Stock Assessment for the Rest of Us: Hard-to-Age, or Low Value, or By-Catch Groundfish Stocks

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TESA workshop "Small Pelagic Fishes"
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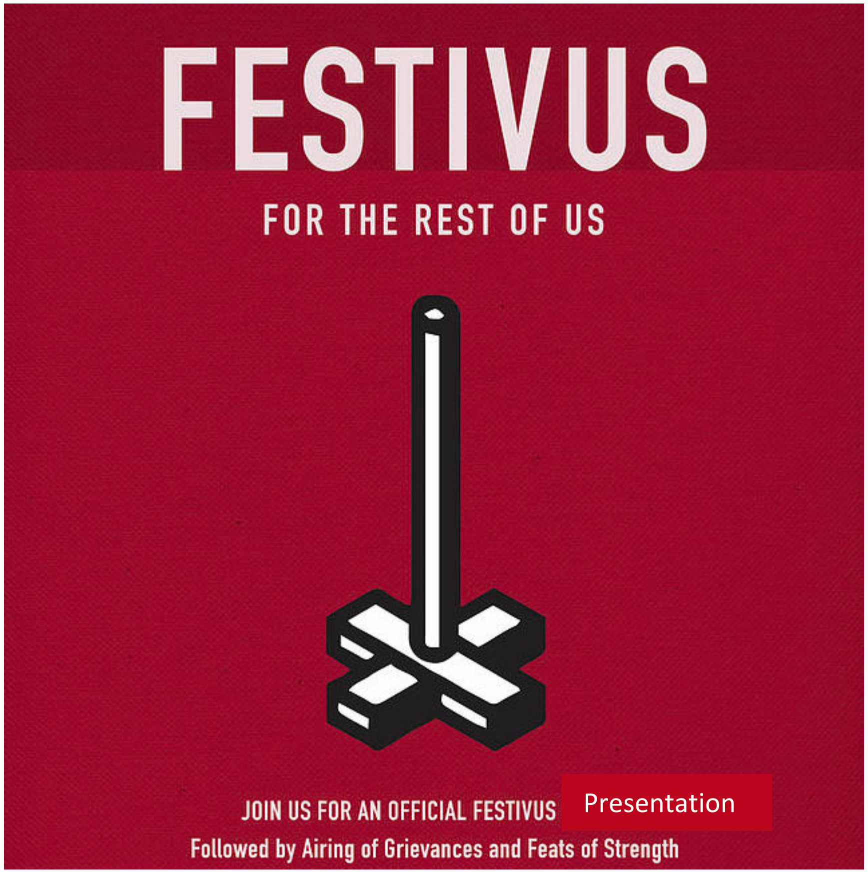
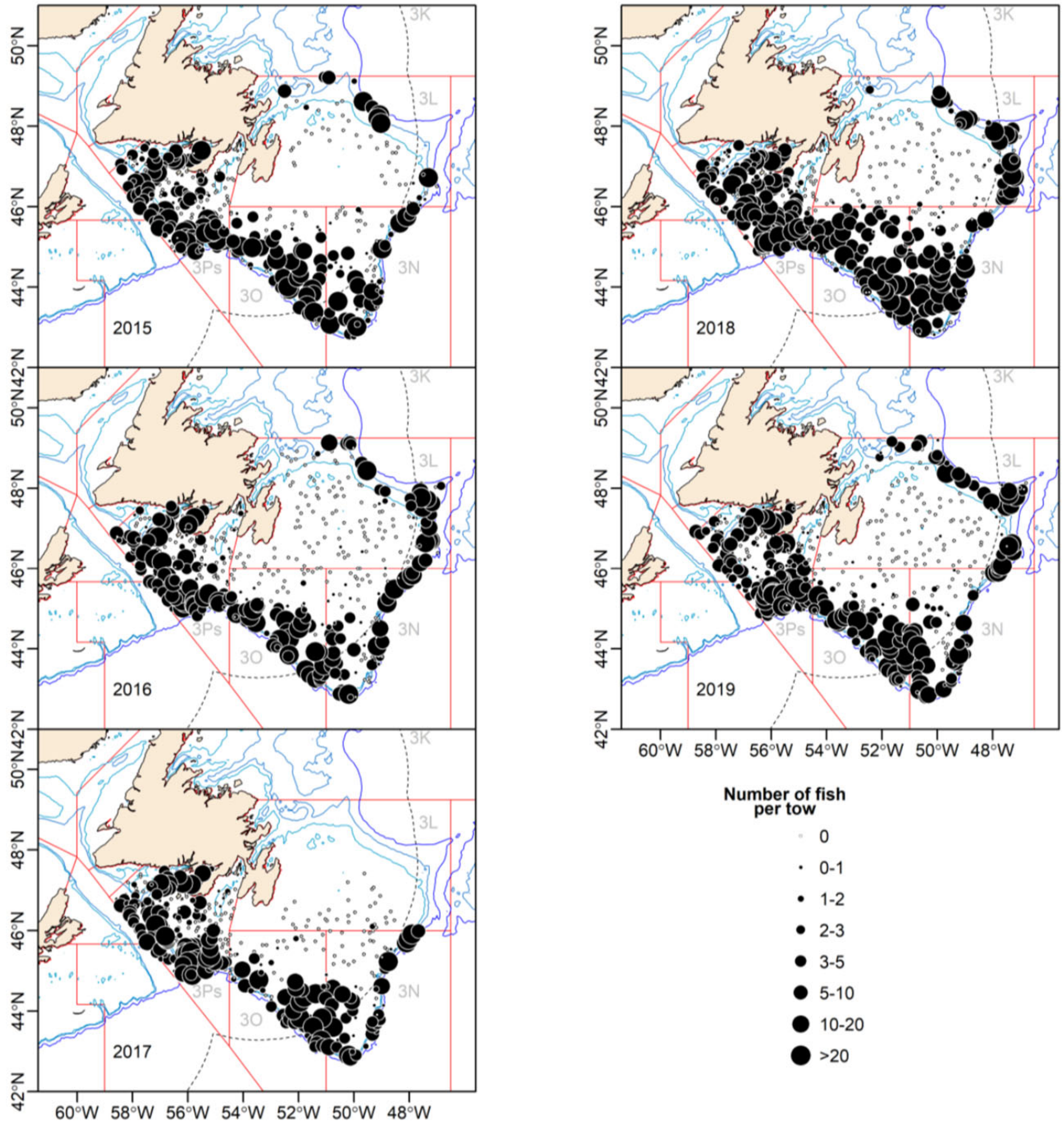
Gulf Fisheries Centre, Moncton



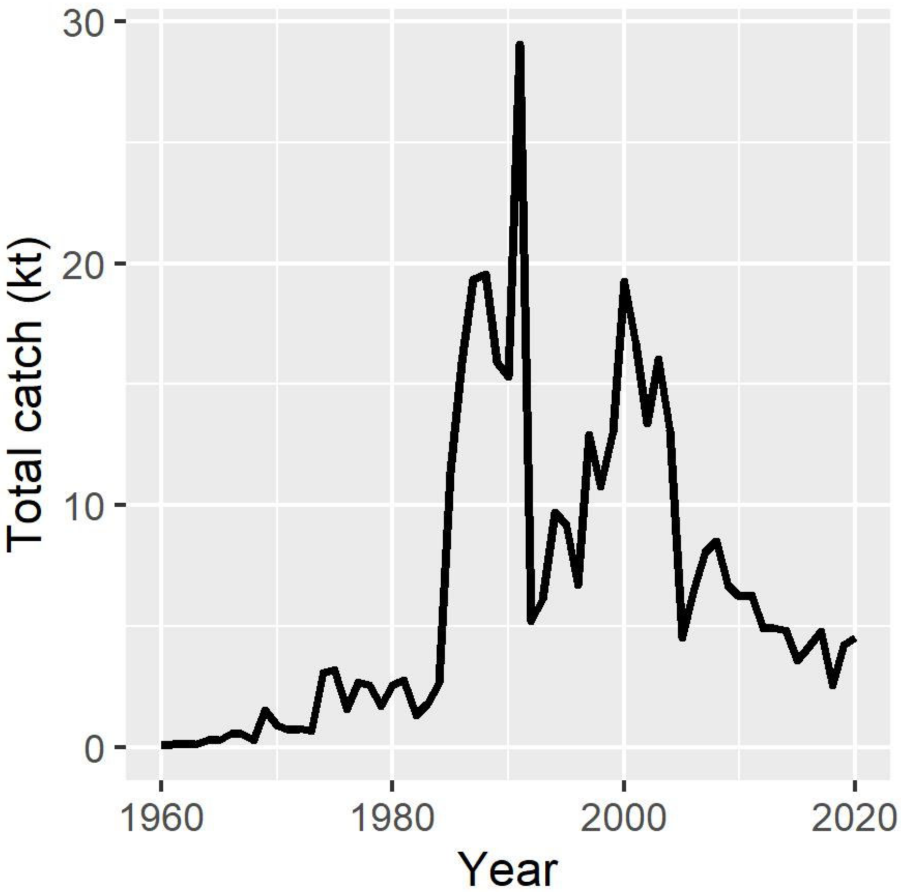
The Context

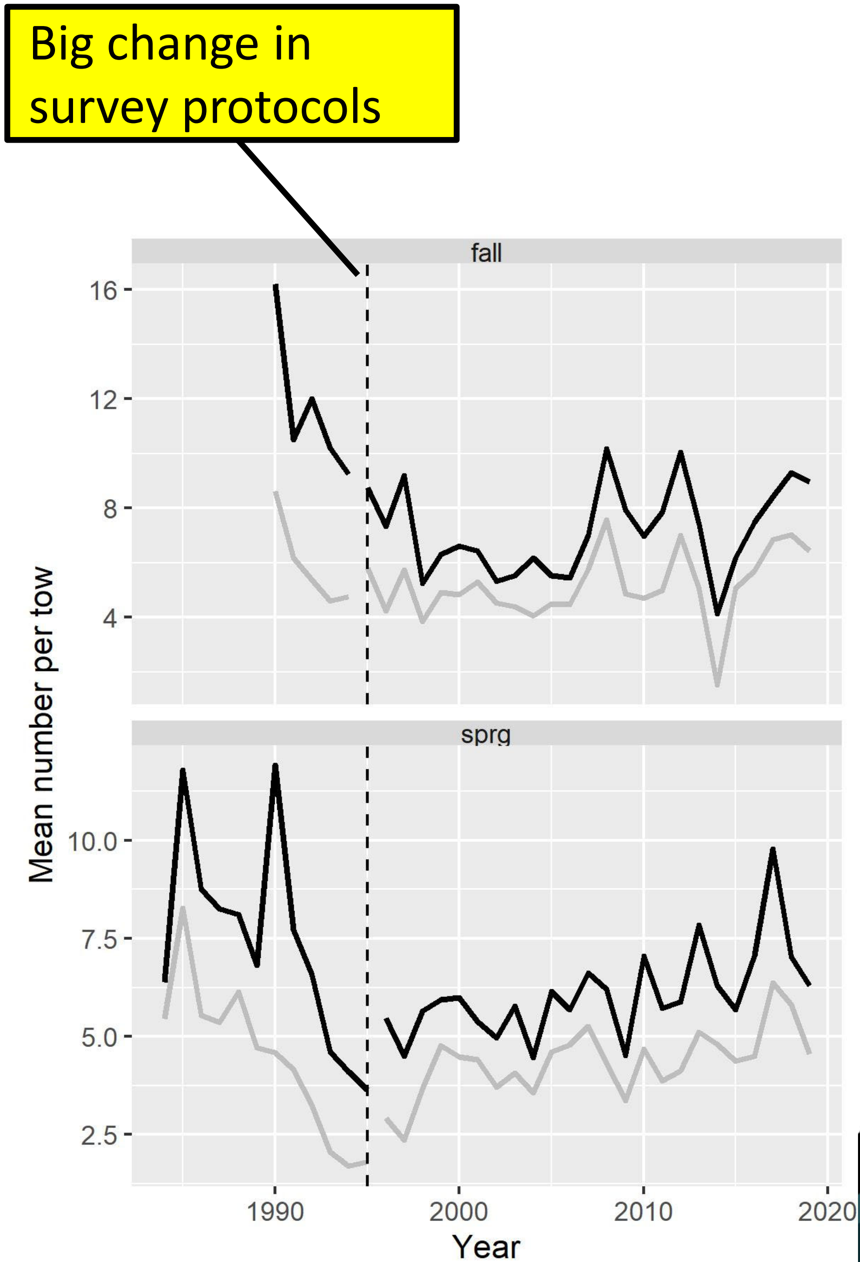
- Many stocks are not sampled regularly, if at all, for age
- Sampling of commercial fishery catches for sizes etc. can be poor (this may be more a NL problem?)
- The east coast of Canada is fortunate to have (usually) annual high-quality surveys for groundfish species
- An assessment situation I have been dealing with:
  - Primary information, time-series of length-based survey indices
  - No fishery size comps
  - Landings estimates, usually of poorly known accuracy
  - I refer to this as amorphous uncertainty
- This is my focus today

