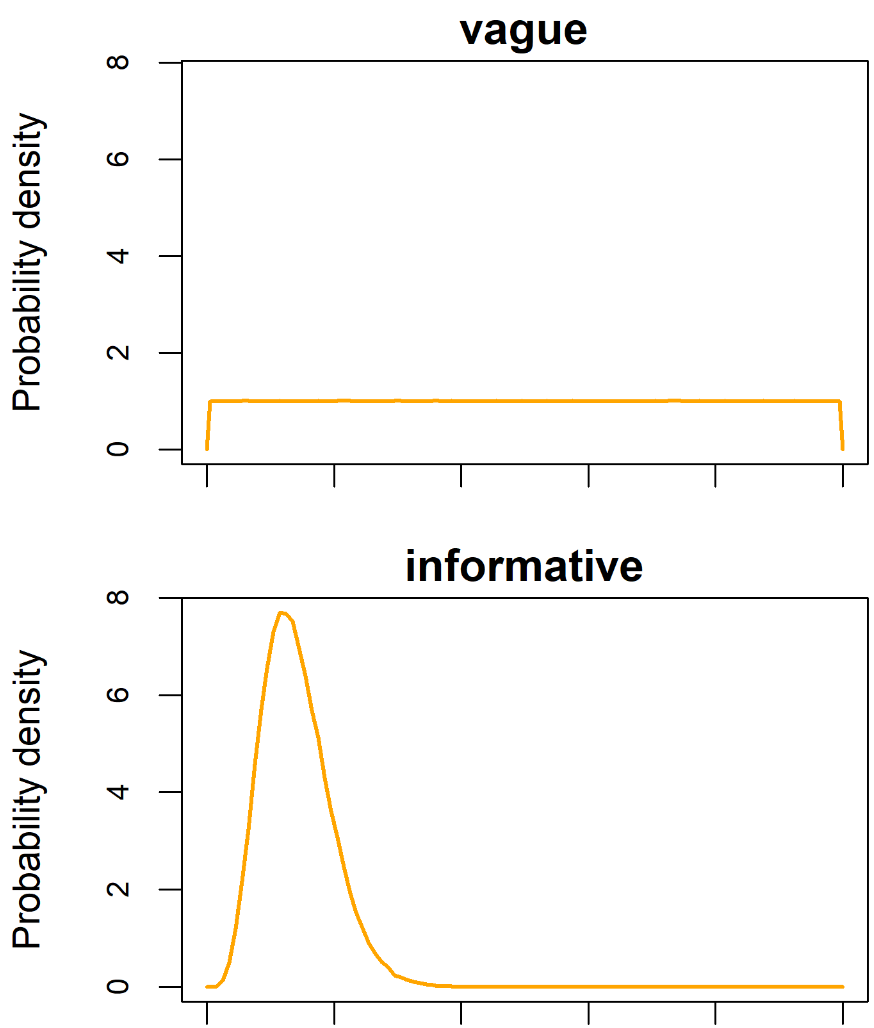
PIT tag survival analysis

- Bayesian Cormack-Jolly-Seber (CJS) Model
- Apparent survival rate (φ) between release and detection locations modelled by adjusting number of detections at each location for probability of detection (p)
- Few fish detected at a location can be due to low survival or low detection probability
- Sparse data due to smaller release numbers can result in high uncertainty
- Informative priors developed for all model parameters to reduce uncertainty



Bayesian priors

- Reduce uncertainty in model parameter estimates by incorporating knowledge via ‘informative’ prior distributions
- Represent ‘degree of belief’ and summarise what is known about parameter values from data or expert judgement
- Where little or no information available ‘vague’ or uninformative priors can be used



How much information is too much?

