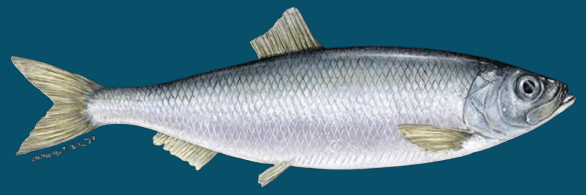
A model of intermediate complexity to understand predation pressures on the emblematic Prince William Sound Pacific herring

Matheus de Barros and Trevor Branch

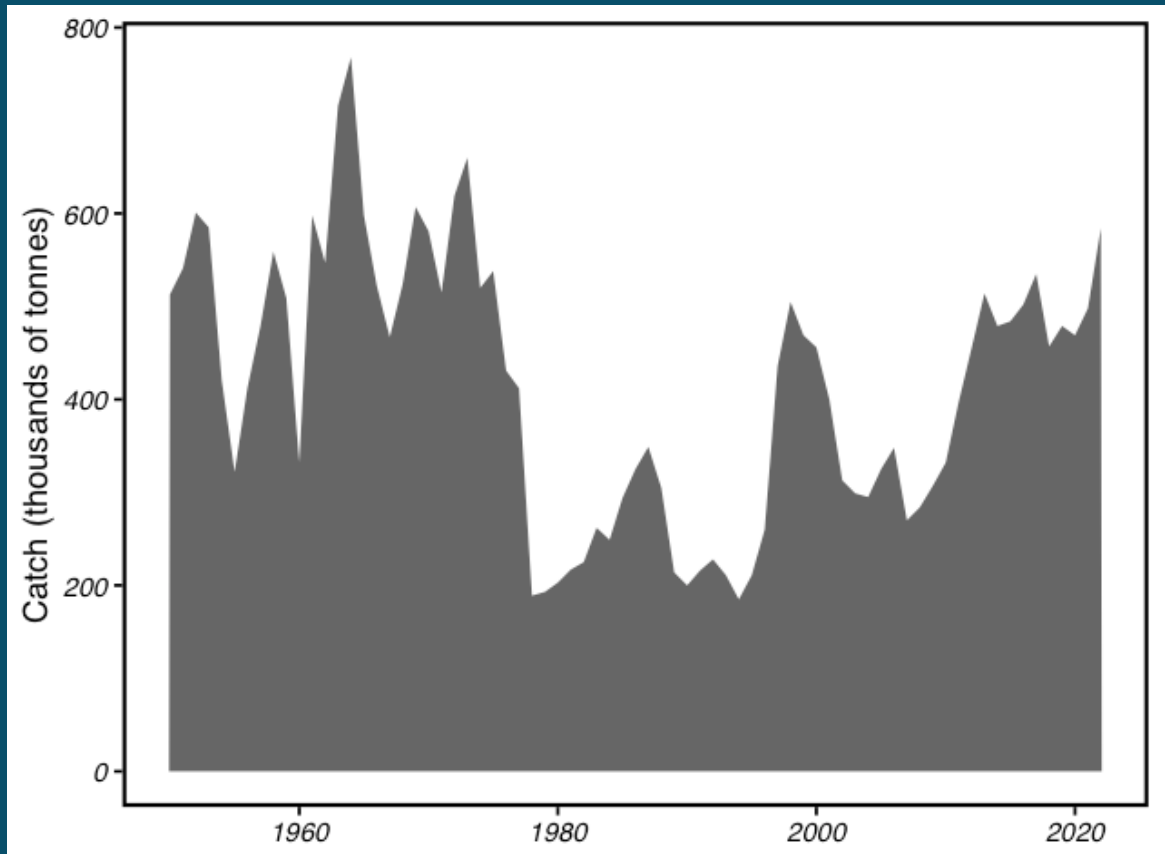
School of Aquatic and Fishery Sciences, University of Washington Seattle



Pacific herring (*Clupea pallasii*)



- Small pelagic fish with schooling behaviour
- In North America, found from Baja California to Alaska and the Bering Sea
- High productivity
- Forage fish
  - Abundant
  - Very high energy density



Source: FishStatJ (FAO)