State-space age-based catch-at-length model (ACL) for Thorny Skate (*Amblyraja radiata*) in 3LNOPs

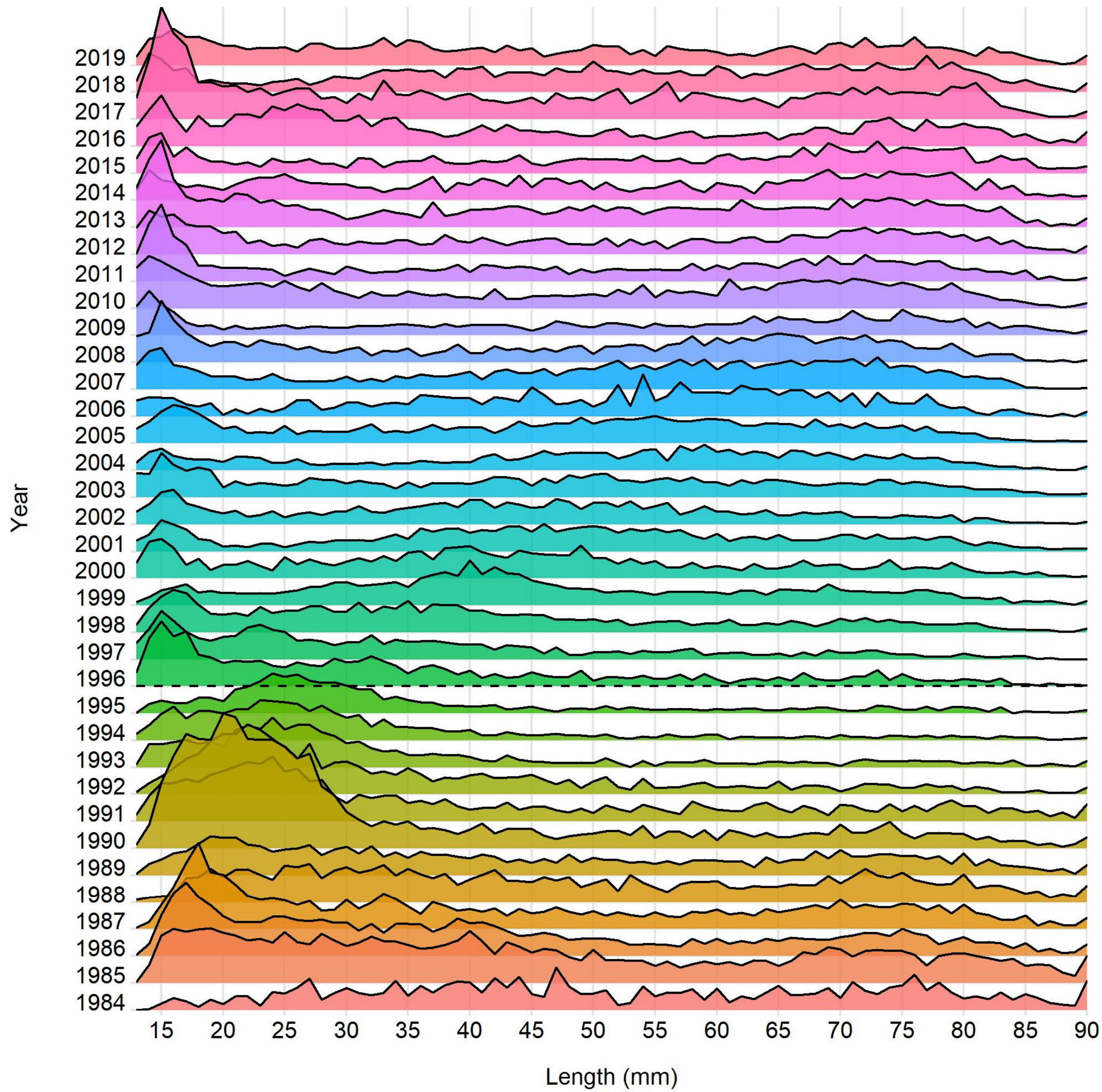


The data: landings and surveys

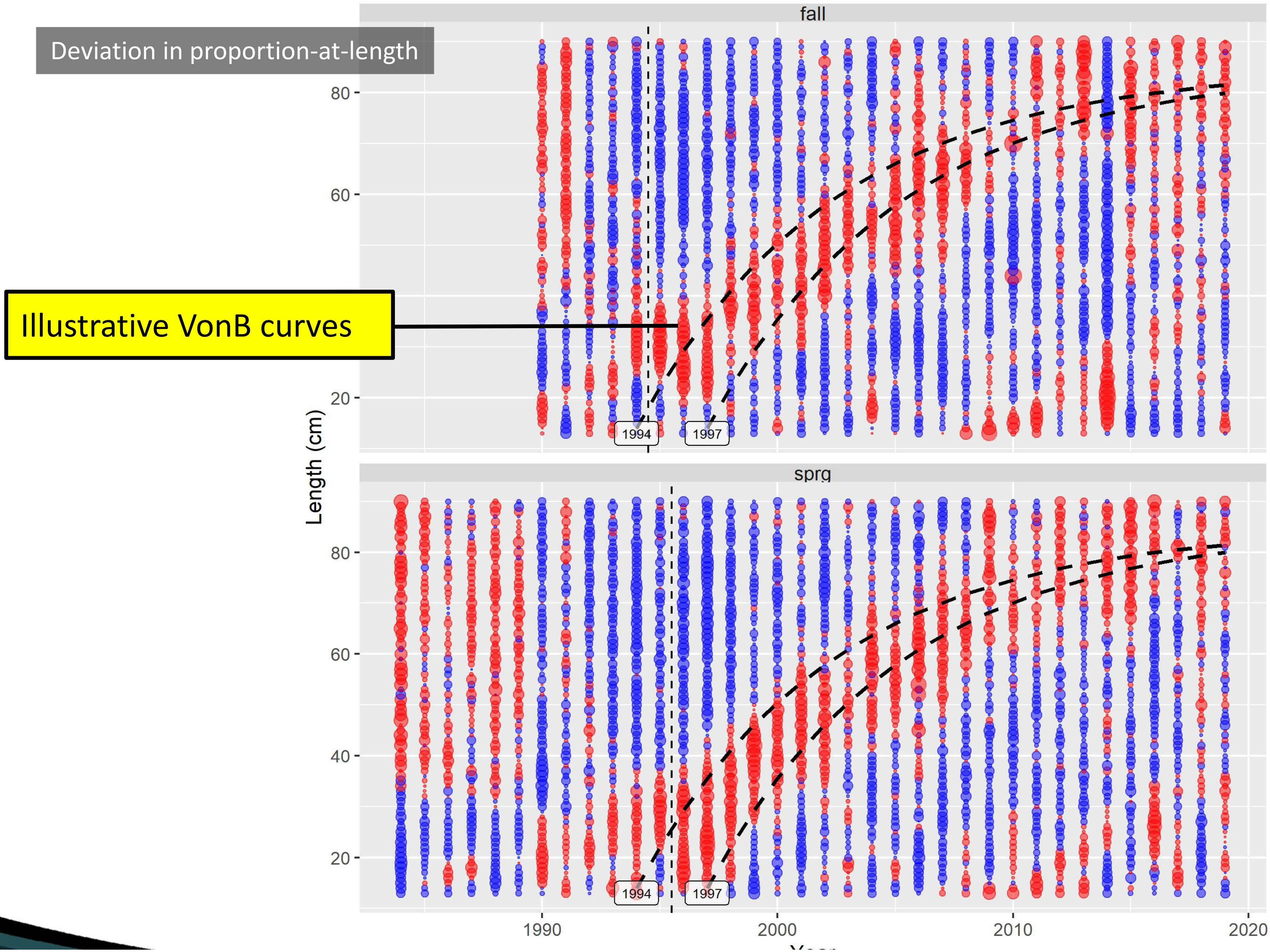




Data: Spring RV mnpt-at-length



RV Length Comps



Age-Structure Catch-at-Length, ACL

- Not much new here!
- The model internal populations dynamics are age-based, just like SAMs, etc.
- We estimate a stochastic Von Bertalanffy (VonB) growth curve and use this to estimate the probability that a fish is in length-bin *l*, given the fish is age *a*.
- Let's assume *l* is also the mid-point and that length-bins have 1cm width
- so that a fish in length-bin *l* has a $L \in (l - 0.5, l + 0.5)$.
- Use the stochastic VonB probabilities to convert N@A → N@L

VonB Size Probabilities

- Assume the distribution of length-at-age (L@A) is normal with a mean $\lambda(a)$ that is a VonB function of age a,
- VonB: $\lambda(a) = \lambda_\infty\{1 - (1 - p_o)\exp(-ka)\}$
  - $p_o = \lambda(0)/\lambda_\infty$ and $\lambda_\infty = \lim_{a\to\infty} \lambda_\infty$
- And the standard deviation of L@A is proportional (τ) to the mean (common choice) or some appropriate model.
  - $L@A \sim N\{mean = \lambda(a), SD = \tau\lambda(a)\}$
- Then
- $Pr\{L(a) \in l\} = \Phi\left\{\frac{l-\lambda(a)+0.5}{\tau\lambda(a)}\right\} - \Phi\left\{\frac{l-\lambda(a)-0.5}{\tau\lambda(a)}\right\}$

N(0,1) (i.e. pnorm)

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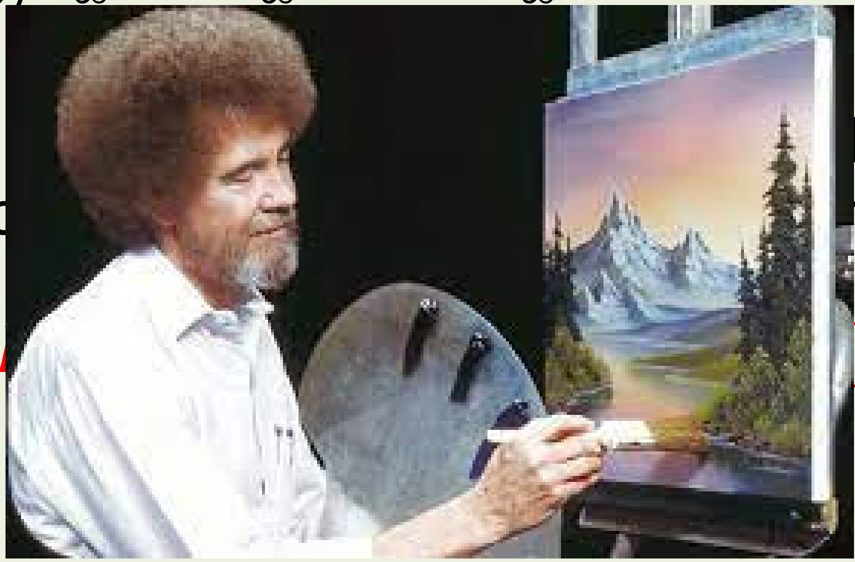

