

Woods Hole Assessment Model Overview

Yellowtail Flounder Research Track Peer-review
18-22 November 2024

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NOAA
FISHERIES

Outline

- WHAM model features
 - Random effects options
 - Environmental covariate effect options
 - Observation likelihood options
 - Biological Reference Point options
 - Projection options
 - Useful features: OSA residuals, auto-generated output, simulations

An open-source state-space assessment framework

- An R package available from Github
- Models can be completely configured using R package functionality
- Several tutorial vignettes
- Automatically produce a variety of output useful for both evaluating models and providing management advice.
- Tests to check package development.
- Several collaborators: **Brian Stock** (IMR) and others

The Woods Hole Assessment Model
WHAM:



A screenshot of the WHAM GitHub repository homepage. The header features the repository name "wham" in a yellow box, followed by links for "Vignettes", "Functions", "Source code", and "News". On the right, there are links for "Issues" and "Contact". Below the header, the title "WHAM: a state-space age-structured assessment model" is displayed. A detailed description follows, mentioning it's a general state-space age-structured stock assessment framework designed to include environmental effects on population processes. It highlights its ability to estimate observation and process error, as well as naturally propagate random effect parameters in stock projections. The repository can be configured to estimate a range of assessment models (see [Ex 1](#) and [Ex 6](#)). The description lists several key features: statistical catch-at-age (SCAA) model with recruitments as fixed effects, SCAA with recruitments as random effects, 'full state-space model', abundance at all ages are random effects, and environmental effects on the above ([Ex 2](#) and [Ex 5](#)). A note states that WHAM advances fisheries assessment because it can estimate constrained random deviations, i.e. random effects, on parameters such as: recruitment / numbers-at-age ([Ex 2](#) and [Ex 6](#)), selectivity ([Ex 4](#)), natural mortality ([Ex 5](#)), and environmental effects on the above ([Ex 2](#) and [Ex 5](#)). A final note says that a nice property of treating population and environmental processes as random effects is that their uncertainty is naturally propagated in projections/forecasts ([Ex 3](#)). An overview of the WHAM presentation (Jan 8 2021) is also mentioned.

The Woods Hole Assessment Model (WHAM) is a general state-space age-structured stock assessment framework designed to include environmental effects on population processes. The state-space framework is attractive because it can estimate observation and process error, as well as naturally propagate random effect parameters in stock projections. WHAM can be configured to estimate a range of assessment models (see [Ex 1](#) and [Ex 6](#)):

- statistical catch-at-age (SCAA) model with recruitments as fixed effects,
- SCAA with recruitments as random effects
- 'full state-space model', abundance at all ages are random effects

WHAM advances fisheries assessment because it can estimate constrained random deviations, i.e. random effects, on parameters such as:

- recruitment / numbers-at-age ([Ex 2](#) and [Ex 6](#)),
- selectivity ([Ex 4](#)),
- natural mortality ([Ex 5](#)), and
- environmental effects on the above ([Ex 2](#) and [Ex 5](#))

A nice property of treating population and environmental processes as random effects is that their uncertainty is naturally propagated in projections/forecasts ([Ex 3](#)).

Overview of WHAM presentation (Jan 8 2021):



National Stock Assessment Workshop Seminar
The Woods Hole Assessment Model (WHAM): A General State-Space Assessment Framework

Speakers:
Dr. Brian Stock
Ocean Associates, Inc.

Watch on YouTube

FANTASTIC

Join us via Webinar
January 7, 2021

Links
[Browse source code](#)
[Report a bug](#)

License
[GPL-3](#)

Community
[Contributing guide](#)
[Citation](#)
[Citing wham](#)