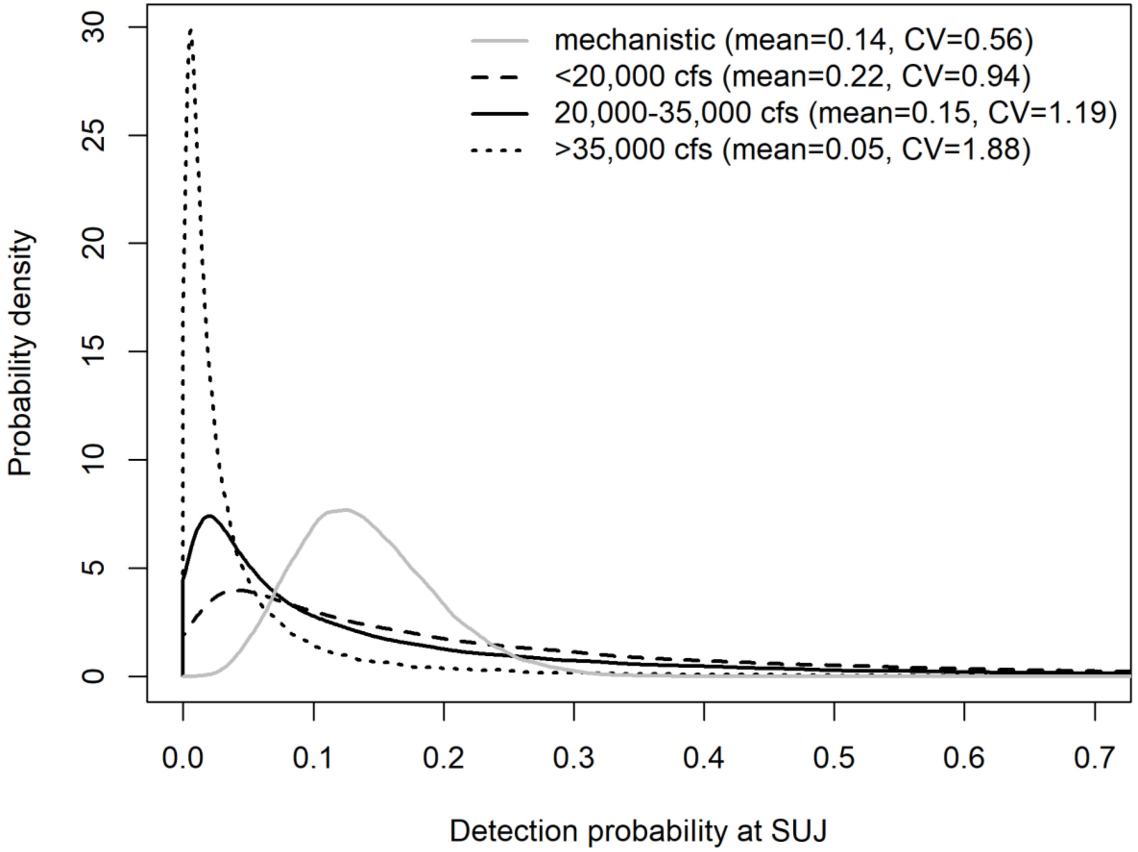
- One concern with the use of informative priors is when they are more informative than the data
- If priors overwhelm the data, posterior distributions will reflect the priors and may mask the true parameter values for the study population
- Could lead to biased survival rate estimates being applied in life cycle models that would affect predictions about population dynamics
- General rule that prior CV (=SD/mean) should be greater than 0.5 but problem of over-informative priors is difficult to diagnose as conditions leading to data being less informative than priors usually unknown.
- Simulation-estimation analysis a useful tool to understand data conditions

Prior for detection probability at WFF

- Adult Chinook salmon and steelhead returning to the Willamette River must ascend the Willamette Falls Fishway (WFF)
- Four PIT-detection antennae located upstream and downstream of fish counting window
- Detection probability at WFF likely very close to 1
- Rather than assume p_{WFF} = 1 and remove all uncertainty can use a highly informative prior
  - p_{WFF} ~ Beta(191.1,3.9)
  - Mean = 0.98, CV = 0.01

