Environmental, ecological, and fishery effects on size-at-age of Pacific halibut

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INTERNATIONAL PACIFIC HALIBUT COMMISSION

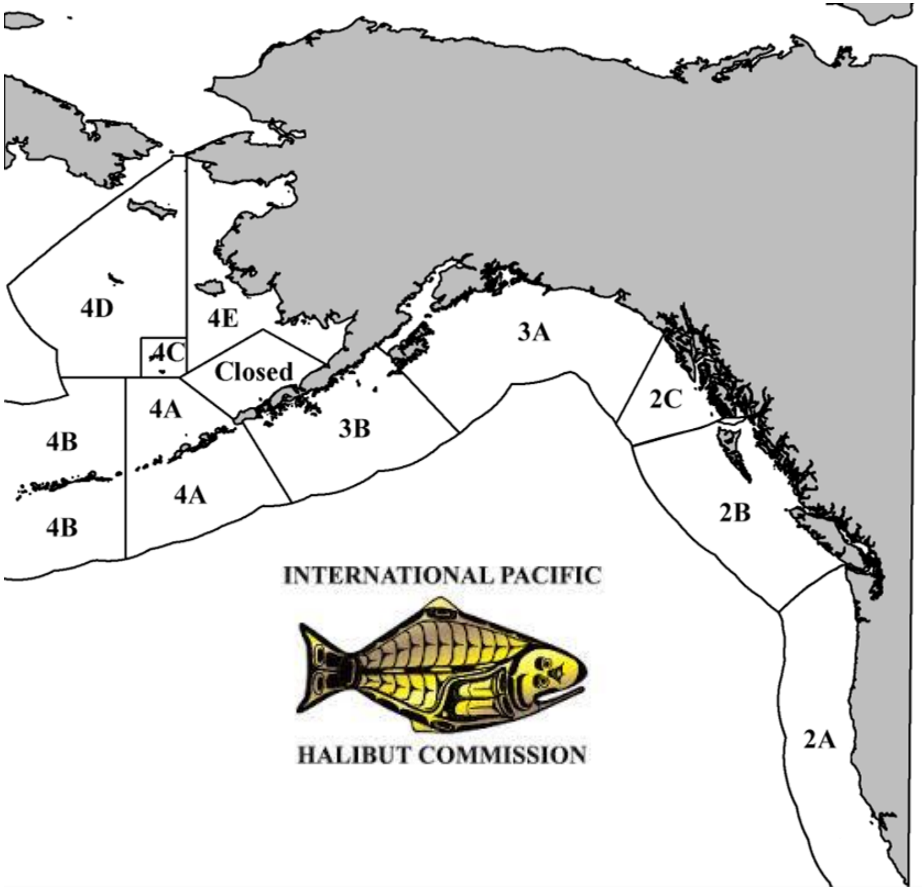
Study Objectives

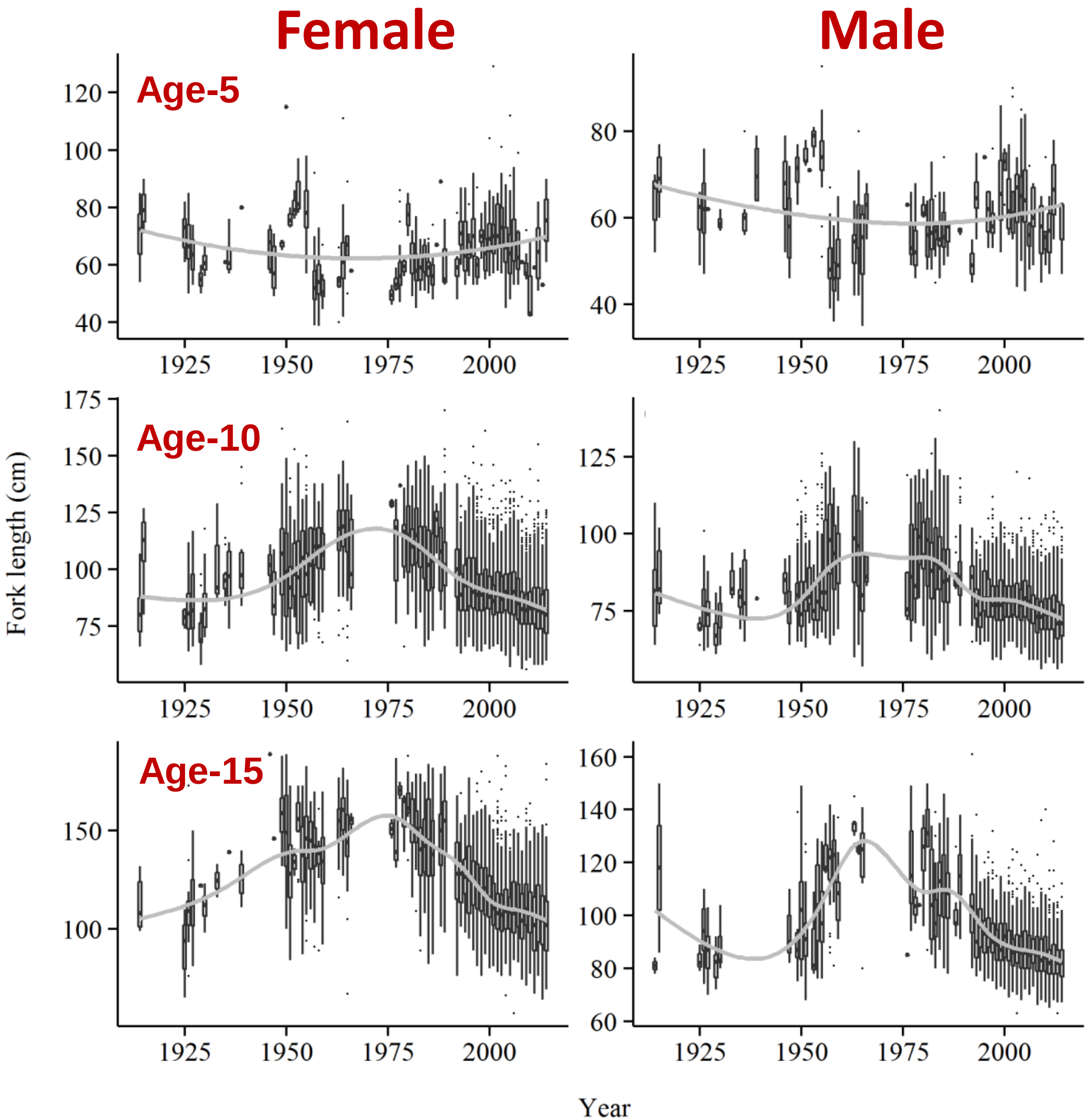
1. **Describe temporal and spatial trends in SAA of Pacific halibut.**
2. **Identify potential environmental and ecological covariates influencing growth of Pacific halibut.**
3. **Determine whether observed changes in SAA can be explained by fishery removals and size-selective fishing.**

