Science, Service, Stewardship

Dusky shark assessment: Modeling methods and results

SEDAR 21 Review Workshop

Paul Conn, NMFS AFSC

Enric Cortes, NMFS SEFSC

NOAA FISHERIES SERVICE

Outline

1. Age-Structured Catch Free Model (ASCFM)– general model structure and assumptions
2. Sensitivity models
3. Projection methods
4. Results

NOAA
FISHERIES
SERVICE

Outline

1. Age-Structured Catch Free Model (ASCFM)– general model structure and assumptions
2. Sensitivity models
3. Projection methods
4. Results

NOAA
FISHERIES
SERVICE

Catch data are unreliable

But do have…

- Life history information
- Indices of abundance
- Anecdotal observations/expert knowledge

Use age-structured catch-free model following Porch et al. *Fish Bull.* 2006 (also used in 2006 dusky assessment)

NOAA FISHERIES SERVICE

Catch-free assessment model

An age-structured production model scaled relative to unfished (virgin) levels

Initial unfished age structure

$$N_{a,1} = \begin{cases} 1 & a = a_r \\ N_{a-1,1} e^{-M_{a-1}} & a_r < a < A \\ N_{A-1,1} e^{-M_{A-1}} / (1 - e^{-M_A}), & a = A \end{cases} \qquad (1)$$

where a_r = the youngest age class in the analysis;
A = a "plus-group" representing age classes A and older; and
M = the natural mortality rate.

NOAA FISHERIES SERVICE

Catch-free assessment model

Historical abundance

$$N_{a,y} = \begin{cases} r_y & a = a_r \\ N_{a-1,y-1} e^{-F_{y-1} v_{a-1} - M_{a-1}} & a_r < a < A \\ N_{A-1,y-1} e^{-F_{y-1} v_{a-1} - M_{a-1}} + \\ N_{A,y-1} e^{-F_{y-1} v_A - M_A}, & a = A \end{cases} \qquad (2)$$

where r_y = the annual recruitment to age class a_r relative to virgin levels;

F = the fishing mortality rate on the most vulnerable age class; and

NOAA FISHERIES SERVICE

Catch-free assessment model

Recruitment – parameterization for sharks

- Beverton-Holt spawner-recruit curve parameterized in terms of maximum reproductive rate at low density (Myers et al. 1999)
- Myers' α equivalent to slope of the spawner-recruit curve at the origin times unexploited numbers of spawners per recruit
- Slope of spawner-recruit function at origin equivalent to density independent pup survival (Brooks et al. 2009)

Catch-free assessment model

Recruitment – parameterization for sharks

α = pup.survival X virgin.spawners.per.recruit

$$\varphi_0 = \sum_{age} fec_{age} \cdot mat_{age} \prod_{j=1}^{age-1} \mathrm{e}^{-M_j}$$

Steepness = α / (α+4)

Catch-free assessment model

Recruitment

Assumed to follow a Beverton-Holt curve (with recruitment deviations set to zero)

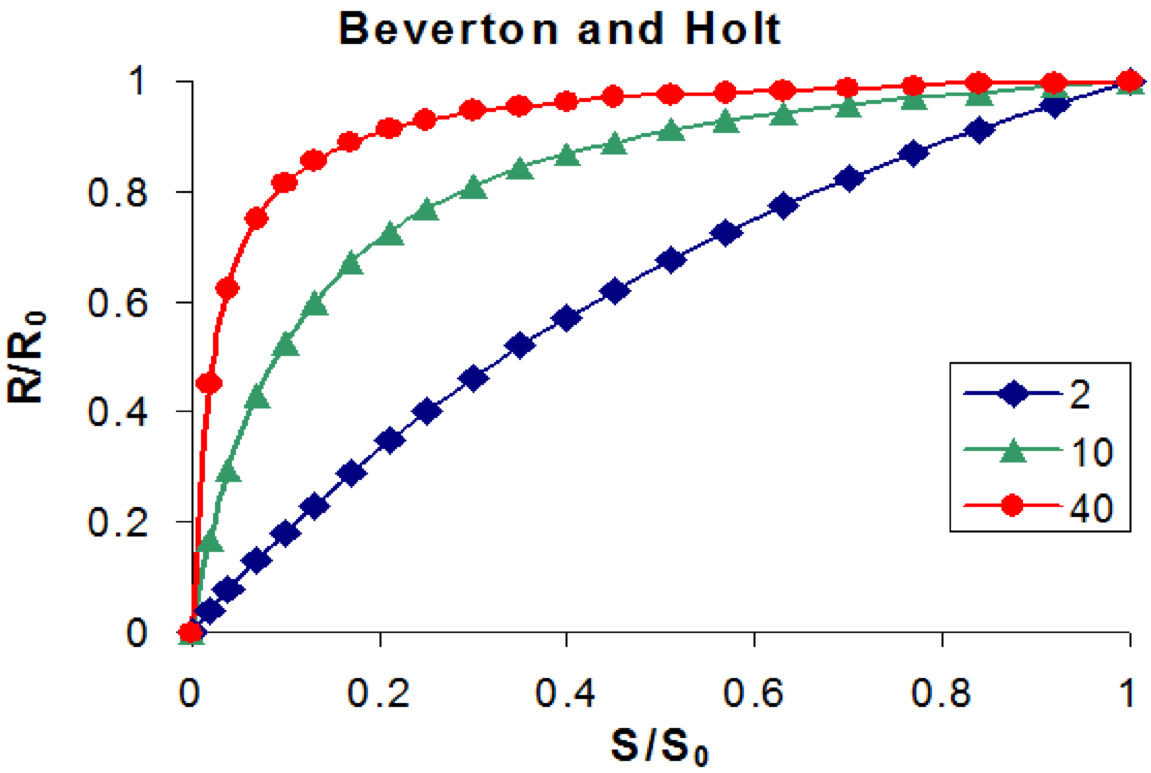
$$r_y = \frac{e^{-M_0} \varphi_0 S_{y-a_r}}{1 + (e^{-M_0} \varphi_0 - 1) S_{y-a_r}}$$

$$S_y = \frac{\sum_{a=a_r}^{A} E_a N_{a,y} \exp(-(F_{a,y} + M_a) t_j)}{\sum_{a=a_r}^{A} E_a N_{a,1} \exp(-M_a t_j)}$$

where S_y is a measure of spawning biomass (E_a is the expected number of pups per age *a* female)

NOAA FISHERIES SERVICE

Graphical portrayal of rescaled spawner-recruit relationship



NOAA FISHERIES SERVICE

Catch-free assessment model

Fishing mortality

Three historical ‘eras’

Historical: 1960-1979 small PLL, little-no BLL, Rec

Modern 1: 1980-1999 ramping up of BLL, Rec effort

Modern 2: 2000-2009 dusky landings prohibited

NOAA
FISHERIES
SERVICE

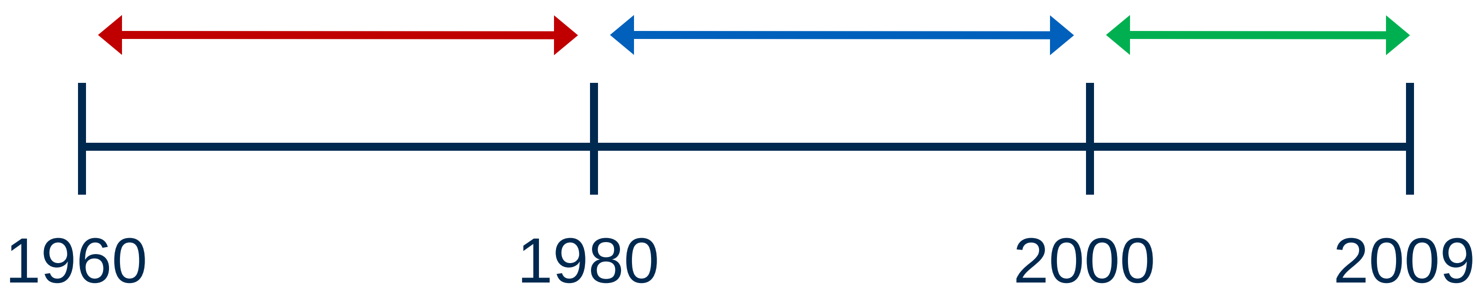
Catch-free assessment model

Fishing mortality

F proportional to PLL effort (assume PLL selectivity)