- And the sta portional (τ) to the mean (c opriate model.
  - $L@A \sim$ $\}$
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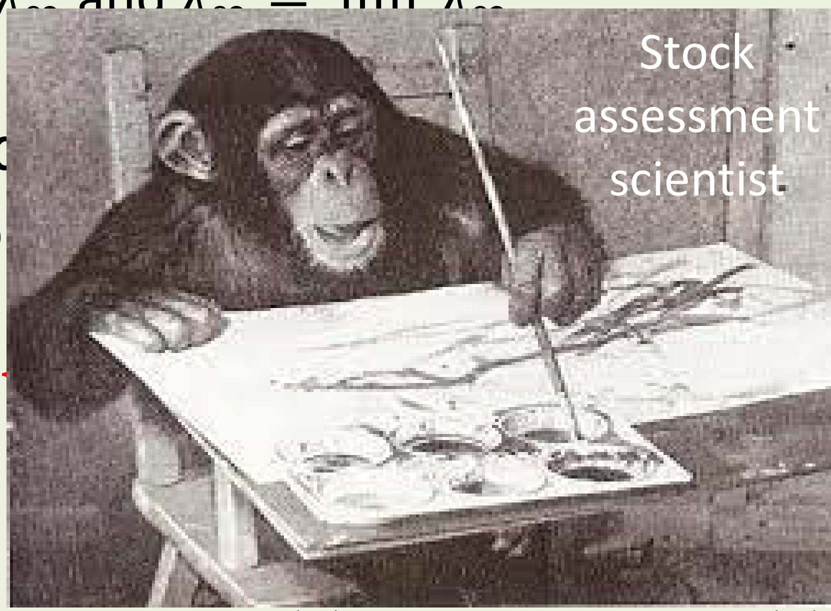

- And the stand ortional (τ) to the mean (co priate model.
  - $L@A \sim N$
- Then
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Numbers-at-age -> Numbers-at-length

- Let $P_{la} = Pr\{L(a) \in l\}$ based on λ_∞, p_o, k, and τ.
- $N_{ly} = \sum_a N_{ay} \, P_{la}$
- Assume the same for catches,
- $C_{ly} = \sum_a C_{ay} \, P_{l,a+0.5}$
- Note that we have assumed the distribution of size-at-age in the population is the same as the catch, which might not be true if mortality is length-dependent (need another model for that, e.g., Zhang and Cadigan, 2021)

F. Zhang and N. G. Cadigan. 2022. An age and length structured statistical catch-at-length model for hard-to-age fisheries stocks. Fish and Fisheries, 23, 1121-1135

ACL Population Dynamics

- The usual cohort model:

$$N_{a+1,y+1} = N_{ay}\exp(-Z_{ay})$$

- And Baranov Catch Equation:

$$C_{ay} = N_{ay}(1-e^{-Z_{ay}})\frac{F_{ay}}{Z_{ay}}$$

- $Z_{ay} = F_{ay} + M_{ay}$
- We estimate N_{ay}'s and F_{ay}'s based on assumed values for M_{ay}'s
- I use Lorenzen M's based on weight~length parameters and initial guesses of VonB parameters
- Will also estimate some annual M deviations for Thorny Skate – this is somewhat new

ACL Estimation: Survey indices

- Estimation is based on a time (*y*) series of <u>length-based</u> (*l*) survey (*s*) indices, R_{sly}.
- Stock numbers-at-age and length at the time of survey s,
  - $N_{say} = N_{ay}\exp(-f_s Z_{ay})$
  - $N_{sly} = \sum_a N_{say} P_{sla}$, $P_{sla} = P_{l,\boldsymbol{a+f_s}}$

Project to time of survey, $\boldsymbol{f_s}$

- Model survey index prediction
- $E(R_{sly}) = q_{sl} N_{sly}$
- Observation equation, $\log(R_{sly}) = \log(q_{sl} N_{sly}) + \varepsilon_{sly}$
- For simplicity I assume $\varepsilon_{s,\{l_1,\ldots,l_L\},y} \overset{iid}{\sim} MNV(0, \Sigma_s)$

Including correlation across lengths is important!

ACL Estimation: Catch Biomass

- Estimation is based on a time series of "observed" (o) fishery catch weights (CB_{oy})
- CB_y based on Baranov catch numbers-at-age (C_{ay}):
  - $C_{ly} = \sum_a C_{ay} P_{cla}$, $P_{cla} = P_{l,\mathbf{a+0.5}}$ Project to mid-year
  - $CB_y = \sum_l W_l C_{ly}$, where W_l is weight-at-length
- Observation equation, censored (e.g., Bousquet et al., 2010)
- **I am not using any information on the size composition of fishery catches ☹ - this is different!**

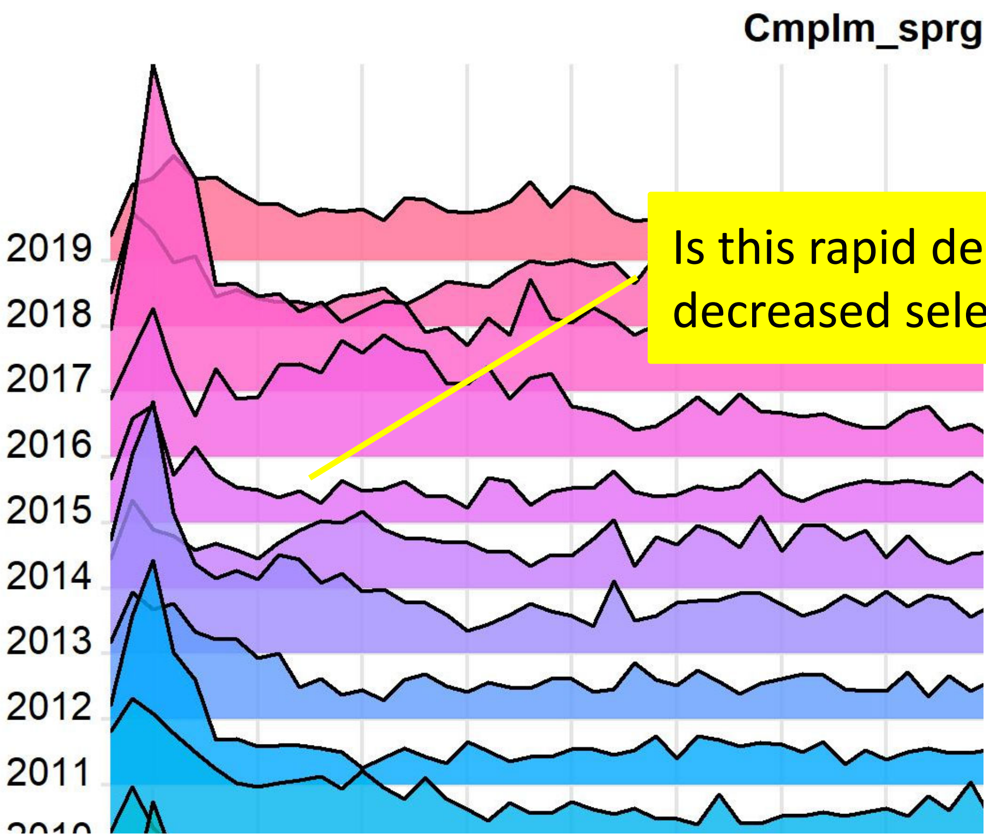
Bousquet, N., Cadigan, N., Duchesne, T. and Rivest, L.P., 2010. Detecting and correcting underreported catches in fish stock assessment: trial of a new method. CJFAS, 67, 1247-1261.

Aggregate Indices

- I aggregated survey indices at small and large sizes
  - Summed all observed catches >= 90 cm
  - Summed all observed catches <= 13 cm
- Use the same observation equations and simply sum the model predictions
  - Summed all model predicted catches >= 90 cm
  - Summed all model predicted catches <= 13 cm
- Model ages: 1:30+, lengths 1:110. A=30+ a plus group.
- Need A=30+ to be large enough to capture most growth dynamics to Linf
- Need L=110 to be large enough to capture size of most fish at ages 1,…,30+

Lorenzen M not good for Thorny Skate!

- The survey size comps suggested <u>either</u>:
  - Much higher M at young ages (e.g. 1, 2, maybe 3) than the Lorenzen formula, or
  - Or Strange selectivity



Is this rapid decrease due to decreased selection or mortality?

If it is Z than I assume it is M because no evidence of fishery catches (F) at these sizes?

More Assumptions

- RV indices indicate high M at 10-20cm, so I set M at age 1 at a high level.
  - Rationale: Hatching occurs when the embryo is approximately 10 to 12 cm TL, so fish at these sizes may experience high early life stage M
- I fixed L0 = 5. I tried L0=10 but this led to an unrealistic growth curve.
- Fix q length pattern for one survey, but estimated the others (like SURBA)
- I fixed F =0 at ages 1-2. SCR doc indicates little catch <= 25 cm so this seemed reasonable. Otherwise, separable F.
- The model has limited ability to estimate age pattern in F because it does not use size information of fishery catches.
- Have process error on M