Fisheries-Independent Length-at-Age Data

~394,000 observations from IPHC in eastern North Pacific (1914-2014)

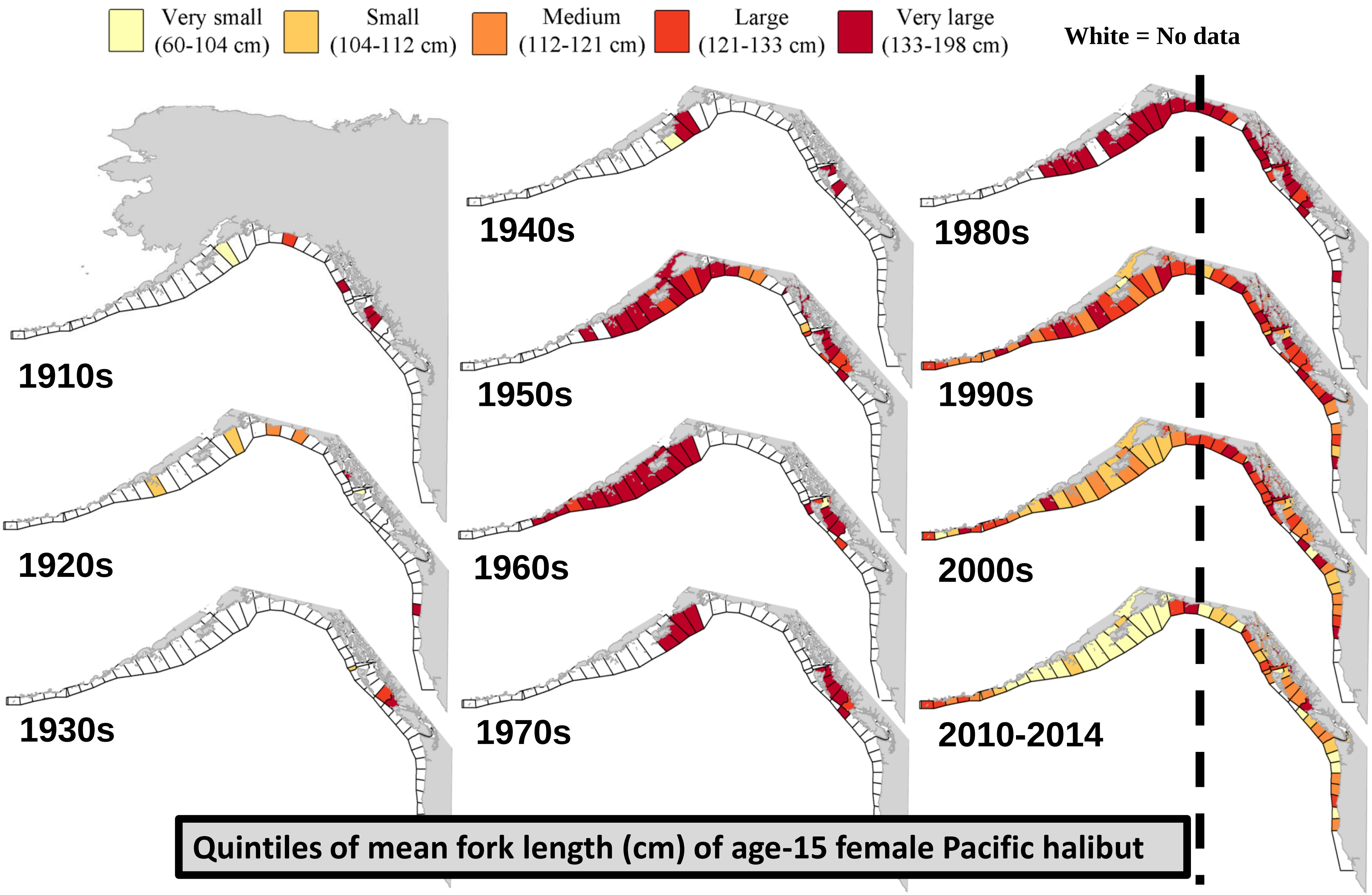
- 1914-1959: experiments
- 1960-1995: trawl and setline surveys
- 1996-2014: modern IPHC setline survey