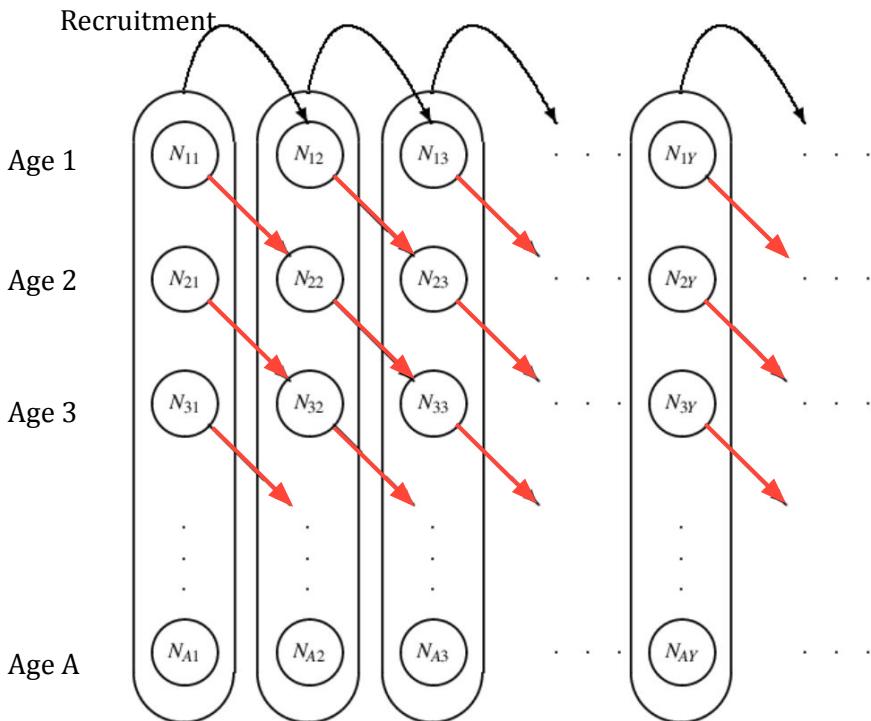
Developers
Tim Miller
Author, maintainer

Brian Stock
Author
[More about authors...](#)

Dev status

[repo status](#)

WHAM is an age-structured model



Configuration options for abundance at age:

- 1) Statistical catch-at-age (no random effects)

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

- 2) Statistical catch-at-age, random recruitment

$$\log N_{1,y} = \log(f(\text{SSB}_{y-1})) + \varepsilon_{1,y}$$

- 3) "Full state-space" (survival random effects)

$$\log N_{a,y} = \log(N_{a-1,y-1}) - Z_{a-1,y-1} + \varepsilon_{a,y}$$

Random effects

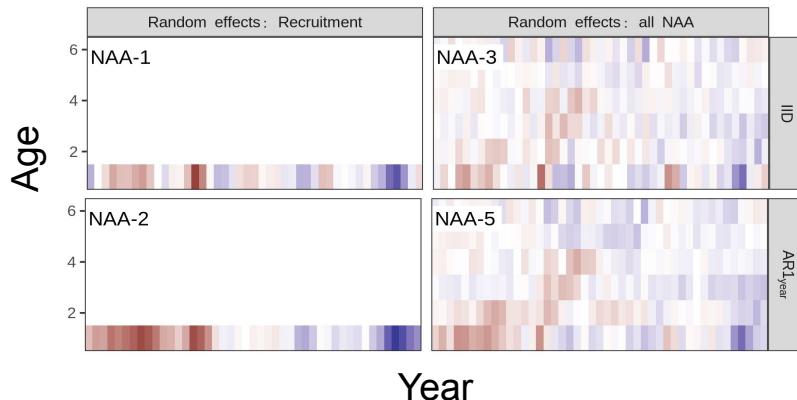
Options for alternative covariance structures (AR1, iid, etc)

- Recruitment (year)
- Interannual transitions in abundance at age ("survival") (year, age)
- Natural mortality (year, age)
- Selectivity (fishery or index) (year, age)
- Catchability (year)
- Hidden (imperfectly observed) environmental/climate variables (year)
- Movement (year,age)(development branch)
- *Growth (development branch)*

Time- and age-varying processes

Biological processes are often
correlated by year and age

- Recruitment
- Inter-annual transitions ("Survival")
- Natural mortality
- Selectivity
- Catchability
- Movement



```
NAA_re = list(sigma="rec+1", cor="iid"))
```

Code	Description	Parameters
"none"	time-constant (no deviation)	
"iid"	independent, identically-distributed	σ^2
"ar1"	autoregressive-1 (correlated across ages/parameters)	σ^2, ρ_a
"ar1_y"	autoregressive-1 (correlated across years)	σ^2, ρ_y
"2dar1"	2D AR1 (correlated across both years and ages/parameters)	σ^2, ρ_a, ρ_y

$$\text{Cov}(\varepsilon_{a,y}, \varepsilon_{\tilde{a},\tilde{y}}) = \frac{\sigma_a \sigma_{\tilde{a}} \rho_a^{|a-\tilde{a}|} \rho_y^{|y-\tilde{y}|}}{(1 - \rho_a^2)(1 - \rho_y^2)}$$