Pacific herring life cycle

Eggs
~ 2 weeks to hatch
Spawn on kelp



Larvae
~ 2 months
Nearshore



Juvenile
~ 3 years
Nearshore



Adults
Reach 9+ years
Congregate in the shallows to spawn

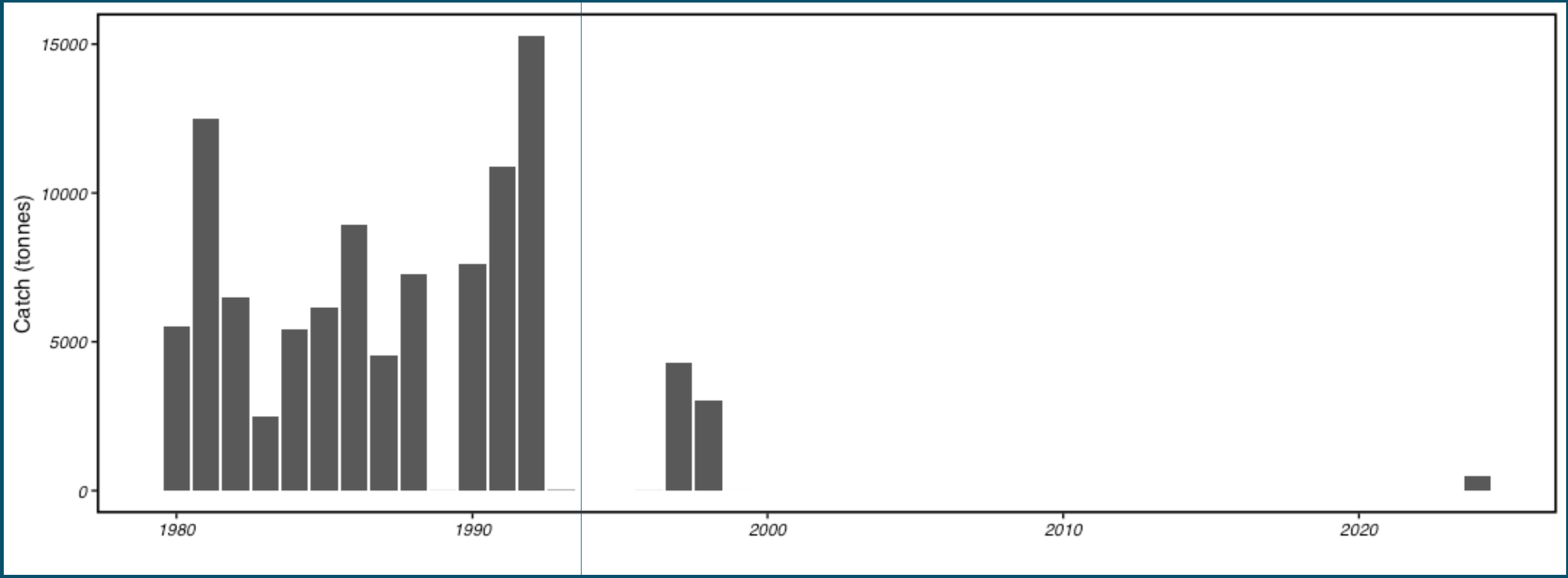


Pacific herring fisheries in Prince William Sound, AK





Pacific herring fisheries in Prince William Sound, AK



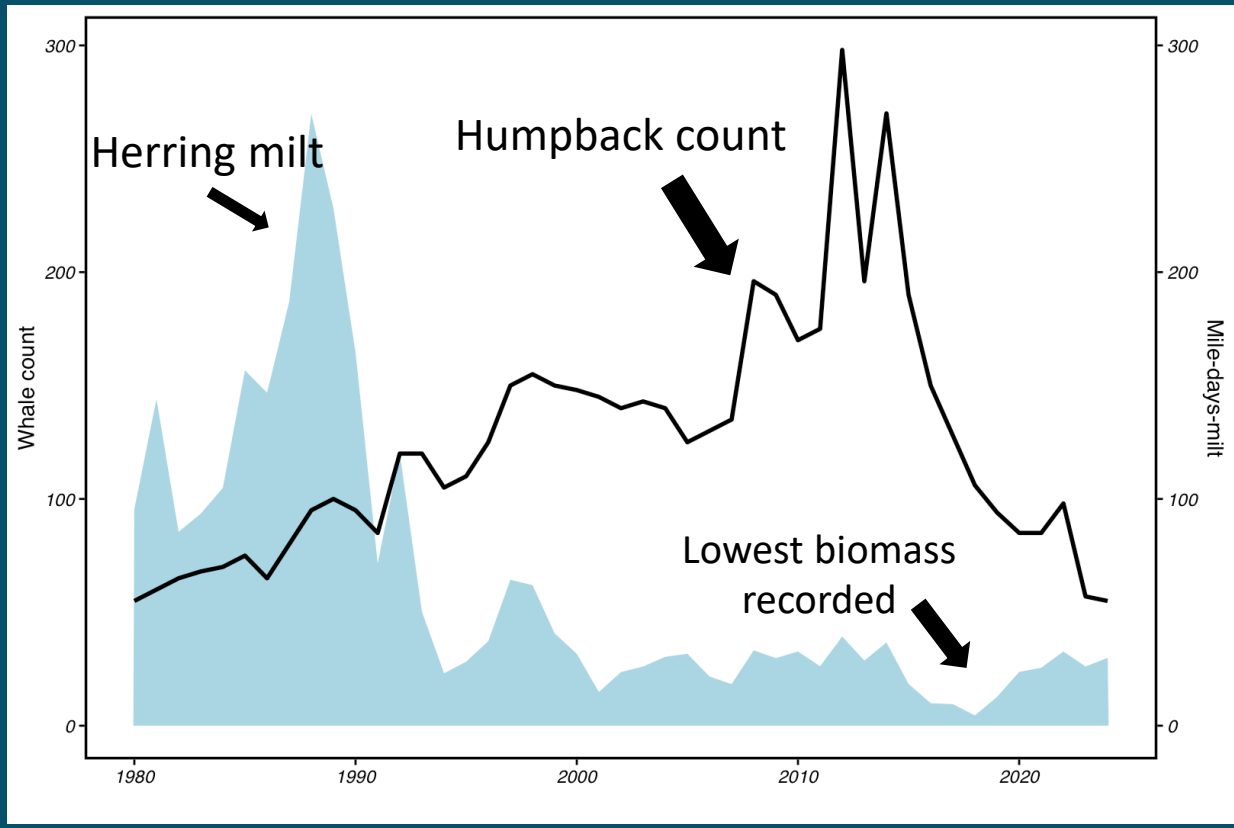
Overfishing? Disease? Predators?

Important pacific herring predators

Humpback whales *(Megaptera novaeangliae)*



- Visit PWS during Spring-Summer, with a fraction staying to overwinter
- Overwintering whales feed on mature herring
- Peaked before recent herring lows (2016 – 2018)

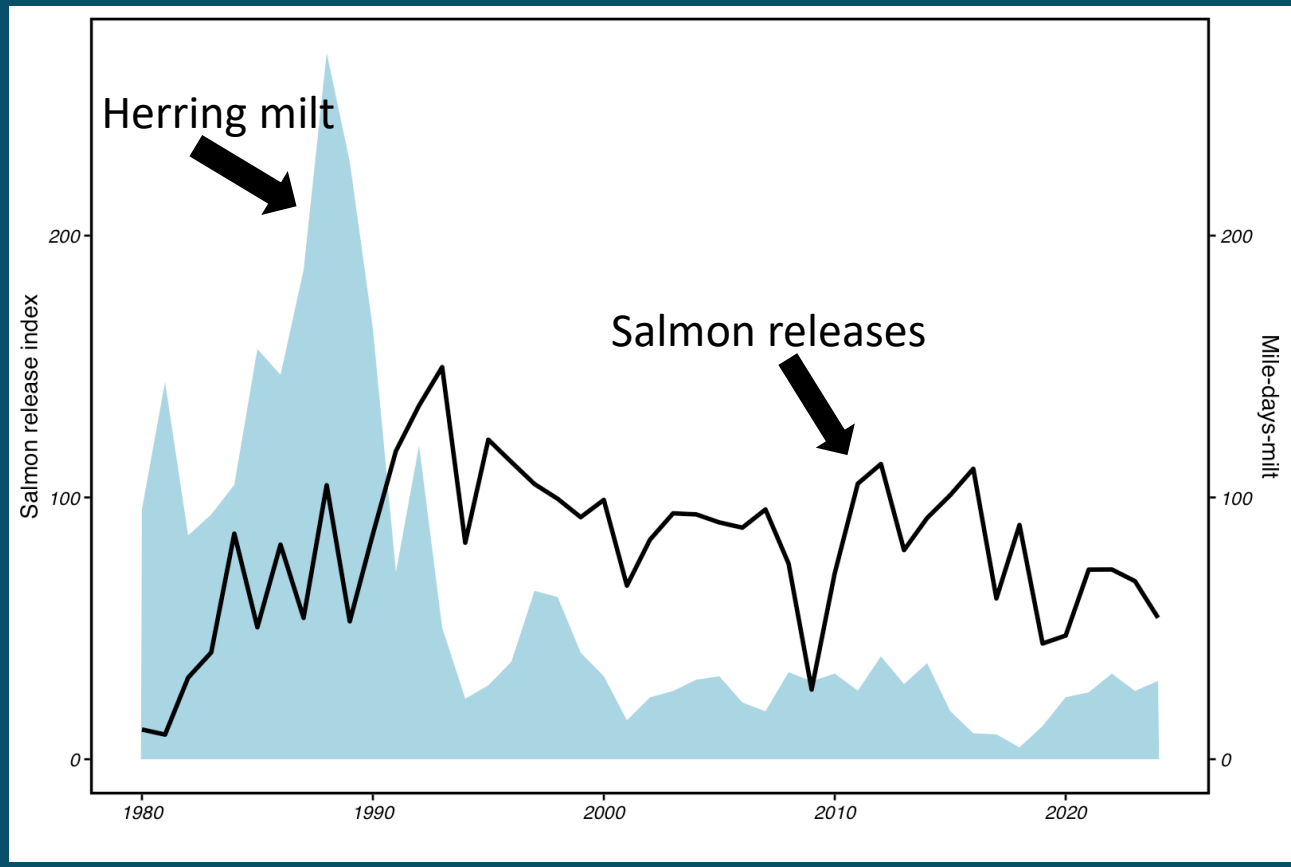


Important pacific herring predators

Pink salmon *(Oncorhynchus gorbuscha)*

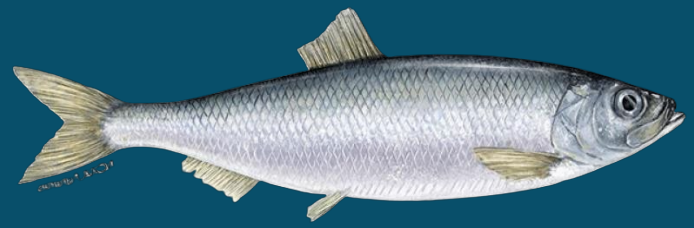


- Compete with herring as juveniles and eat herring as adults
- Overlap with herring in the nearshore
- Peak hatchery releases coincided with the 1993 herring collapse



Study objective

Build a model of intermediate complexity (MICE) to test the effects of pink salmon and humpbacks on herring