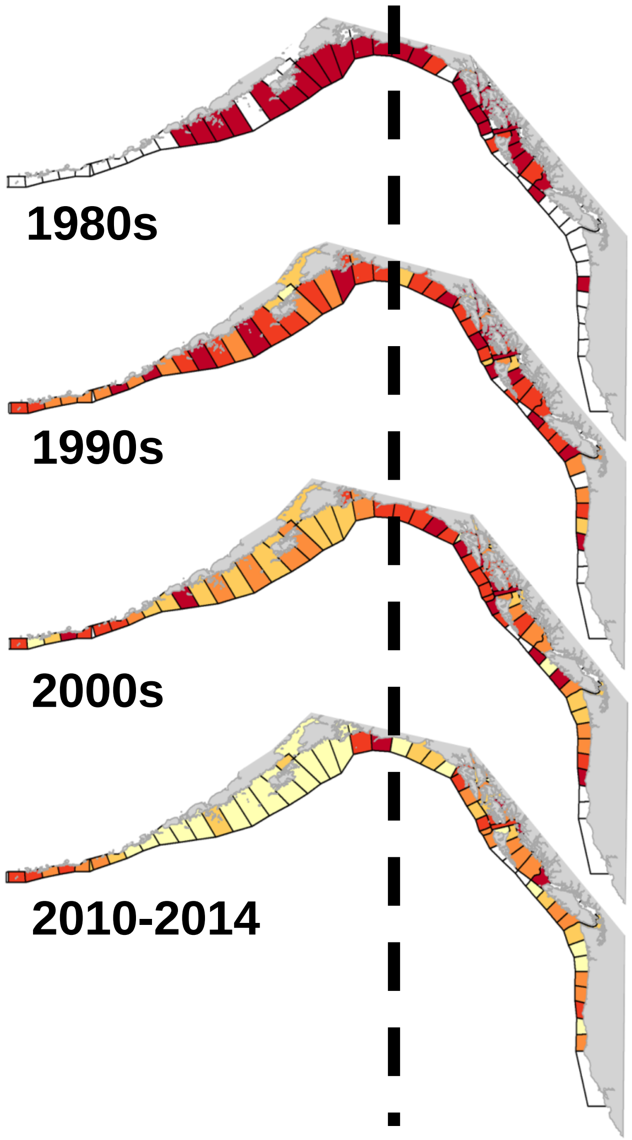


Coastwide trends in SAA

- Highly variable (CV 0.14-0.20)
- Weak trends for fish <age-8
- Low in 1920s, increase until 1980s, sharp decline

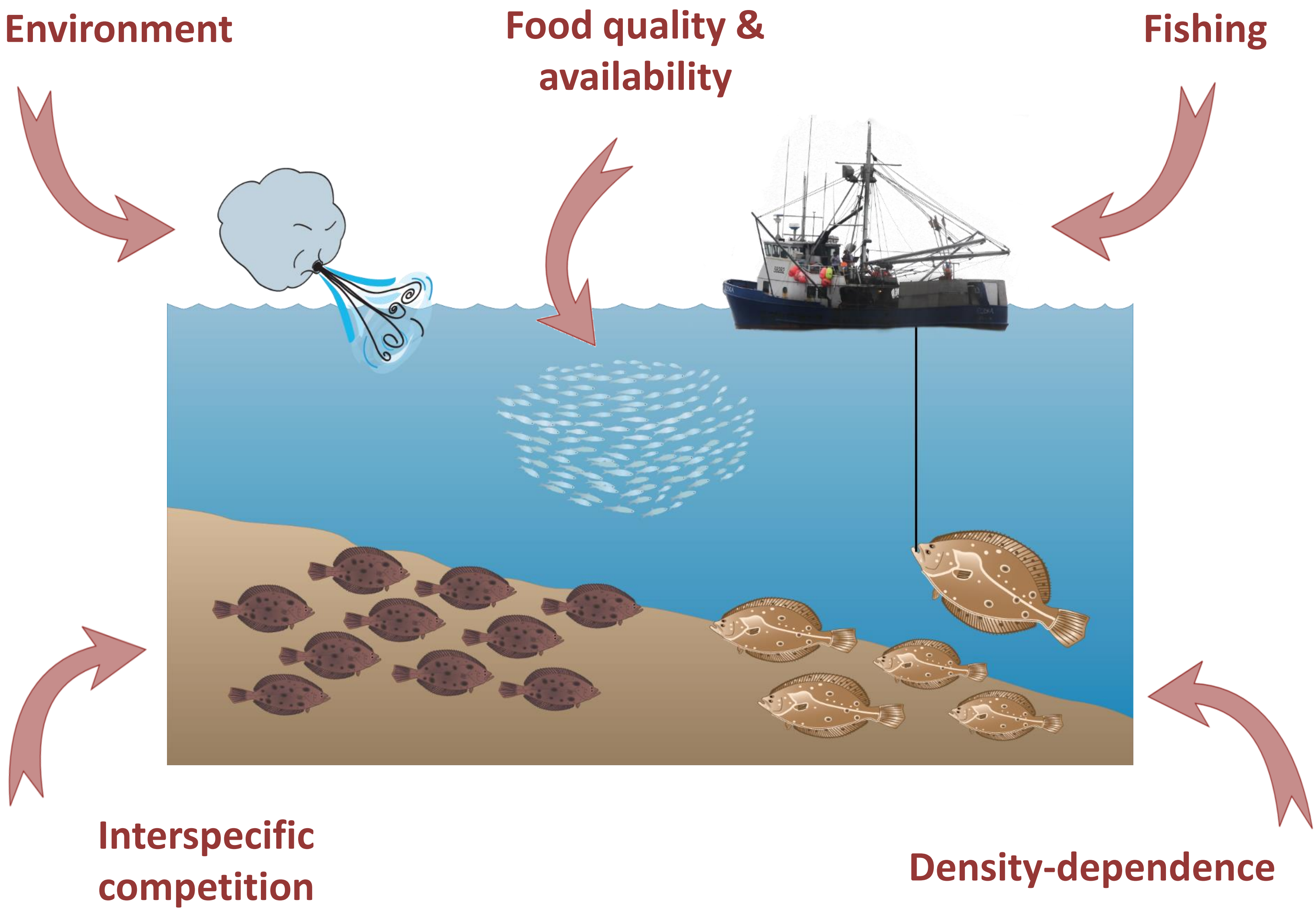


Very small (60-104 cm)
Small (104-112 cm)
Medium (112-121 cm)
Large (121-133 cm)
Very large (133-198 cm)
White = No data
1910s
1920s
1930s
1940s
1950s
1960s
1970s
1980s
1990s
2000s
2010-2014
Quintiles of mean fork length (cm) of age-15 female Pacific halibut

