NOAA FISHERIES

NEFSC
Woods Hole, MA

The Woods Hole Assessment Model: WHAM:

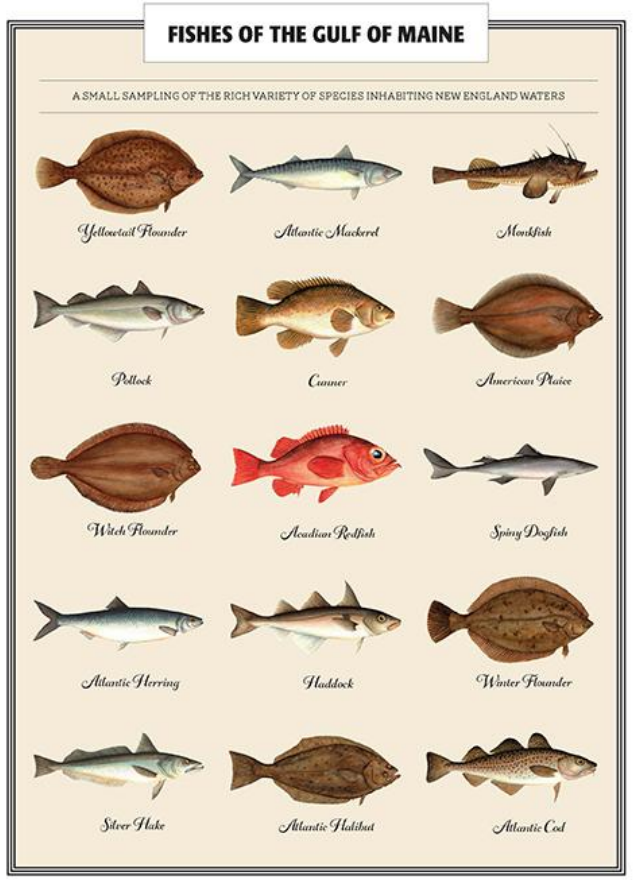
Incorporating environmental covariates into a state-space assessment framework

Brian Stock and Tim Miller

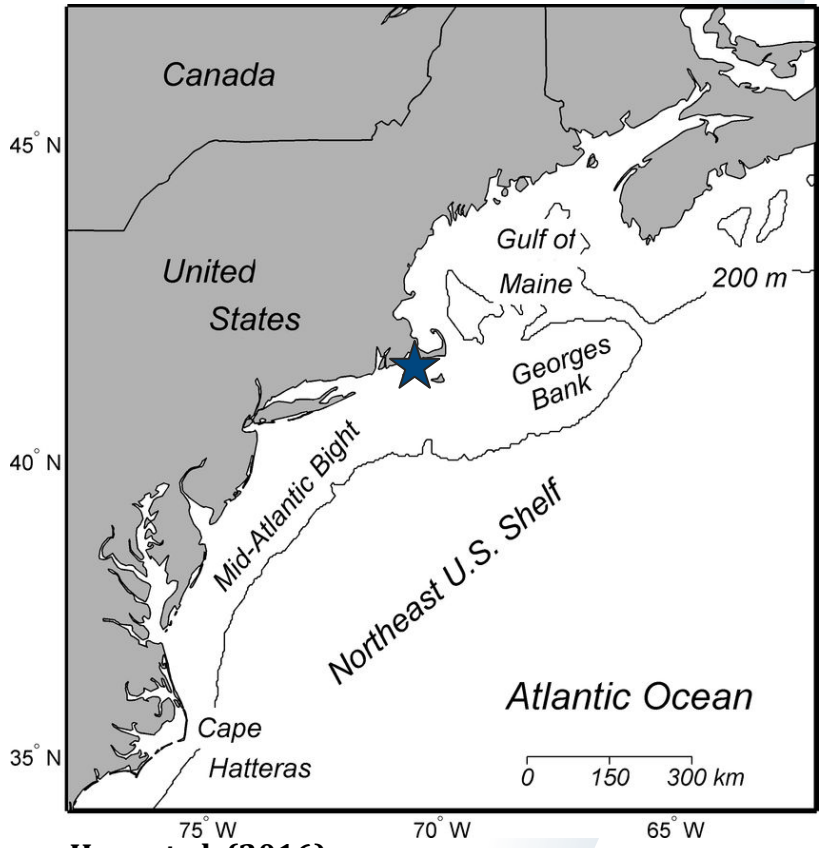
CAPAM Next-Gen
Nov 7, 2019

Northeast U.S. assessments

- Long history, high F (pre-data)
- Empirical weight-at-age



Brenda Gillespie/chartingnature.com



Hare et al. (2016)

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Northeast U.S. assessments

- Long history, high F (pre-data)
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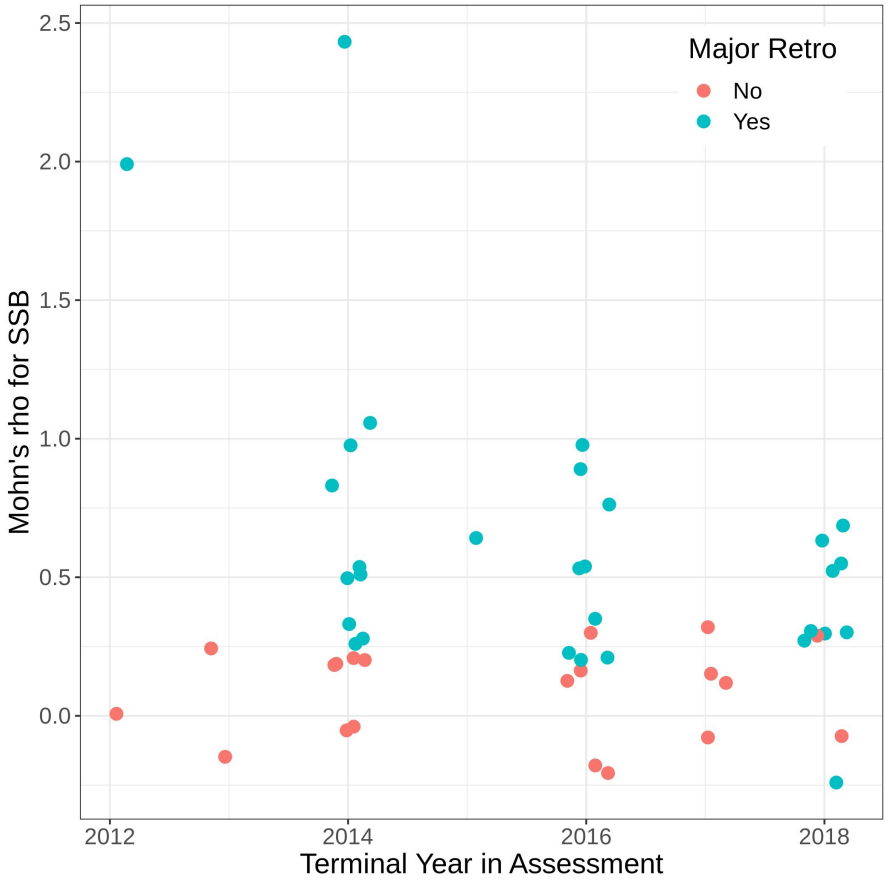
- Retrospective patterns