Effects on recruitment



Effects on spawners

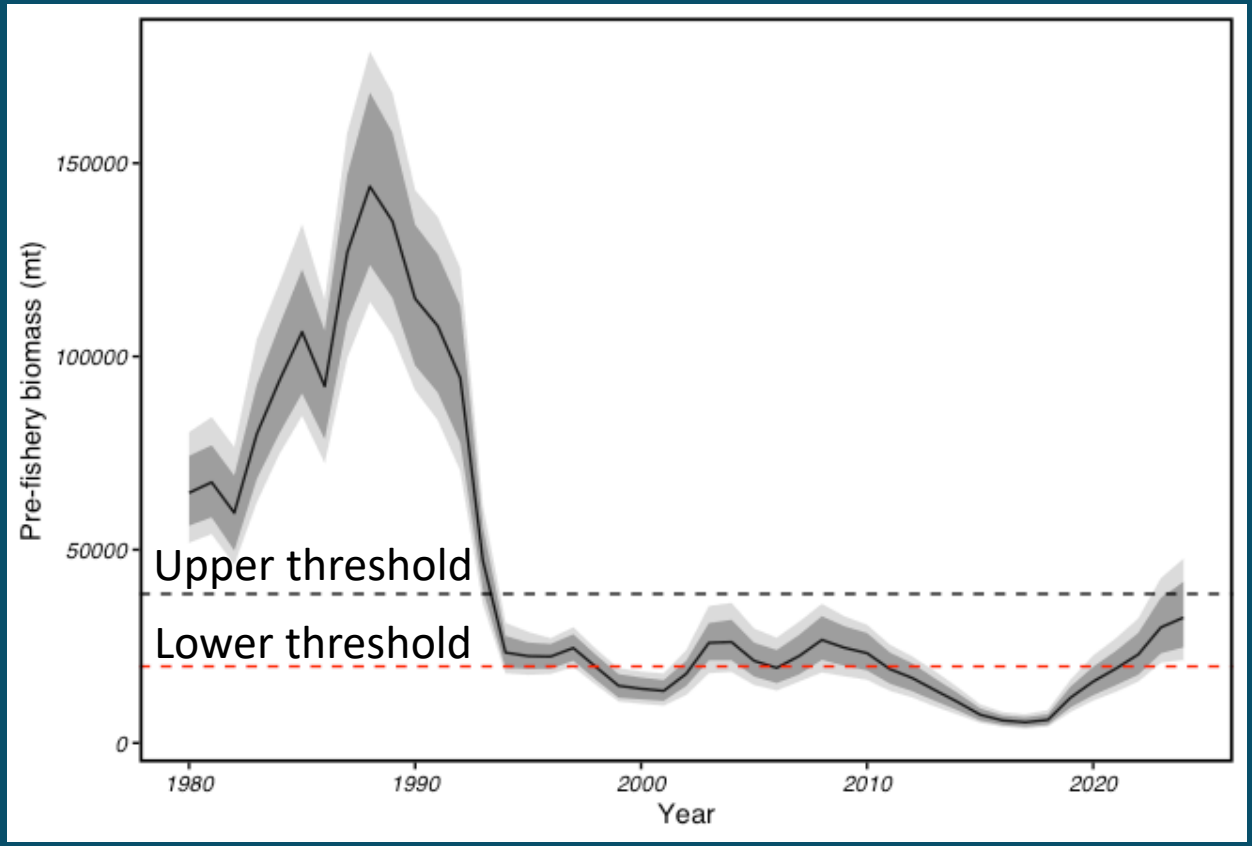


The Bayesian Age-Structured Assessment (BASA)

Abundance surveys
Age structure
Catches

→ BASA →

Absolute biomass estimate



The Bayesian Age-Structured Assessment (BASA)

$$N_{y+1,a=0} = \bar{R}e^{\delta_y}$$

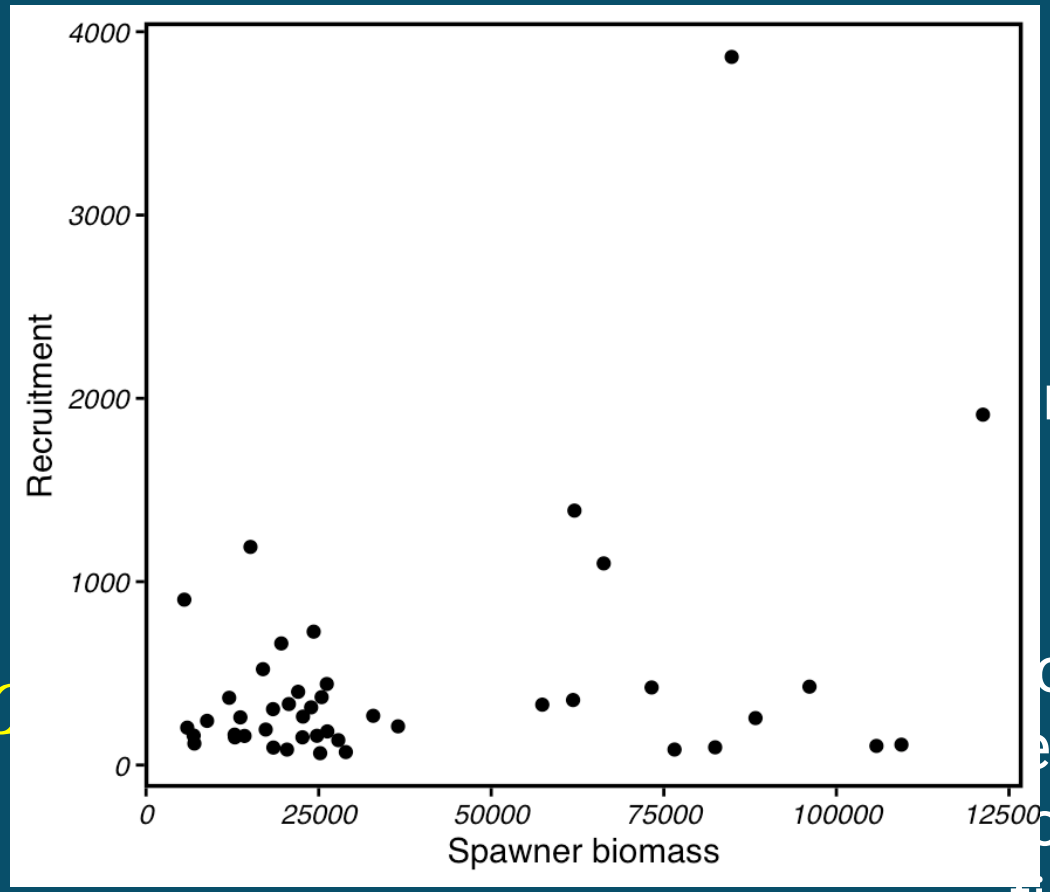
from a long-term mean

$$S_{y,a} = e^{-0.5M_{y,a}}$$

n of natural mortality

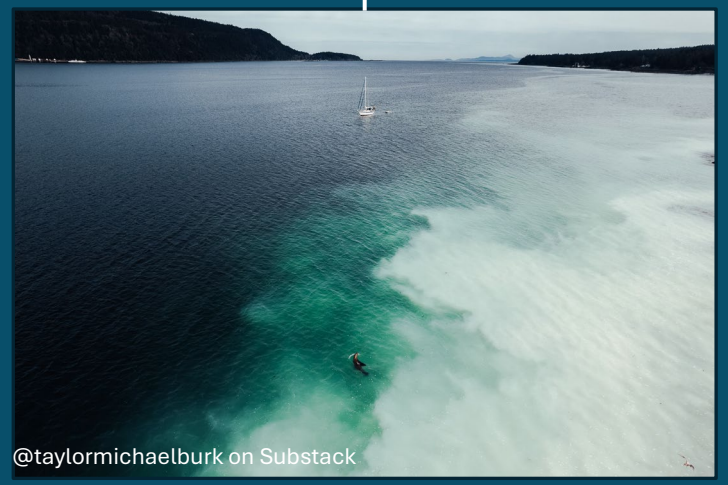
$$N_{y+1,a+1} = [(N_{y,a} - C$$

on dynamics in
time steps to
or spring and fall
fisheries



The Bayesian Age-Structured Assessment (BASA): data sources

Mile-days-milt aerial survey



Measures the extent of milt clouds during the spring spawning season

Ongoing since the 1980s, main data source for spawner abundance

Juvenile aerial survey



Measures the number of juvenile schools

Recruitment index

More recent (2010 – onward)