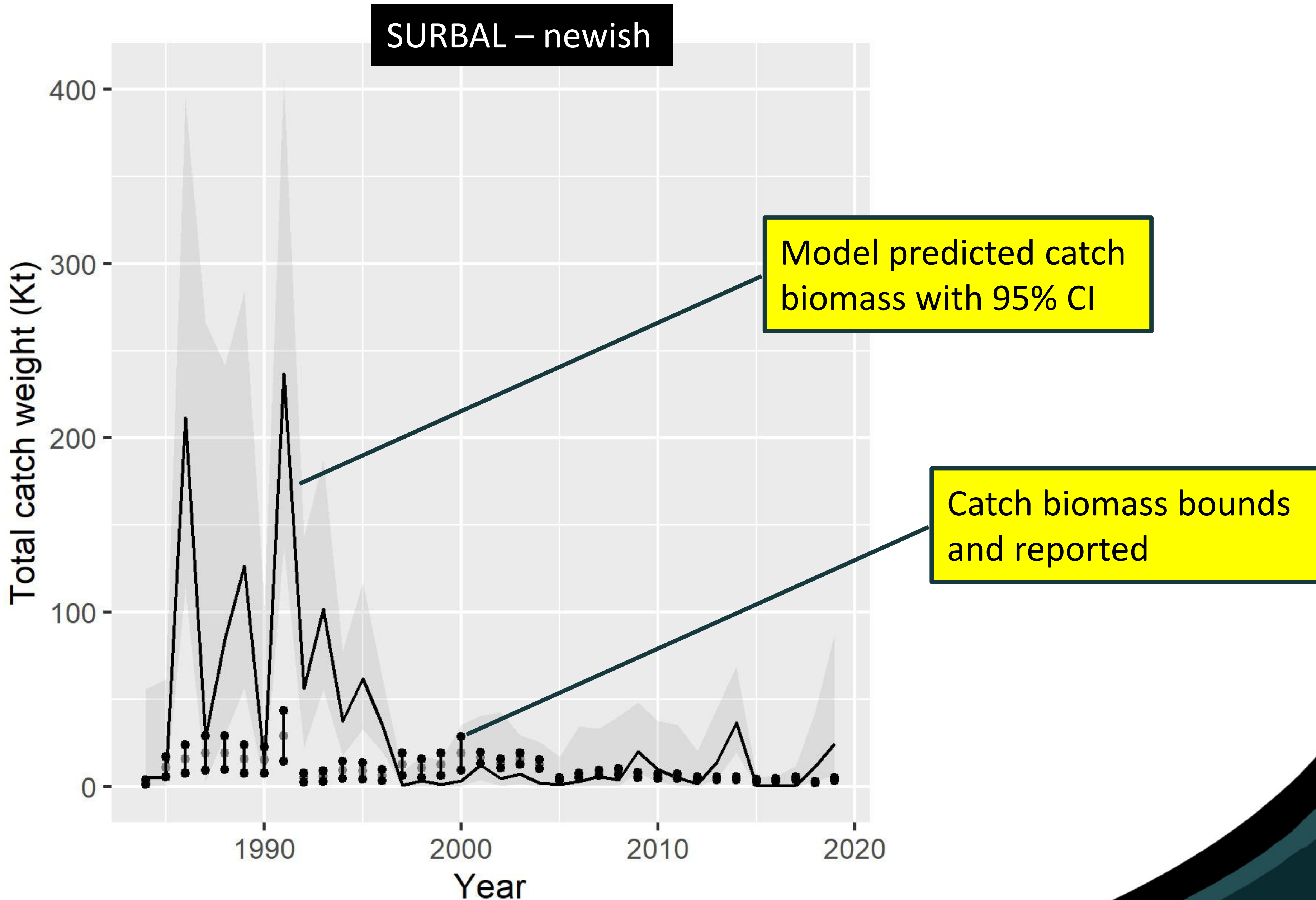
Model Selection

- The M process error SD parameter did not converge

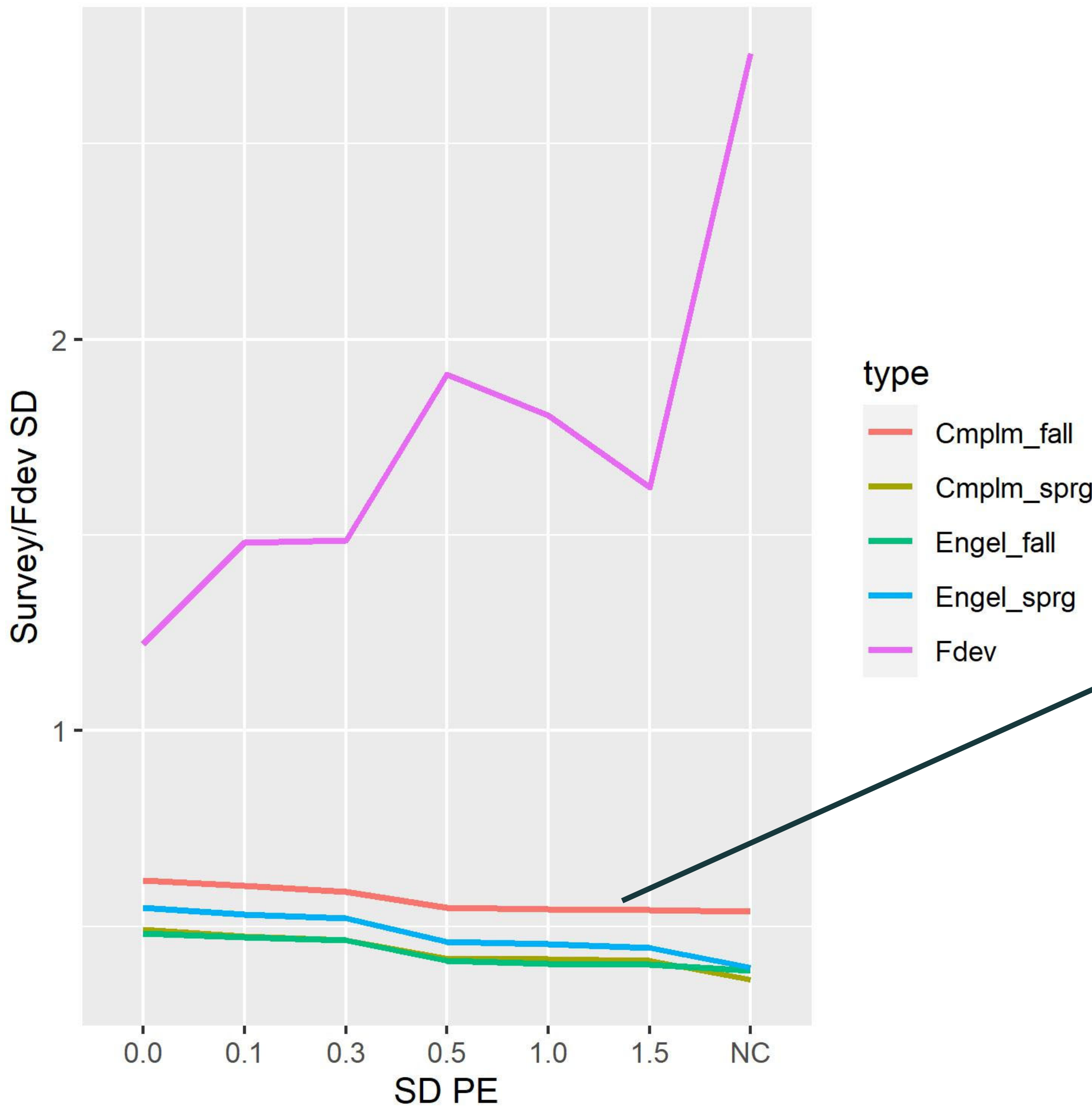
Name	σ_M	nll	AIC	BIC	ΔAIC	ΔBIC
M1	0.0	2806.6	5655.2	5792.6	352.3	345.8
M2	0.1	2788.2	5620.4	5764.3	317.5	317.5
M3	0.3	2777.1	5598.3	5742.2	295.3	295.3
M4	0.5	2725.3	5494.6	5638.6	191.7	191.7
M5	1.0	2644.7	5333.5	5477.4	30.5	30.5
M6	1.5	2629.5	5302.9	5446.9	0.0	0.0

- Why?

Model without landings, predicted landings

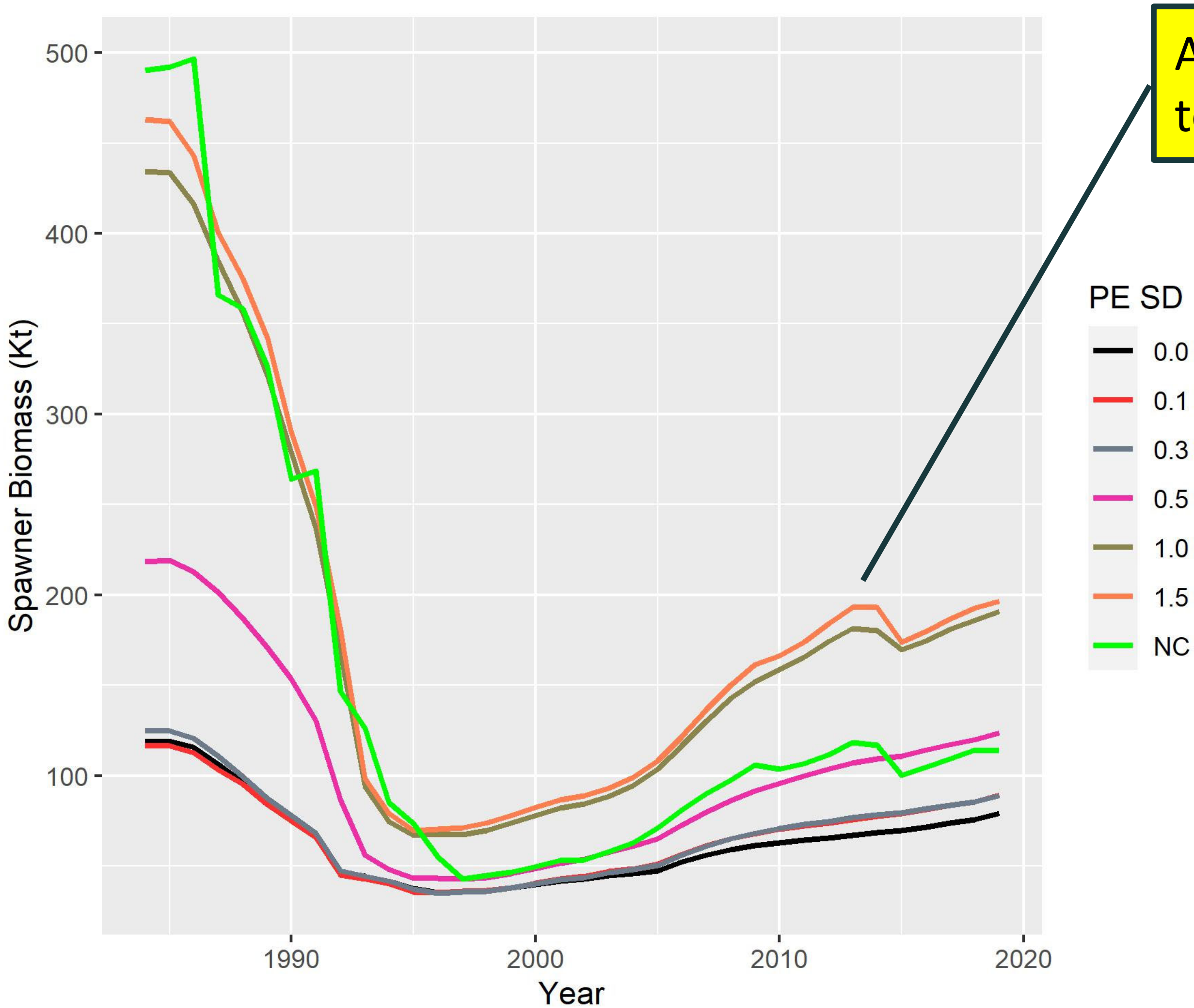


Model Selection



Little improvement in survey fits for σ_M>0.5

Model Selection



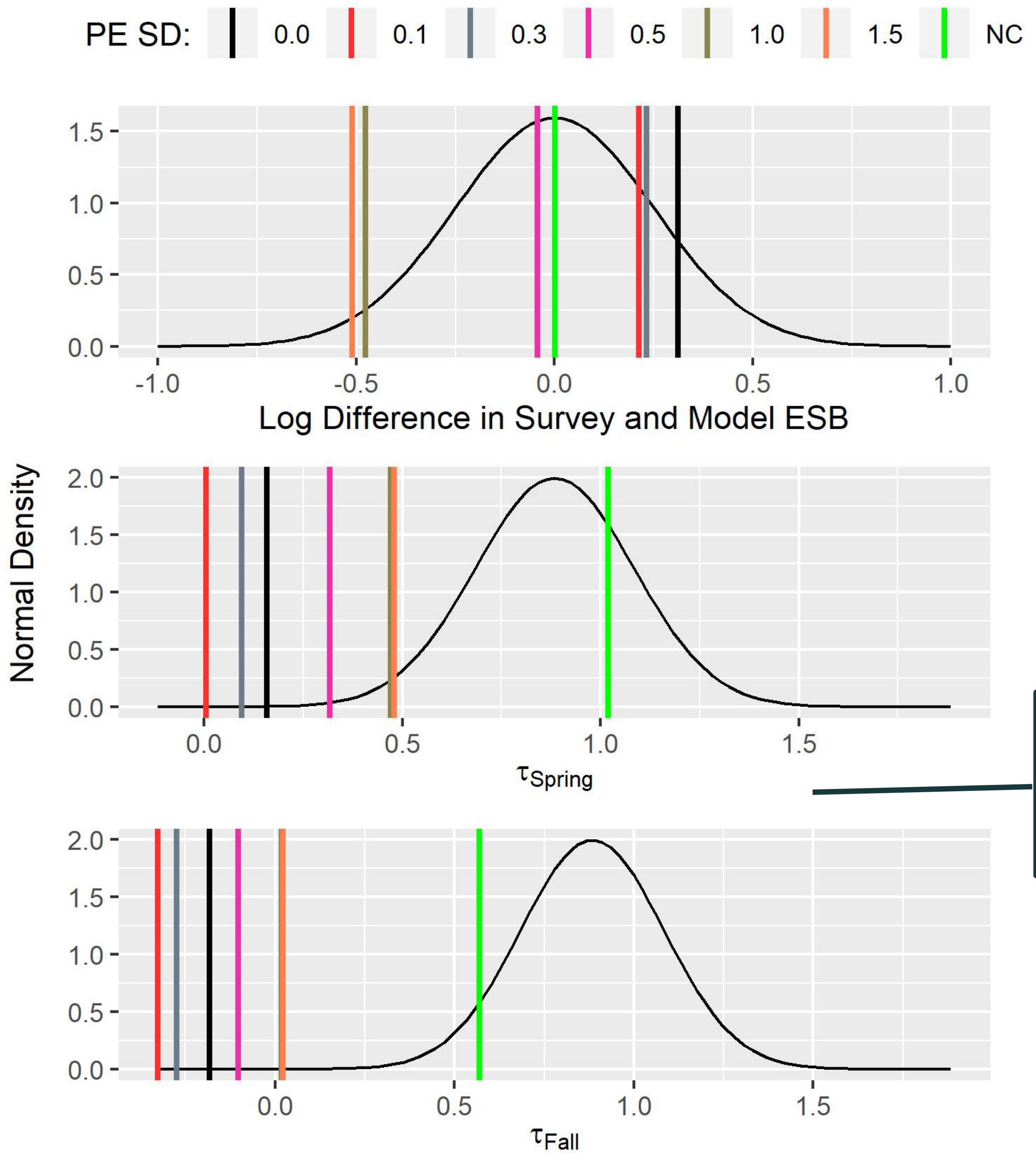
Assessment is sensitive to higher values of σ_M