C. Legault (draft)

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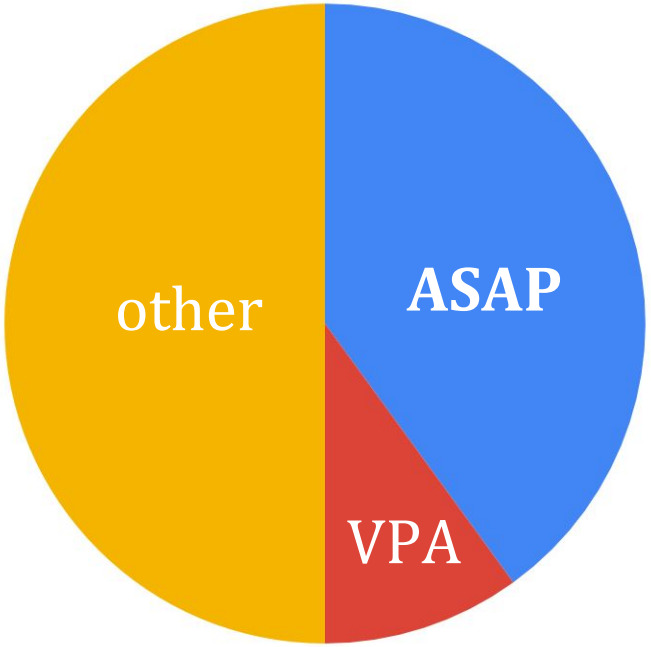
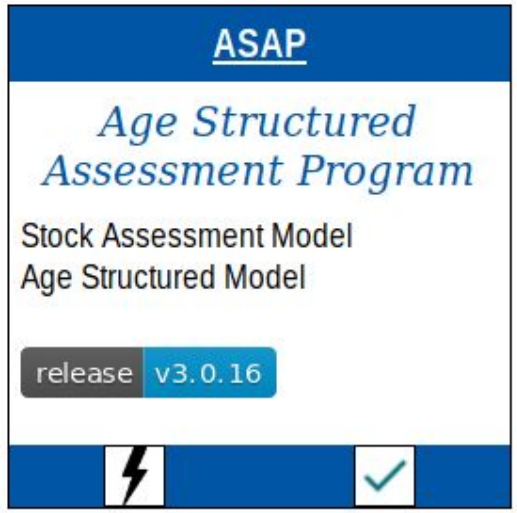
Northeast U.S. assessments

- Long history, high F (pre-data)
- Empirical weight-at-age
- Retrospective patterns
- Models used (roughly)



ASAP = traditional SCAA
Legault & Restrepo (1998)



admb
FAST, ACCURATE, STABLE OPTIMIZATION

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Northeast U.S. assessments

- Long history, high F (pre-data)
- Empirical weight-at-age
- Retrospective patterns
- Models used (roughly)
- “Operational” vs. “Benchmark”

Operational	Benchmark
Tactical	Research
Minor tweaks	Structural changes
1-2 years	5 years

ASAP ← WHAM

2023 ?

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Motivation #1: state-space

ICES CIEM Methods Working Group

"Compare traditional SCAA vs. state-space models"

- SCAA: **ASAP, SS, a4a**
- State-space: **SAM, WHAM**

Fitting models to data for 13 North Atlantic stocks

- minimal tinkering
- required writing scripts to convert input files:

SAM → ASAP
VPA → ASAP

ASAP → ICES

ASAP → WHAM

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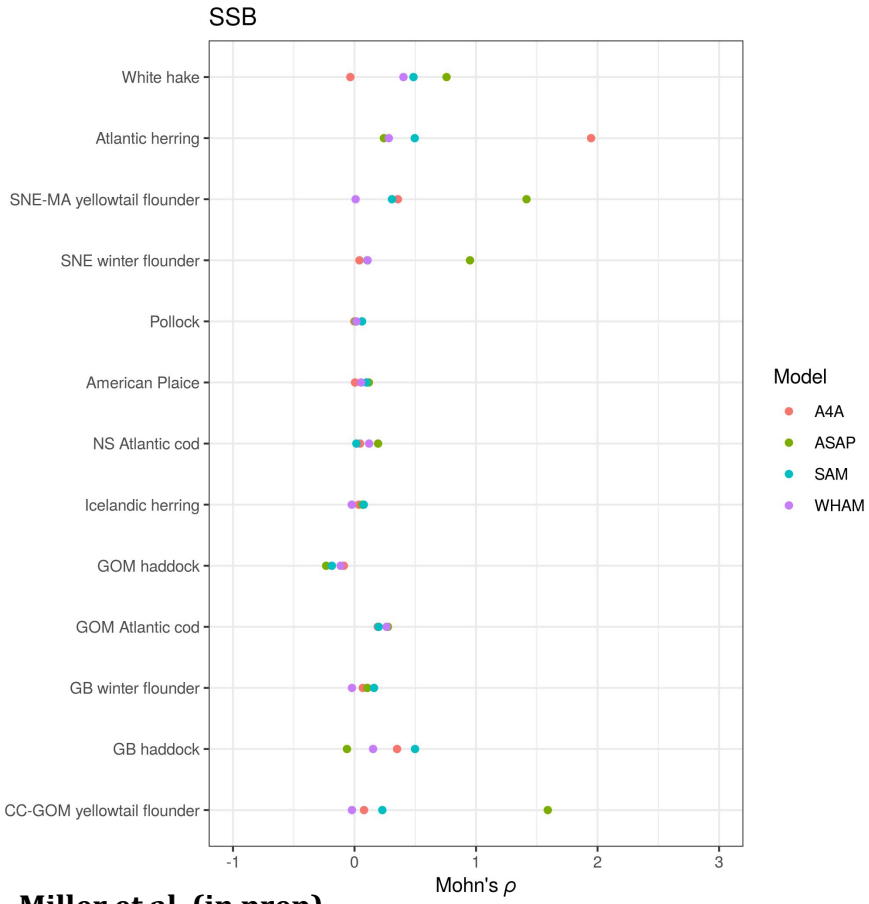
Motivation #1: state-space

Preliminary results

1. State-space models *tended* to have **less retrospective patterns** than SCAA models without time-varying fishery selectivity
2. Comparisons within WHAM framework:
   a. State-space models perform better (**lower AIC**)
   b. **More realistic (larger) uncertainty** in output from state-space models



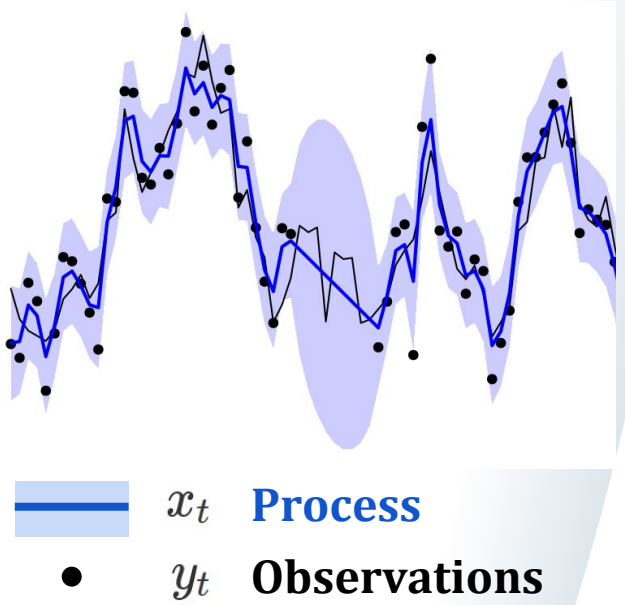
Miller et al. (in prep)

Motivation #1: state-space

In addition...

- Estimates **process and observation error**
- Easily handles **missing observations**
- Easily includes **variation** in demographic processes

  Recruitment, mortality, maturity, growth, catchability, etc.



Useful with or without environmental effects

Numbers-at-age options in WHAM

Statistical catch-at-age

$$\log N_{a,y} = f(\log N_{a-1,y-1})$$

ASAP
Legault & Restrepo (1998)

Statistical catch-at-age w/ random recruitment

$$\log N_{a,y} = f(\log N_{a-1,y-1}) \quad \log N_{1,y} \sim \mathcal{N}\left[\underset{f(SSB)}{\log R_0}, \sigma_R^2\right]$$