F modeled as a correlated random walk

F_{2000} estimated as free parameter; correlated random walk after that



NOAA
FISHERIES
SERVICE

Catch-free assessment model

Fishing mortality

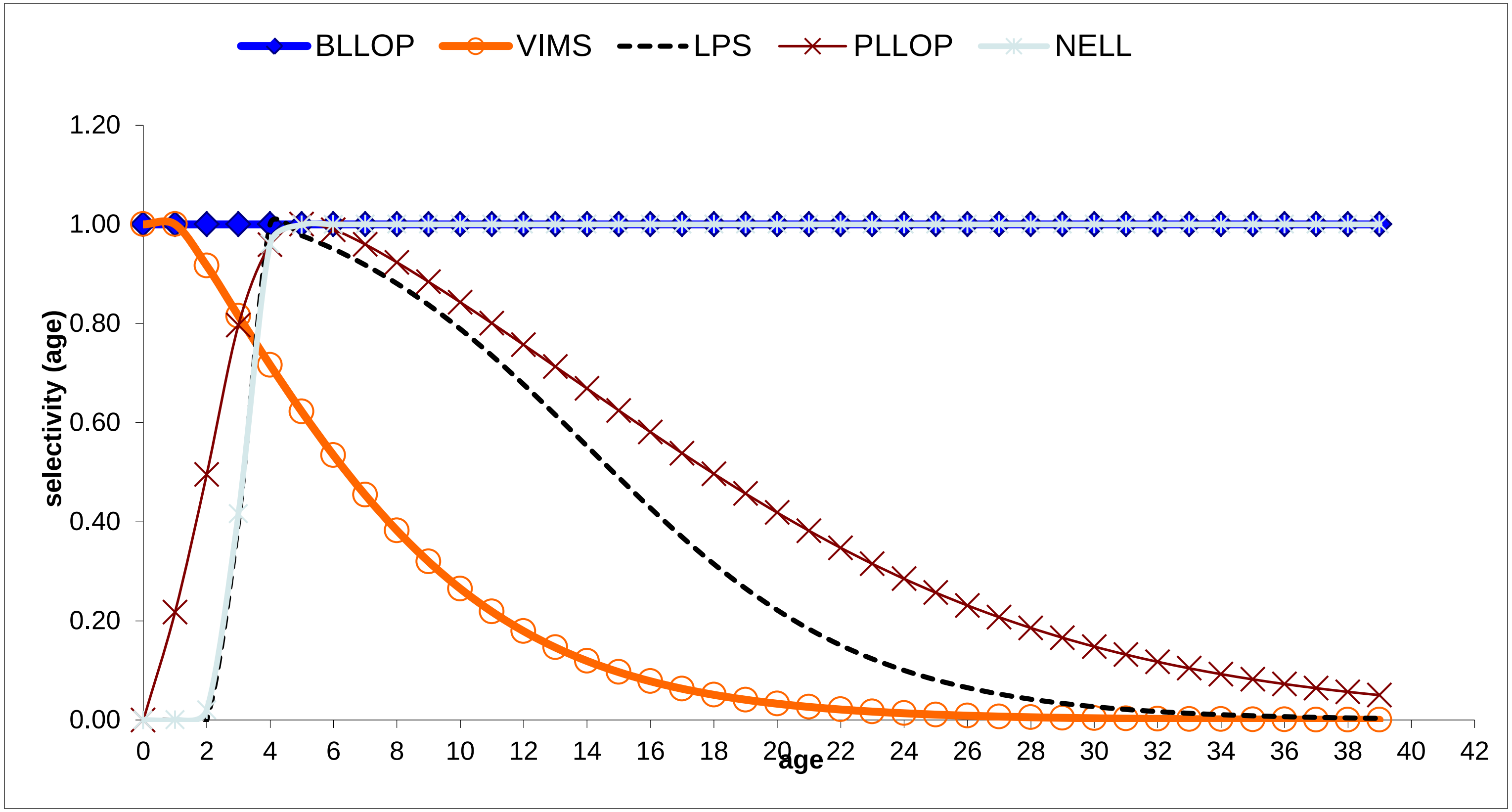
$$F_{a,y} = Fapical_y \bar{v}_{a,y}$$

$$Fapical_y = \begin{cases} \beta_1 \times Effort_{PLL,y} & y < 1980 \\ Fapical_{y-1} \exp(\delta_y) & 1980 \le y \le 2009 \end{cases}$$

$$\delta_y = \begin{cases} \varepsilon_y & y = 1980 \\ \rho\delta_{y-1} + \varepsilon_y & 1981 \le y \le 1999 \\ \tau & y = 2000 \\ \rho\delta_{y-1} + \varepsilon_y & 2001 \le y \le 2009 \end{cases}$$

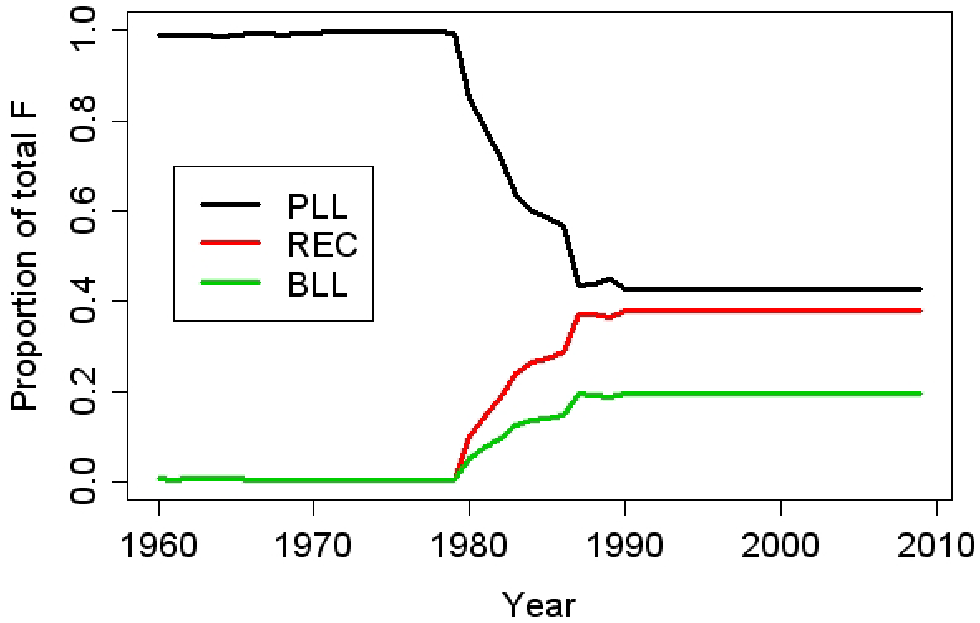
NOAA FISHERIES SERVICE

Selectivity



NOAA FISHERIES SERVICE

Selectivity for removals

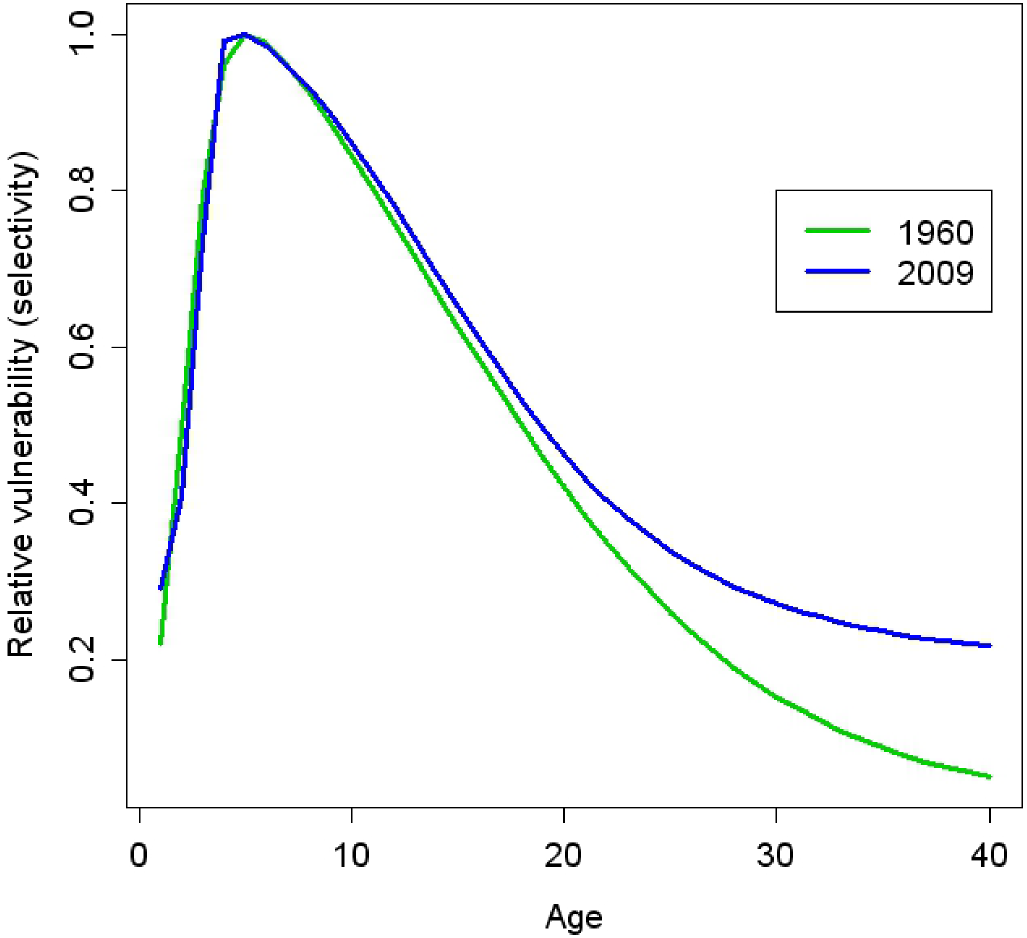


$$\bar{v}_{a,y} = \frac{\sum_{fleet} v_{fleet,a} Effort_{fleet,y}}{\sum_{fleet} Effort_{fleet,y}}$$

Annual selectivity (for modeling F) calculated as a weighted average of all sectors (effort time series used to provide weights)

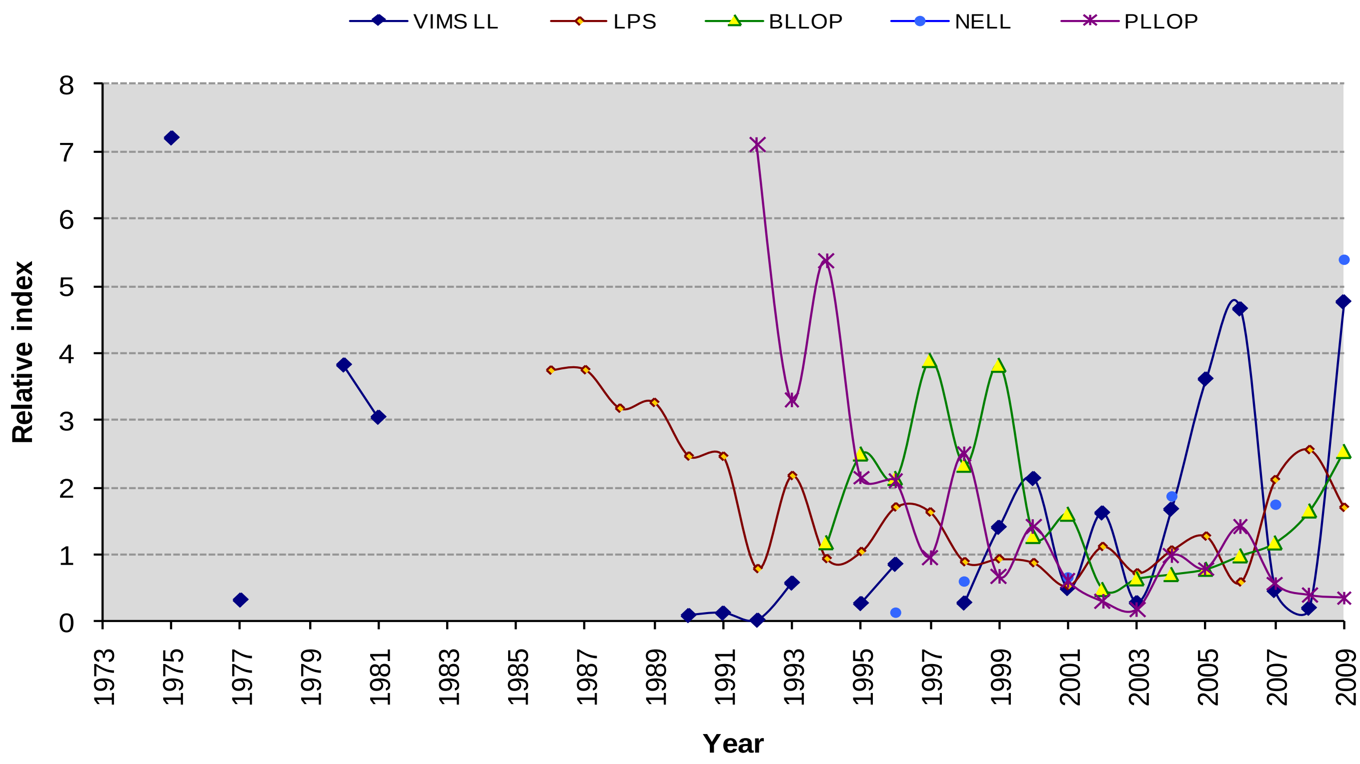
NOAA FISHERIES SERVICE

Selectivity for removals



NOAA FISHERIES SERVICE

ASCFM: Fitting to indices



ASCFM: Fitting to indices

Wanted a cohesive framework for estimating 'additional variance' for each index (above and beyond observation error).