Time- and age-varying processes

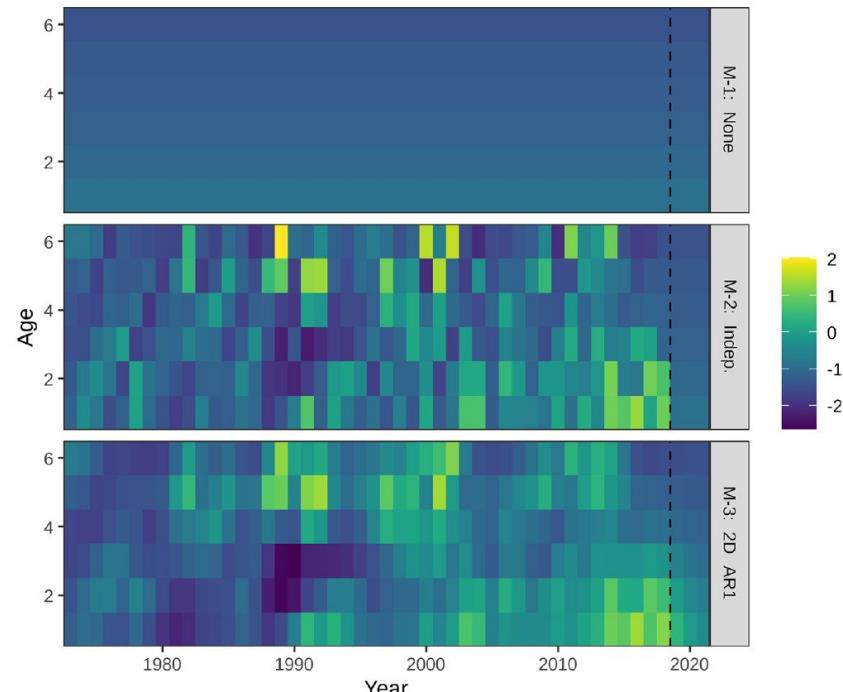
Biological processes are often **correlated by year and age**

- Recruitment
- Inter-annual transitions ("Survival")
- **Natural mortality**
- Selectivity
- Catchability
- Movement

$\log(M)$ Gaussian random effects (iid, 2DAR1)

Estimate or fix mean M parameters:

- constant across ages
- age-specific
- function of weight-at-age

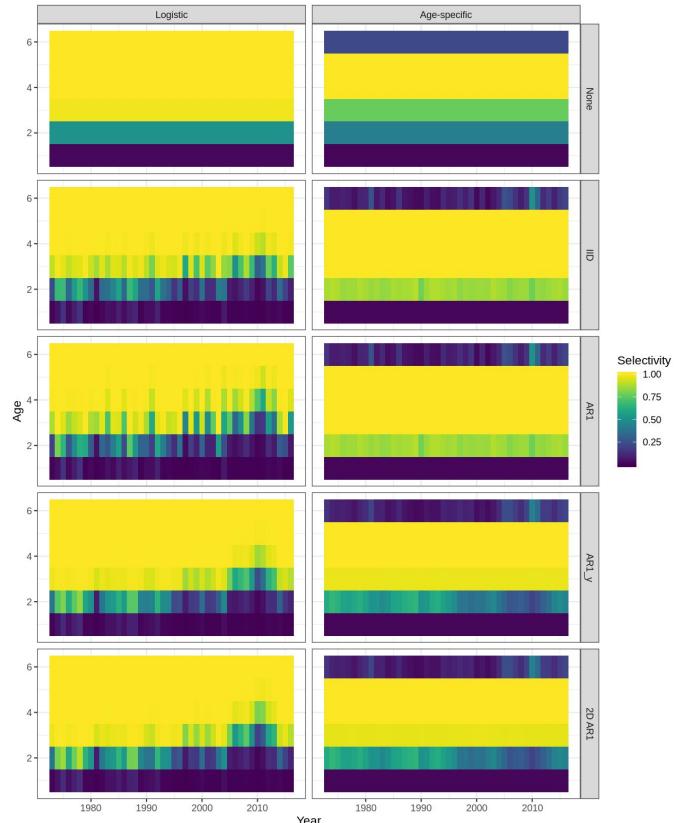


Time- and age-varying processes

- Recruitment
- Inter-annual transitions ("Survival")
- Natural mortality
- **Selectivity**
- Catchability
- Movement

"blocks" indexed to particular years of indices and fleets

- logistic (increasing or decreasing), double logistic, or age-specific
- constant, iid, or 1D or 2D AR1 processes for annual parameter values
- Gaussian on logit scale