Full state-space

$$\log N_{a,y} \sim \mathcal{N}\left[f(\log N_{a-1,y-1}), \sigma_a^2\right]$$

Easily test against
current assessment model

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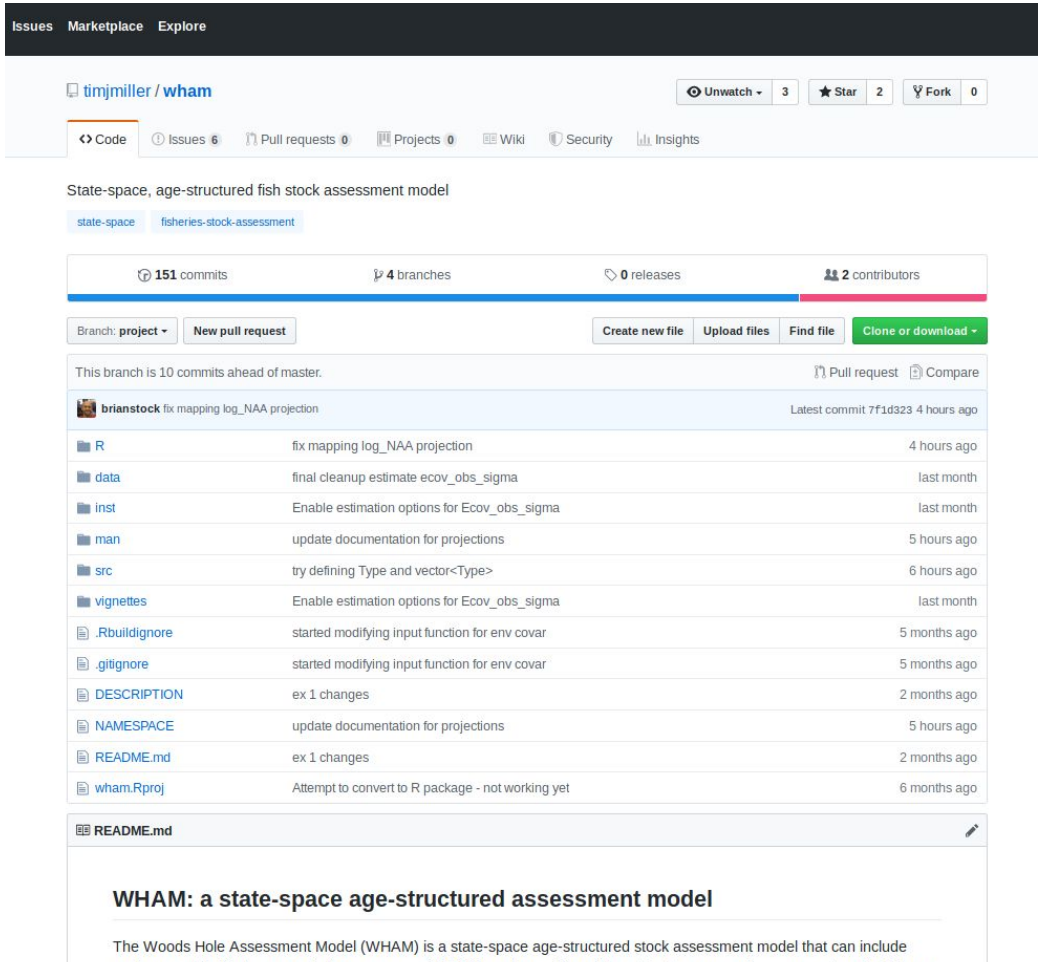
https://github.com/timjmiller/wham



Basic use:

```
devtools::install_github("timjmiller/wham")
```

Compiles .cpp

```
library(wham)
```

```
asap3 <- read_asap3_dat("ex1_SNEMAYT.dat")
```

```
input <- prepare_wham_input(asap3,
```

```
mod <- fit_wham(input, do.retro=TRUE, do.osa=TRUE)
```

\+ TMB

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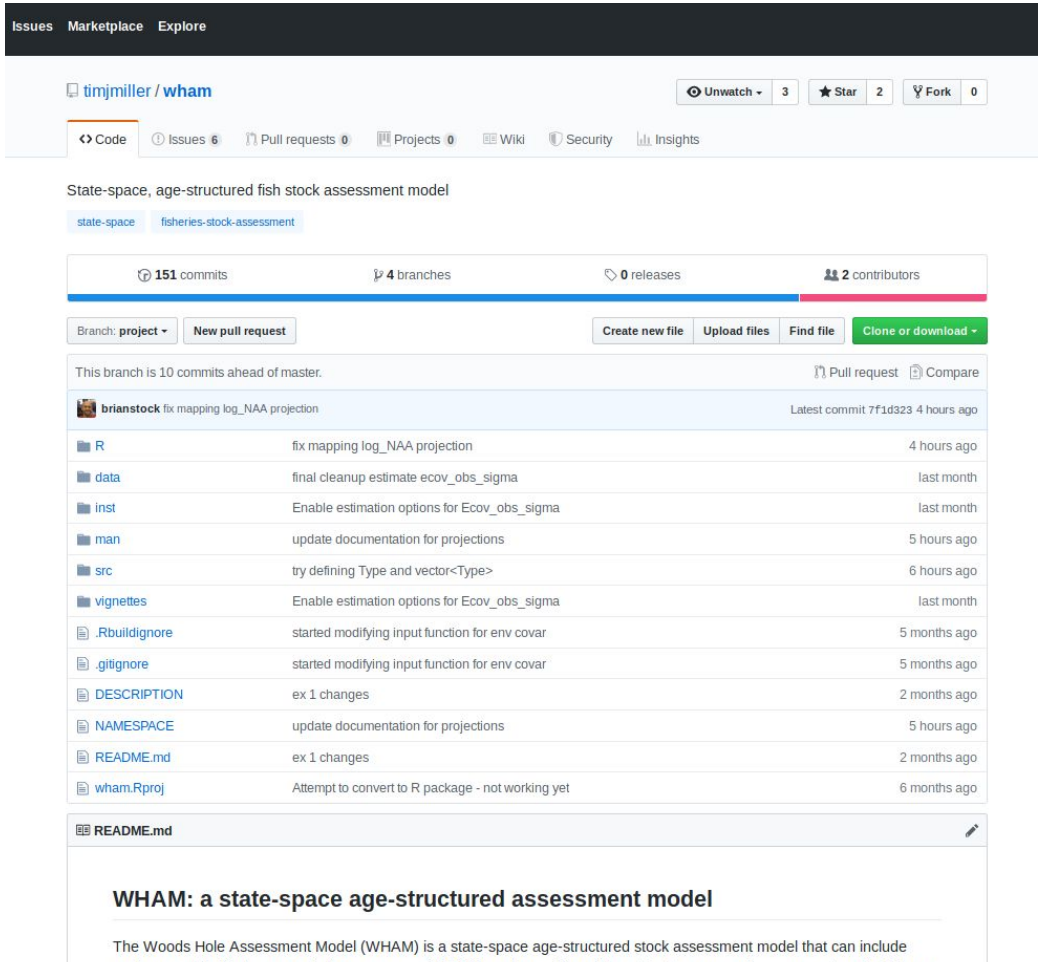

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```

```
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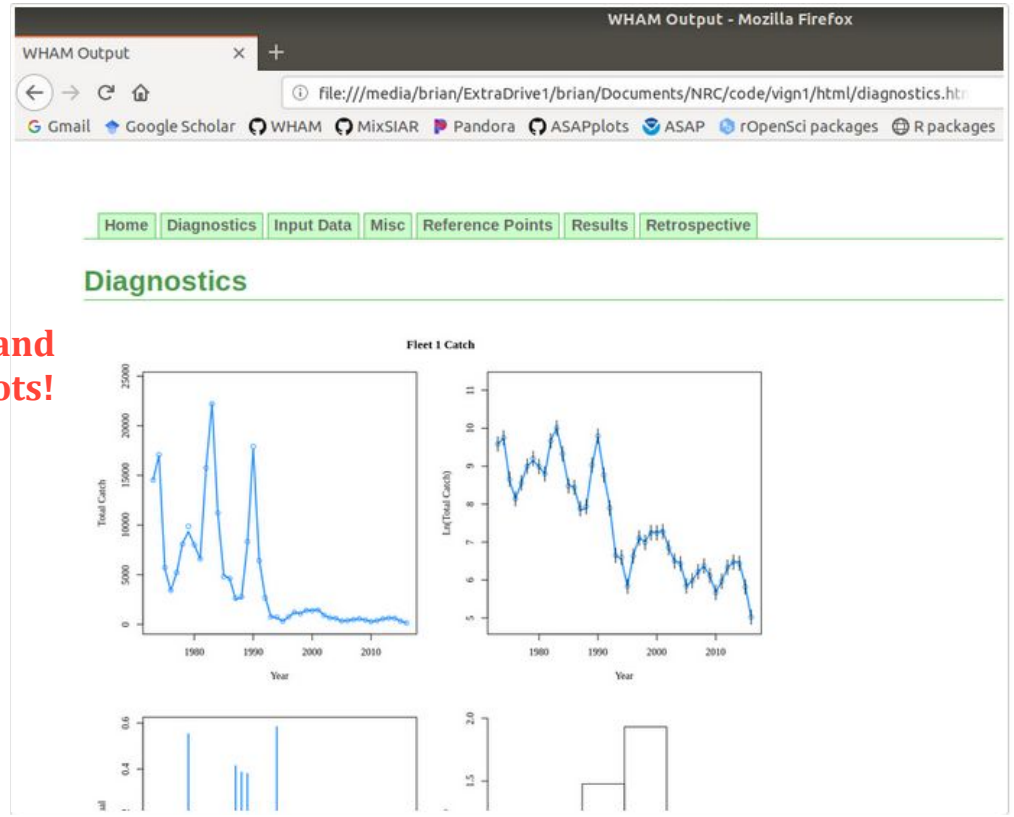
```

```
fit_tmb
retro
    fit_peel
        fit_tmb
osa
project_wham
    prepare_projection
    fit_wham
```

https://github.com/timjmiller/wham

```
plot_wham_output(mod=m4, out.type='html')
```