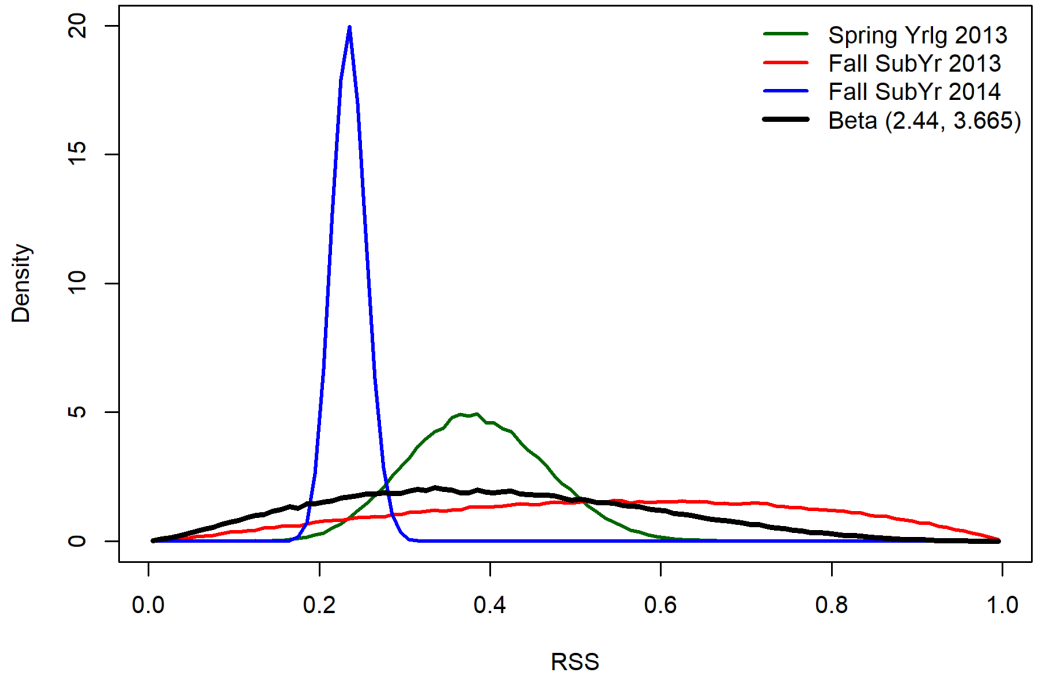
Prior for detection probability at SUJ

- Mechanistic prior specified using data obtained during normal discharges over Willamette Falls
  - Function of proportion of smolts passing through powerhouse, guidance efficiency through bypass, bypass antenna efficiency
- Empirical estimates of p_{SUJ} obtained in low/medium/high flow conditions from PNNL and USGS radio-telemetry studies
  - p_{SUJ} lower when discharge is high as fish swept over Falls, and vice versa
- Mechanistic prior updated by empirical estimates using hierarchical model
- Resulted in flow-specific prior to use in CJS models



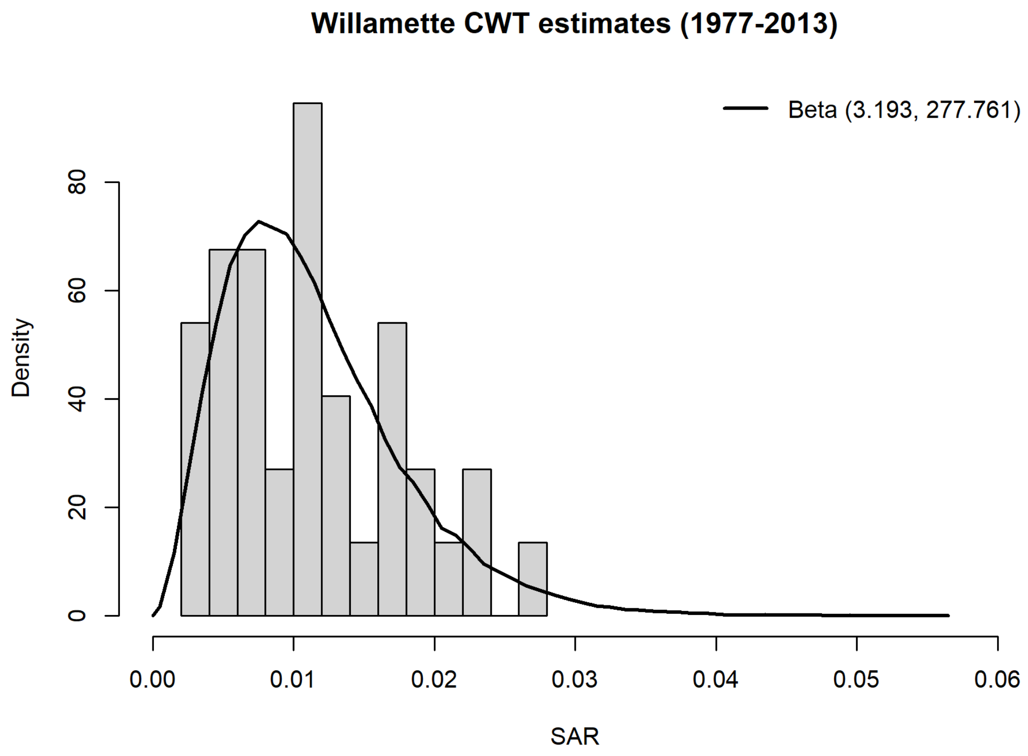
Prior for tailrace-smolt at SUJ survival (φ_{RSS})

- Summarised information from USGS radio-telemetry studies
  - Survival from Detroit reservoir to Portland 2013 & 2014
  - Mean and 95% CI for survivals from Minto to Portland
- Integrated distributions to specify Beta prior for φ_{RSS}
  - Median = 0.388, CV = 0.46



Prior for smolt-adult survival (φ_{SAS})