Egg deposition survey

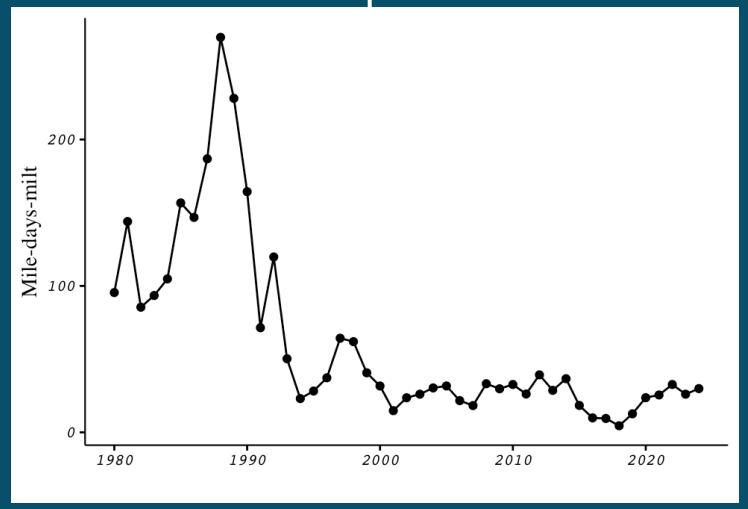


Diver survey that measures the absolute number of herring eggs

Grounds the model to absolute abundance

The Bayesian Age-Structured Assessment (BASA): data sources

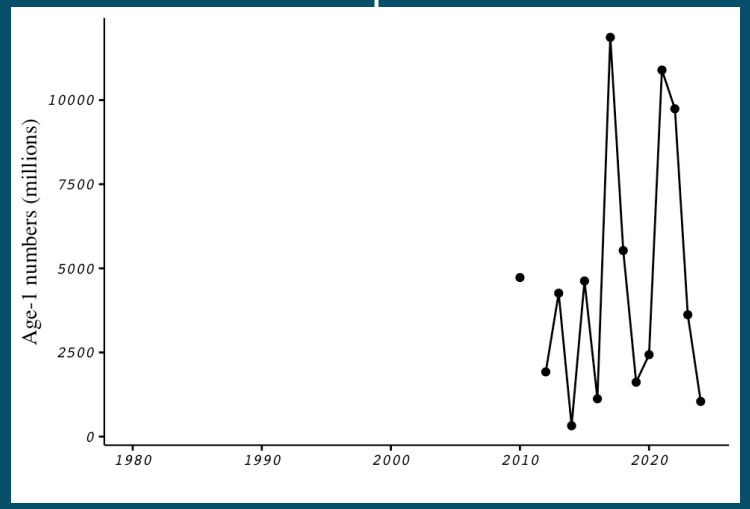
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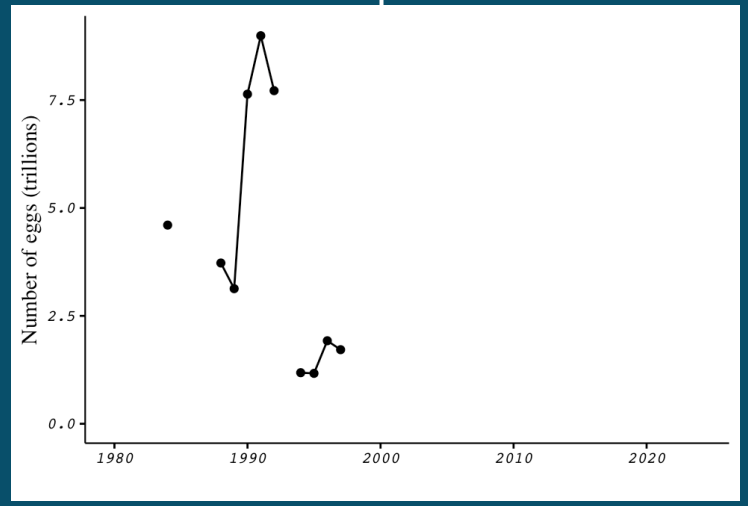


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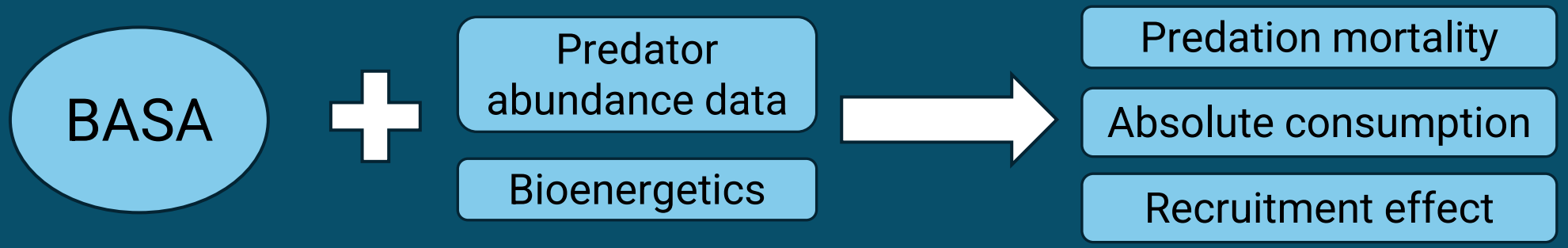
Egg deposition survey



Diver survey that measures the absolute number of herring eggs

Grounds the model to absolute abundance

The PWS Model of Intermediate Complexity (PWS MICE)



The PWS Model of Intermediate Complexity (PWS MICE)

BASA

+

Predator abundance data

Bioenergetics

→

Predation mortality

Absolute consumption

Recruitment effect



$$N_{y+1,a=0} = \bar{R} e^{\delta_y}$$

→

$$N_{y+1,a=0} = \bar{R} X_y e^{\delta_y}$$

$$X_y = e^{\beta_{salmon} I_y}$$

Recruitment as log-deviations from a long-term mean modified by the salmon covariate term

The PWS Model of Intermediate Complexity (PWS MICE)

BASA + Predator abundance data + Bioenergetics → Predation mortality, Absolute consumption



$$S_{y,a} = e^{-0.5(M^1_{y,a} + M^P_{y,a})}$$

$$M^P_{y,a} = -\log\left(1 - \frac{\sum_j C^P_{y,a,j} P_{y,j}}{N_{y,a}}\right)$$

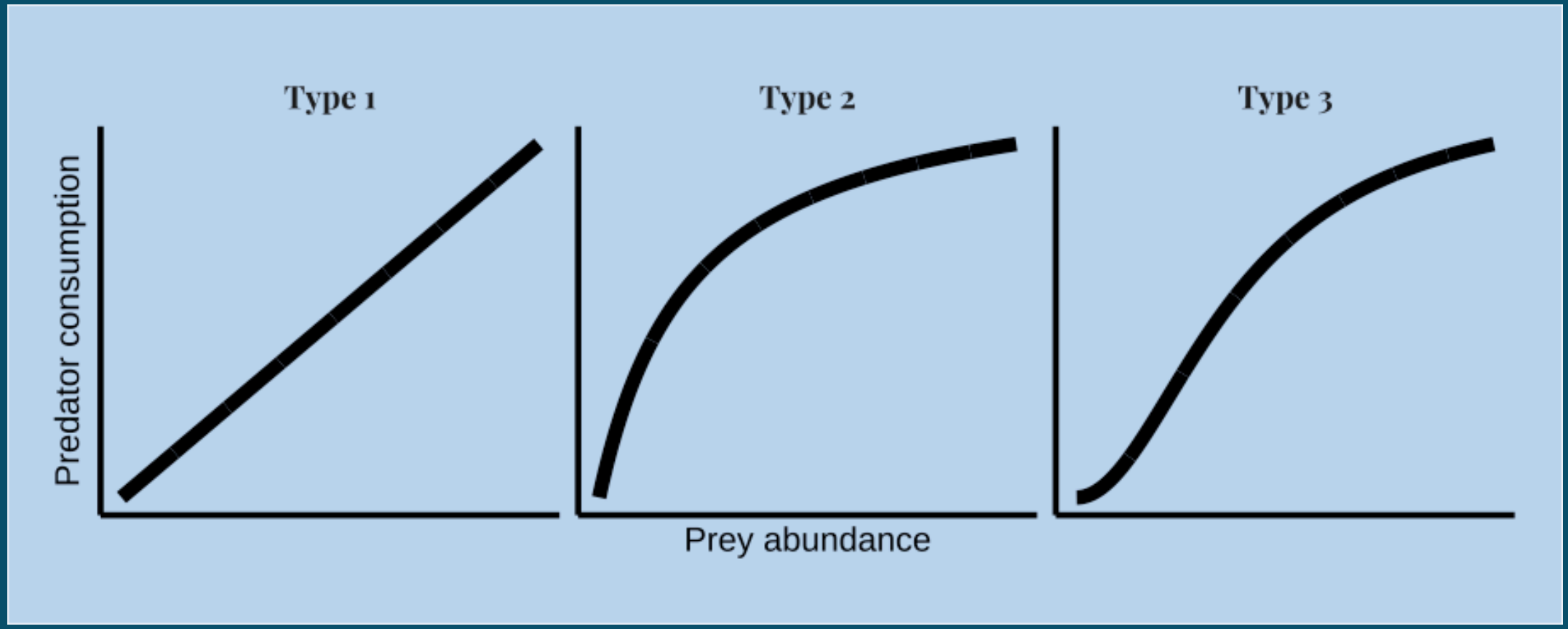
At a given year, predation mortality is a function of per-capita consumption and number of predators relative to herring abundance