Thanks to r4ss and ASAPplots!

```
check_convergence(m1)
```

```
#> stats:nlminb thinks the model has converged: mod$opt$conve
#> Maximum gradient component: 1.01e-07
#> Max gradient parameter: log_F1
#> TMB:sdreport() was performed successfully for this model
```

```
res <- compare_wham_models(mods, fname=
```

```
#>        AIC  rho_R rho_SSB rho_Fbar
#> m4 -1466.9 0.3610  0.0091  -0.0106
#> m2 -1172.7 3.1589 -0.0735  -0.0167
#> m3  4107.1 0.1287  0.0304  -0.0162
#> m1  4846.5 0.8207  0.1905  -0.2322
```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How is WHAM different from SAM?

1. Catch observation model is like ASAP, not SAM

7 likelihood options

$$\log C_y \sim \mathcal{N}(\log \hat{C}_y, \sigma^2_{C_y})$$
$$\boldsymbol{p}_{\boldsymbol{C_y}} \sim \text{logisticNormal}$$

$$\log C_{y,a} \sim \mathcal{N}(\log \hat{C}_{y,a}, \sigma^2_{C_{y,a}})$$

2. F vs. selectivity

$$Sel_a \sim \text{4 options}$$
$$logF_y = logF_{y-1} + \delta_y$$
$$F_{y,a,f} = F_{y,f} \cdot Sel_a$$

$$\log F_y = \log F_{y-1} + \xi_y$$
$$\xi_y \sim \mathbf{N}(0, \Sigma)$$

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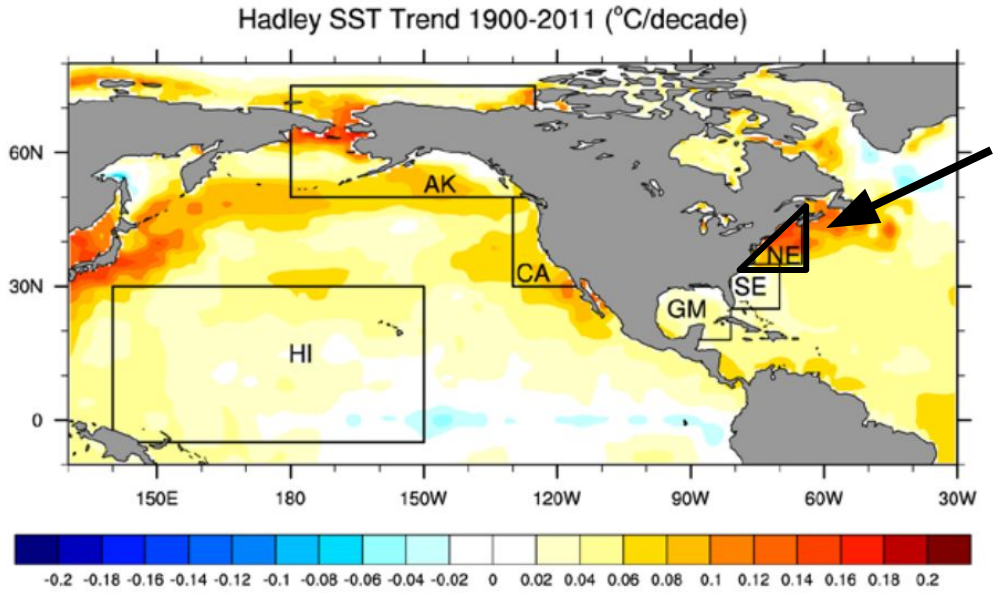
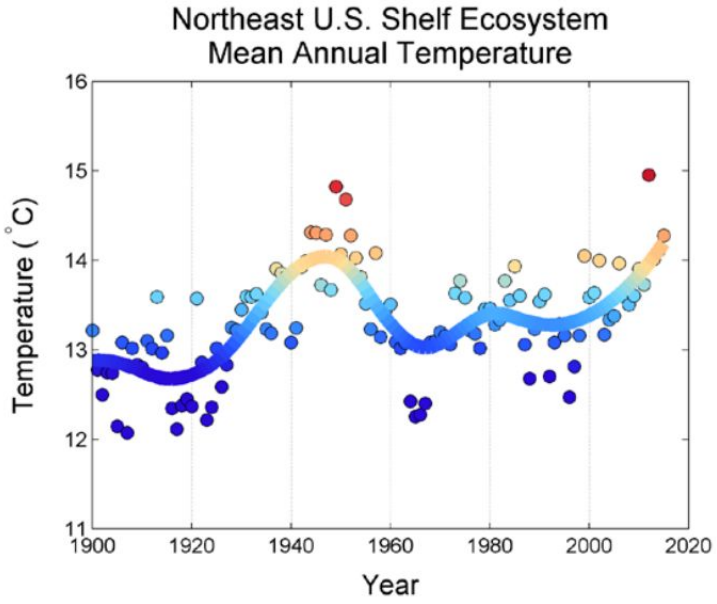
Why is WHAM different from SAM?

- Useful if it can approximate ASAP
- WHAM observation model natural for landings data as weight + age comp (w/ separate survey sampling for age comp)
- Traditional treatment of F and selectivity can be useful for projections
  - e.g. you want to specify F to calculate a reference point instead of continuing a F time-series process

Motivation #2: environmental effects

- **Changing conditions** on NE U.S. Shelf





Priority #1: Continue development of stock assessment models that include environmental terms

(Hare et al. 2016)

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Motivation #2: environmental effects

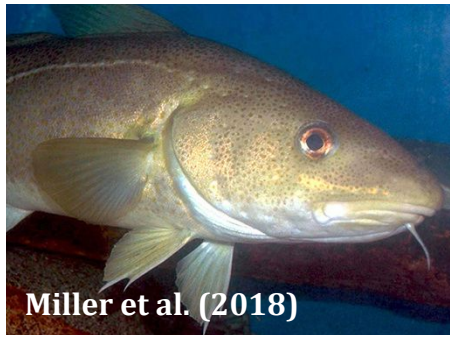
- **Changing conditions** on NE U.S. Shelf
- Allows for **testing of environment-stock-recruitment** relationships
- **Reduced retrospective** patterns
- **Lower residual variance**