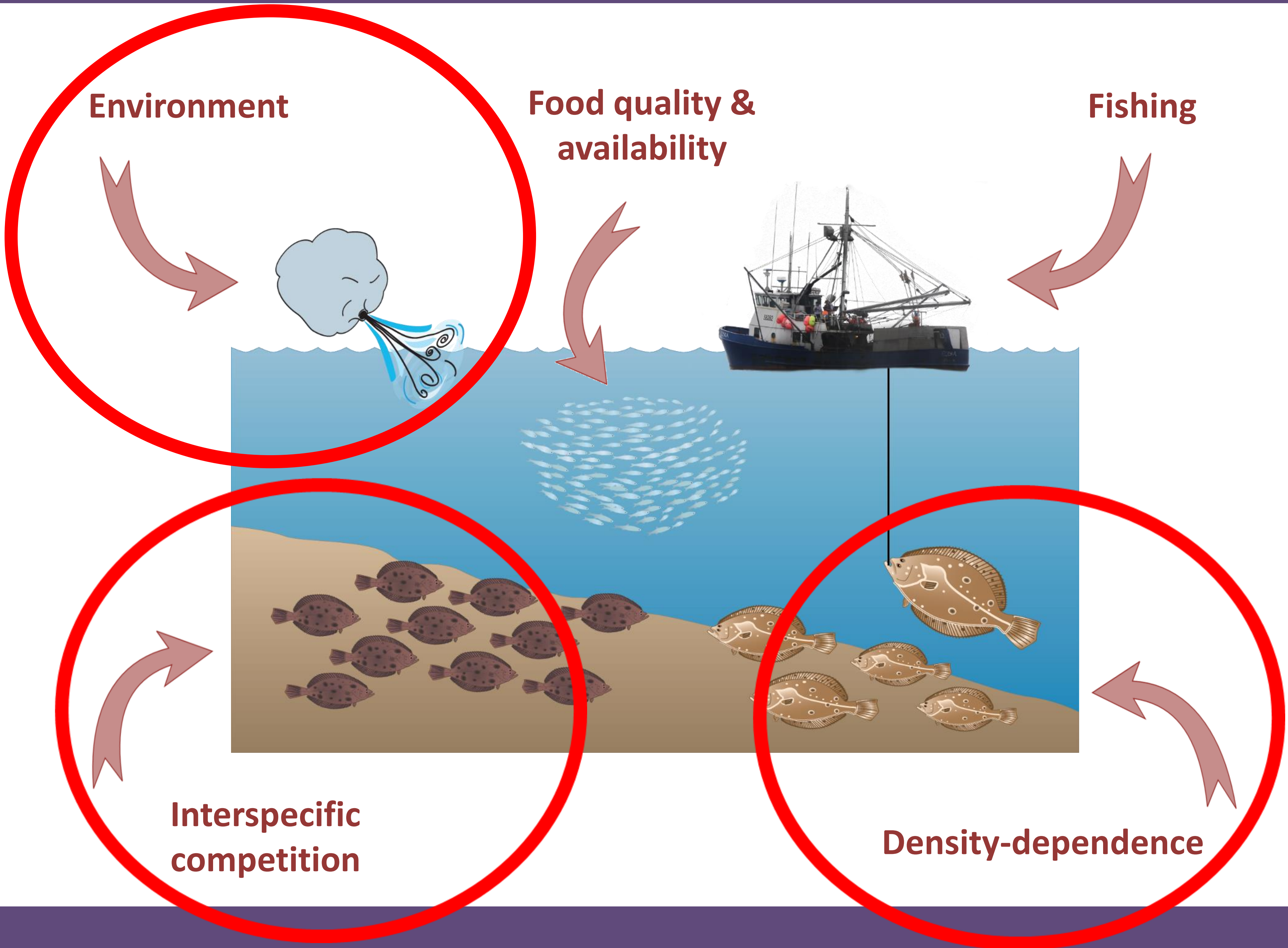


Trends in SAA by IPHC statistical area:

- Low sample sizes & limited spatial coverage in early years
- Western GOA: steep
- Eastern GOA: moderate



Environment
Food quality & availability
Fishing
Interspecific competition
Density-dependence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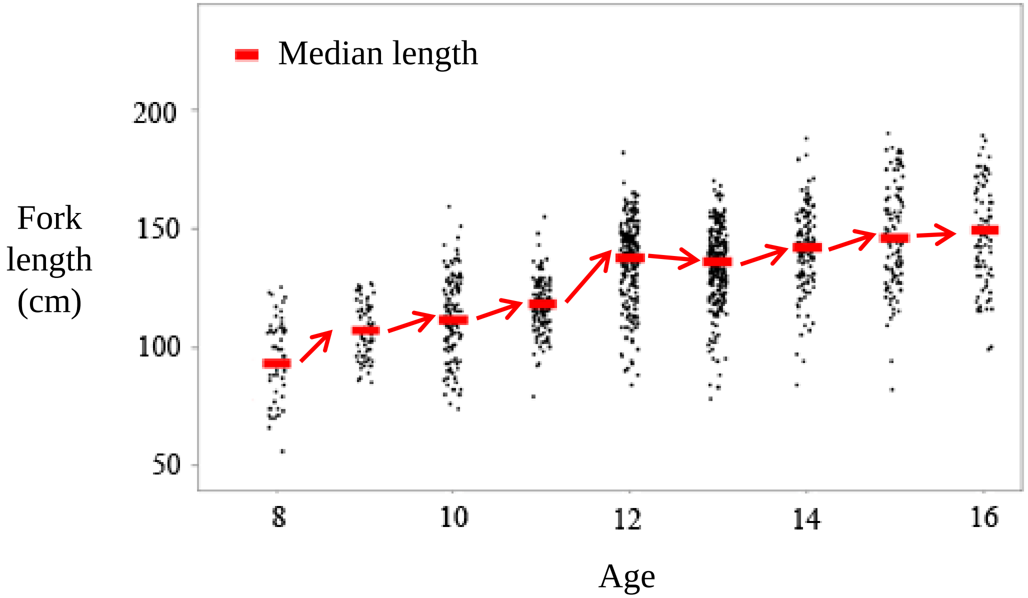
Hypotheses about Size-at-age (SAA)

1. SAA negatively related to Pacific halibut biomass owing to intraspecific competition (density dependence)
2. SAA negatively related to arrowtooth flounder biomass owing to interspecific competition
3. No relationship with temperature

Developing an Index of Halibut Growth

Proportional growth (*G*) - median annual change in length conditioned on initial size for unique combinations of sampling year *i*, cohort *j*, and sex *k:*

$$G_{a,i,j,k} = (\bar{L}_{a,i,j,k} - \bar{L}_{a-1,i-1,j,k}) / \bar{L}_{a-1,i-1,j,k}$$



Statistical Methods

- Analyses limited to Areas 2B, 2C, 3A, and 3B
- We explored relationships between *G* and environmental and ecological covariates with a generalized additive modeling (GAM).
- Results suggested that relationships can be generally described by as linear or quadratic.
- Multiple linear regression models were fit using weighted (inverse variance) least squares to account for higher variance of observations prior to the modern survey period.
- Candidate models were selected using the Akaike Information Criterion, AIC.