Model Selection and Data-based Priors

Survey swept area biomass in 2018-19

Campelen-Engel comparative fishing

Campelen-Engel comparative fishing

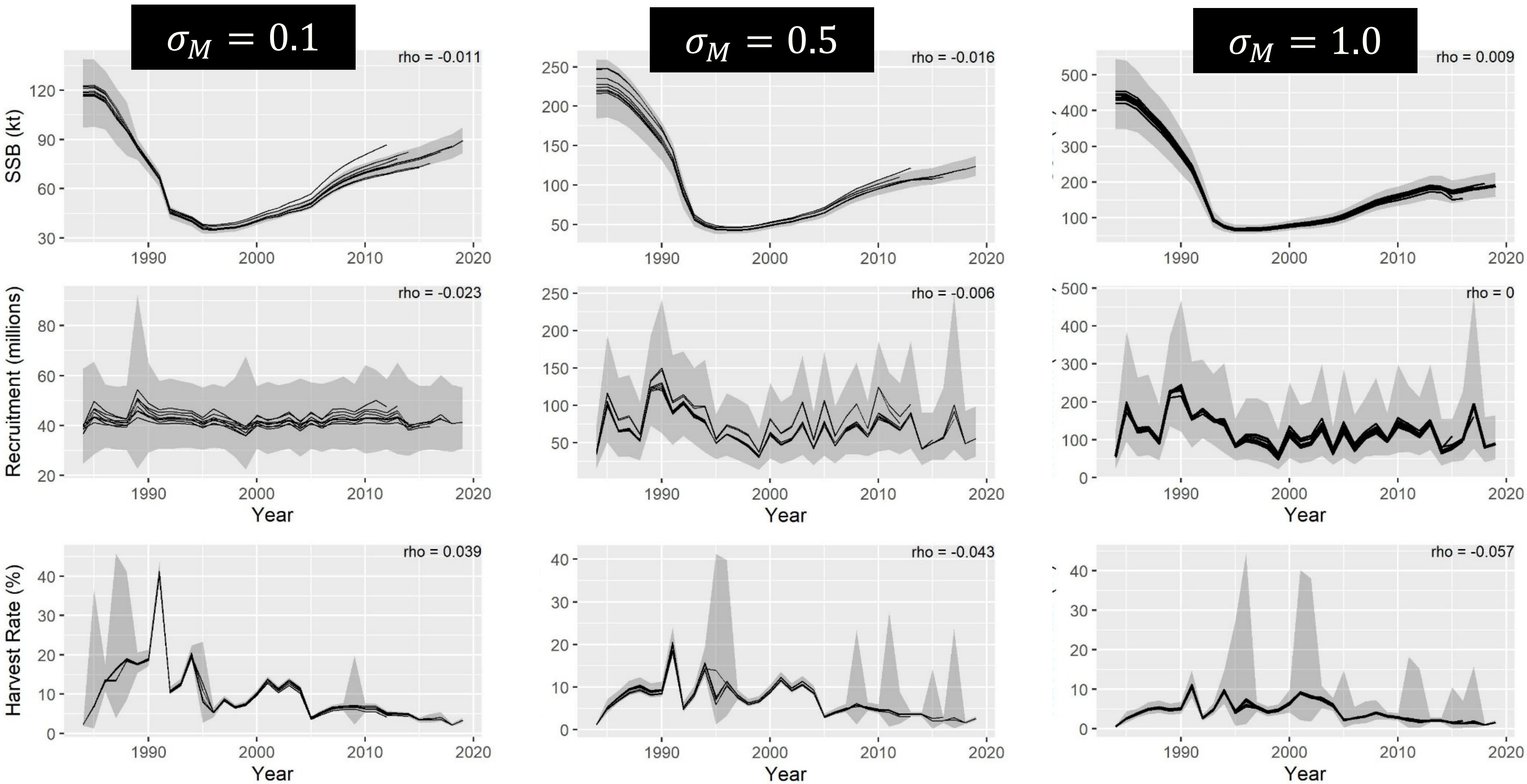


Models with catch are struggling to get the tilt right

Cadigan and Simpson. 2023. Contemporary analyses of comparative fishing data: a case study of Thorny Skate in NAFO Divisions 3LNOP. Journal of Northwest Atlantic Fishery Science. 54

Model Selection

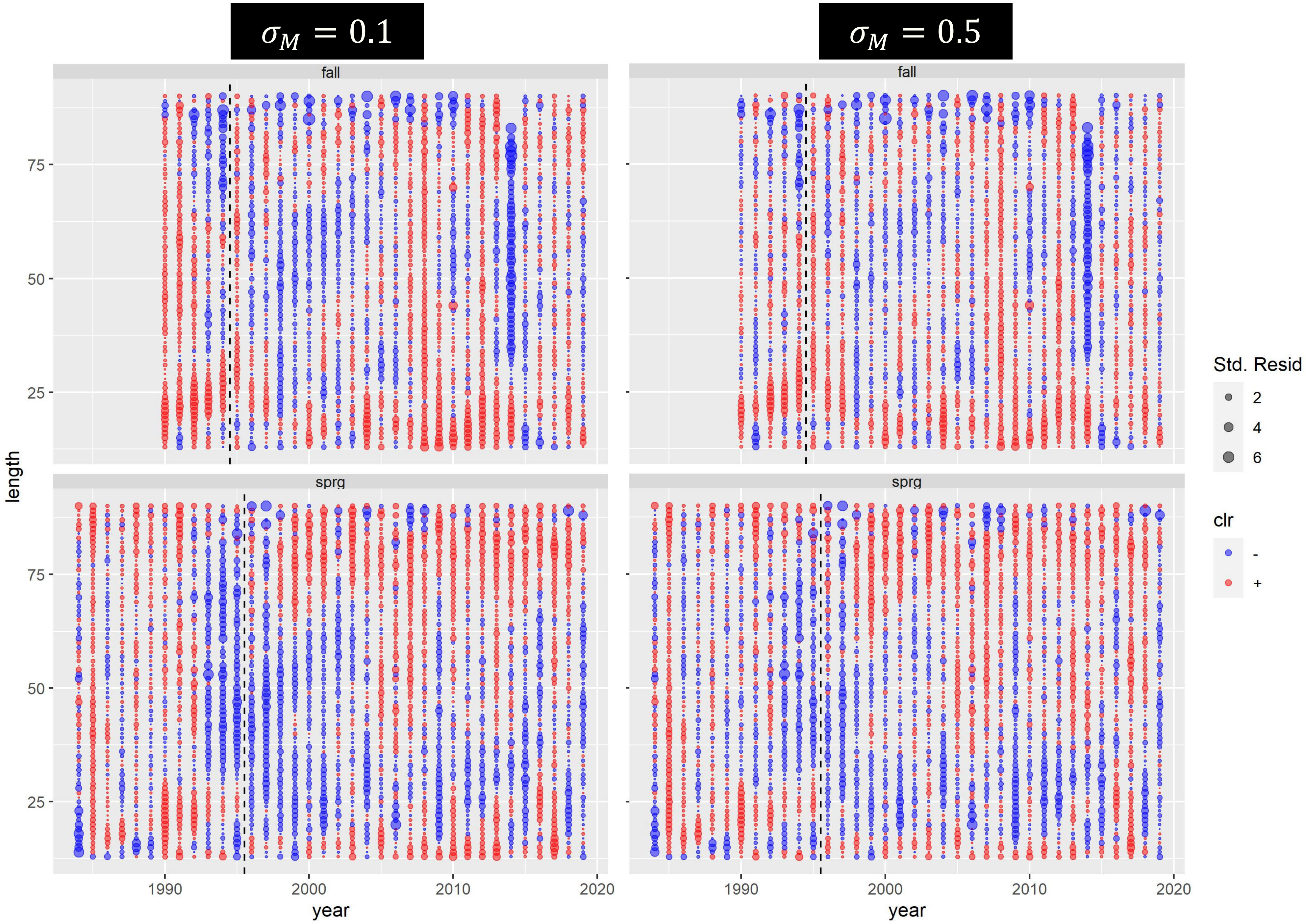
- Large σ_M produces higher retrospective variability