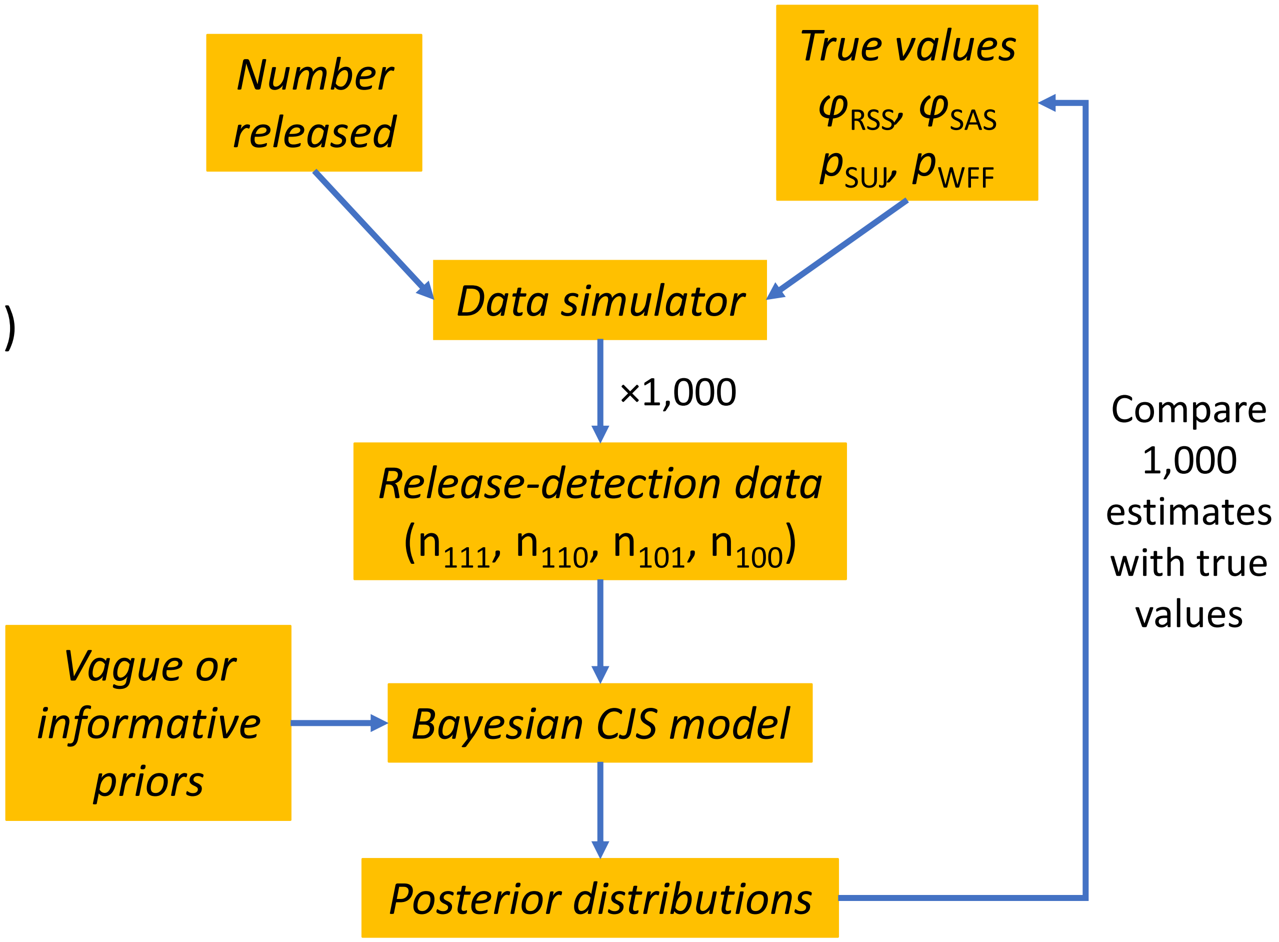
- Summarised information on SAR from Willamette CWT data 1977-2013
    - Combined across all hatcheries
- Fitted Beta distribution to annual values
- Median = 0.011, CV = 0.55
- Hatchery-origin fish, SAS in natural-origin population expected to be higher – can adjust for this



Data: Welch et al. (2021)