$$C^P_{y,a,j} = f(N_{y,a})$$

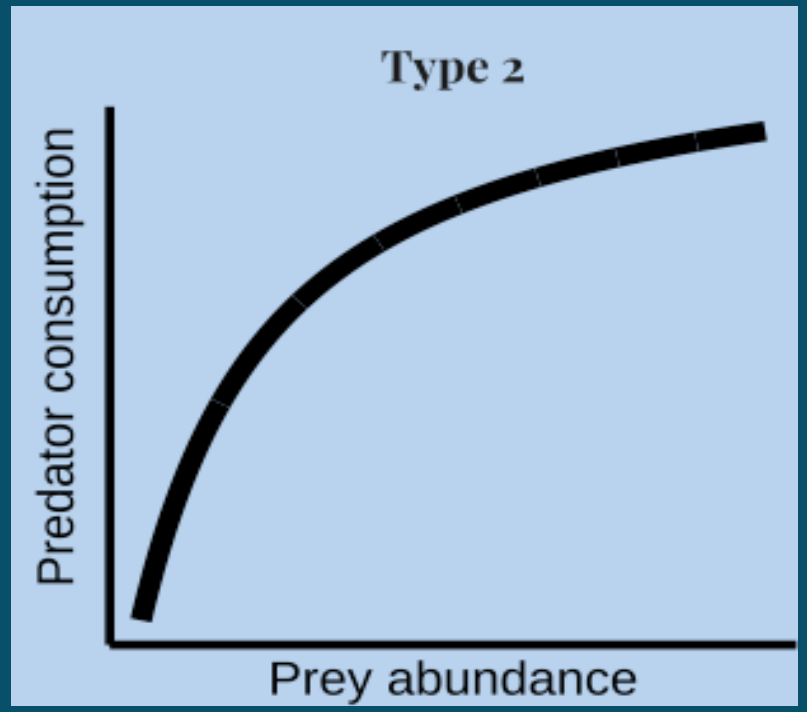
Per-capita consumption is a function of herring abundance

The PWS Model of Intermediate Complexity (PWS MICE)

$$C^{P}_{y,a,j} = f(N_{y,a})$$



The PWS Model of Intermediate Complexity (PWS MICE)



Per-capita consumption is a function of attack rate scaled by vulnerability-at-age and herring abundance, and asymptotes due to handling time

$$\lim_{N\to\infty} \frac{\alpha N}{1+\alpha h N} = \frac{1}{h} = C_{max}$$

$$h \sim Normal\left(\frac{1}{C_{max}}, \sigma_h\right)$$

$$C^{P}_{y,a} = \frac{\alpha v_a N_{y,a}}{1+\alpha h v_a N_{y,a}}$$

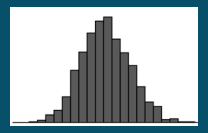
Validating PWS-MICE

- Retrospective analysis (how consistent the model is)

- Prior sensitivity analysis
  - Attack rate (α)
  - Handling time (h)
  - Salmon effect (β_{salmon})
  - Vulnerability parameters (age at peak vulnerability and spread)

- Priors varied up and down 10 and 20% from baseline

- Randomization trials



Shuffle covariate data → Fit model and compute likelihood → Repeat for null distribution → Compute $p_{null} > p_{baseline}$