Reconfigured the ASCFM to have CVs provided with each index to indicate the 'base' level of variance; additional variance can also be estimated

$$U_{i,t} = q_i \exp(\varepsilon_{i,t}) \sum_a N_{a,t} s_{a,t}$$

$$\varepsilon_{i,t} \sim \mathrm{Normal}(0, \log(1 + CV_{i,t}^2) + \nu_i)$$

"Additional variance"

ASCFM: Fitting to indices

Accounting for pups

Problem formulation

- Original ASCFM starts with age 1's
- Several indices (VIMS, BLLOP) include pups
- Pup survival assumed density dependent, but functional form of density dependence not specified

Solution

Apply half year mortality for pups to match indices; annual pup survival estimated as $N_{t+1,a=1}/S_t$

NOAA FISHERIES SERVICE

ASCFM: Fitting to indices

Accounting for pups

$$\tilde{U}_{j,y} = \frac{q_j v_{j,0} N_{1,y+1}}{\theta_y^{1-t_j}} + q_j \sum_{a=1}^{A} v_{j,a} N_{a,y} \exp(-(M_a + F_{a,y}) t_j)$$

$$\theta_y = \frac{N_{1,y+1}}{\sum_a N_{a,y}\, fec_a mat_a}$$

NOAA FISHERIES SERVICE

ASCFM: Objective function (log posterior)

$$\Lambda = \Lambda_1 + \Lambda_2 + \Lambda_3 + \Lambda_4$$

Λ_1	Observed data likelihood
Λ_2	Likelihood for process errors
Λ_3	Prior distributions
Λ_4	Constraints

NOAA FISHERIES SERVICE

ASCFM: Observed data

$$\Lambda_1 = 0.5\sum_i\sum_y \frac{(\log(U_{i,y}) - \log(\tilde{U}_{i,y}))^2}{\sigma_{i,y}^2} + \log(\sigma_{i,y}^2)$$

$$\sigma_{i,y}^2 = \log(1 + \mathrm{CV}_{\mathrm{i,y}}^2) + \sigma_i^2 + \sigma_{\mathrm{overall}}^2$$

Set to zero in base run

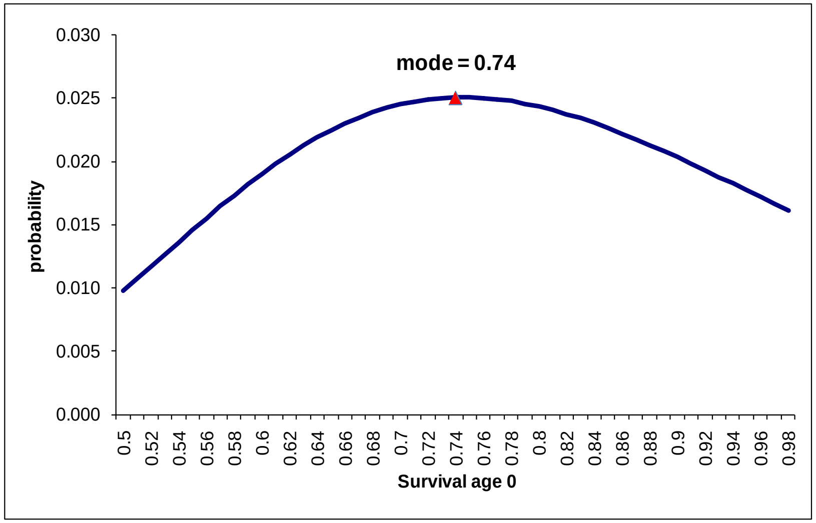
NOAA FISHERIES SERVICE

ASCFM: Process errors in F

$$\Lambda_2 = 0.5 \sum_{1981 \le y \le 1999,\, 2001 \le y \le 2009} \frac{(\varepsilon_y - \rho \varepsilon_{y-1})^2}{0.1} + \log(0.1)$$

NOAA FISHERIES SERVICE

ASCFM: Priors



Prior for S0:
Lognormal with median 0.81, CV = 0.3
(mean = 0.84; mode = 0.74)
bounds: [0.5 , 0.98]

Historical F-Effort relationship

$$p(\beta_1) : \text{Uniform}(0,0.7)$$

Pup survival at low biomass

$$p(\exp(-M_0)) : \text{Lognormal}(\text{median} = 0.814, \text{CV} = 0.3)$$

Catchability

$$p(q_i) : \text{Uniform}(0.0001, 100)$$

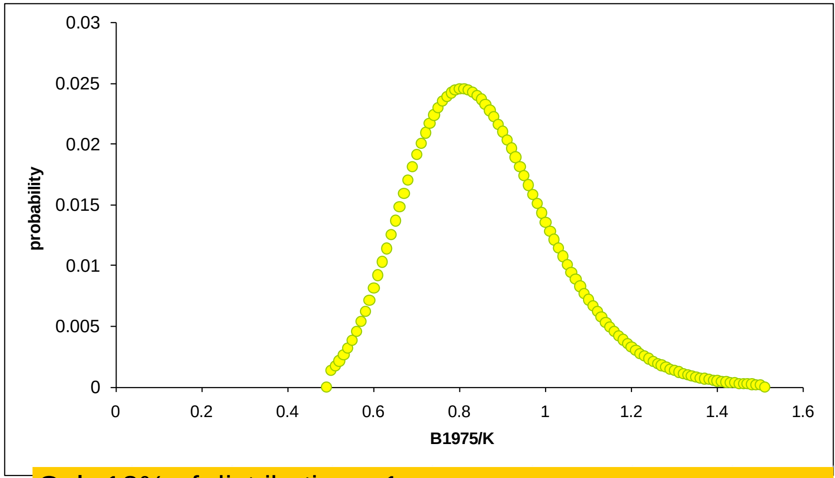
ASCFM: Priors

Depletion in 1975

$$p(B_{1975}) : \text{Lognormal}(\text{median} = 0.83, \text{CV} = 0.2)$$

Additional variance parameters

$$p(\sigma^2) : \text{Uniform}(0, 2.0)$$



Only 18% of distribution > 1 :
B1975/K ~ Lognormal w/ median = 0.83 , CV = 0.202
(mean = 0.85 , mode = 0.80)

ASCFM: Constraints and penalties

- Penalty for $F_{2000} > F_{1999}$

A penalty was implemented to mirror the a priori notion that fishing mortality rates should decrease following prohibition of dusky landings: $P_1 = I_{F_{2000} > F_{1999}} (F_{2000} - F_{1999})^2 \times 1000$

- Penalty for apical F exceeding 1.0

$$P_2 = \sum_y I_{Fapical_y > 1.0} (Fapical_y - 1.0)^2 \times 1000$$

- Also, set F in 2009 to be the average of F from 2006, 2007, and 2008 (within the model)

NOAA
FISHERIES
SERVICE

ASCFM: Computing

Minimization of log joint posterior using AD Model Builder Software

Uncertainty characterized using Hessian-based standard errors and, where appropriate, the “profile likelihood” option for approximating marginal posteriors (MCMC prohibitively time consuming due to poor mixing, etc.).

NOAA FISHERIES SERVICE

Outline

1. Age-Structured Catch Free Model (ASCFM)– general model structure and assumptions
2. Sensitivity models
3. Projection methods
4. Results

Outline

1. Age-Structured Catch Free Model (ASCFM)– general model structure and assumptions
2. Sensitivity models
3. Projection methods
4. Results

NOAA
FISHERIES
SERVICE

Sensitivity runs

- S1: Use of a single, hierarchical index in place of the five indices used in the base run
- S2: Decrease in catchability starting in 2000 for the bottom long line sector
- S3: A high natural mortality scenario
- S4: A U-shaped natural mortality curve allowing senescence
- S5: A run using index input CV's only (no "additional" or estimated variance)
- S6: A run using only VIMS, NELL indices
- S7: A run using all fishery independent indices, including UNC, NMFS historical
- S8: A run using all indices ("base" + "sensitivity" indices)
- S9: Logistic selectivity specified for the pelagic long line sector
- S10: Equal index weighting
- S11: Utilize a priori rankings from data workshop to weight indices
- S12: Fishing mortality from 1960-1979 modeled with a power curve

S1: Hierarchical index analysis

- CIE review of data workshop suggested trying to get a handle on the degree to which indices track true abundance as opposed to artifacts of the sampling process (localized changes, spatial shifts in target population etc.)
- Employed a hierarchical Bayesian approach to try to estimate a single best index for each stock given reported CVs as well as additional (estimated) process variation for each index (see Conn 2010 CJFAS)