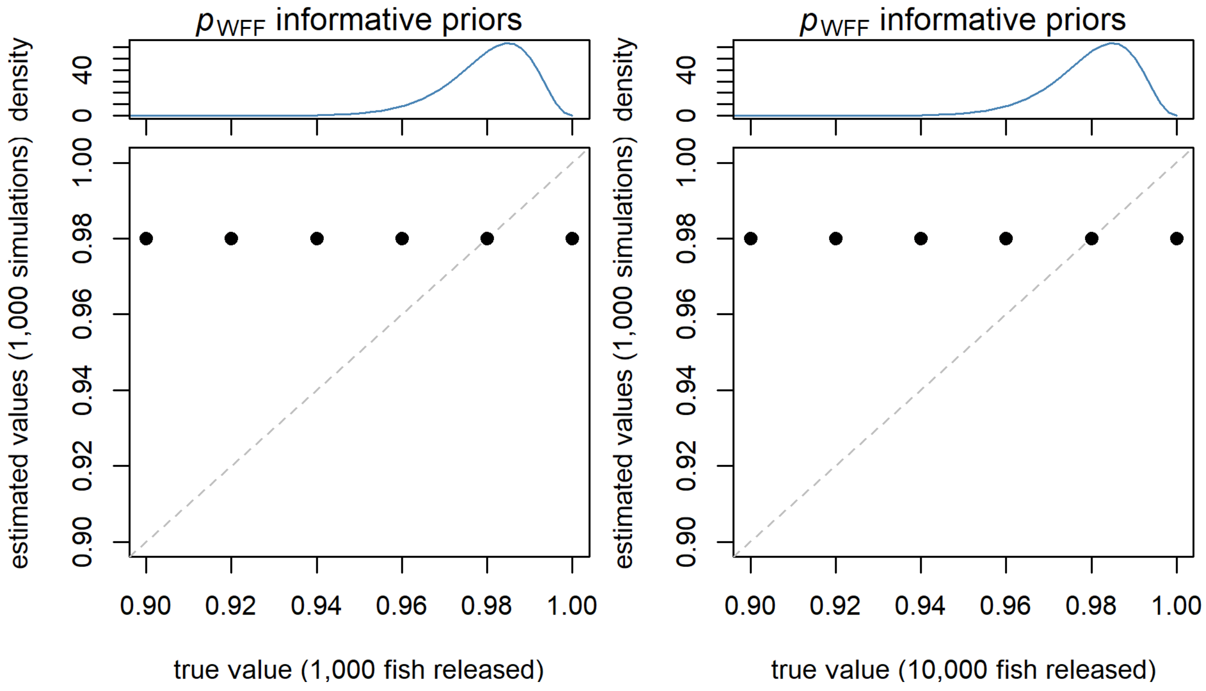
Simulation-estimation study

- Simulate release-detection data using base case set of 'true' parameter values
  - $\varphi_{RSS} = 0.4$; $\varphi_{SAS} = 0.01$; $p_{SUJ} = 0.15$; $p_{WFF} = 0.98$
- Two release sample sizes of juvenile fish
  - 1,000 (natural-origin beach seine capture)
  - 10,000 (hatchery-origin release)
- One parameter varied at a time to generate set of 1,000 simulated datasets for each sample size and true value
- Use Bayesian CJS model to estimate parameters
  - Vague priors, e.g., Beta(1,1)
  - Informative priors



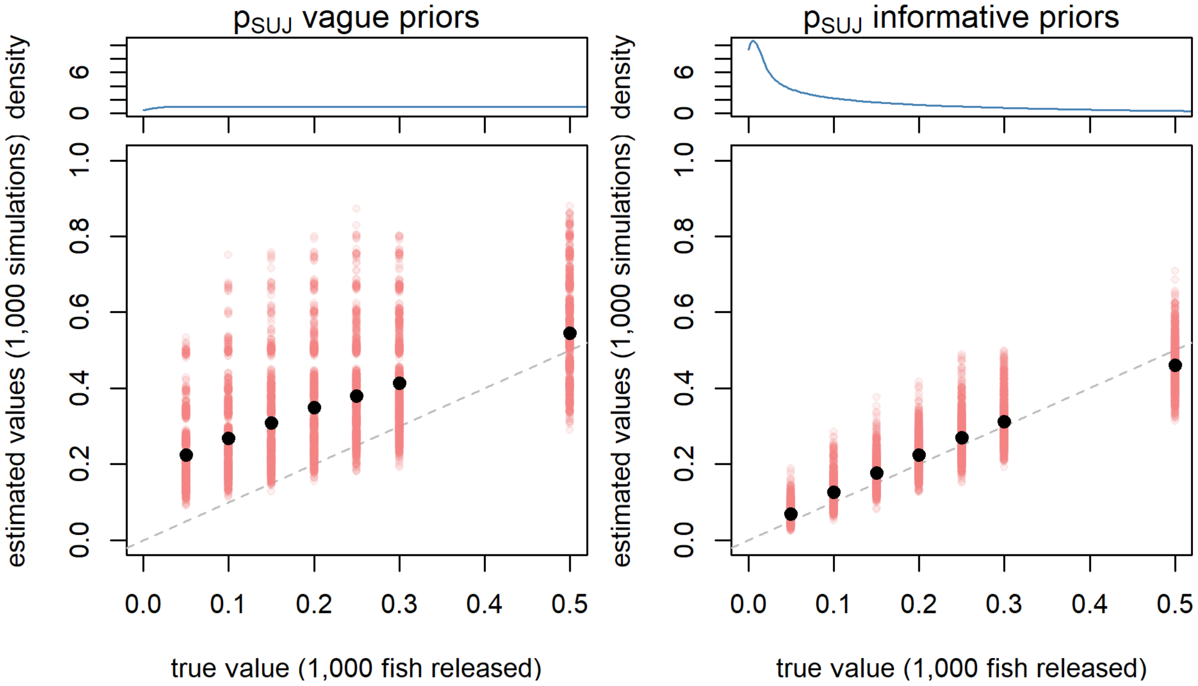
Estimation of detection probability at WFF

- Posterior mean = 0.98 across range of true values from 0.9 to 1.0
- Expected as a highly informative prior
- Necessary for both p_{WFF} and φ_{SAS} to be identifiable in the CJS model (rather than as their product)