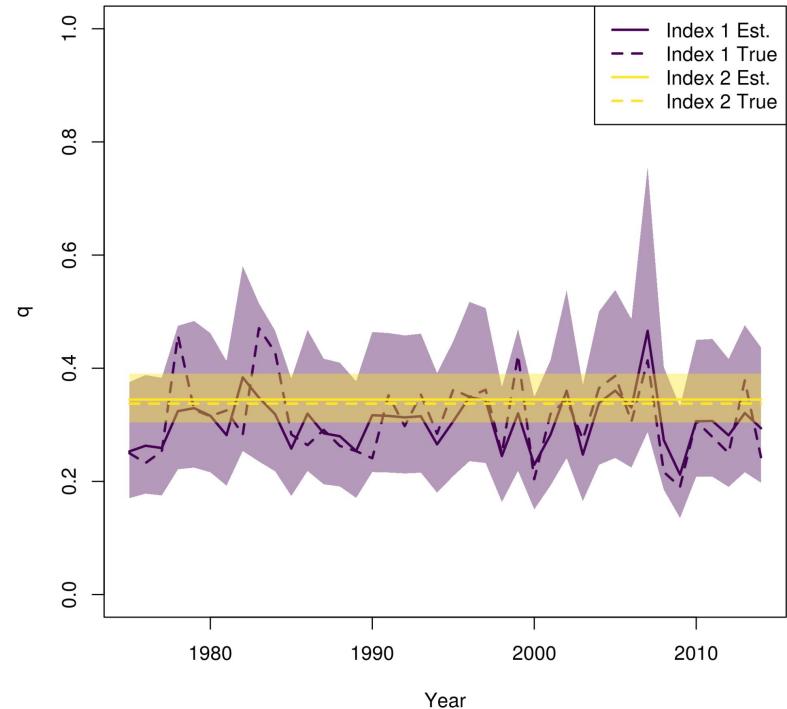


Time- and age-varying processes

- Recruitment
- Inter-annual transitions ("Survival")
- Natural mortality
- Selectivity
- **Catchability**
- Movement

Gaussian iid, or AR1 processes on logit scale

$$\log \left(\frac{q_y - b_l}{b_u - q_y} \right) = \mu_q + \epsilon_{q,y}$$



Time- and age-varying processes

- Recruitment
- Inter-annual transitions ("Survival")
- Natural mortality
- Selectivity
- Catchability
- **Movement**

- Fixed effects (mean, variance, correlation parameters) are stock, region->region, season specific
- random effects by year and/or age
- movement can be modeled as
 - probabilities sequential to mortality
 - instantaneous rate simultaneous to mortality rates

$$f(\mu_{s,r,r',t,y,a}) = \theta_{s,r,r',t} + \epsilon_{s,r,r',t,y,a} \quad r \neq r'$$

$$Cov(\epsilon_{s,r,r',t,y,a}, \epsilon_{s,r,r',t,y',a'}) = \frac{\rho_{s,r,r',t,A}^{|a-a'|} \rho_{s,r,r',t,Y}^{|y-y'|} \sigma_{s,r,r',t}^2}{(1 - \rho_{s,r,r',t,A}^2) (1 - \rho_{s,r,r',t,Y}^2)}$$

additive logit transformation for probabilities sequential to survival:

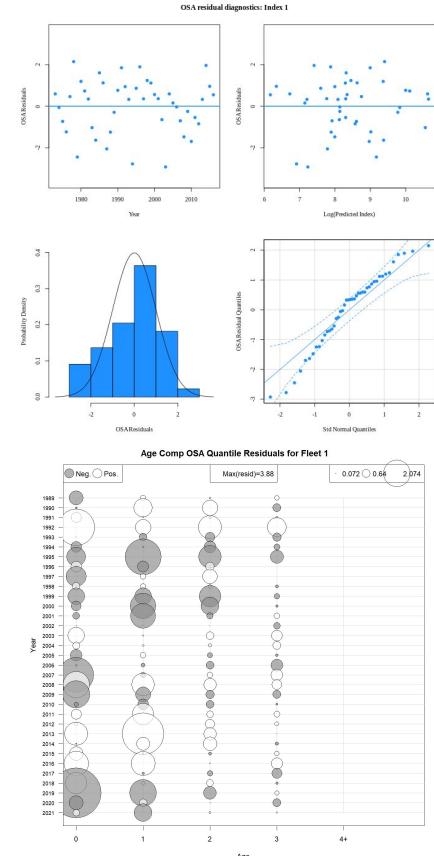
$$f(\mu_{s,r,r',t,y,a}) = \log \left(\frac{\mu_{s,r,r',t,y,a}}{1 - \sum_{r'} \mu_{s,r,r',t,y,a}} \right)$$

log transformation for instantaneous rates:

$$f(\mu_{s,r,r',t,y,a}) = \log(\mu_{s,r,r',t,y,a})$$

Data components

- Aggregate catch (fleet-specific)
 - log-normal
- Catch age composition (fleet-specific)
 - Several likelihood options: multinomial, Dirichlet-multinomial, logistic normal, Dirichlet
- Aggregate indices (biomass or numbers)
 - log-normal
- Index age composition (biomass or numbers)
 - Same options as catch age composition
- **Optional:** Environmental/Climate observations
 - normal
- *Tagging data not yet included*