NOAA FISHERIES SERVICE

Hierarchical index: motivation

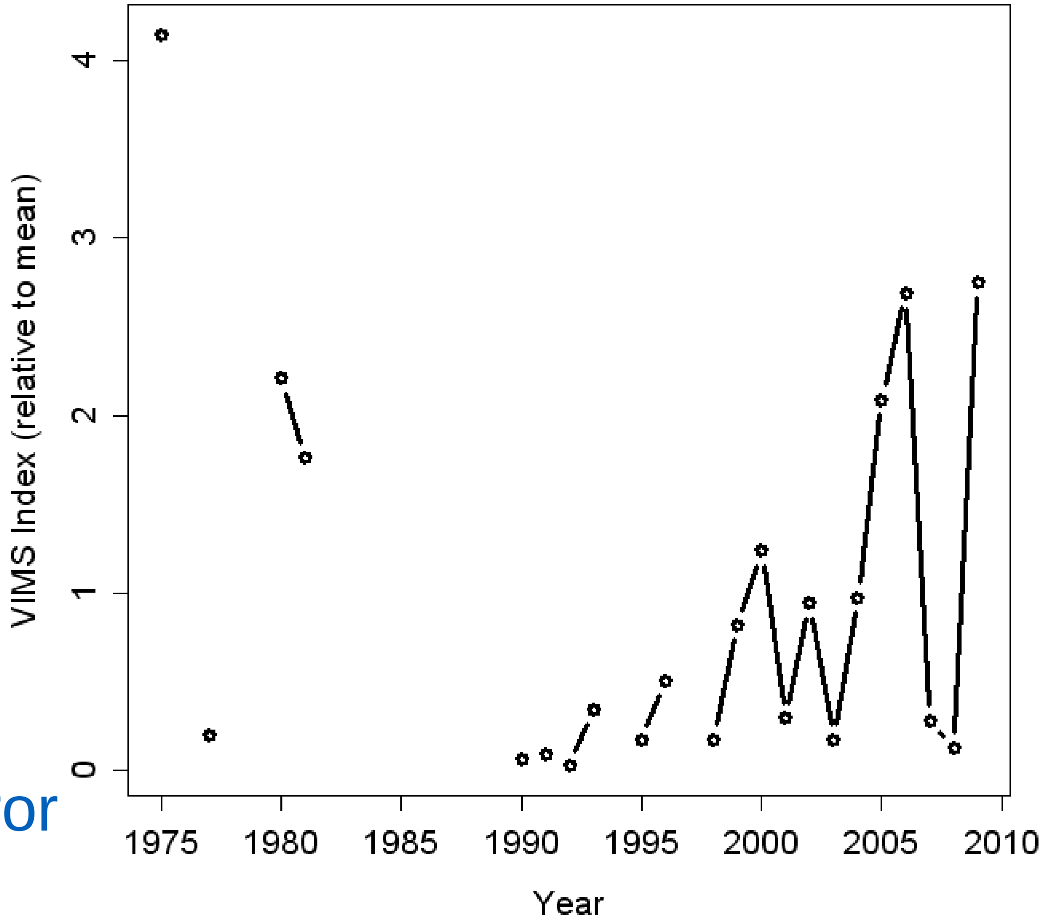
Example:

•CV for 1975 = 0.5

•CV for 1977=1.9

Not able to explain drastic increases and decreases with sampling error alone

➡ Residual process error



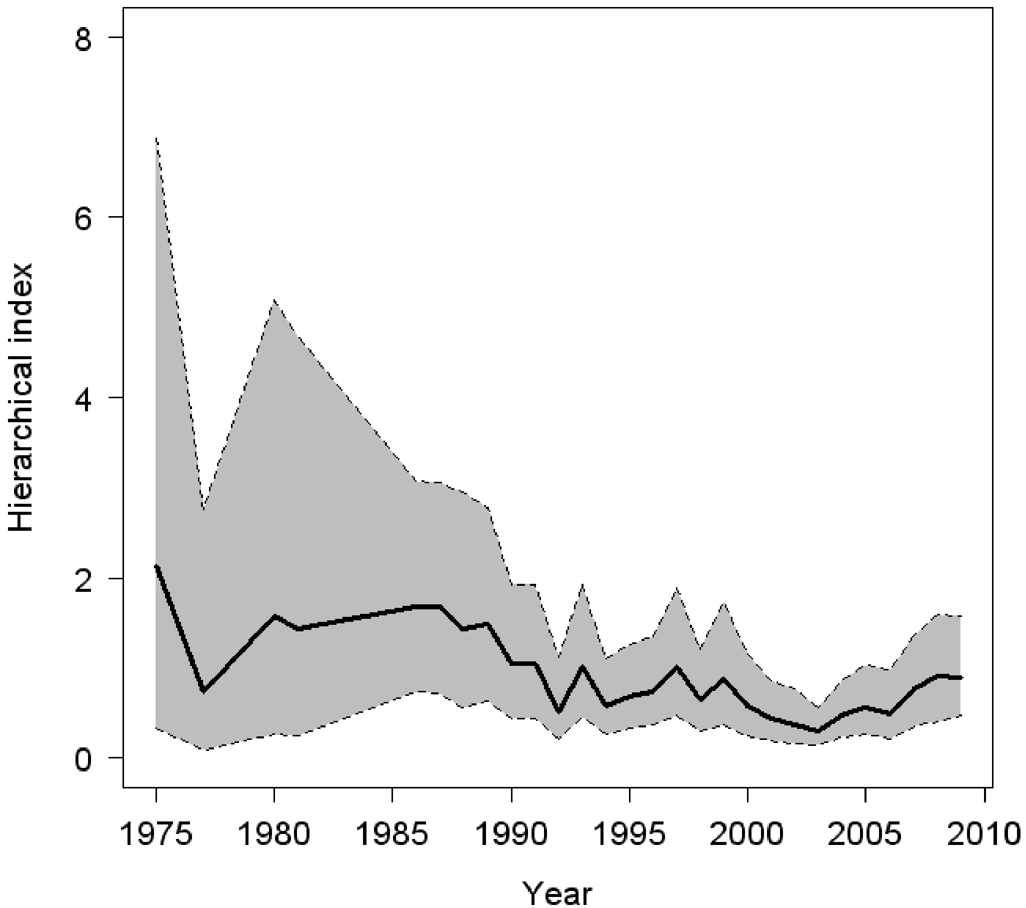
S1: Hierarchical index (in a nutshell)

- Assume that each index is sampled from a common population trend with subject to both sampling and process error (assumed lognormal)
- Estimate ‘common population trend’ and process errors via Bayesian hierarchical analysis w/ diffuse prior distributions (WinBUGS)
- Method does not use life history to constrain estimates or attempt to account for selectivity differences so is inferior to full assessment modeling

For further information, see Conn CJFAS 2010

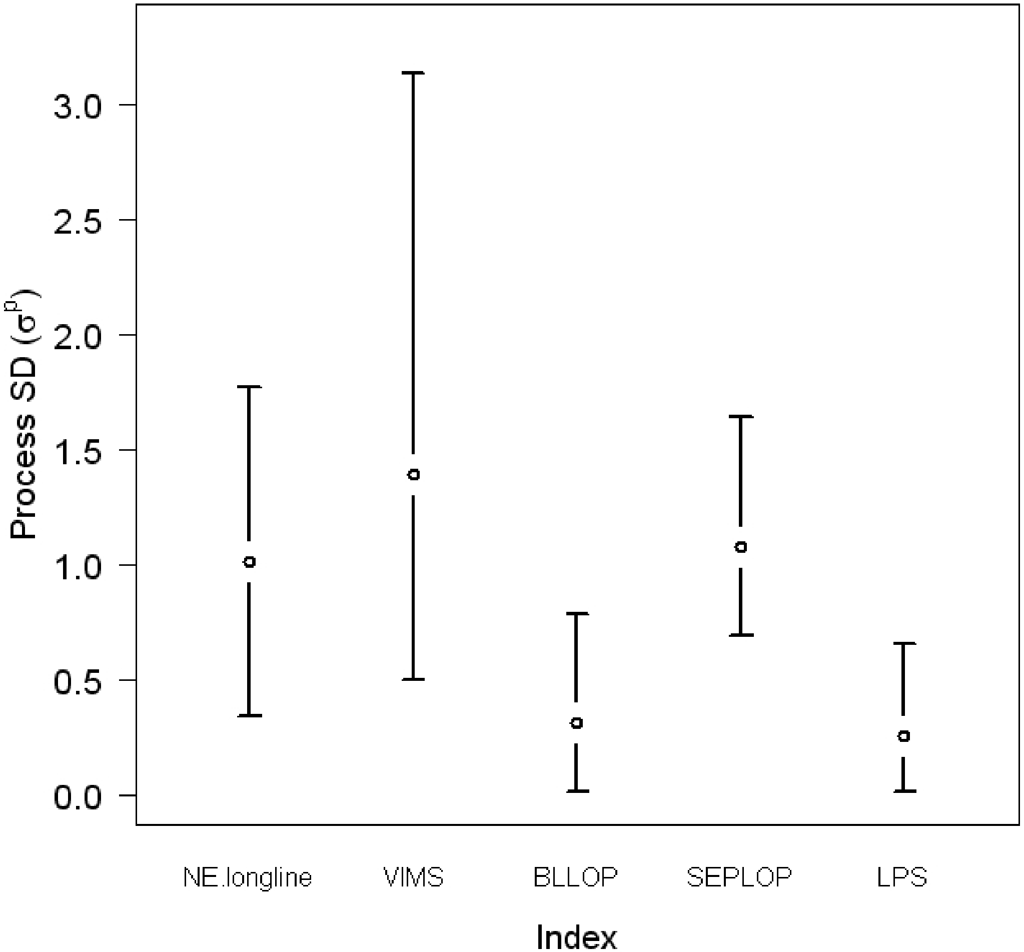
Hierarchical Index: Dusky

- Estimated single trend using all indices recommended for base run: VIMS, NE Longline, BLLOP, SEPLOP, LPS