Cold Pool, Gulf Stream

Recruitment

Bottom temperature

Growth + maturity



Gulf Stream

Natural mortality + recruitment

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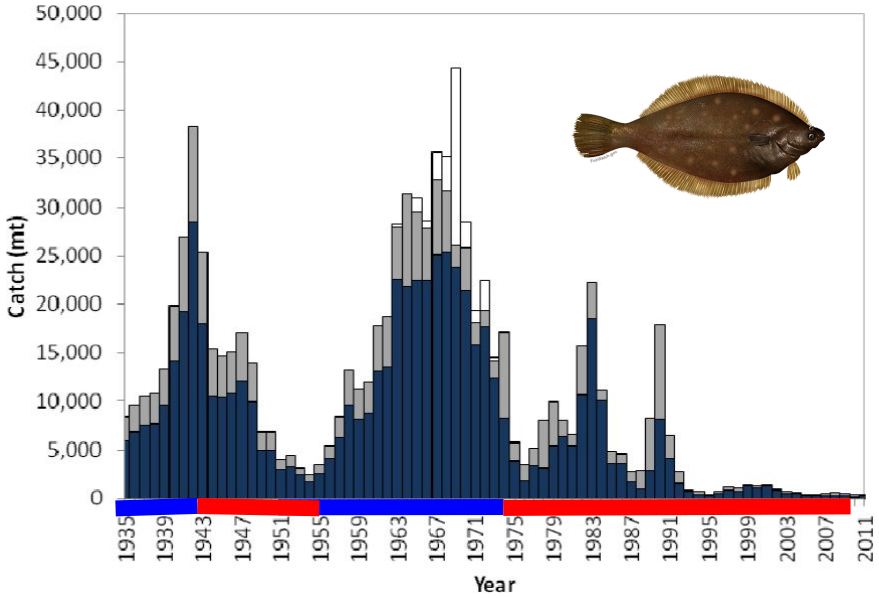
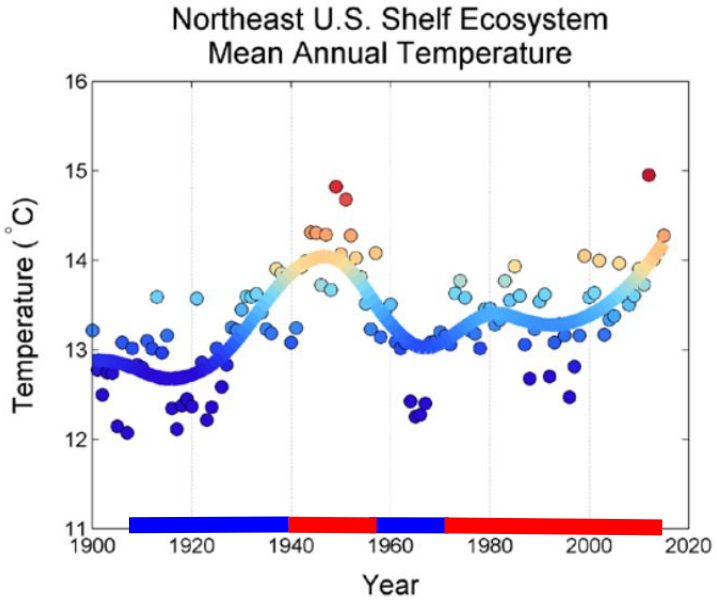
Ex: Recruitment of yellowtail flounder

Long-hypothesized temperature effect

Taylor et al. (1957), Sissenwine (1974), Steves et al. (2000), Sullivan et al. (2000, 2005)





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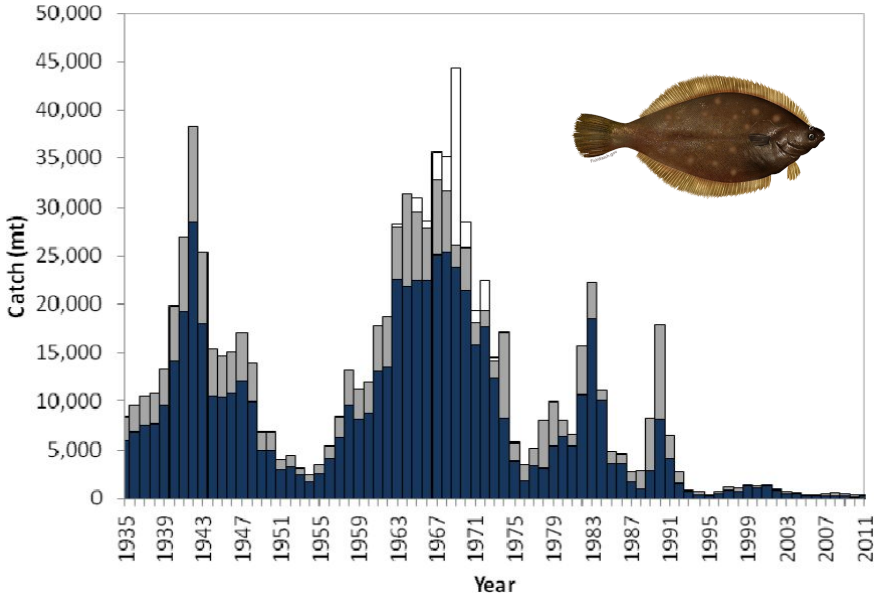

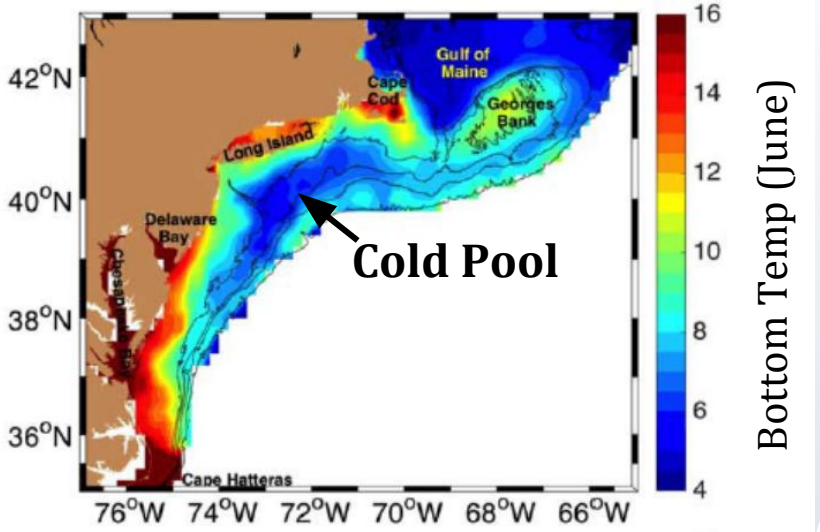

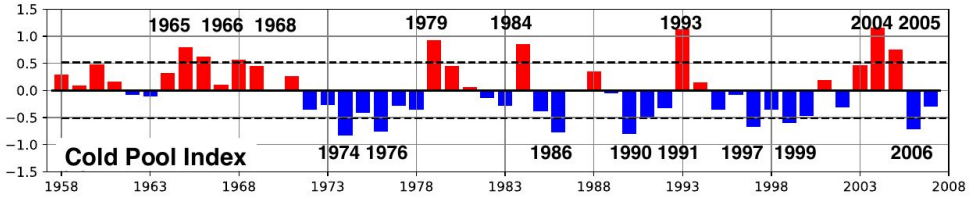

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Ex: Recruitment of yellowtail flounder

Cold Pool models:

1. Random walk

$$\boldsymbol{\theta} = (x_1, \sigma_x^2, \sigma_y^2)$$
$$\boxed{x_t} = x_{t-1} + \mathcal{N}(0, \sigma_x^2)$$
$$y_t = x_t + \mathcal{N}(0, \sigma_y^2)$$

2. AR1

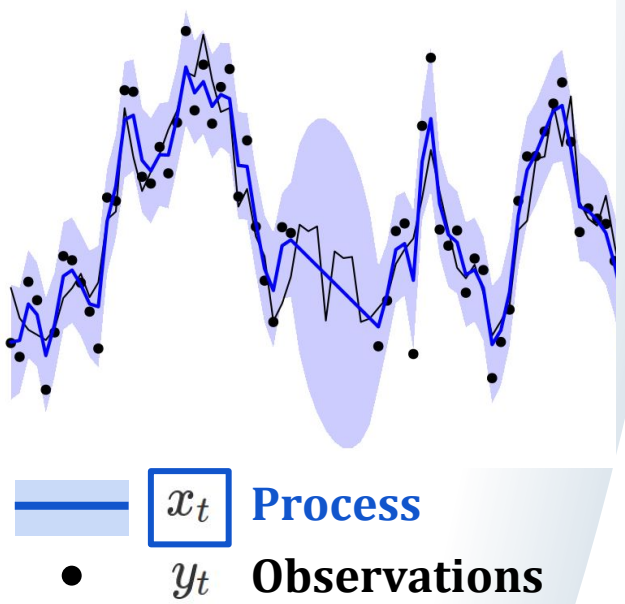
$-1 < \phi < 1$

$$\boldsymbol{\theta} = (\mu, \sigma_x^2, \sigma_y^2, \phi)$$
$$\boxed{x_t} = \mu + \phi x_{t-1} + \mathcal{N}(0, \sigma_x^2)$$
$$y_t = x_t + \mathcal{N}(0, \sigma_y^2)$$