Release size matters in estimation of p_{SUJ}

1,000 juveniles released



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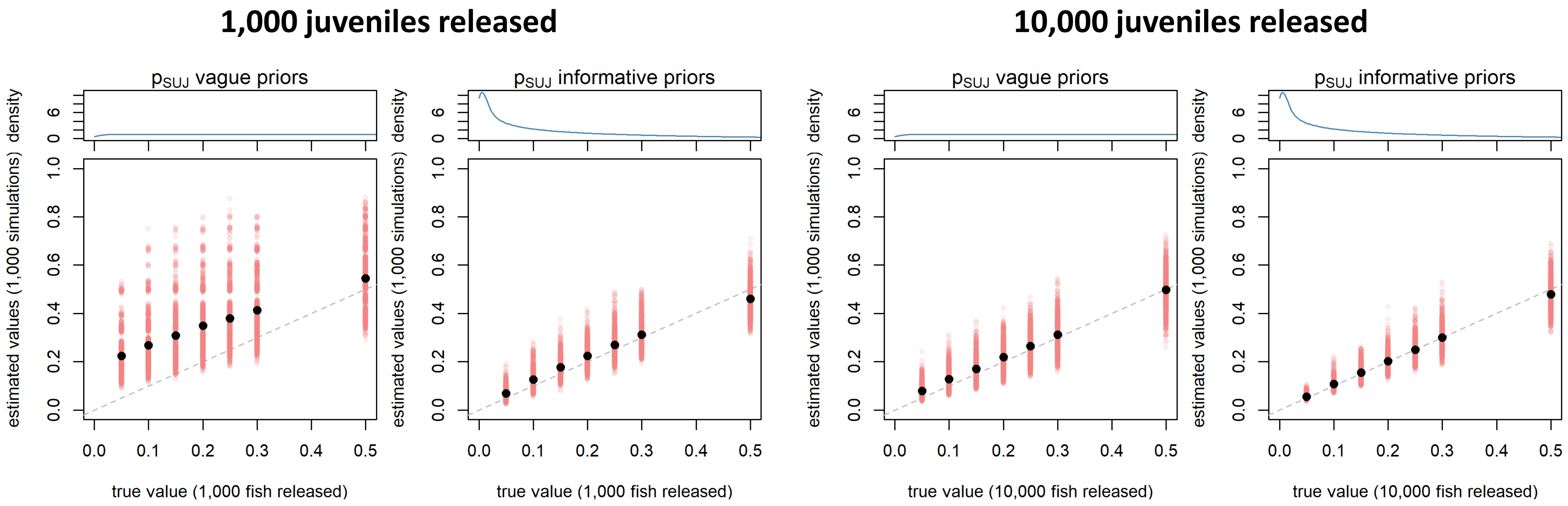