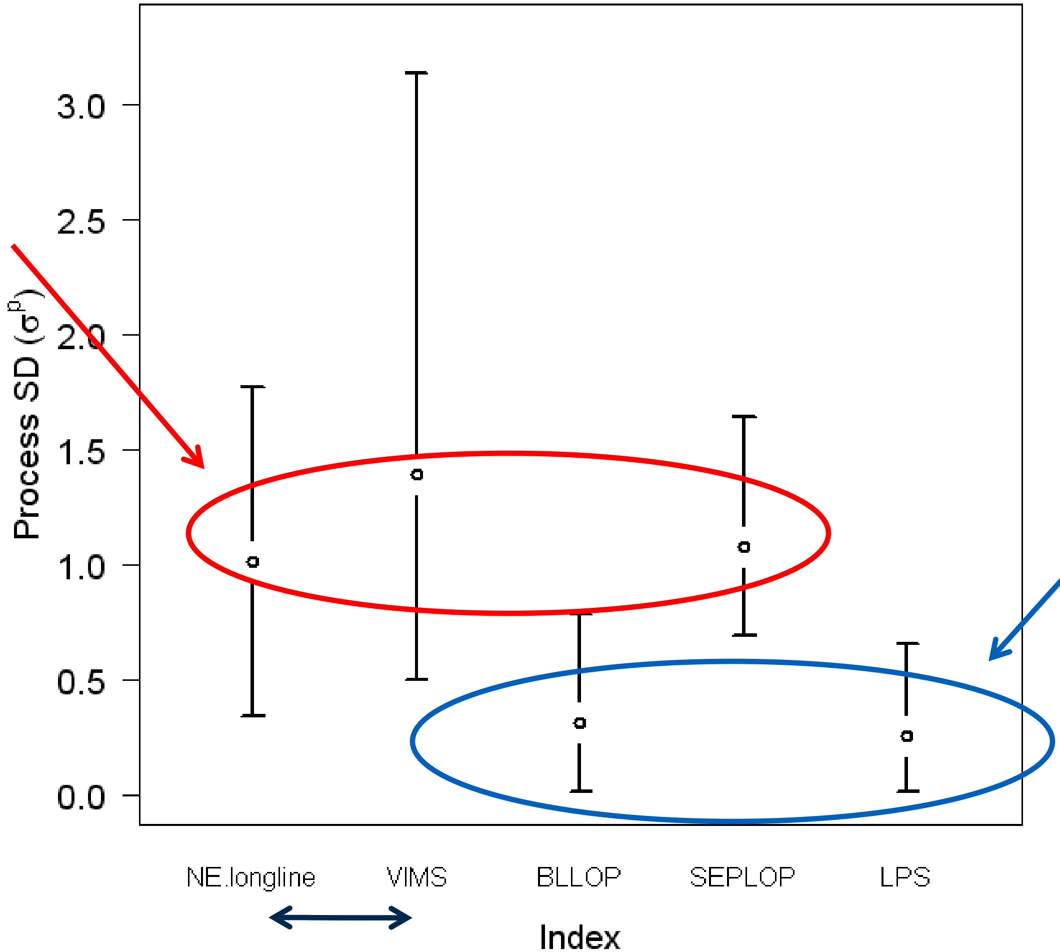
NOAA
FISHERIES
SERVICE

Hierarchical Index: Dusky



Hierarchical Index: Dusky

Process CV
b/w 1.7 and 6.0



Process CV ≈ 0.1

NOAA FISHERIES SERVICE

S2: Decrease in catchability in 2000

Calculated change in index between 1997/1998/1999 and 2000/2001/2002 and used as proxy for change in catchability for BLL following dusky prohibition in 2000

→66% Decrease in catchability!

Divided BLL index from 2000-2009 by 0.34 for use in sensitivity run

NOAA
FISHERIES
SERVICE

S3: High natural mortality

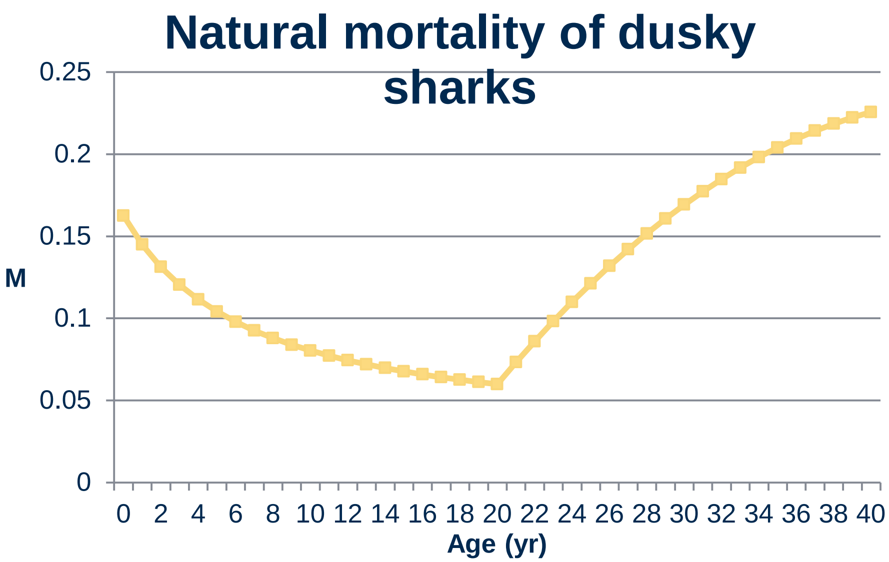
Concern that the “maximum survival” approach used to set natural mortality may have gone “too far” (e.g., spreadsheet did not include a + group)

Multiplied natural mortality vector by a fixed constant c=1.342 to result in spr0=2.0 (which imposes a lower bound of 0.5 for pup survival at low biomass)

S4: U-shaped natural mortality

Concern that initial model runs indicated presence of a large plus group (*cryptic biomass*)

- U-shaped natural mortality curve implemented to kill off the plus group; followed the Chen and Watanabee method



S5: A run using index input CV’s only (no “additional” or estimated variance)

S6: Fishery independent indices only

S7: A run using all fishery independent indices, including UNC, NMFS historical

S8: All indices (Base + Sensitivity)

For S7 and S8, PLL selectivity used for UNC, NMFS historical

NOAA FISHERIES SERVICE

S9: Logistic selectivity specified for the pelagic long line sector

All ages after age at peak of dome shaped selectivity curve assumed to have a selectivity of 1.0

S10: Equal index weighting

$$U_{i,t} = q_i \exp(\varepsilon_{i,t}) \sum_a N_{a,t} s_{a,t}$$

$$\varepsilon_{i,t} \sim \text{Normal}(0, \sigma^2_{overall})$$

S11: DW Index rankings used to specify CVs

	Index rank (w_i)
VIMS	3
LPS	4
BLL	1
NELL	1
PLL	2

$$\varepsilon_{i,t} \sim \text{Normal}(0, w_i \sigma^2_{overall})$$

S12: Fishing mortality in historic period modeled with a power curve

Initial peer review expressed concern that F-effort relationship could be driving results (only applies to historic period). Therefore, we considered an alternative where

$$F = \alpha(year_i - 1959)^{\beta}$$

An upper bound of β=1.6

was imposed to promote model convergence

Outline

1. Age-Structured Catch Free Model (ASCFM)– general model structure and assumptions
2. Sensitivity models
3. Projection methods
4. Results

NOAA FISHERIES SERVICE

Outline

1. Age-Structured Catch Free Model (ASCFM)– general model structure and assumptions
2. Sensitivity models
3. Projection methods
4. Results

NOAA
FISHERIES
SERVICE

Projection methods

Managers required estimates on absolute scale to set quotas, etc.

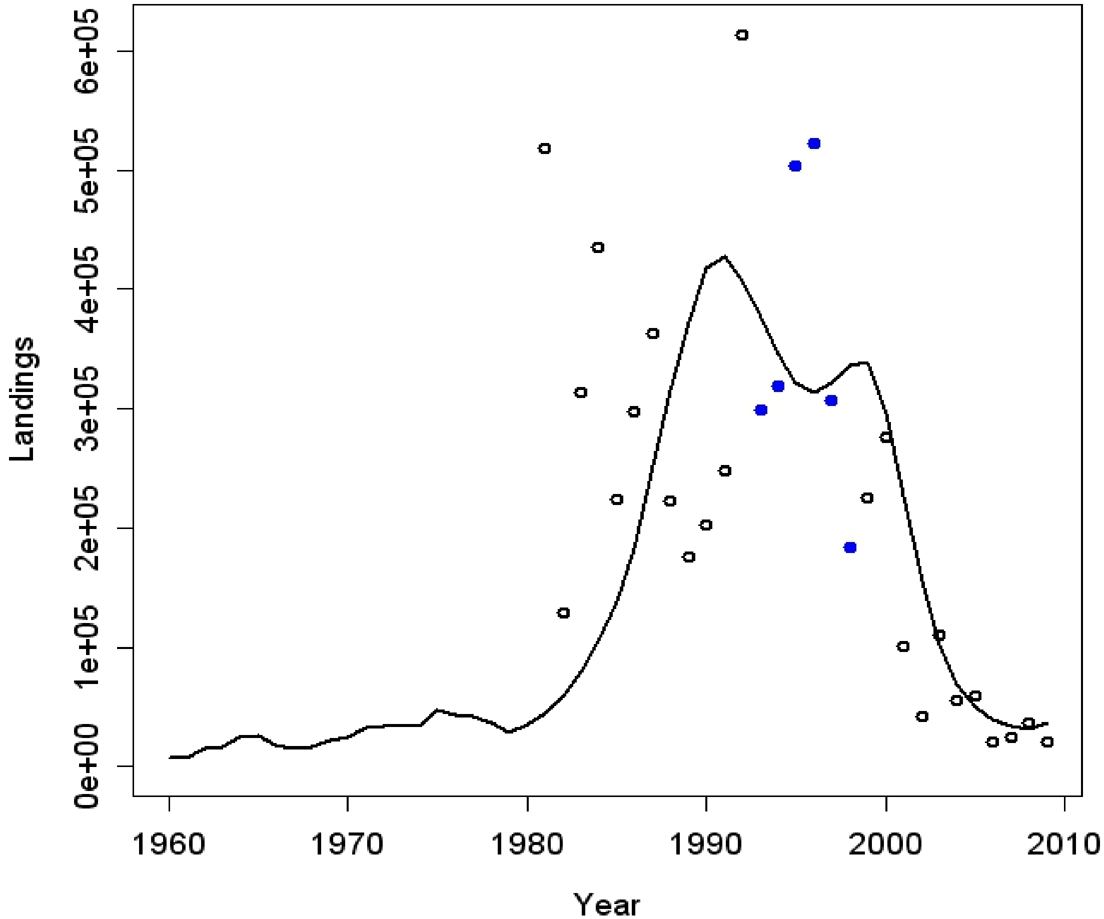
Using landings from 1993-1998 (probably the most reliable period), estimated a scaling parameter, Ψ, that minimizes

$$\Lambda_5 = 0.5\sum_i \sum_y \frac{(\log(L_{i,y}) - \log(\tilde{L}_{i,y}))^2}{\sigma_L^2} + \log(\sigma_L^2)$$

where $$\tilde{L}_{i,y} = \psi \sum_a N_{a,y} \frac{F_{a,y}}{Z_{a,y}} (1 - \exp(-Z_{a,y})) w_a$$

NOAA FISHERIES SERVICE

Projection methods



NOAA
FISHERIES
SERVICE

Projection methods

Population projected forward using same set of equations from the stock assessment

Stochasticity induced by bootstrapping, where each bootstrap replicate had productivity (M0), 2009 biomass, and 2009 F sampled from a multivariate normal approximation to the joint posterior.