σ_y^2 Observation error options:

- User-specified
- Estimate one value σ_y^2
- Estimate year-specific $\sigma_{y,t}^2$

$$\sigma_{y,t}^2 \sim \mathcal{N}(m, s)$$



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Ex: Recruitment of yellowtail flounder

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$$y_t = x_t + \mathcal{N}(0, \sigma_y^2)$$

Recruitment models:

1. Random walk
2. Random about mean
3. Beverton-Holt
4. Ricker

$$\hat{R}_t =$$

$$R_{t-1}$$

$$e^{\gamma x} R_0$$

$$\frac{\alpha S e^{\gamma x}}{1 + \beta S} \Big/ \frac{\alpha S}{1 + \beta S e^{\gamma x}} \Big/ \frac{\alpha S}{e^{\gamma x} + \beta S}$$

$$\alpha S e^{-\beta S + \gamma x} \Big/ \alpha S e^{-\beta S (1 + \gamma x)}$$

Iles & Beverton (1998)

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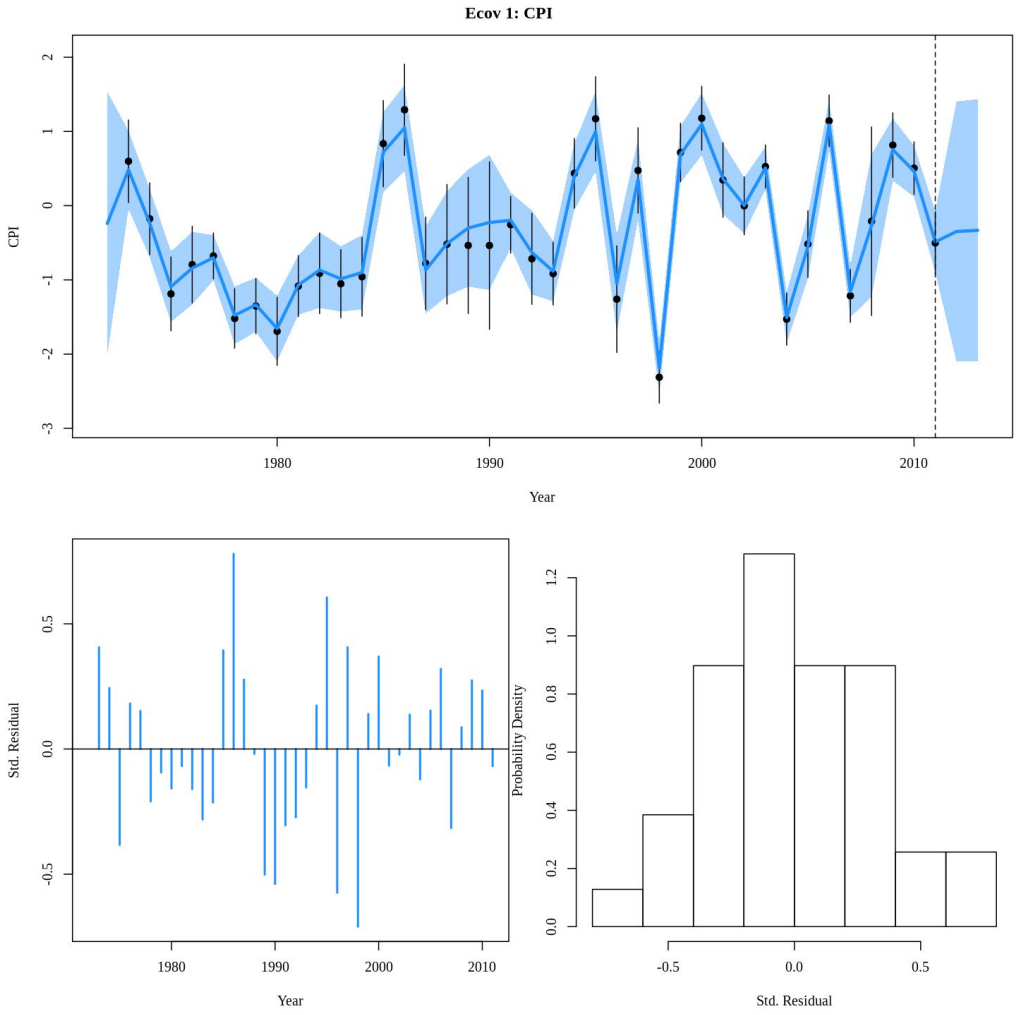
Ex: Recruitment of yellowtail flounder

```
Ecov <- list(
  label = "CPI",
  mean = as.matrix(env.dat$CPI),
  sigma = as.matrix(env.dat$CPI_sigma),
  year = env.dat$Year,
  use_obs = matrix(1, ncol=1, nrow=dim(env.dat)[1]), # use all obs (all = 1)
  lag = 1, # CPI in year t affects recruitment in year t+1
  process_model = df.mods$Ecov_process[m], # "rw" or "ar1"
  where = "recruit", # CPI affects recruitment
  how = df.mods$Ecov_how[m]) # 0 = no effect, 1 = controlling, 2 = limiting
```