Release size matters in estimation of φ_{RSS}

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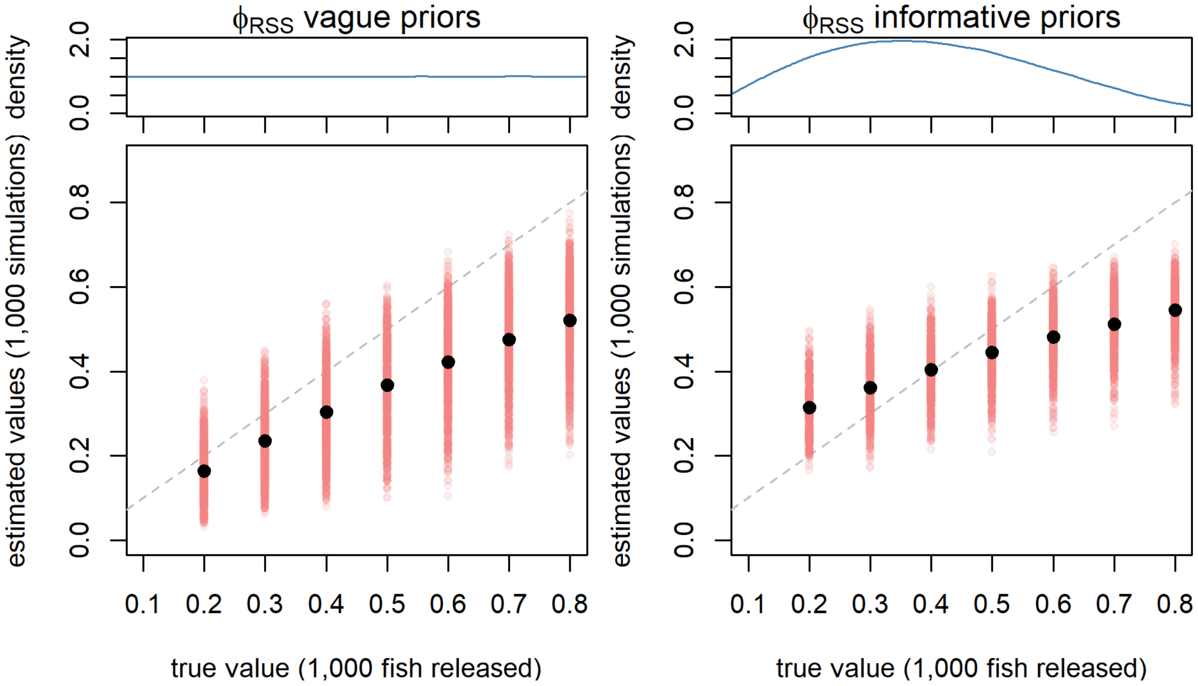
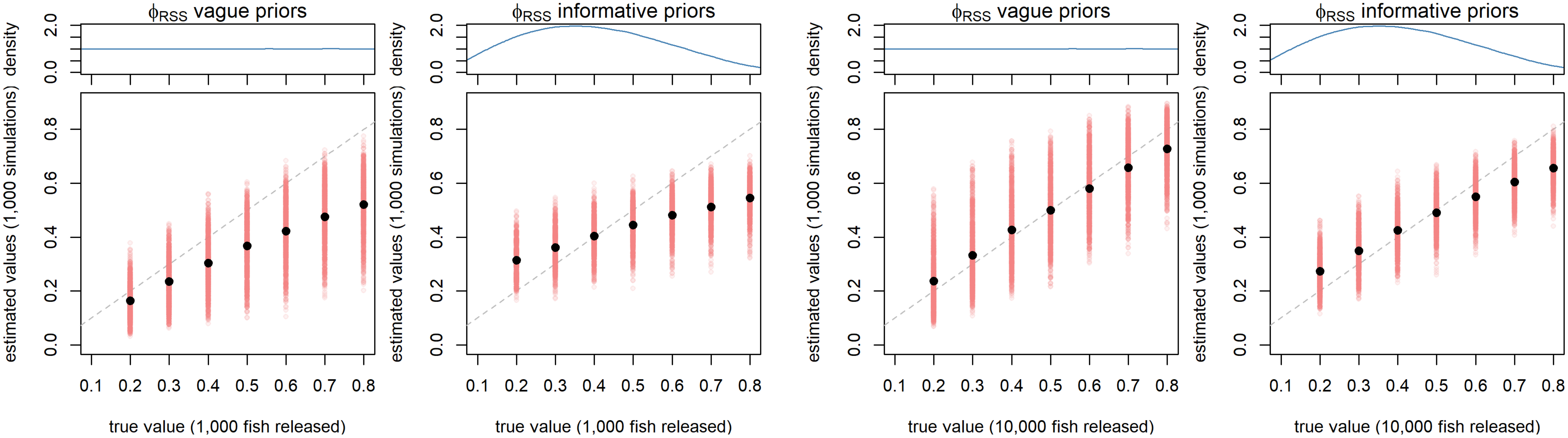