Projection runs

•Fcurrent:	Fishing mortality constant at 2009 levels
•F0:	No fishing mortality
•Fmsy:	Fishing mortality constant at MSY levels
•Ftarget:	Fishing mortality set with P*=0.3
•Frebuild50:	The maximum fishing mortality that would allow a 50% chance of rebuilding by 2108
•Frebuild70:	The maximum fishing mortality that would allow a 70% chance of rebuilding by 2108
•Fmax	F that would allow largest cumulative harvest over time frame, while still allowing a 70% chance of rebuilding by 2108; in practice, results for this scenario were the same as the *Frebuild70*
•Fixed Removals	Assumes the maximum fixed removals allowing a 70% chance of rebuilding by 2108

NOAA FISHERIES SERVICE

Outline

1. Age-Structured Catch Free Model (ASCFM)– general model structure and assumptions
2. Sensitivity models
3. Projection methods
4. Results

Outline

1. Age-Structured Catch Free Model (ASCFM)– general model structure and assumptions
2. Sensitivity models
3. Projection methods
4. Results

NOAA
FISHERIES
SERVICE

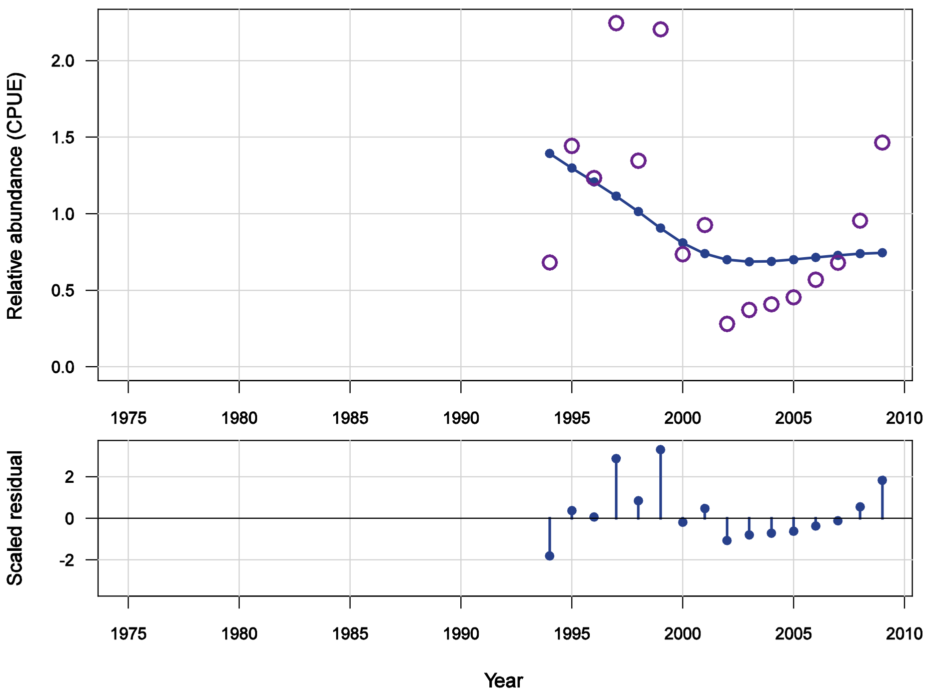
Results: base run

Fit to indices: “Additional variance”