PWS-MICE estimates are similar to BASA's

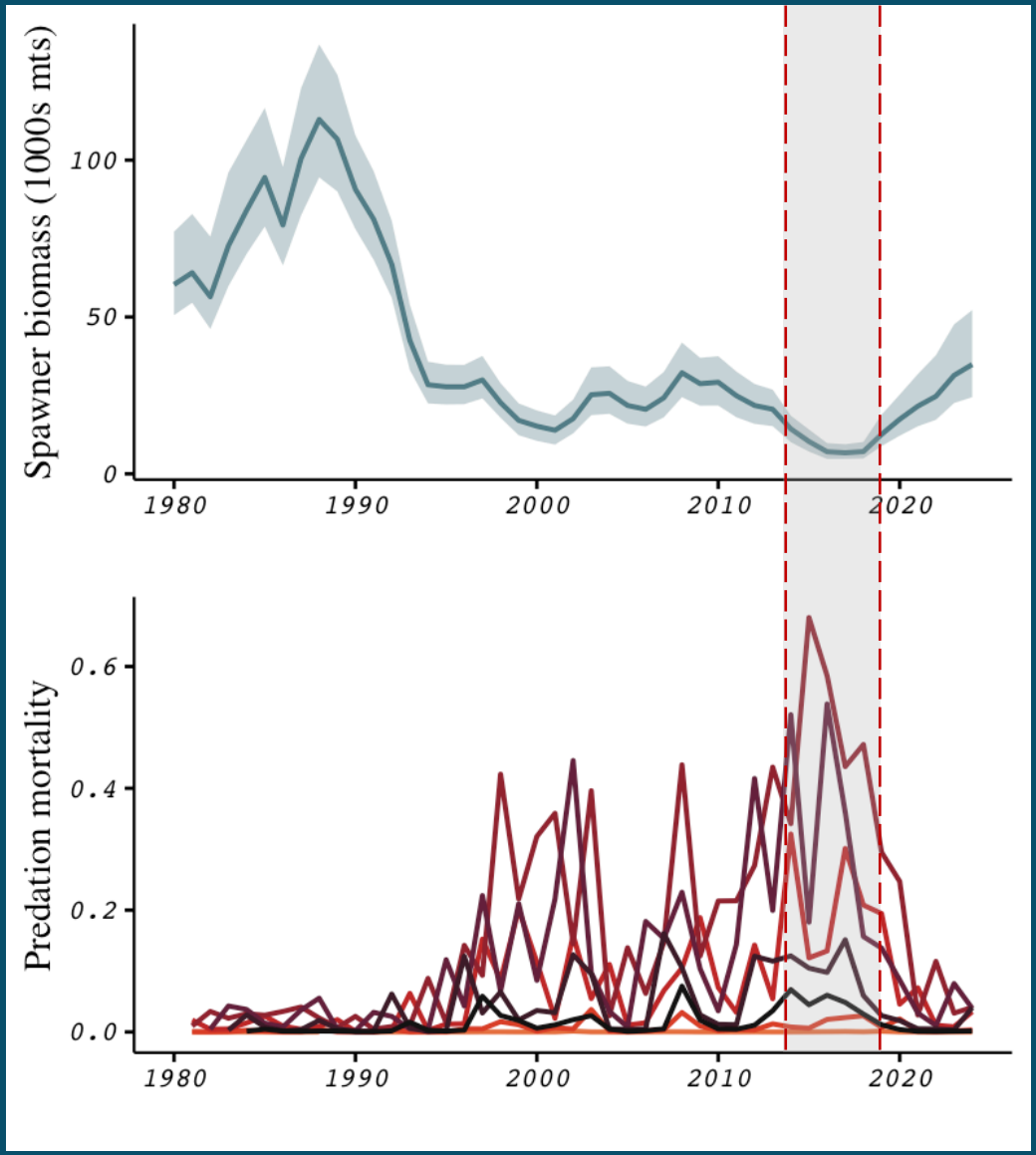


Close agreement
on lowest biomass



Salmon and humpbacks negatively affect herring

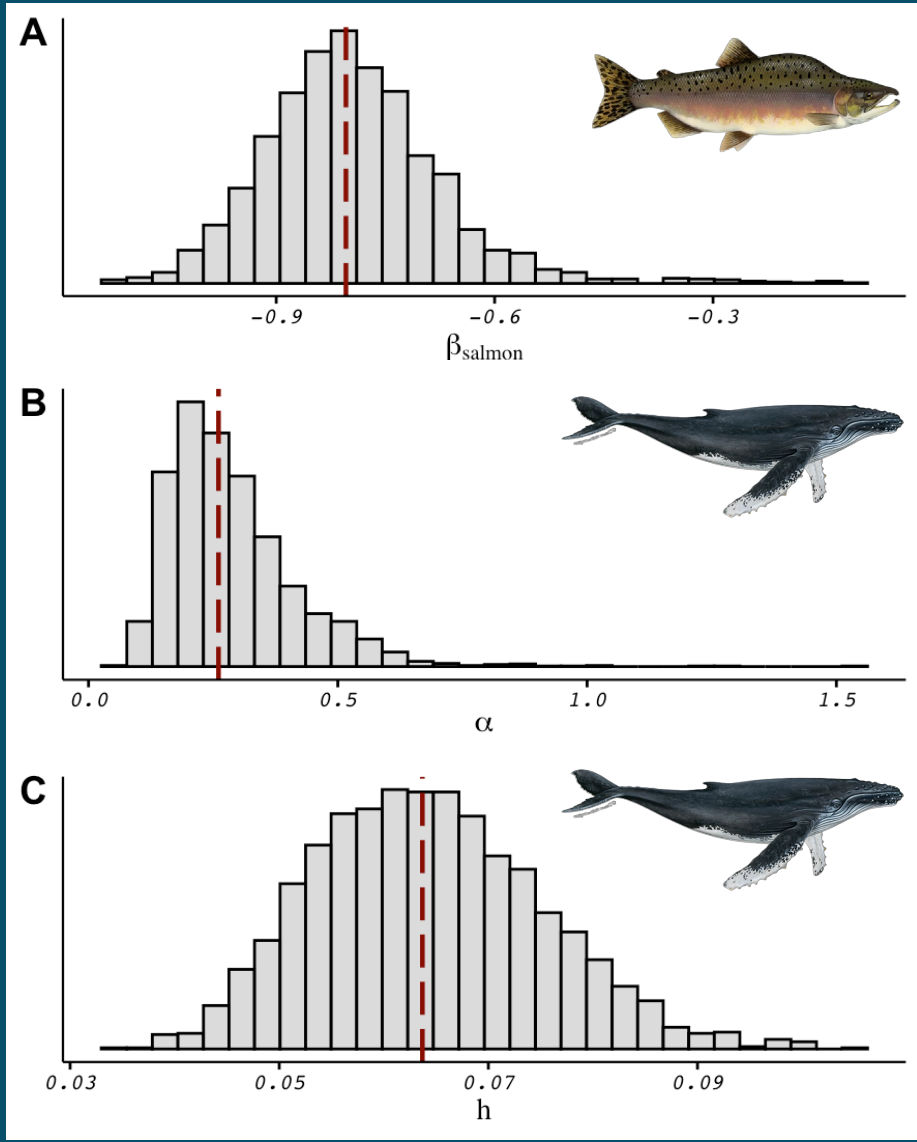
Salmon and humpbacks negatively affect herring



Lowest herring biomass occurred when whale predation mortality peaked at more than 0.6 year^{-1} for mature ages