M retros get worse

Fits get worse

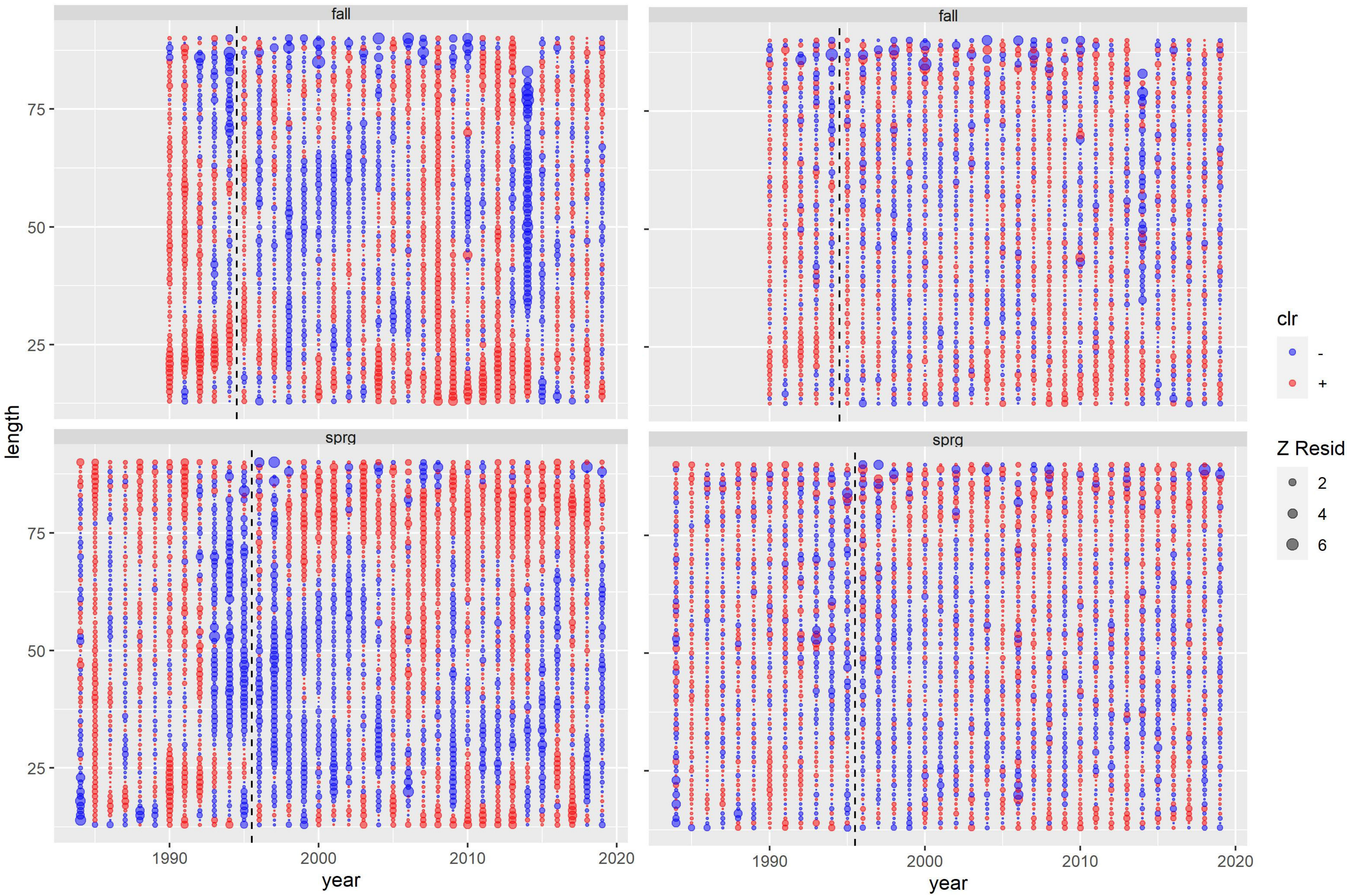
Model Differences



Model Differences

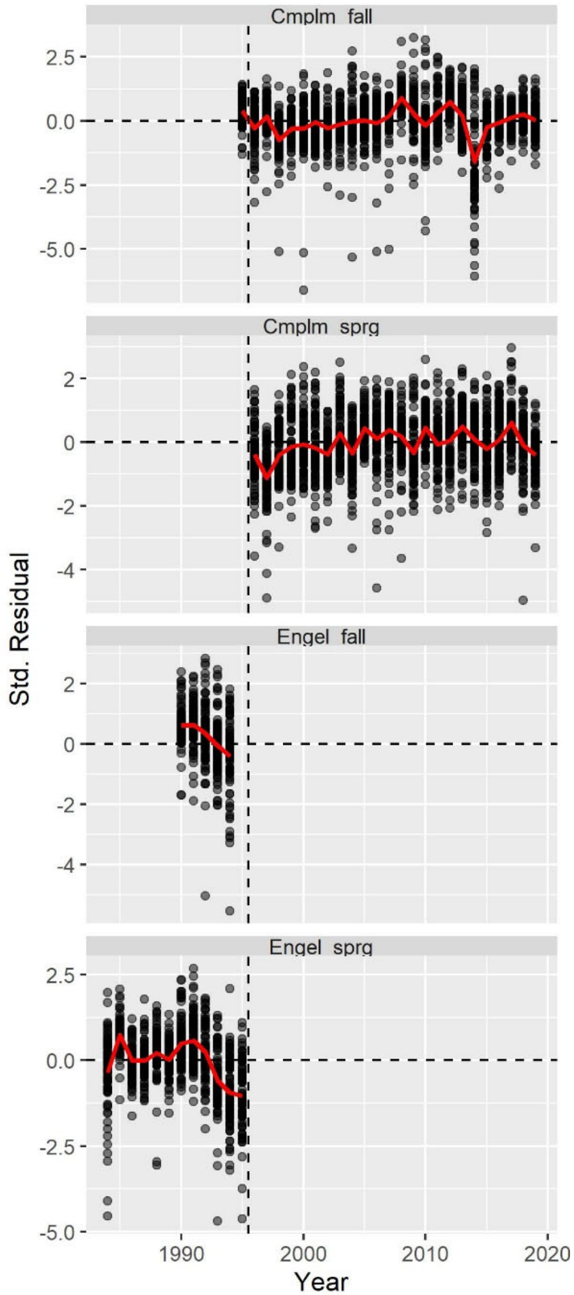
$\sigma_M = 0.1$

residuals

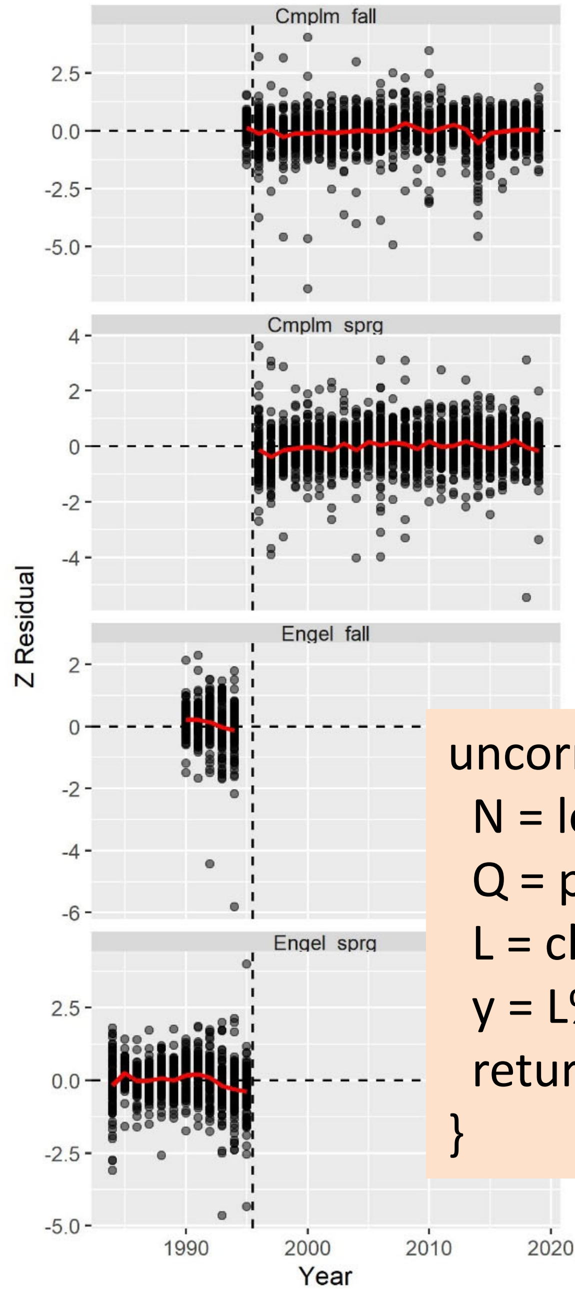


Model Differences

$(O - E)/SE$

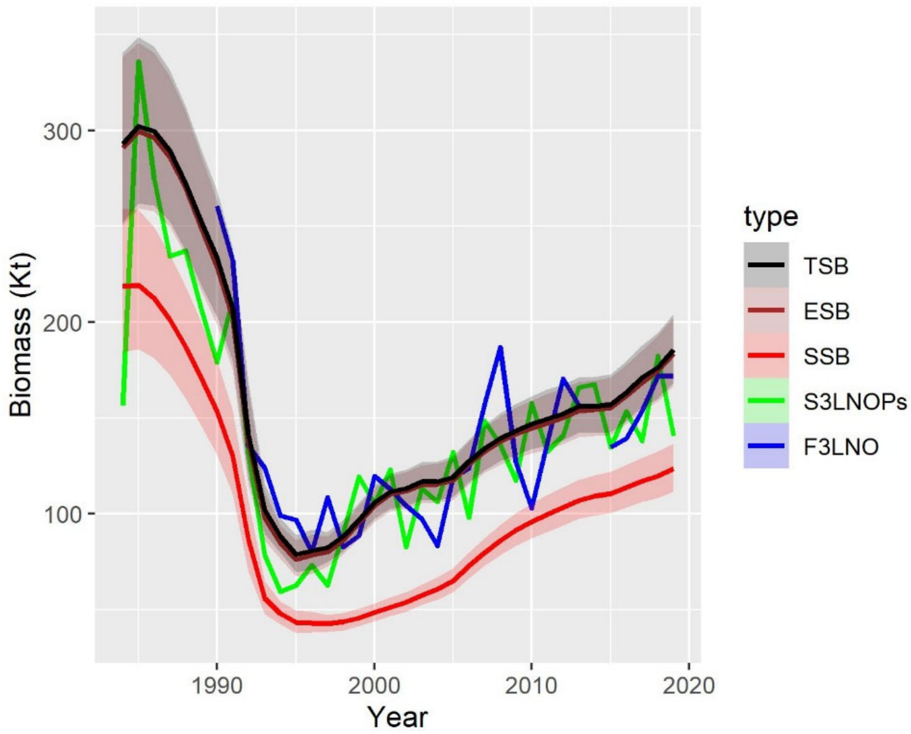


residuals



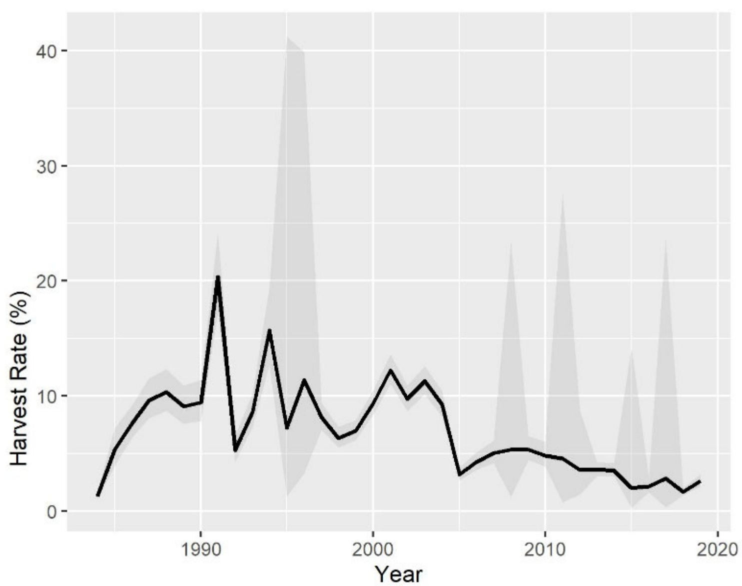

```
uncorr_resid = function(x){
  N = length(x)
  Q = precision.ar1(N, rep$phi_resid)
  L = chol(Q); #L%*%solve(Q)%*%t(L) = I;
  y = L%*%as.vector(x)
  return(y)
}
```