Release size matters in estimation of φ_{RSS}

1,000 juveniles released **10,000 juveniles released**



Release size matters in estimation of φ_{SAS}

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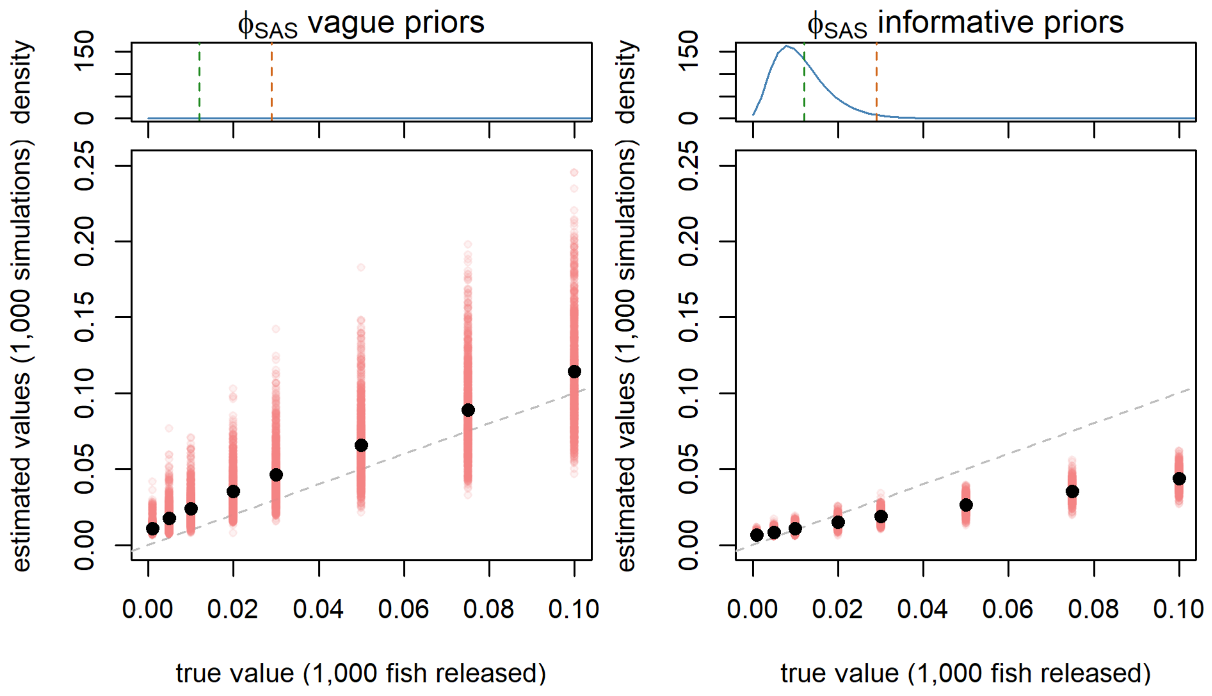
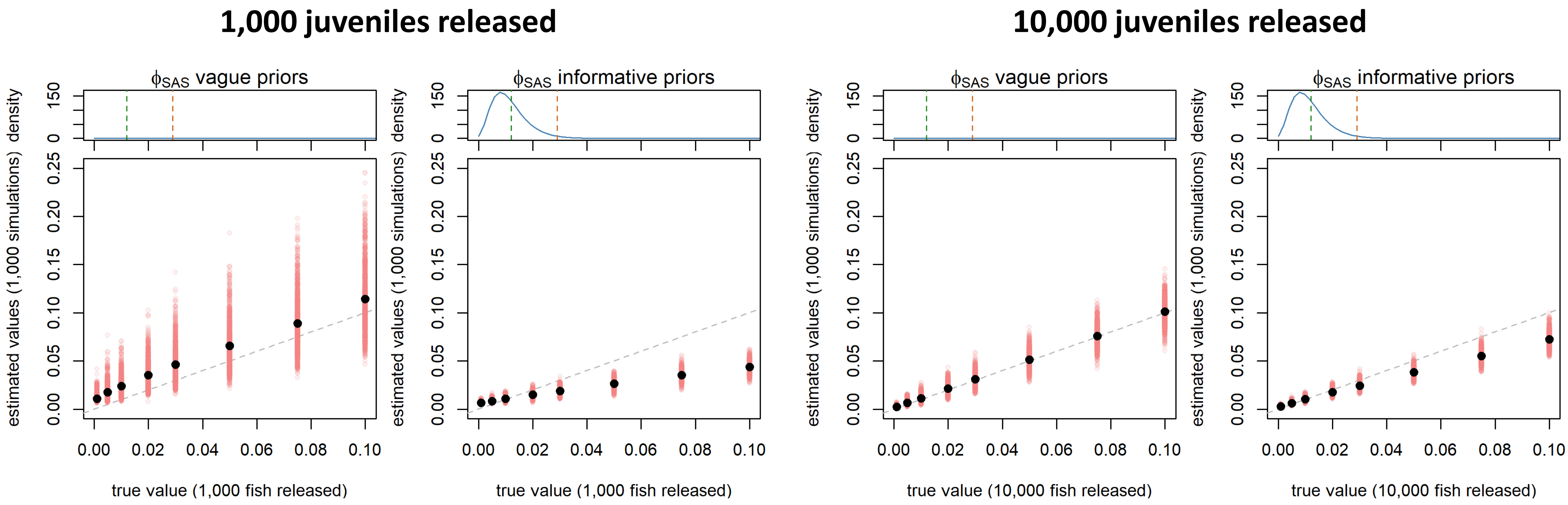


Willamette River max φ_{SAS} since 2011 (Welch et al. 2022)

Snake River max φ_{SAS} since 2011 (McCann et al. 2022)

Release size matters in estimation of φ_{SAS}



--- Willamette River max φ_{SAS} since 2011 (Welch et al. 2022)

--- Snake River max φ_{SAS} since 2011 (McCann et al. 2022)

Summary points

- 1,000 fish release size:
  - Vague priors resulted in biased estimates of all parameters
  - Informative priors performed better except where the true values were in the upper tails of the prior distributions, e.g., true φ_{SAS} values ≥ 0.05.
  - Informative priors resulted in lower variation among posterior mean estimates
  - φ_{SAS} prior resulted in less biased estimates for true values within the range of recent Chinook salmon φ_{SAS} estimates (0.012 for Willamette, 0.029 for Snake River)
  - φ_{RSS} prior resulted in less bias for all true values except 0.2, although estimates for values >0.7 were poorly estimated similar to the vague prior model
  - p_{SUJ} prior resulted in estimates that were close to the true values across the range examined
- 10,000 fish release size:
  - Bias in estimates reduced using both vague and informative prior models
  - Vague priors performed better for true values in tails of the informative priors

Conclusions

- Findings have implications for researchers looking to use PIT tag data for estimation of survival rates where release sizes are relatively low, which is perhaps typical for those of natural-origin fish
- In these situations, use of informative priors can help considerably to improve the reliability of survival rate estimates
- Informative priors do not overwhelm the data but estimates may be biased if true values are in the tails of prior distribution – how supported are the prior beliefs?
- Future PIT tag studies would need operational arrays at SUJ and WFF

Acknowledgements

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