At the low biomass levels of ~ 15000 mts, whales have consumed ~ 4000 mts

PWS-MICE estimates are significant

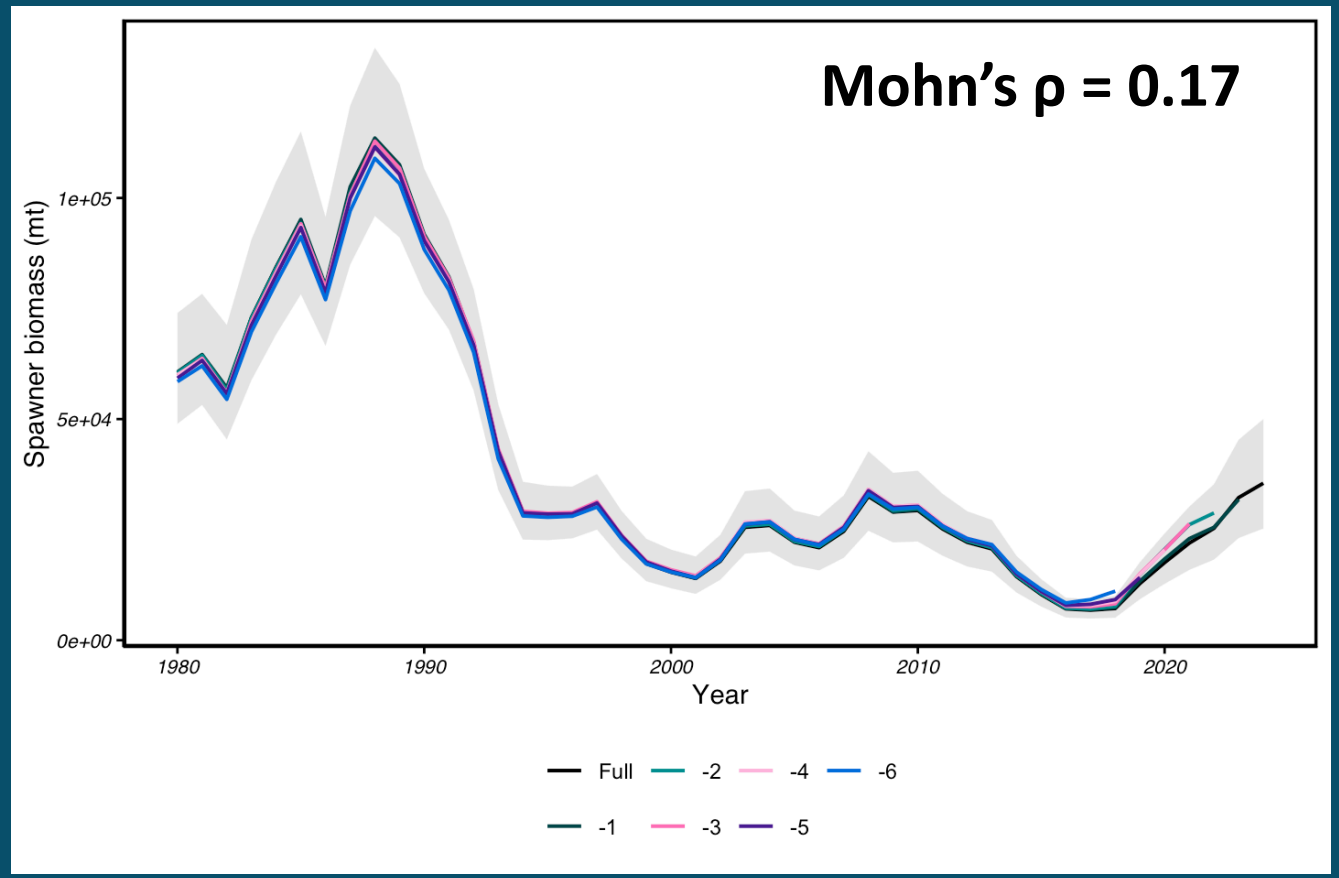


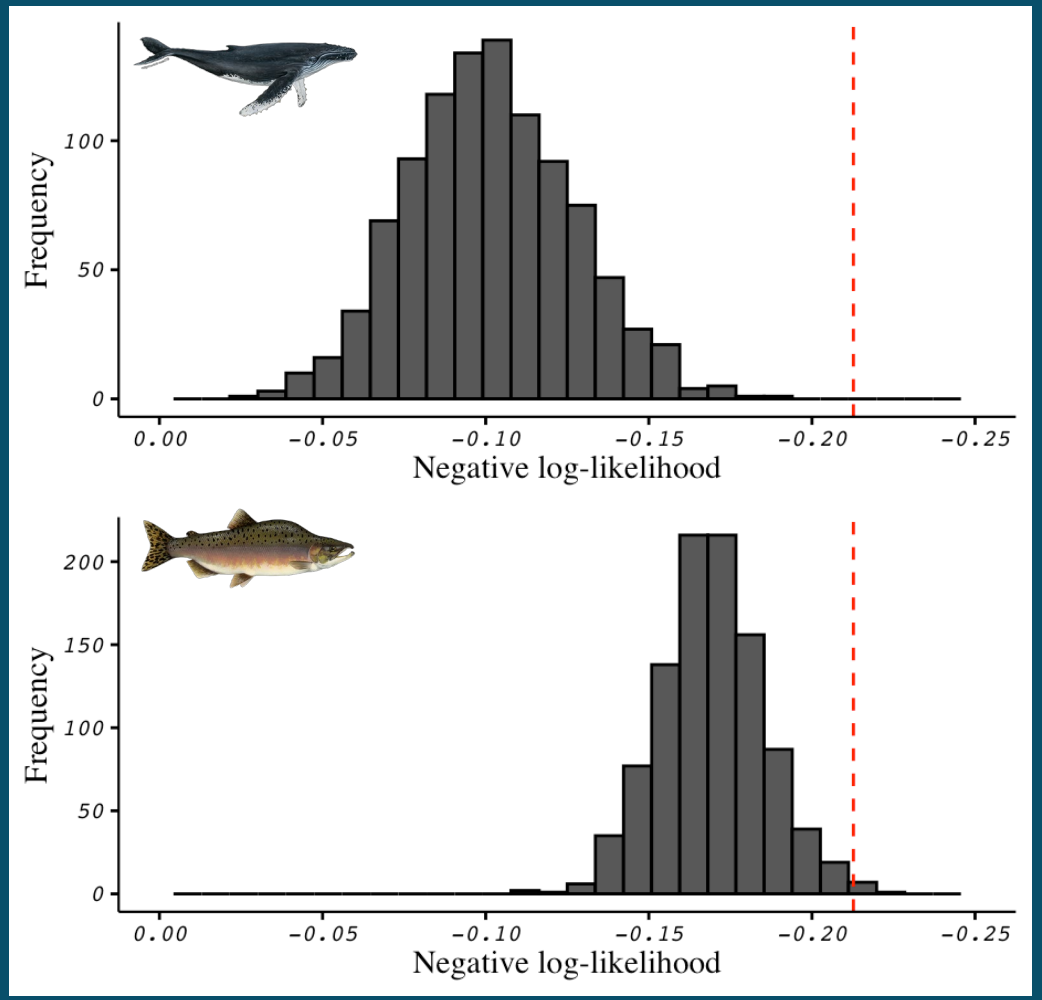
At average release levels, herring recruitment is ~ 55% lower compared to that without salmon

α = 0.28 year^{-1} M at intermediate herring densities

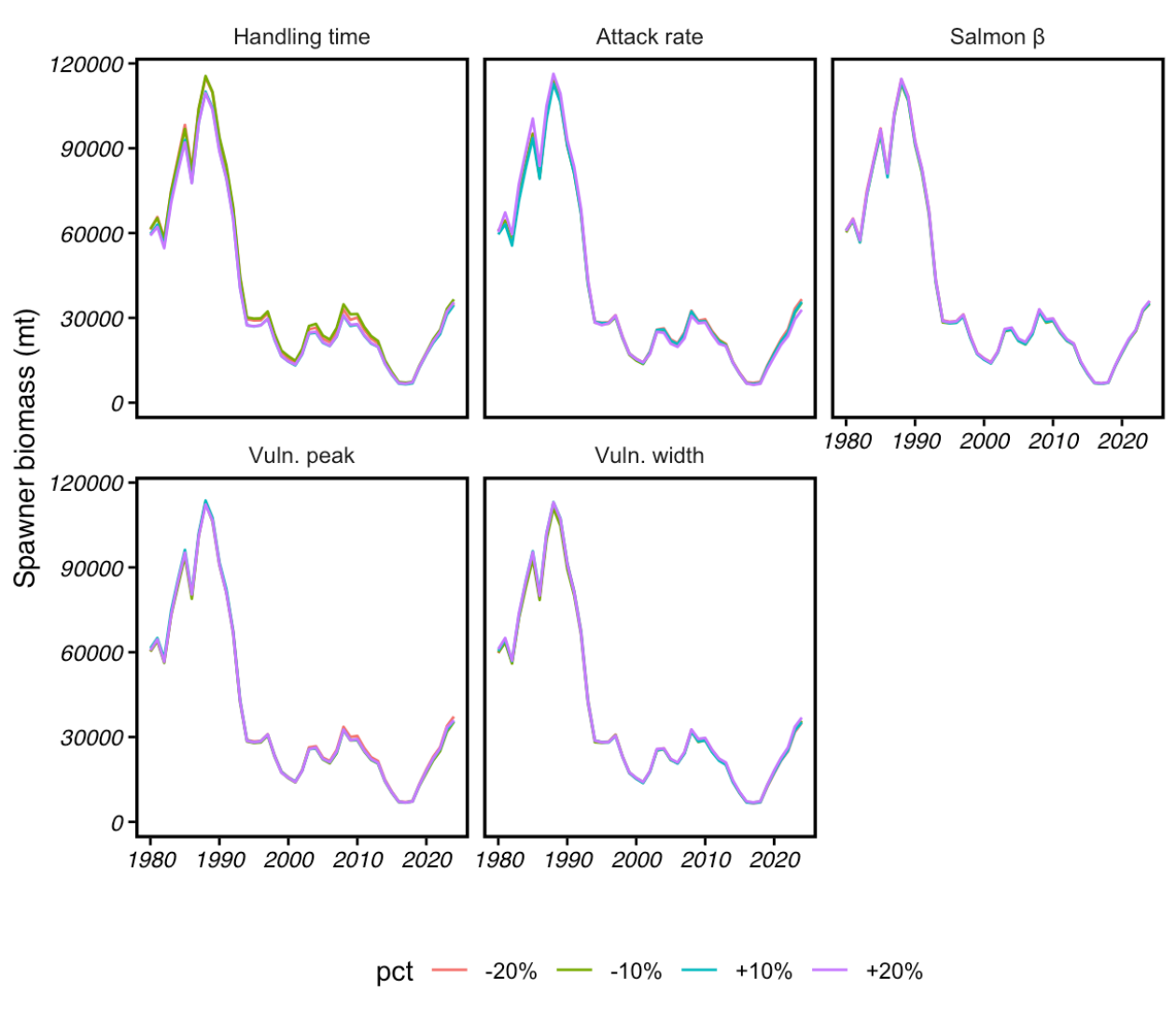
Implies maximum consumption of 7 tons of herring per whale in a single year (C_{max} = 1/h)