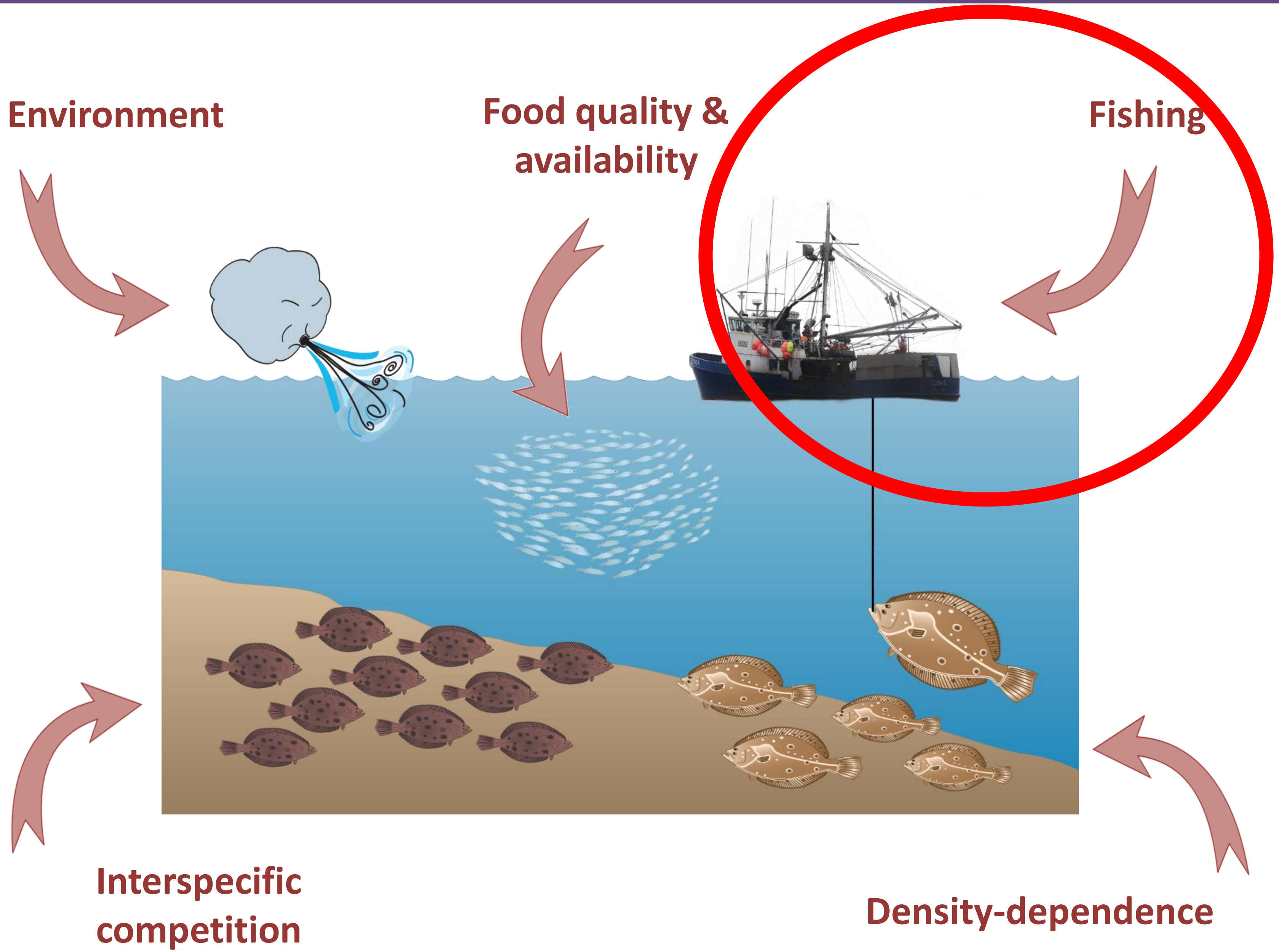
Results

- Alternative candidate models included halibut, arrowtooth flounder, and PDO (one candidate model).
- SST was not included in any candidate models.
- The best fit model had a marginal R^2 of 0.23 and a conditional R^2 of 0.28, indicating that 23% of the observed variance in the data can be explained by the fixed effects and 28% can be explained by the fixed and random effects (unexplained year-to-year variability) combined.
- Other candidate models yielded similar or better marginal and conditional R^2 values, but at the cost of additional parameters.

Conclusions

- Some support for negative relationship between SAA and biomass of arrowtooth flounder and halibut
- Only one candidate model included PDO and none included SST, consistent with null hypothesis of relationship between SAA and temperature
- Negative effects of halibut and arrowtooth flounder, and lack of relationships with temperature, are consistent with previous studies

Sullivan, J.Y., G.H. Kruse, and F.J. Mueter. 2018. Do Environmental and Ecological Conditions Explain Declines in Size-at-age of Pacific Halibut in the Gulf of Alaska? In: F.J. Mueter, M.R. Baker, S.C. Dressel, and A.B. Hollowed (eds.), Impacts of a Changing Environment on the Dynamics of High-latitude Fish and Fisheries. Alaska Sea Grant, University of Alaska Fairbanks. https://doi.org/10.4027/icedhlff.2018.06



Environment
Food quality &
availability
Fishing
Interspecific
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Density-dependence

Simulate population during peak size-at-age (1980s)

Sex, age, and size-structured equilibrium model

→

Model Parameters

1. Growth
2. Maturity
3. Survivorship (Martell et al. 2014)
4. Natural mortality (Stewart 2014)
5. Selectivity (Clark 2011)