BLLOP:	0.00
PLLOP:	0.30
LPS:	0.00
VIMS:	1.17
NELL:	1.47

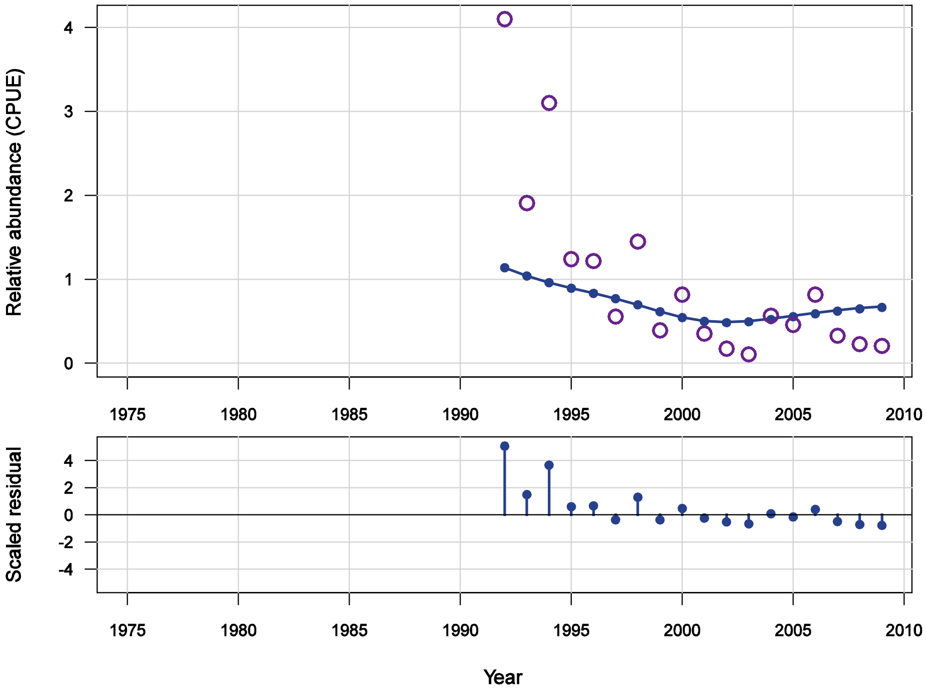
Results: base run

Fit to indices: BLLOP



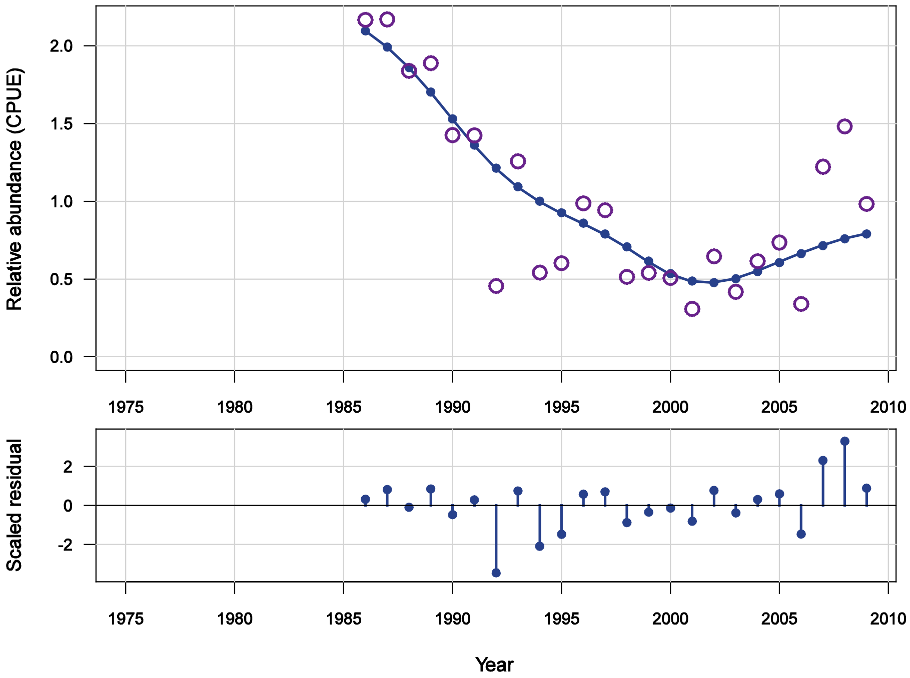
Results: base run

Fit to indices: PLLOP



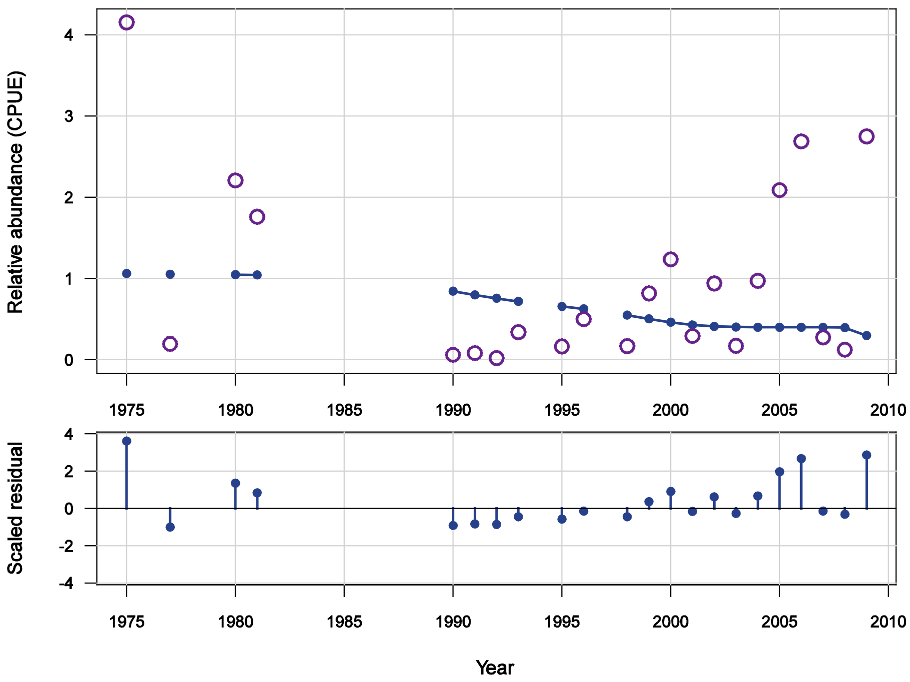
Results: base run

Fit to indices: LPS



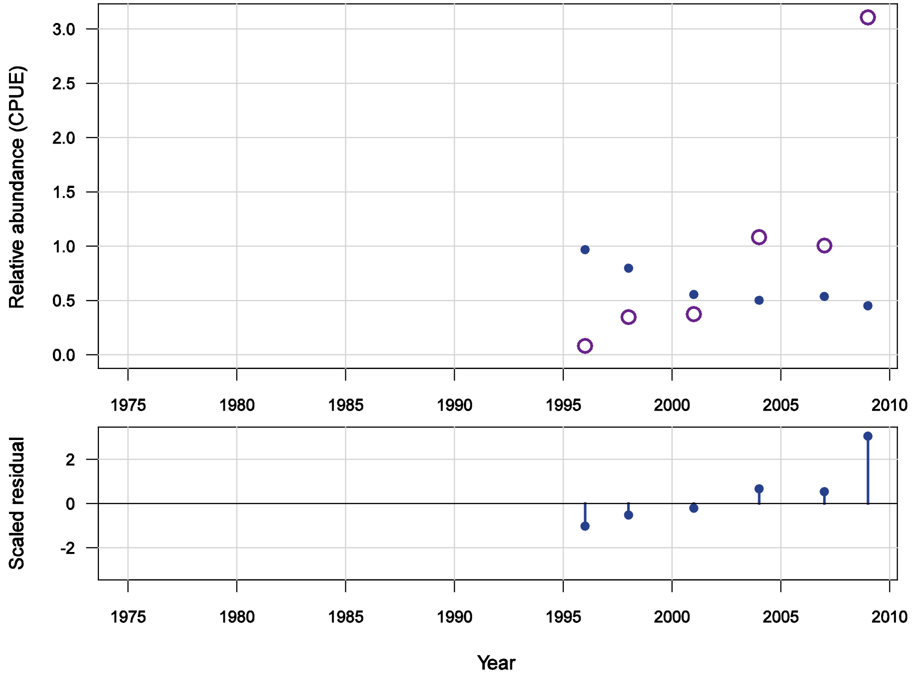
Results: base run

Fit to indices: VIMS



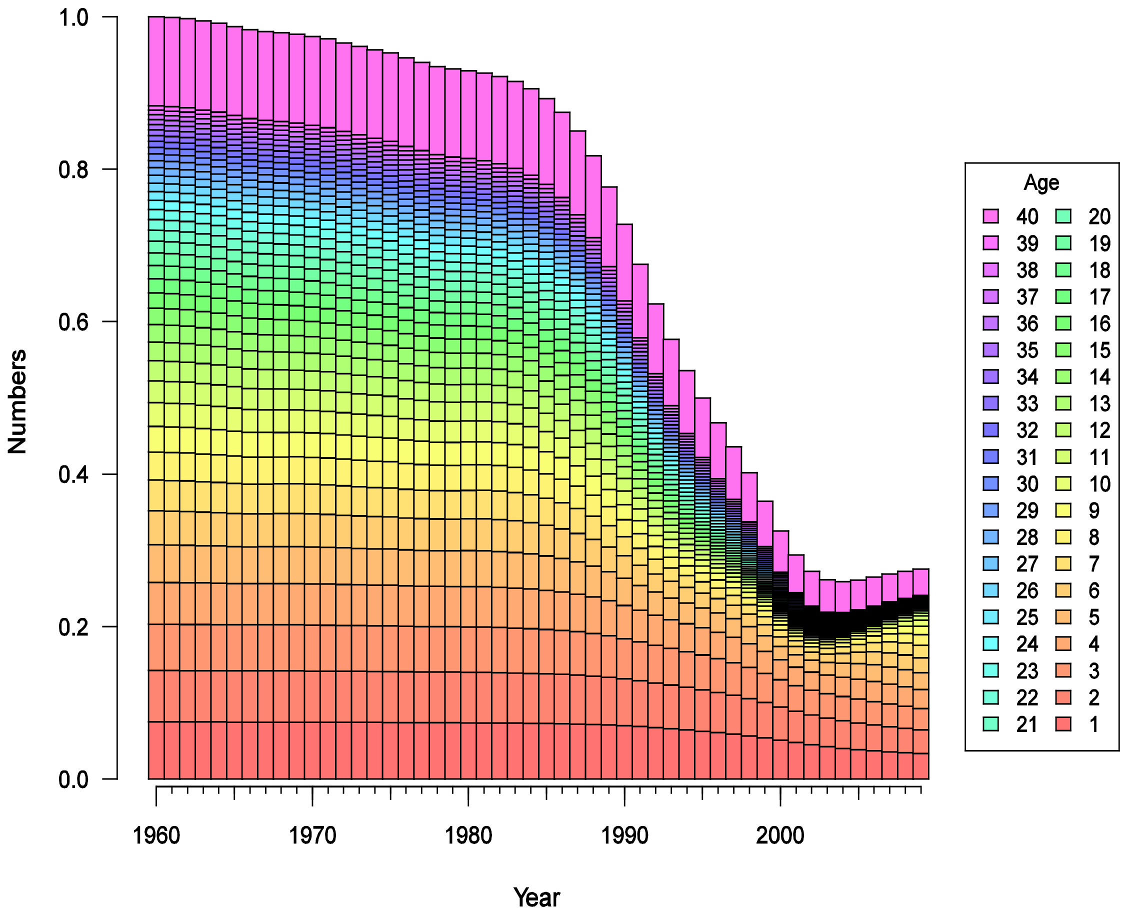
Results: base run

Fit to indices: NELL