$\sigma_M = 0.5$



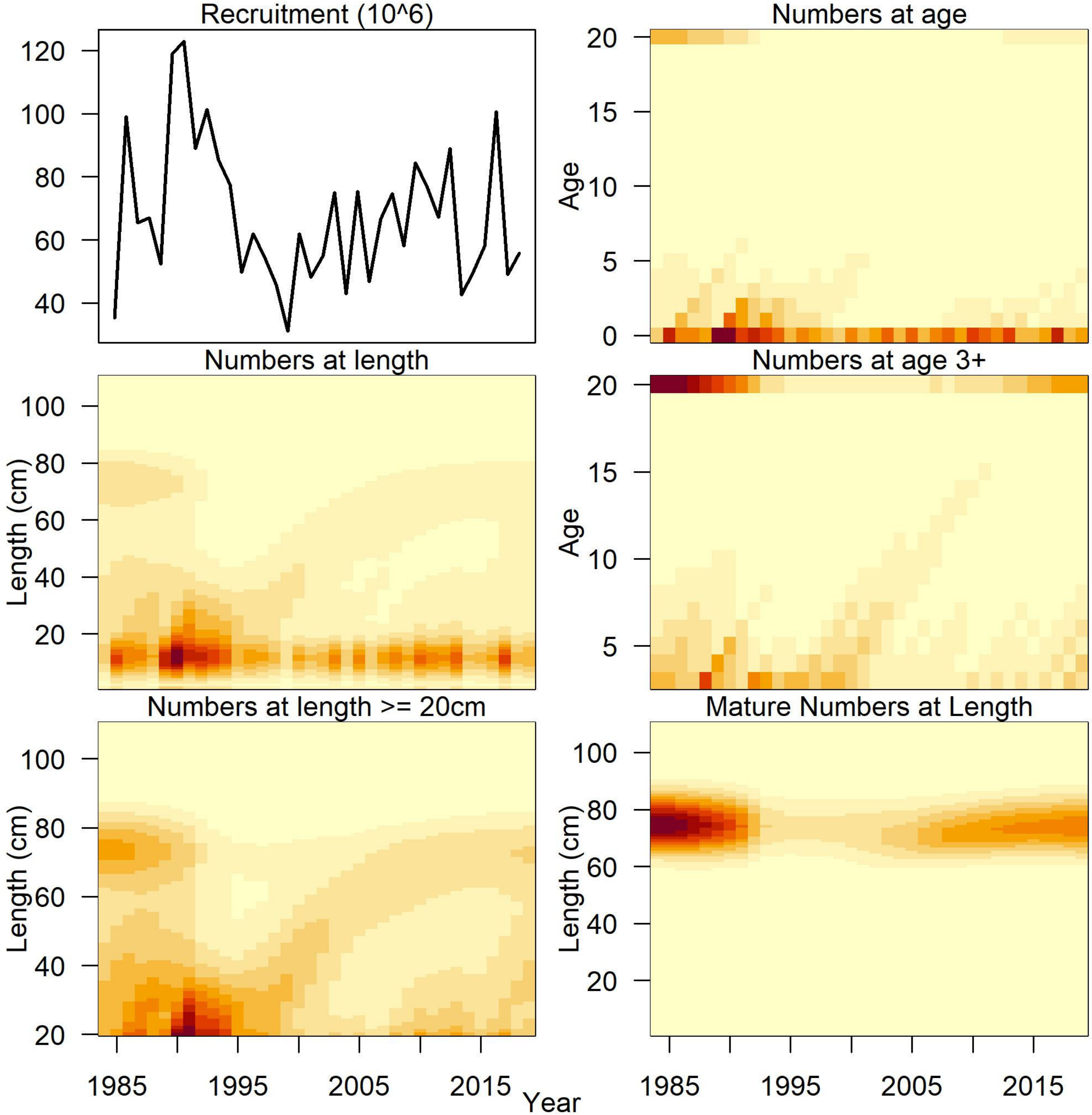
Biomass (Kt)
Year
type
TSB
ESB
SSB
S3LNOPs
F3LNO

F and M (sqrt scale)
Year



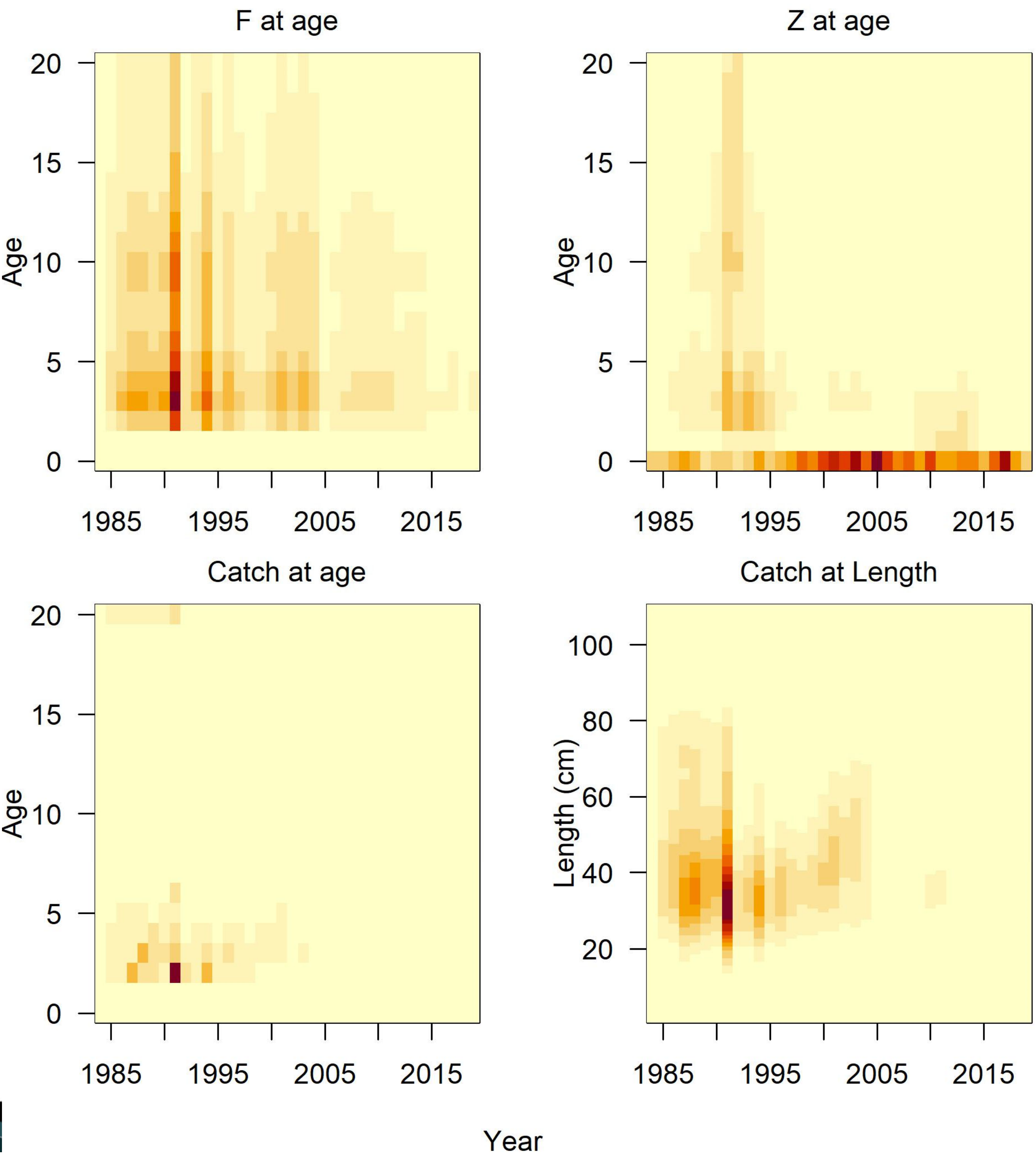
Harvest Rate (%)
Year

$\sigma_M = 0.5$

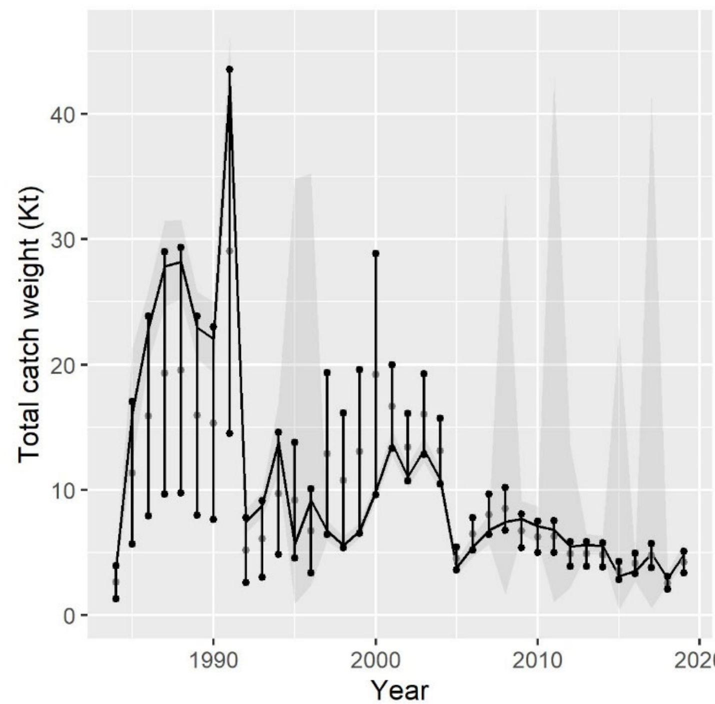


Recruitment (10^6)
120
100
80
60
40
Numbers at age
20
15
10
5
0
Age
Numbers at length
100
80
60
40
20
Length (cm)
Numbers at age 3+
20
15
10
5
Age
Numbers at length >= 20cm
100
80
60
40
20
Length (cm)
Mature Numbers at Length
100
80
60
40
20
Length (cm)
1985
1995
2005
2015
Year
1985
1995
2005
2015

$\sigma_M = 0.5$

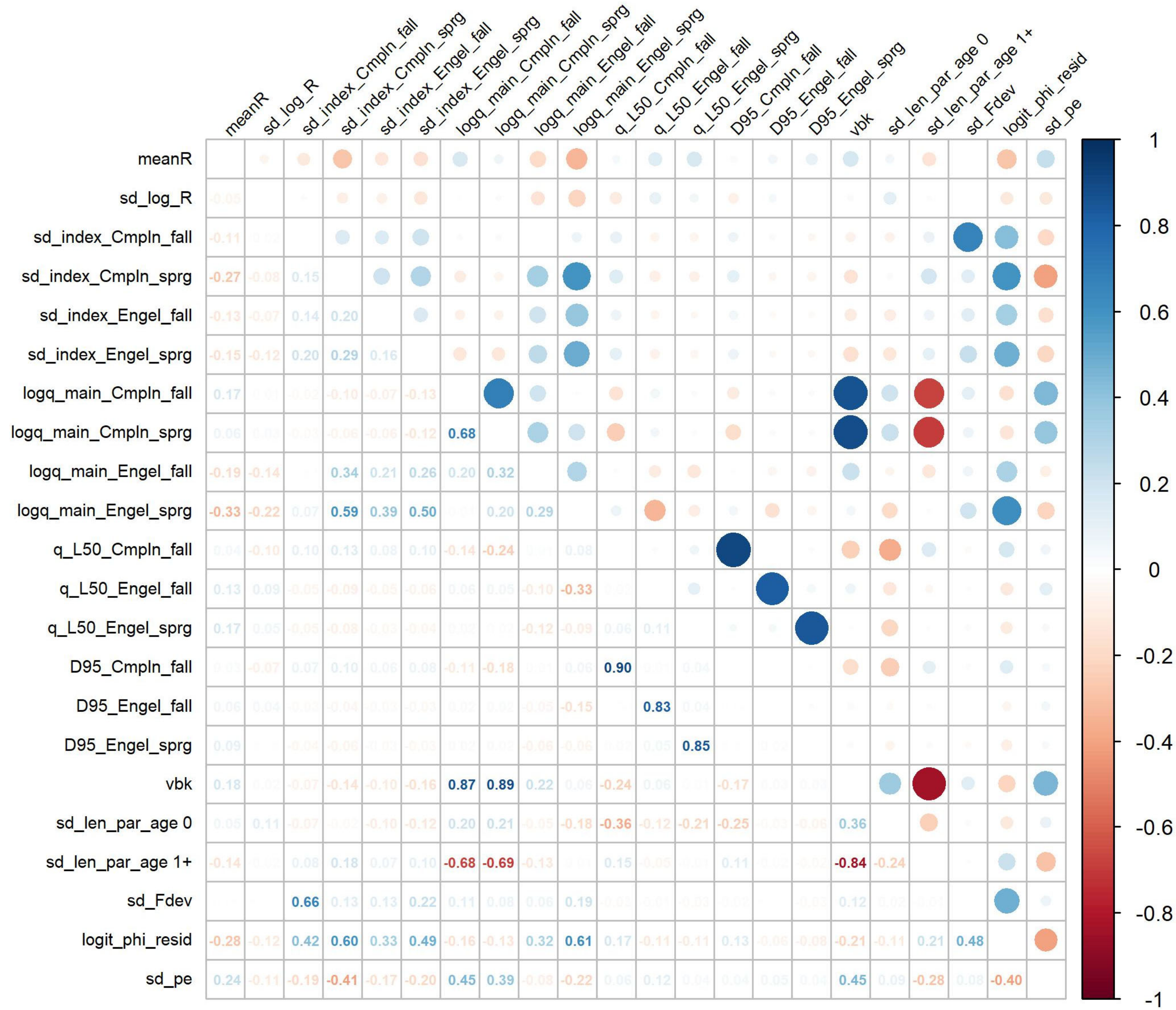


F at age
Z at age
Catch at age
Catch at Length
Age
Length (cm)
Year
1985
1995
2005
2015
0
5
10
15
20
40
60
80
100