→

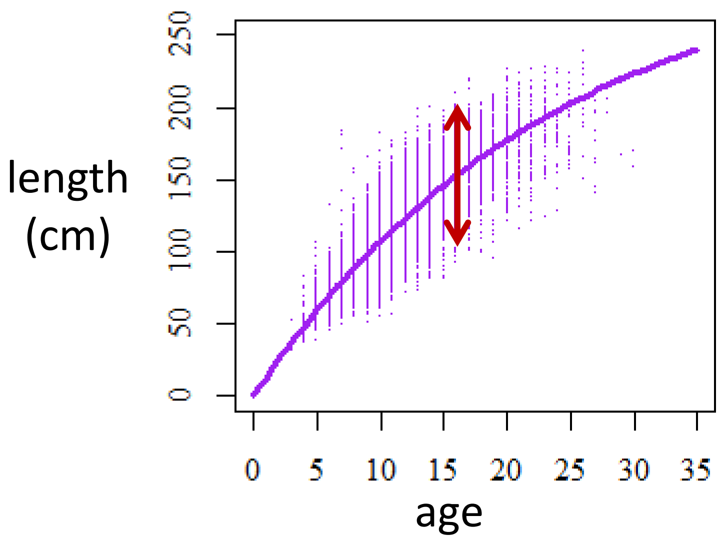
Model Structure

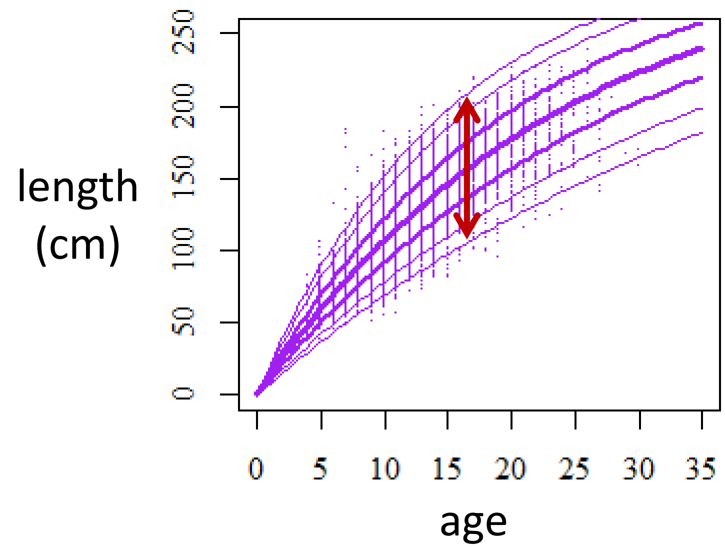
1. Beverton-Holt (stock-recruitment relationship)
2. Fishing mortality & discard mortality modeled jointly
3. Minimum size limit (82 cm)
4. **Growth-type Groups**

(Martell et al. 2015)

Growth-Type Groups

Account for **variability** in growth &
cumulative effects of size-selective fishing
(Walters and Martell 2004)





Growth-Type Groups

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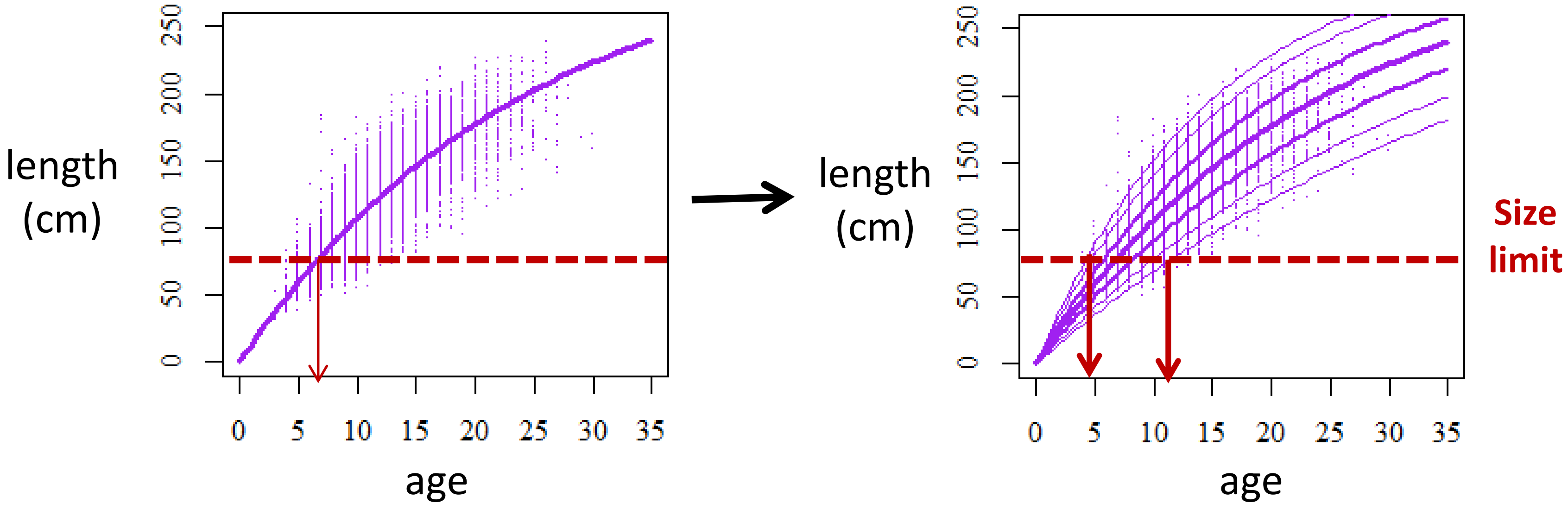