State-space models for the covariate

- Imperfectly observed environmental variables can affect
 - Recruitment
 - Natural mortality (by age)
 - Index catchability
 - Movement
- User-defined lag between covariate and population effect
- Effects options are “linear” or orthogonal polynomial
- Each covariate can have multiple effects
- Multiple covariates can be included

Covariate state-space models:

1. Random walk

$$\theta = (x_1, \sigma_x^2, \sigma_y^2)$$

$$x_t = x_{t-1} + \mathcal{N}(0, \sigma_x^2)$$

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

2. AR1

$$-1 < \phi < 1$$

$$\theta = (\mu, \sigma_x^2, \sigma_y^2, \phi)$$

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

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

Environmental effects on...

Recruitment models:

1. Random walk (No effects)

$$\hat{R}_t =$$

$$e^{\log R_{y-1} + \epsilon_y}$$

2. Mean (no SRR)

$$e^{\mu_R + \beta E_y + \epsilon_y}$$

3. Beverton-Holt

$$\frac{aS_{y-1}e^{\beta E_y + \epsilon_y}}{1 + bS_{y-1}}$$

Controlling

Limiting

Masking

4. Ricker

$$aS_{y-1}e^{-bS_{y-1} - \beta E_y + \epsilon_y}$$

Controlling

Masking

Iles & Beverton (1998)

Catchability models:

linear in logit space

$$\log \left(\frac{q_y - b_l}{b_u - q_y} \right) = \mu_q + \beta E_y + \epsilon_{q,y}$$

M models:

1. log-linear $\log M_{y,a} = \mu_{M,a} + \beta_a E_y + \epsilon_{y,a}$

2. allometric $\log M_{y,a} = \log(a) + b \log(W_{y,a}) + \beta_a E_y + \epsilon_{y,a}$

Movement models:

linear in (additive) logit space or log-space

$$f(\mu_{s,r,r',t,y,a}) = \theta_{s,r,r',t} + \beta E_y + \epsilon_{s,r,r',t,y,a}$$

Environmental and random effects on...

Recruitment models:

1. Random walk (No effects)

$$\hat{R}_t =$$

$$e^{\log R_{y-1} + \epsilon_y}$$

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$$e^{\mu_R + \beta E_y + \epsilon_y}$$

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Iles & Beverton (1998)

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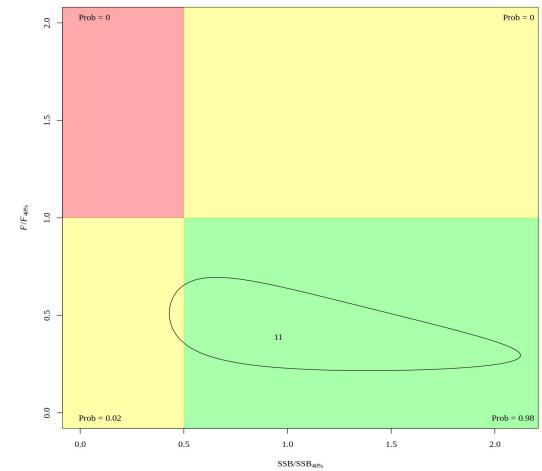
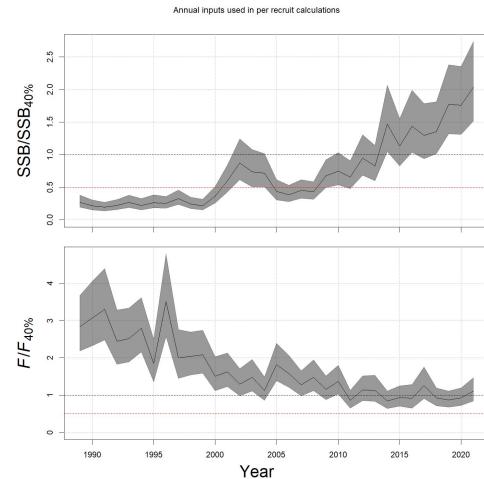
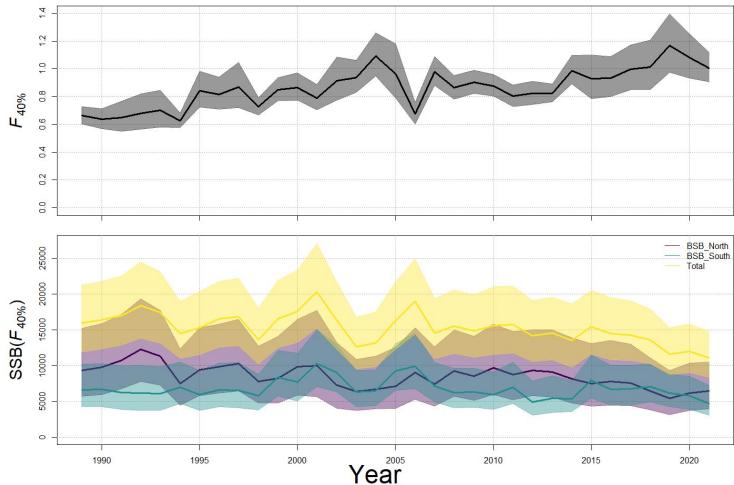
Movement models:

linear in (additive) logit space or log-space

$$f(\mu_{s,r,r',t,y,a}) = \theta_{s,r,r',t} + \beta E_y + \epsilon_{s,r,r',t,y,a}$$

Annual and prevailing BRPs and status

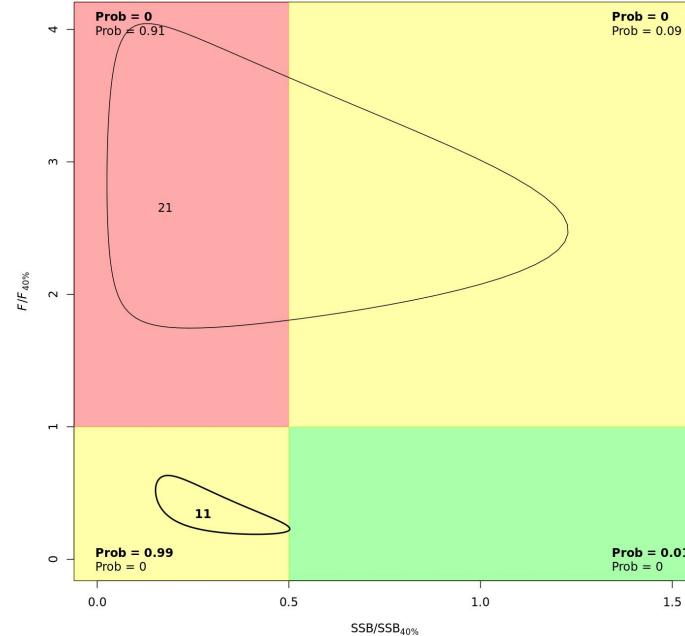
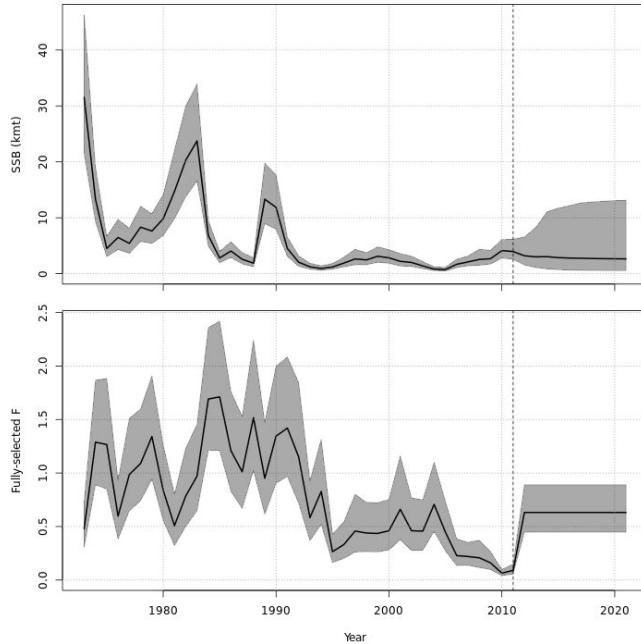
- Internally calculated reference points and status
- Allows uncertainty in parameters to be propagated