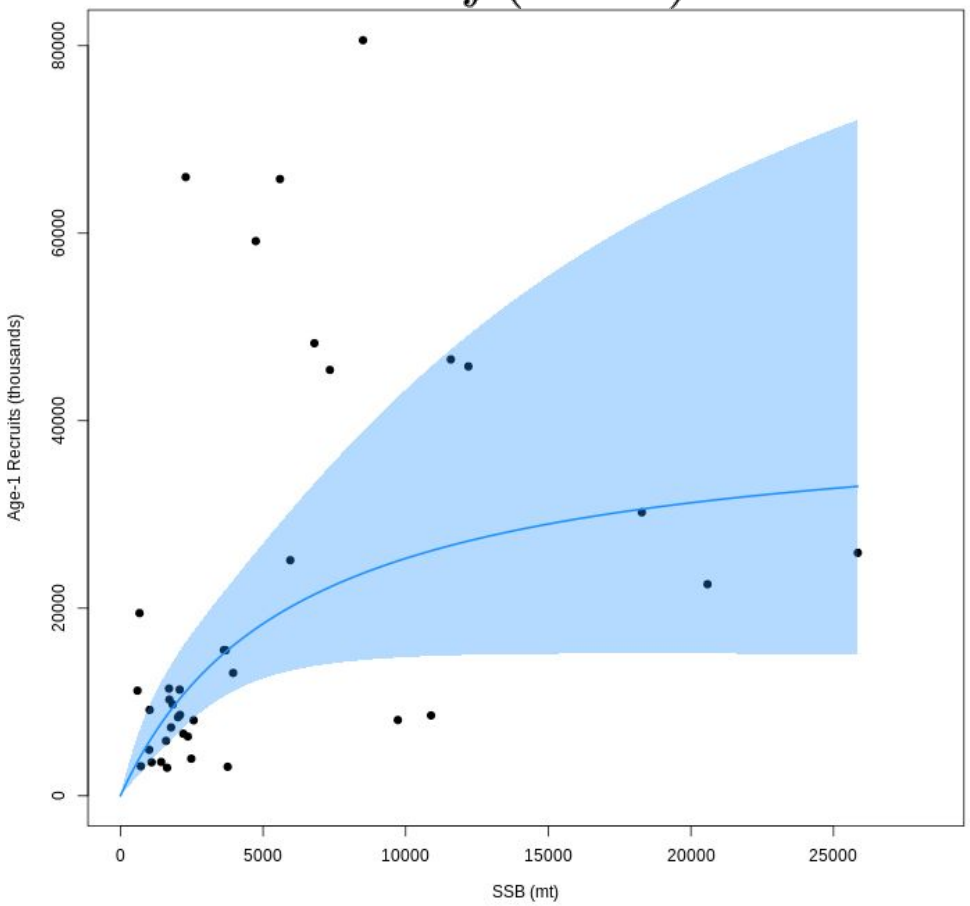
Ex: Recruitment of yellowtail flounder



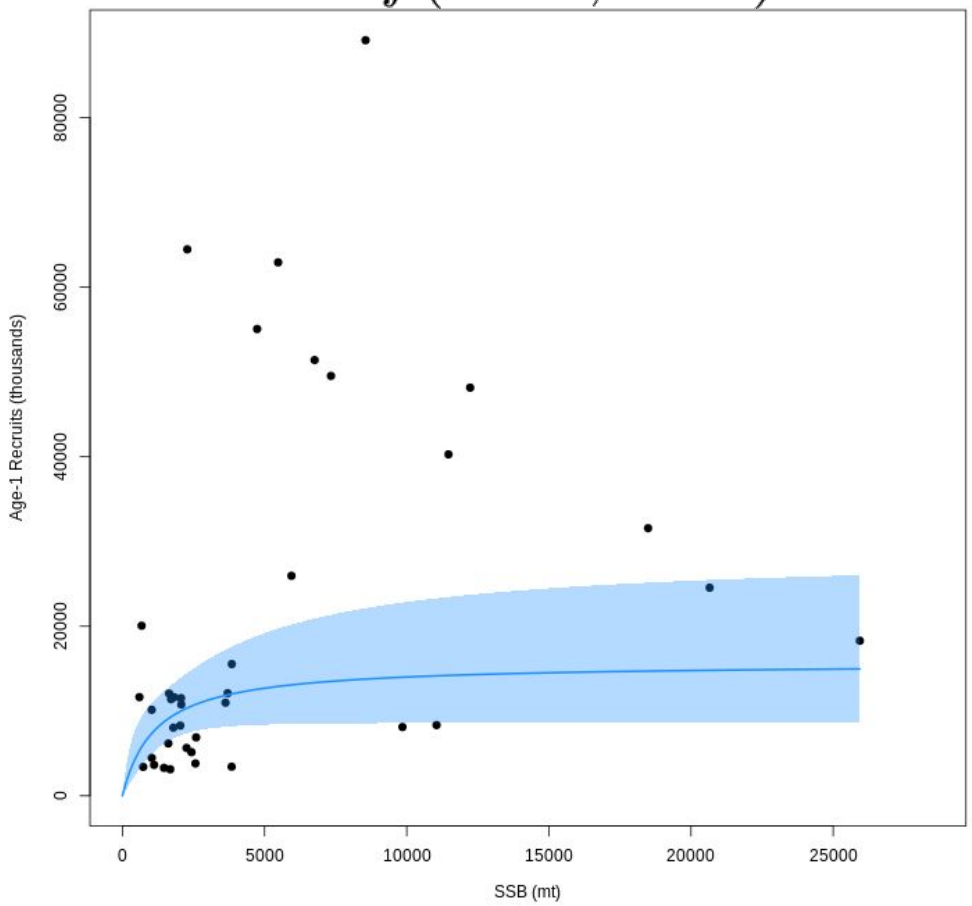
Model	Recruitment	Ecov_process	Ecov_how	dAIC	AIC	rho_R	rho_SSB
m6	Bev-Holt	ar1	Controlling	0.0	-1509.3	0.2084	0.1037
m7	Ricker	ar1	Controlling	0.9	-1508.4	0.2058	0.1002
m5	Bev-Holt	ar1	Limiting	1.1	-1508.2	0.2159	0.1087
m4	Bev-Holt	rw	Limiting	20.5	-1488.8	0.2157	0.1090
m2	Random	rw	Controlling	25.1	-1484.2	0.2310	0.1151
m3	Bev-Holt	rw	---	29.2	-1480.1	0.2331	0.1060
m1	Random	rw	---	37.0	-1472.3	0.2592	0.1124