Steps

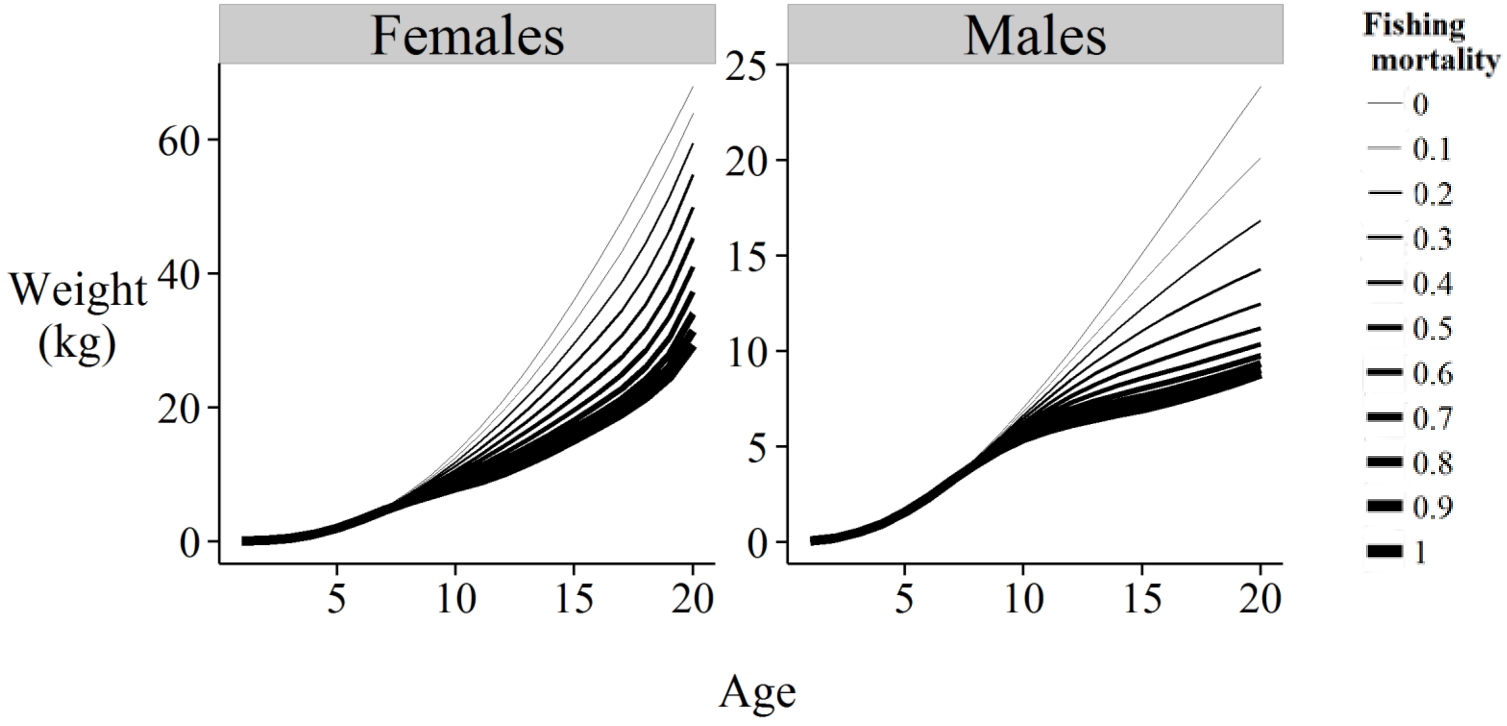
- Expose population to range of fishing mortalities (F)
- Compare observed changes in SAA with model predictions using an estimate of historical F
- We approximated historical mean fishing mortality rate F from the mean exploitation rate (u) over 2000-2014 using the following equation assuming M = 0.2:

$$U = F\,(1-\exp(-Z))/Z$$

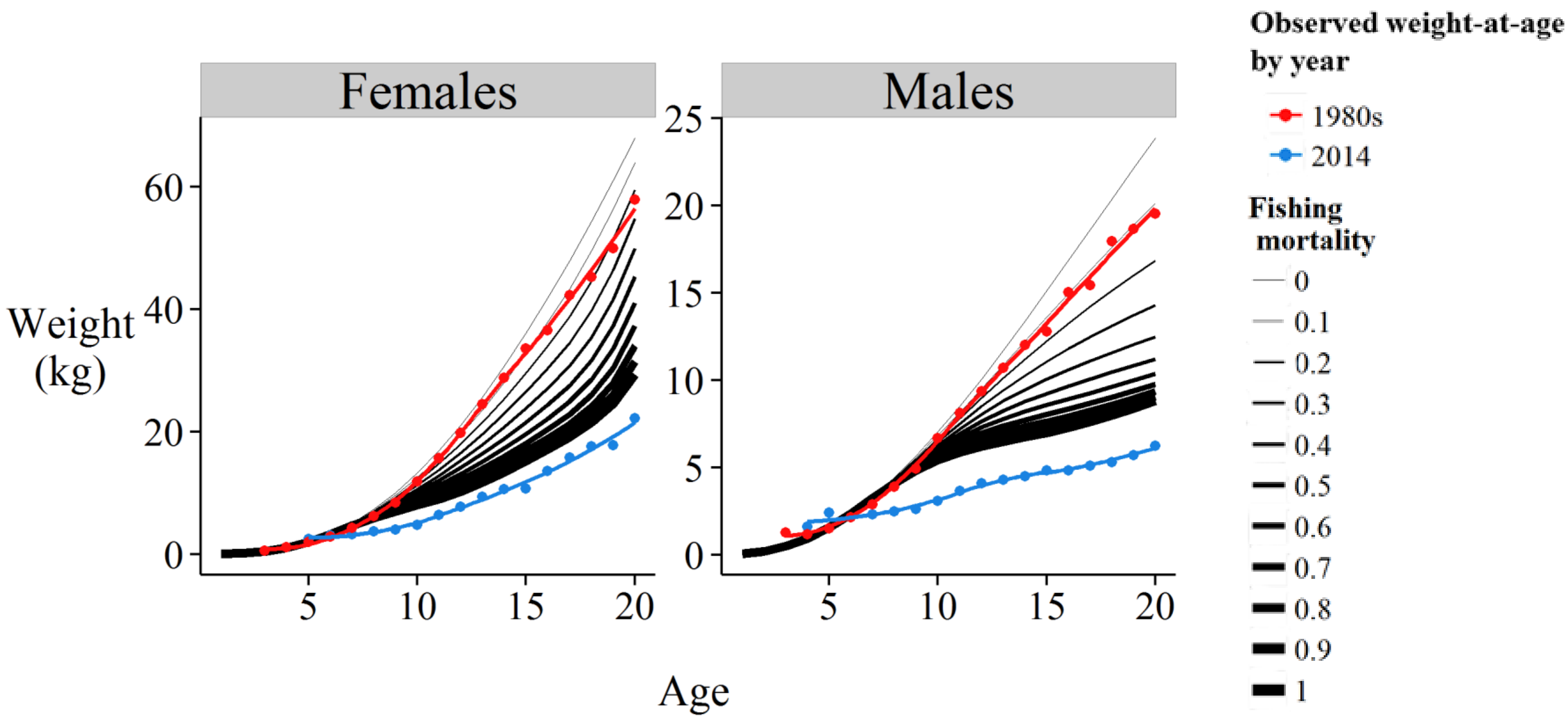
- The analysis was limited to Gulf of Alaska (2B, 2C, 3A, 3B)