Projections

Random effects (and uncertainty) can be projected

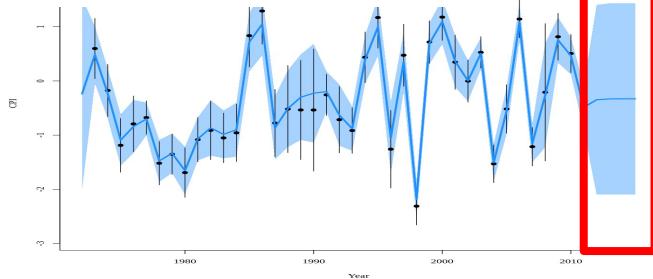
Can specify catch, status quo F, average F, $F(X\%SPR)$, FMSY



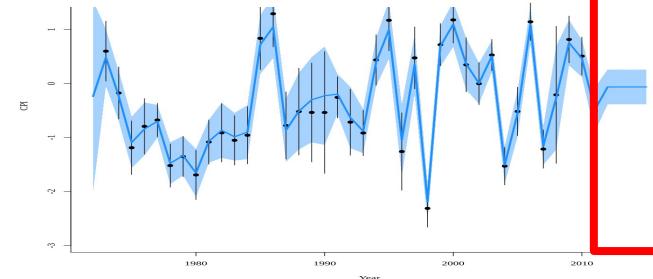
Projections

Several options for treating environmental covariates

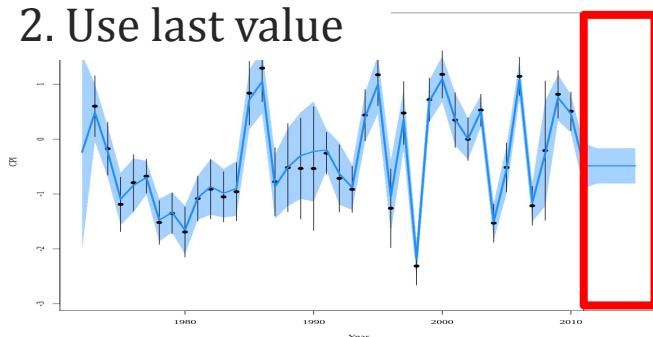
1. Continue RW/AR1



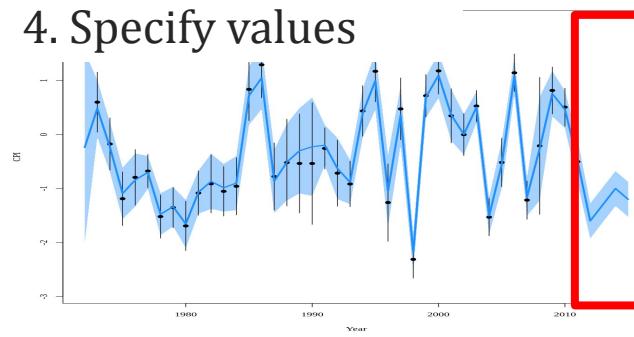
3. Use average value



2. Use last value



4. Specify values



OSA residual diagnostics

One step ahead (OSA) residuals

- provides independent residuals for correlated observations
- available for all observation types: aggregate catch and indices, age composition, environmental covariates

Environ Ecol Stat (2017) 24:317–339
DOI 10.1007/s10651-017-0372-4

Fisheries Research 257 (2023) 106487

Validation of ecological state space models using the Laplace approximation

Uffe Høgsbro Thygesen¹ · Christoffer Moesgaard Albertsen¹ ·
Casper Willesøfte Berg¹ · Kasper Kristensen¹ · Anders Nielsen¹

Contents lists available at ScienceDirect

Fisheries Research

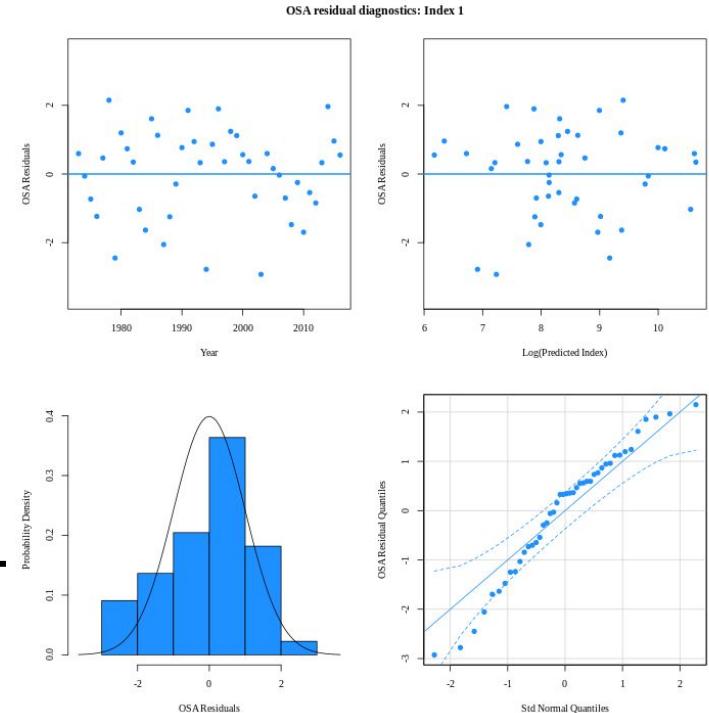
Journal homepage: www.elsevier.com/locate/fishes