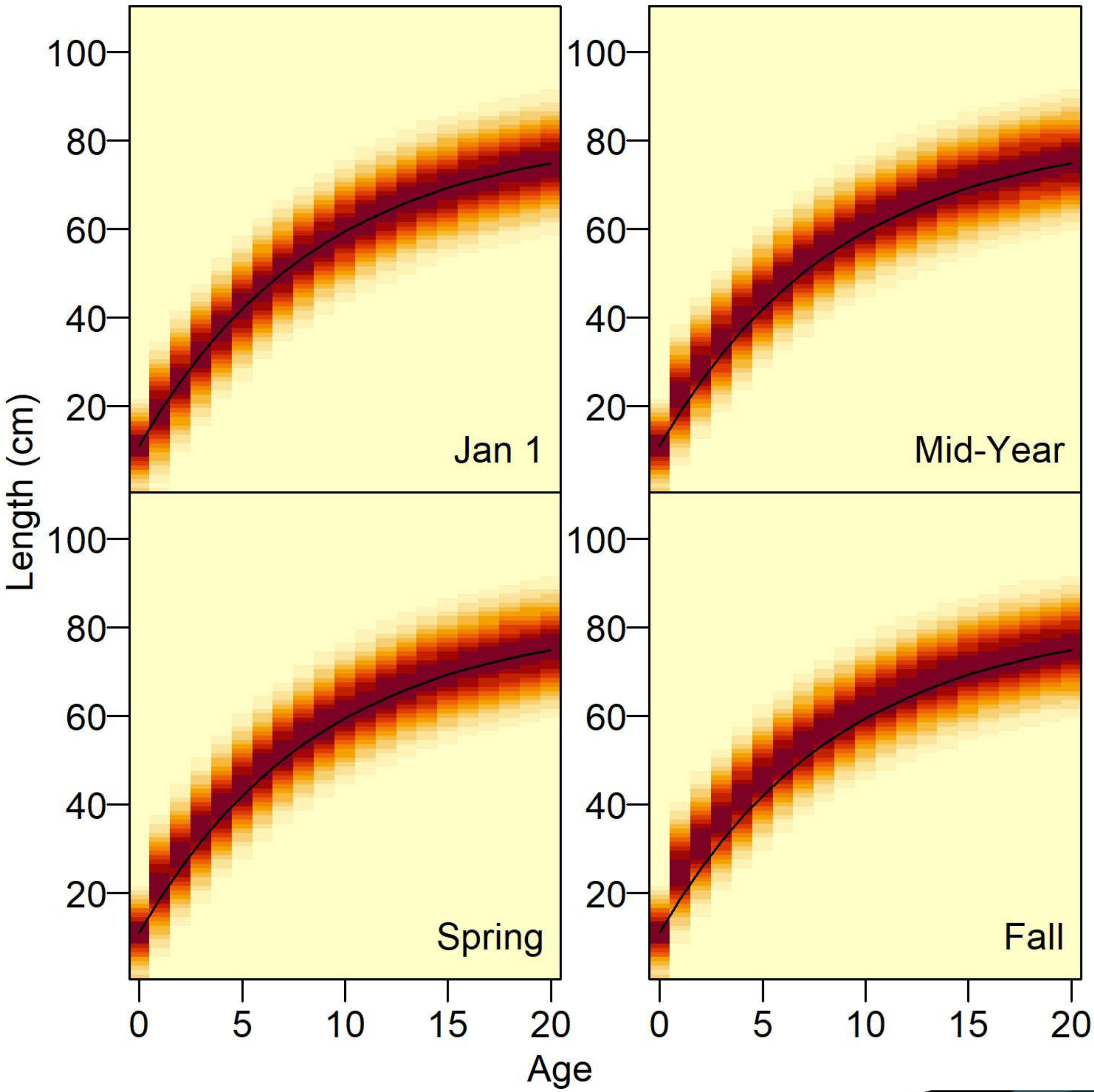
Total catch weight (Kt)
Year
1990
2000
2010
2020
0
10
20
30
40

$\sigma_M = 0.5$



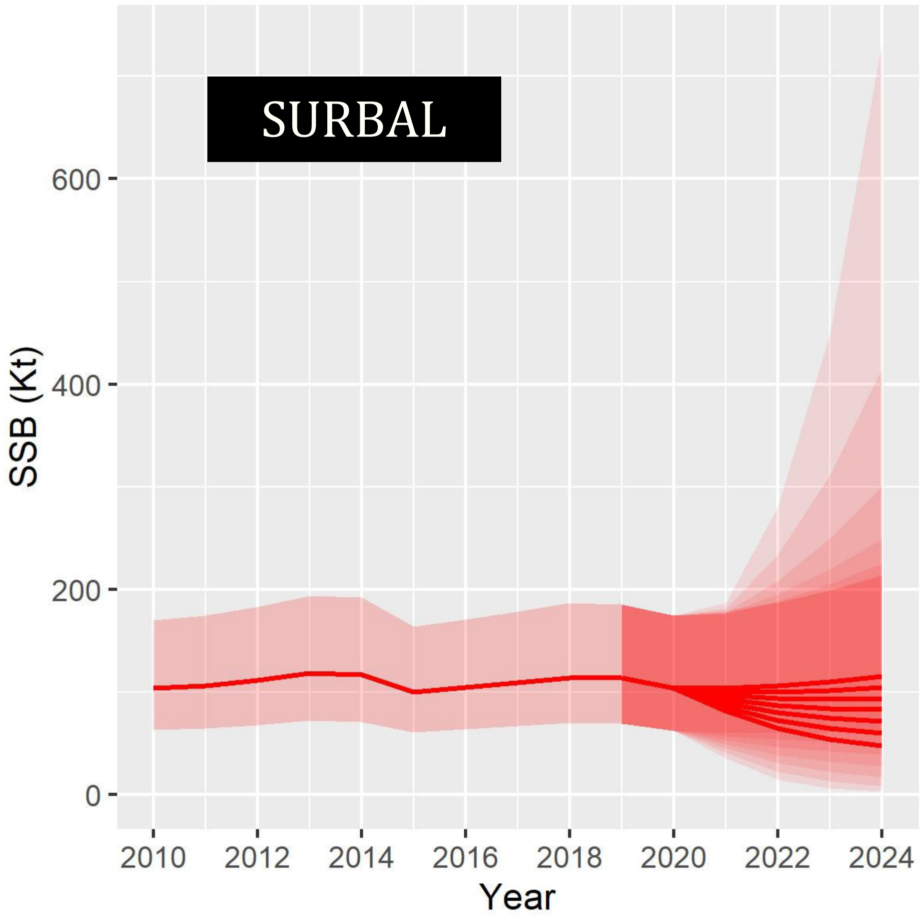
meanR
sd_log_R
sd_index_Cmpln_fall
sd_index_Cmpln_sprg
sd_index_Engel_fall
sd_index_Engel_sprg
logq_main_Cmpln_fall
logq_main_Cmpln_sprg
logq_main_Engel_fall
logq_main_Engel_sprg
q_L50_Cmpln_fall
q_L50_Engel_fall
q_L50_Engel_sprg
D95_Cmpln_fall
D95_Engel_fall
D95_Engel_sprg
vbk
sd_len_par_age 0
sd_len_par_age 1+
sd_Fdev
logit_phi_resid
sd_pe
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1

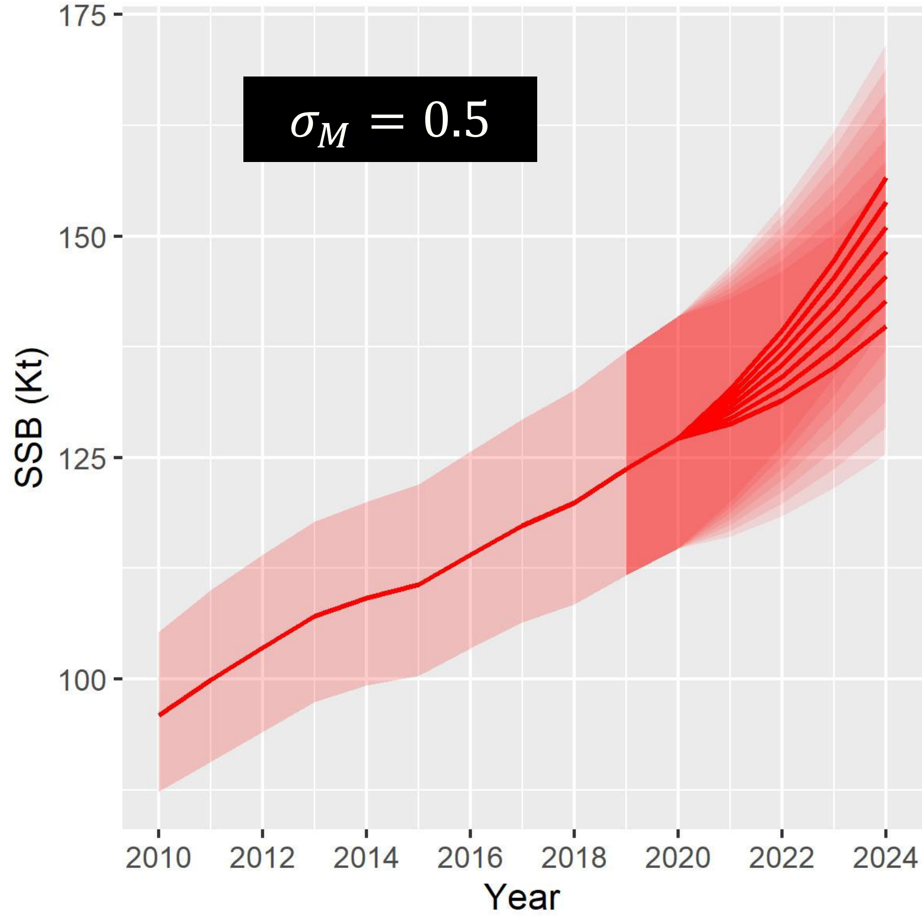
$\sigma_M = 0.5$



Length (cm)
Age
Jan 1
Mid-Year
Spring
Fall
0
5
10
15
20
20
40
60
80
100

Catch Multiplier Projections





Potential Improvements

- More explorations of M
- Work on Q length pattern
- Are there reliable fishery size comps to use (i.e., reliable meaning reflecting whole fishery (Canada + International) or at least most of the catches
- How reliable are the total catch weights?
- If there are some random or conditional age samples then this can be added to the mix
  - Did this for 2J3KL witchflounder and the results suggested huge ageing errors at older ages that preliminary results of an ageing study suggested could be possible

Potential Pelagic Benefits

- Can directly use fleet length sampling even if the fleet has no age samples
- Can use intermittent age samples
- Customized code can use age information “for what it is worth”
  - i.e., if only the first few ages can be reliably determined then fit these with a plus group
- Censored catch
- Maybe I will have more to add here at the end of this workshop?