Ex: Recruitment of yellowtail flounder

$$\hat{R} \sim f(SSB)$$

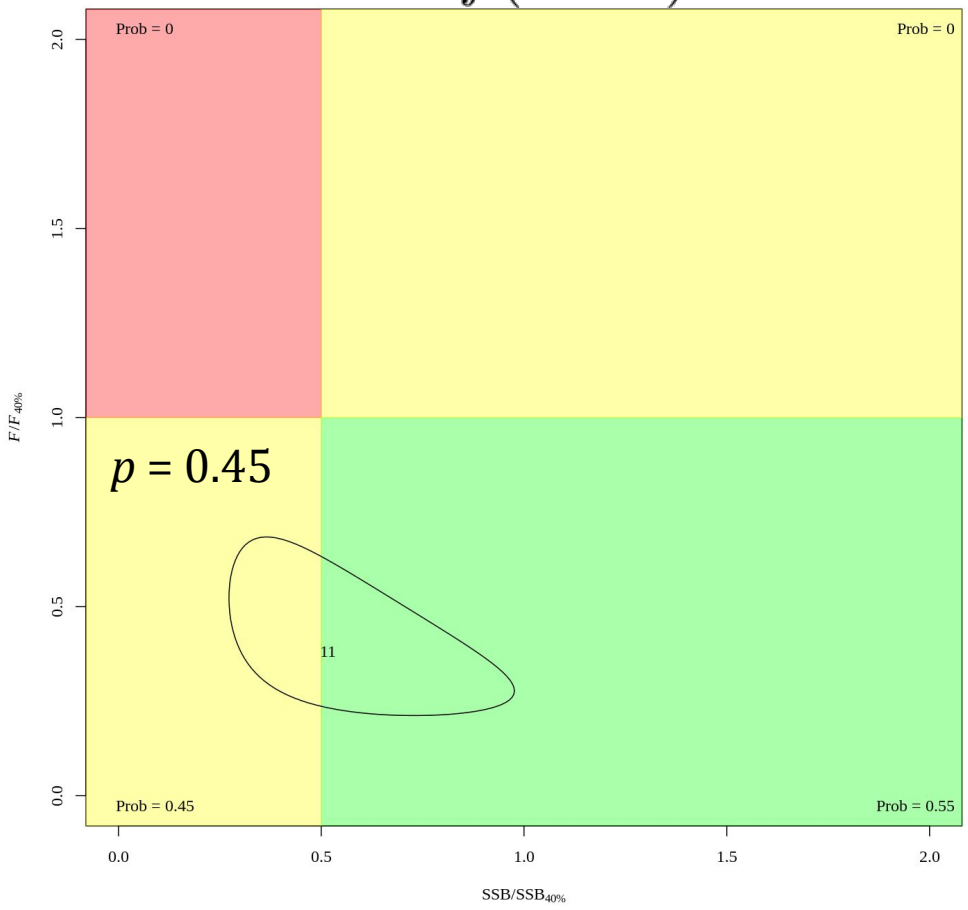


$$\hat{R} \sim f(SSB, CPI)$$

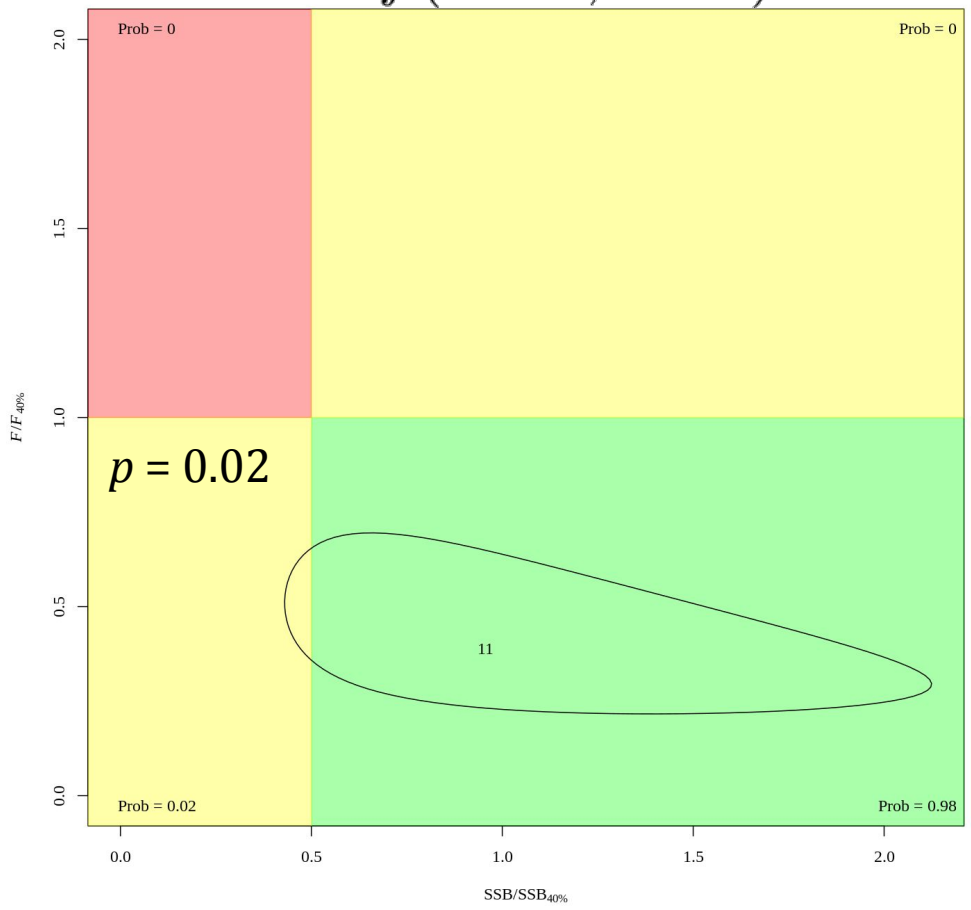


Ex: Recruitment of yellowtail flounder

$\hat{R} \sim f(SSB)$



$\hat{R} \sim f(SSB, CPI)$



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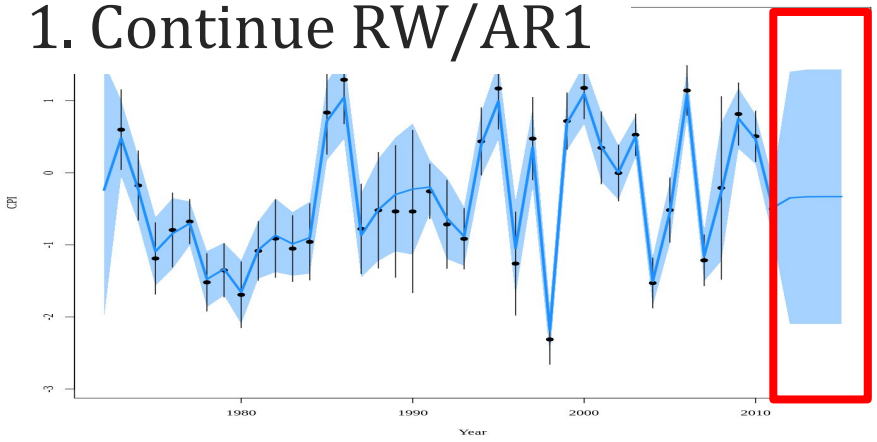
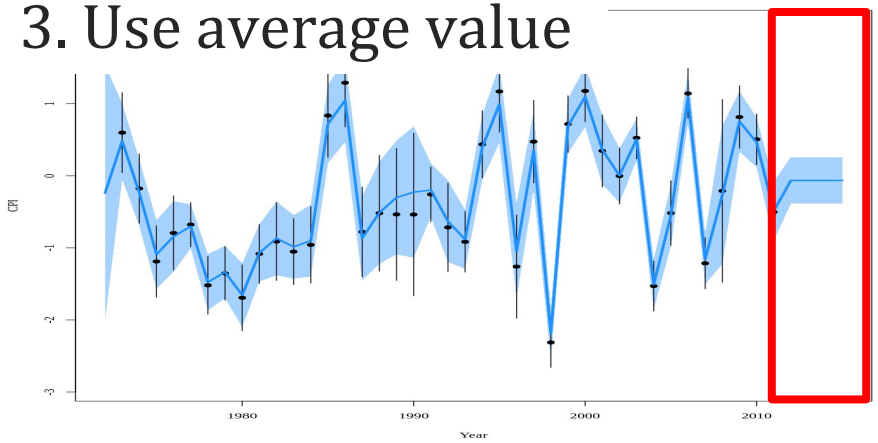
Projection options

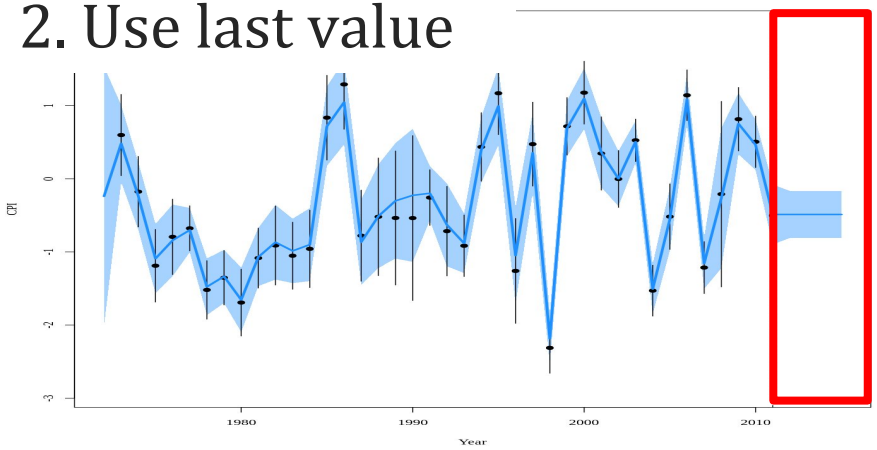
1. Continue RW/AR1



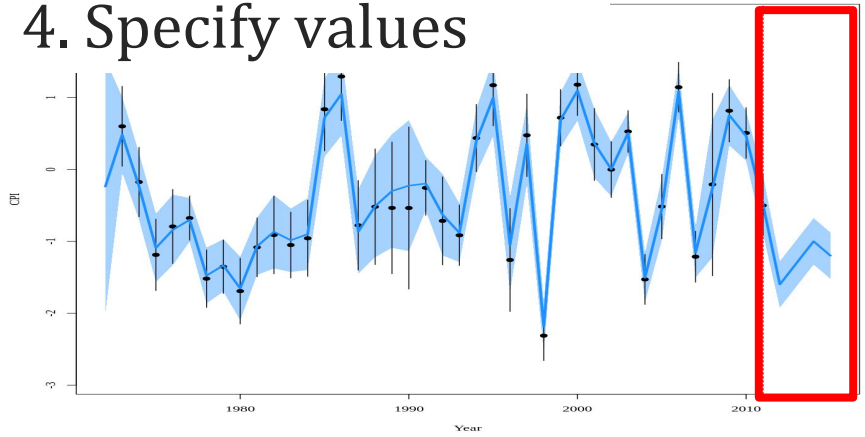
3. Use average value



2. Use last value



4. Specify values



WHAM is (currently) designed for:

Required

Single-species stock assessment

Age-structured population data

Empirical weight-at-age

Optional

Clear, **mechanistic hypothesis** that an environmental variable(s) drives a demographic process(es)

+ **Environmental data**

No crustaceans...

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WHAM status: in development

Happy to help guinea pigs! Advice: wait for release v1.0

timjmiller / **wham** Unwatch

Code | Issues 6 | Pull requests 0 | Projects 0 | Wiki | Security | Insights

line 20 of script returns error #16

Closed **jimianelli** opened this issue on Aug 19 · 7 comments

jimianelli commented on Aug 19

```
input <- prepare_wham_input(asap3, recruit_model=2, model_name="SNEMA Yellowtail Flounder")
Error in rep(1:data$n_years_indices, times = sapply(xl, length)) :
invalid 'times' argument
```

brianstock commented on Aug 19 Collaborator

Thanks for reporting, I'll look into it. Sorry, didn't know others were trying to use this yet. We've made a lot of changes lately on the master branch without fully testing. Our plan going forward, once we

0 releases

Planned work

Features to add

- Automated testing
- AR-k environmental covariate process
- Effects on other population processes (catchability, growth, mortality)

Research projects

- Multivariate, spatial environmental covariates (spatial EOF)
- Time-varying selectivity

Thank you!

NRC postdoc funding

NEFSC Climate & Fisheries

https://github.com/timjmiller/wham

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timothy.j.miller@noaa.gov

Yes, we know there are good reasons to NOT add environmental effects...

- More **uncertain projections** for catch advice
- Environment-productivity **relationships can break down**
- Including environment-productivity links **can lead to worse management** outcomes

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In summary, want an assessment framework that is:

- **state-space**
- includes **environmental effects**
- **easy to test** against status quo SCAA models

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