Model validation for compositional data in stock assessment models: Calculating residuals with correct properties

Vanessa Trioulet ^{a,*}, Christoffer Moesgaard Albertsen ^a, Kasper Kristensen ^a,
Christopher M. Legault ^b, Timothy J. Miller ^b, Anders Nielsen ^a

^a National Institute of Aquatic Resources, Technical University of Denmark, Kemitorvet 201, DK-2800 Kgs. Lyngby, Denmark

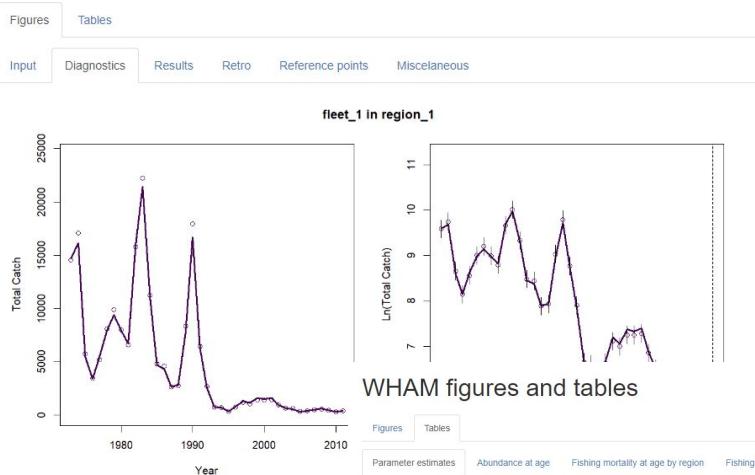
^b Northeast Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 166 Water Street, Woods Hole, MA 02543, USA



Automatically generated outputs

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

WHAM figures and tables



Parameter estimates, standard errors, and confidence intervals. Rounded to 3 decimal places.

	Estimate	Std. Error	95% CI lower	95% CI upper
index 1 fully selected q	2.441	0.272	1.962	3.037
index 2 fully selected q	0.490	0.038	0.421	0.571
index 3 fully selected q	0.297	0.042	0.225	0.393
index 4 fully selected q	0.006	0.001	0.005	0.009
index 5 fully selected q	0.051	0.008	0.037	0.070
Block 1: fleet 1 a_{50}	2.473	0.051	2.374	2.574
Block 1: fleet 1 slope (increasing)	0.417	0.017	0.385	0.452
Block 2: index 1 a_{50}	1.942	0.092	1.766	2.127

```
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
```

Online Tutorials

The screenshot shows a website for "wham 1.0.6" with a navigation bar including "Vignettes", "Functions", "Source code", and "News". A "Contact" link is also visible. A dropdown menu is open over the "Vignettes" link, listing 11 examples:

- Ex 1: The basics
- Ex 2: Recruitment linked to an environmental covariate (Cold Pool Index)
- Ex 3: Projecting / forecasting random effects
- Ex 4: Selectivity with time- and age-varying random effects
- Ex 5: Time-varying natural mortality linked to the Gulf Stream Index
- Ex 6: Numbers-at-age / survival deviations as random effects
- Ex 7: Debugging WHAM models
- Ex 8: Compare ASAP and WHAM model results
- Ex 9: Retrospective predictions
- Ex 10: Operating models and MSE
- Ex 11: Catchability configurations

The main content area discusses WHAM's ability to estimate constrained random deviations (random effects) and its applications in fisheries assessment. It mentions the "full state-space model", abundance at all ages, and random effects on recruitment, selectivity, natural mortality, and environmental effects.

A note at the bottom states: "A nice property of treating population and environmental processes as random effects is that their uncertainty is naturally propagated in projections/forecasts (Ex 3)."

Page footer: <https://timjmiller.github.io/wham/articles/index.html>

Simulations, including MSE

Simulate population (random effects) or just observations

- Self-test functionality for testing reliability of models in stock-specific research and management tracks.

Operating model/MSE usage

- Can be used for closed-loop simulations.
- Used in Index-based Methods Research Track and State-Space Research Track