Results

Model predictions of SAA with increasing fishing mortality *F*

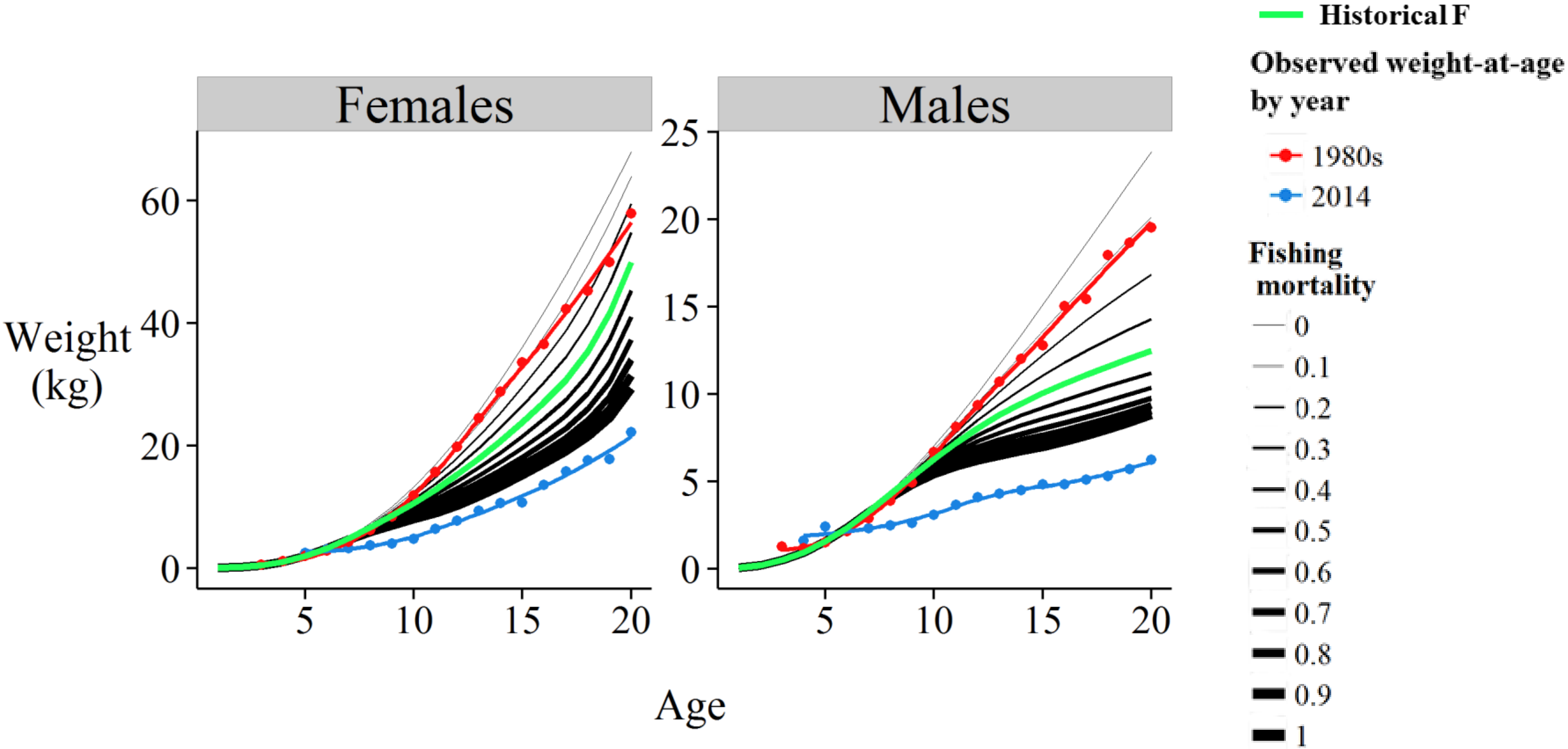


Observed vs. predicted size-at-age under increasing *F* overlaid with average SAA from 1980s and 2014



Observed vs. predicted size-at-age under increasing *F* overlaid with average SAA from 1980s and 2014 and historical *F* estimates

➔ Fishing explains ~50% of the declines since the 1980s



Results by Area

- **Area 2B (British Colombia)** – Fishing can explain 75-100% of declines since 1980
- **Area 2C (Southeast AK)** – Fishing can explain 50-75% of declines since 1980
- **Area 3A (central GOA)** – Fishing can explain ~30% of declines since 1980
- **Area 3B (western GOA)** – Fishing can explain 25-50% of declines since 1980

Conclusions

- Results suggest that fishing may have played a role in declines in SAA of Pacific halibut
- Area-specific models suggest that fishing was more influential in the east than west; however, the steepest declines in SAA occurred in the western GOA.
- Halibut are particularly vulnerable to this phenomenon owing to variability in growth rates among individuals and levels of fishing mortality

Caveats

- **We did not study growth as we do not have repeated measurements of individuals over time**
- **We analyzed length-at-age; weight-at-age would have been better (fish may lose weight but not length)**
- **Fish movement among areas was not addressed**
- **Conditions for growth vary on spatial scales smaller than regulatory areas**
- **Calculation of *F* may overestimate true *F*, as the exploitable biomass used to calculate the harvest rate does not include all of the fish available to the fishery**
- **An equilibrium model is used in non-equilibrium conditions**

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