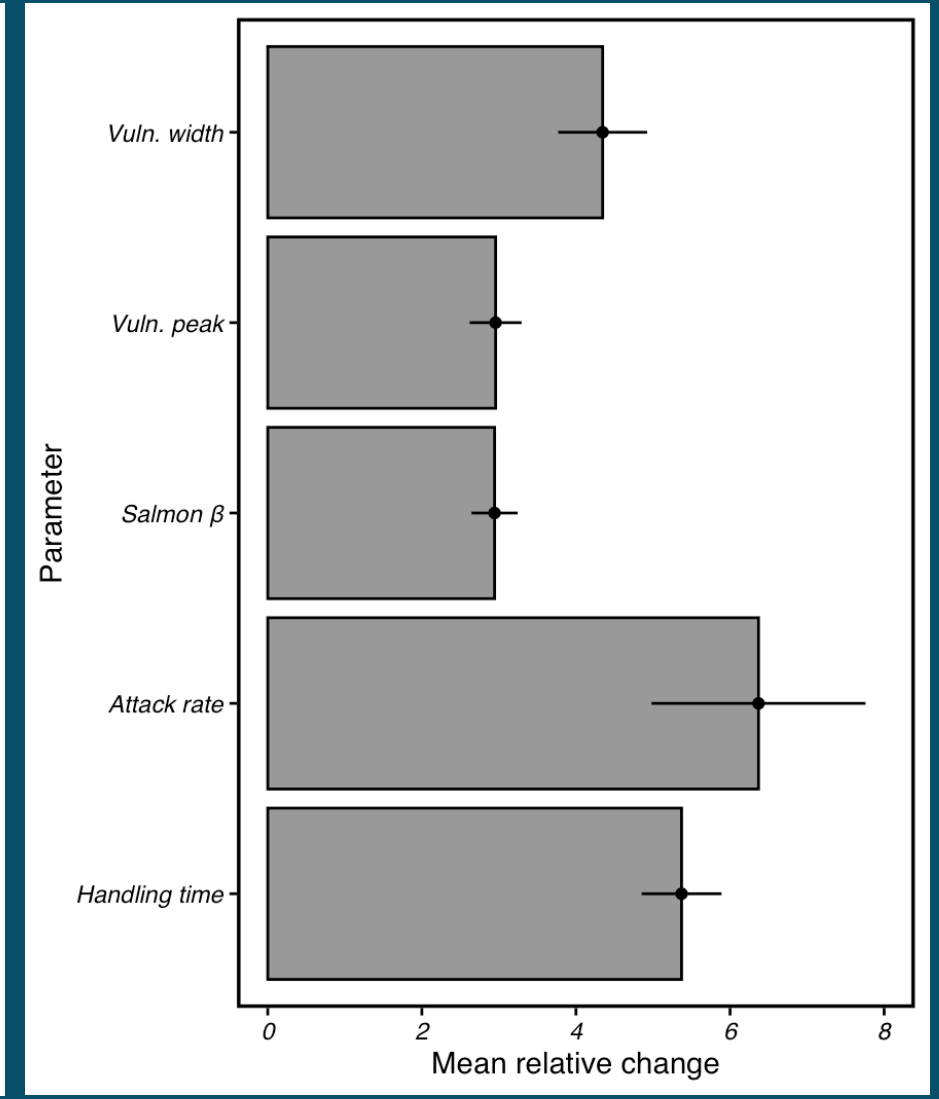
PWS-MICE results are consistent





PWS-MICE results are consistent





Pacific herring in PWS are vulnerable to humpbacks and salmon

- High levels of recruitment impairment by hatchery-origin pink salmon
  - High salmon levels anticipate the historical crash in 1993

INCORPORATING COVARIATES INTO FISHERIES STOCK ASSESSMENT MODELS WITH APPLICATION TO PACIFIC HERRING

RICHARD B. DERISO,[1,2,5] MARK N. MAUNDER,[2,3] AND WALTER H. PEARSON[4,6]

[1]*Scripps Institution of Oceanography, La Jolla, California 92093-0203 USA*
[2]*Inter-American Tropical Tuna Commission, 8604 La Jolla Shores Drive, La Jolla, California 92037-1508 USA*
[3]*Quantitative Resource Assessment LLC, San Diego, California 92129 USA*
[4]*Battelle Marine Sciences Laboratory, 1529 West Sequim Bay Road, Sequim, Washington 98382 USA*

Found salmon hatchery returns to be significant in explaining reduced survival

Applying Bayesian model selection to determine ecological covariates for recruitment and natural mortality in stock assessment

John T. Trochta [1,*] and Trevor A. Branch[2]

Salmon hatchery and total returns best explain trends in biomass

Main takeaways

- Pink salmon hatchery releases are a significant negative driver for herring recruitment
  - Can be incorporated into future stock assessment alongside recruitment surveys to finally be able to forecast recruitment! (to be tested…)

- Significant humpback whale predation on adult herring might prevent their recovery to pre-collapse levels



Credit: Rafael Fernandez Cabellero (BBC Ocean Photography Competition, 2024)

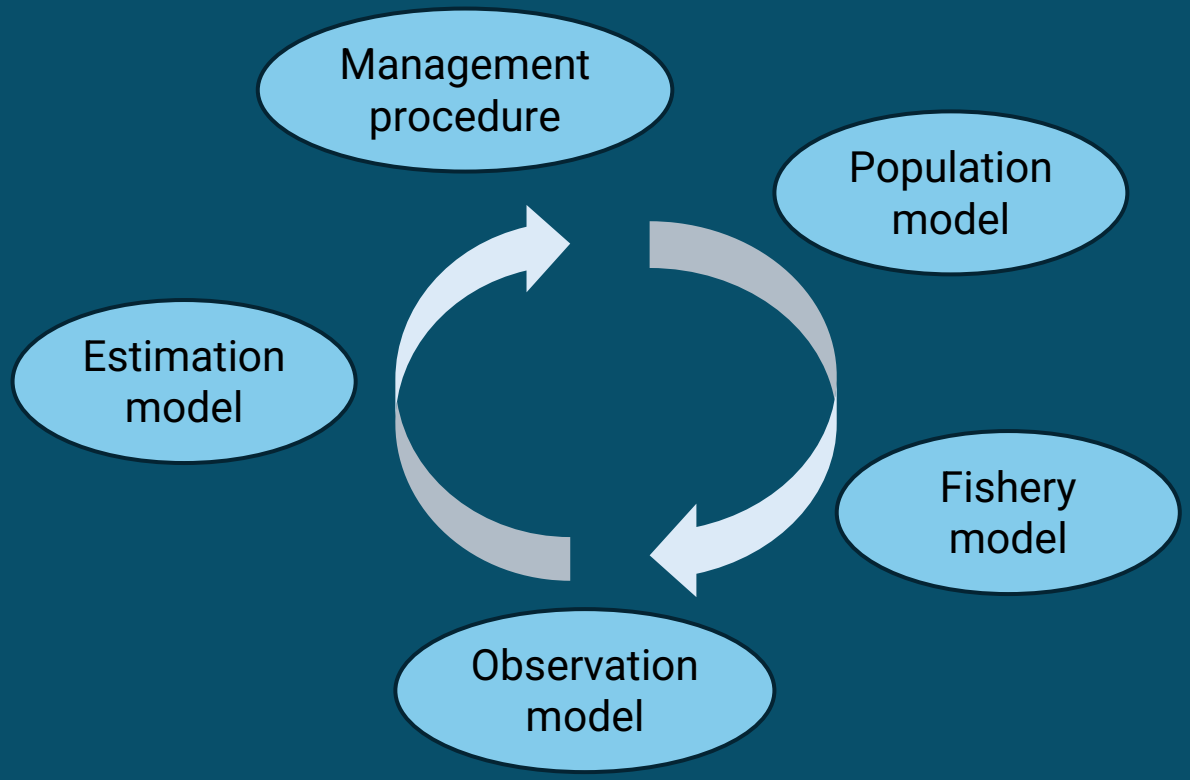
Steps forward

- Incorporate adult salmon data
  - Separate effects of even/odd years
  - Estimate predation mortality and consumption just like for whales



Steps forward

- Use PWS-MICE to condition a multispecies MSE
  - Simulate effects of varying predator levels on future herring biomass
  - How adaptive management can perform under different predator scenarios



THANKS!

QUESTIONS?