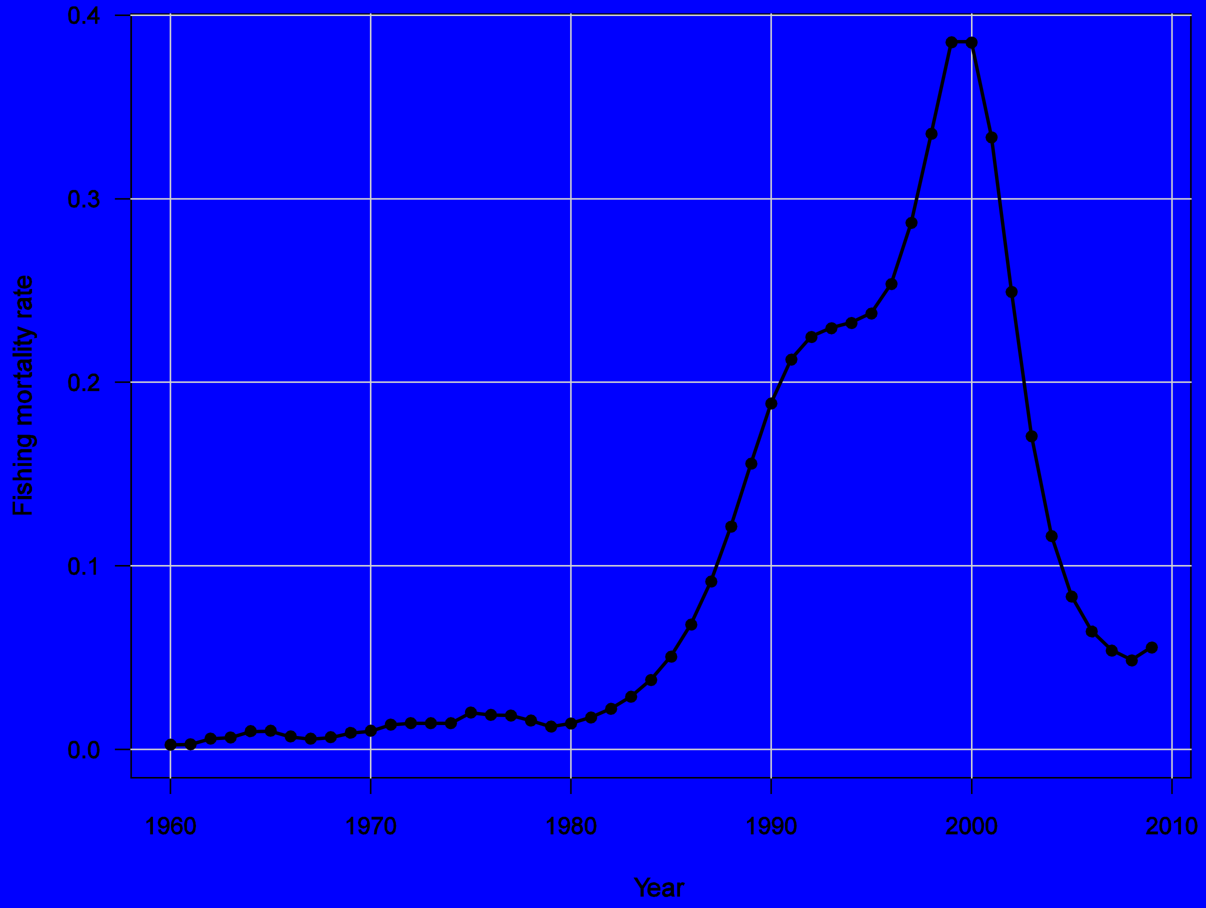
Results: base run

Relative abundance at age



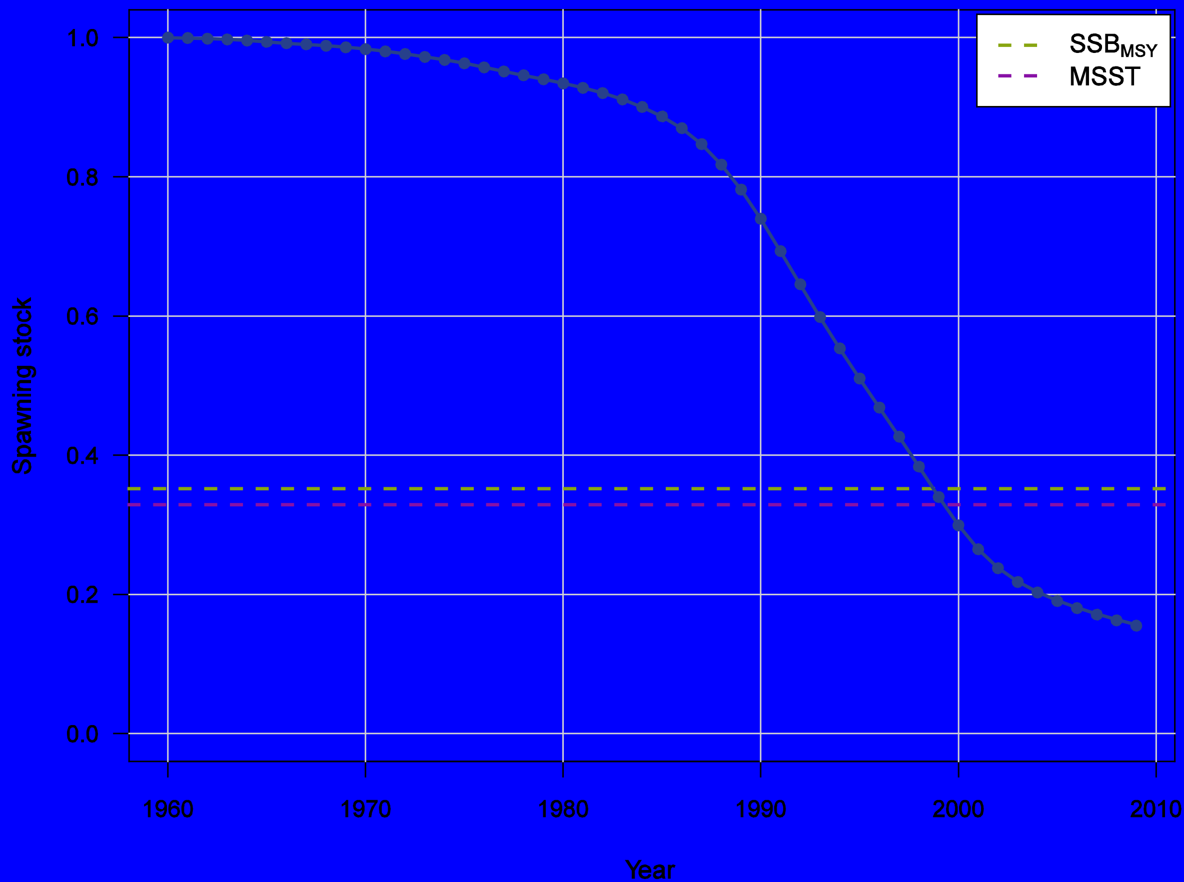
Results: base run

Apical fishing mortality



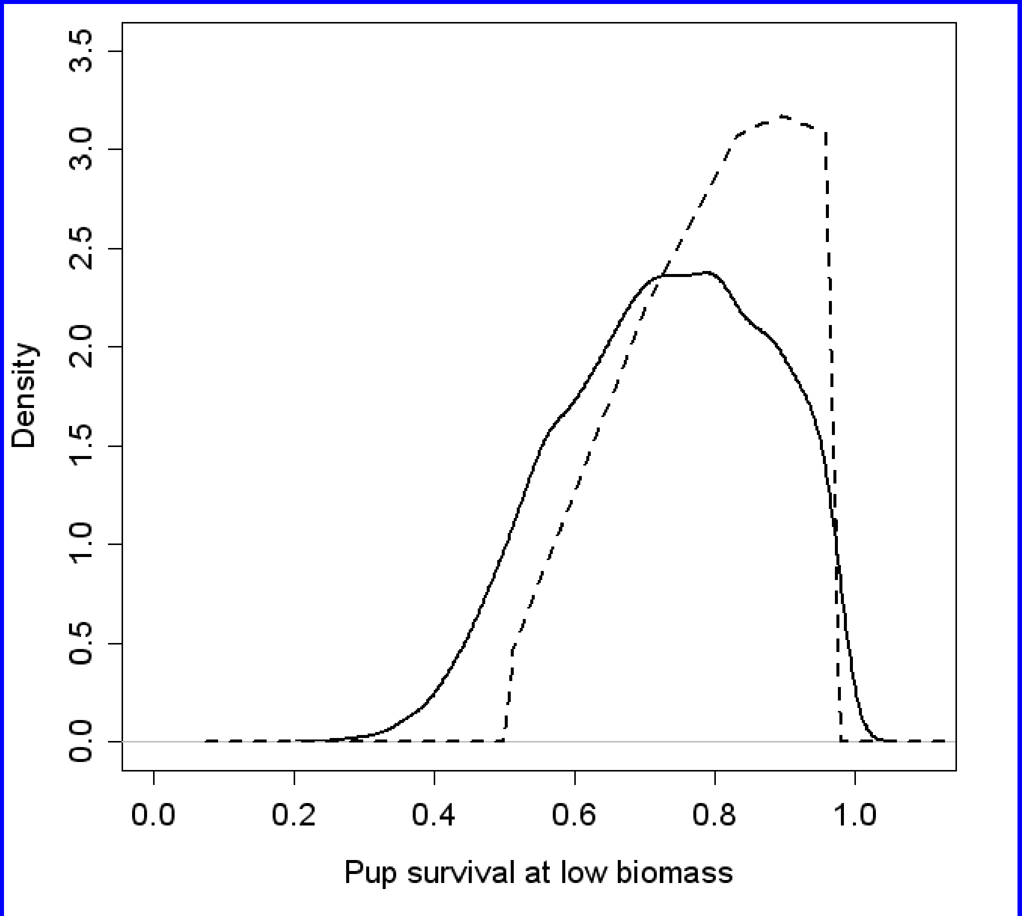
Results: base run

Relative biomass time series



Results: base run

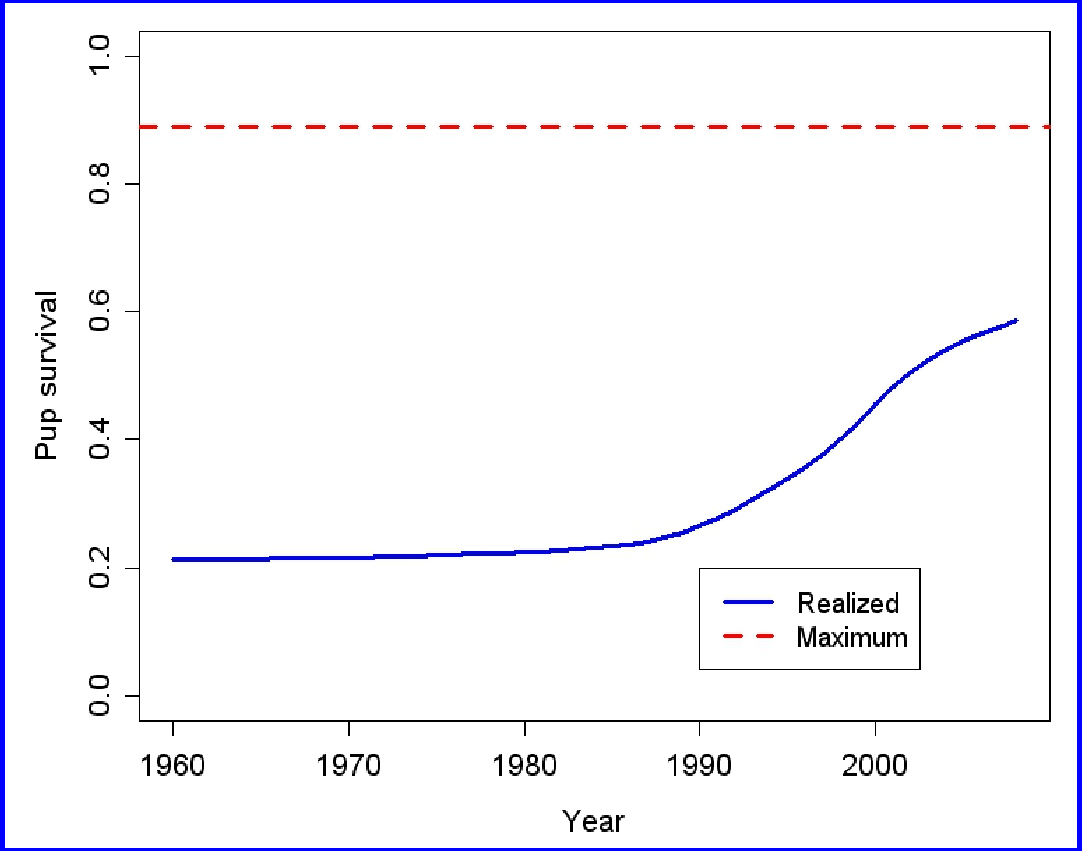
Pup survival at low biomass



Solid=prior
Dashed=posterior

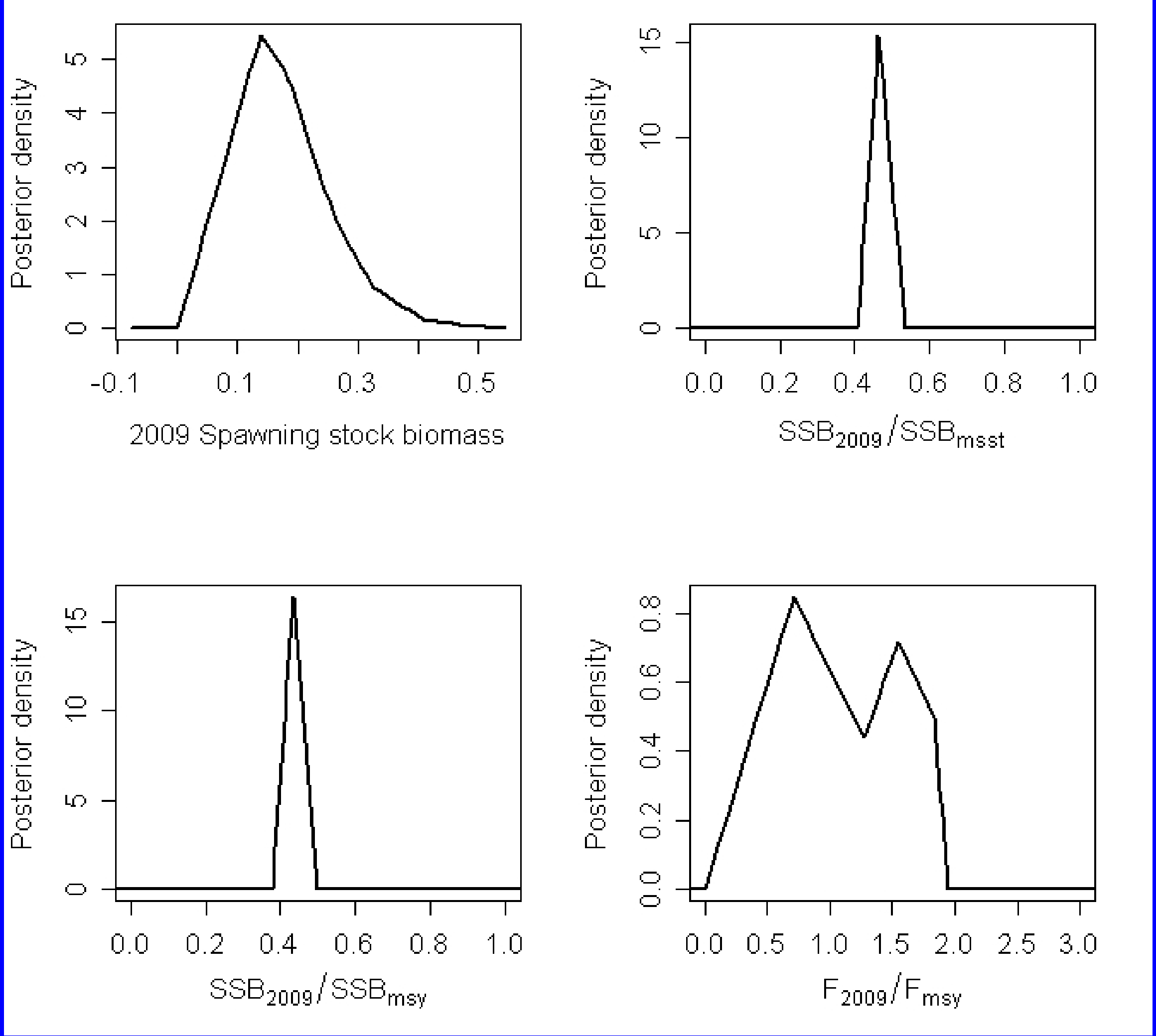
Results: base run

Pup survival time series



Results: base run

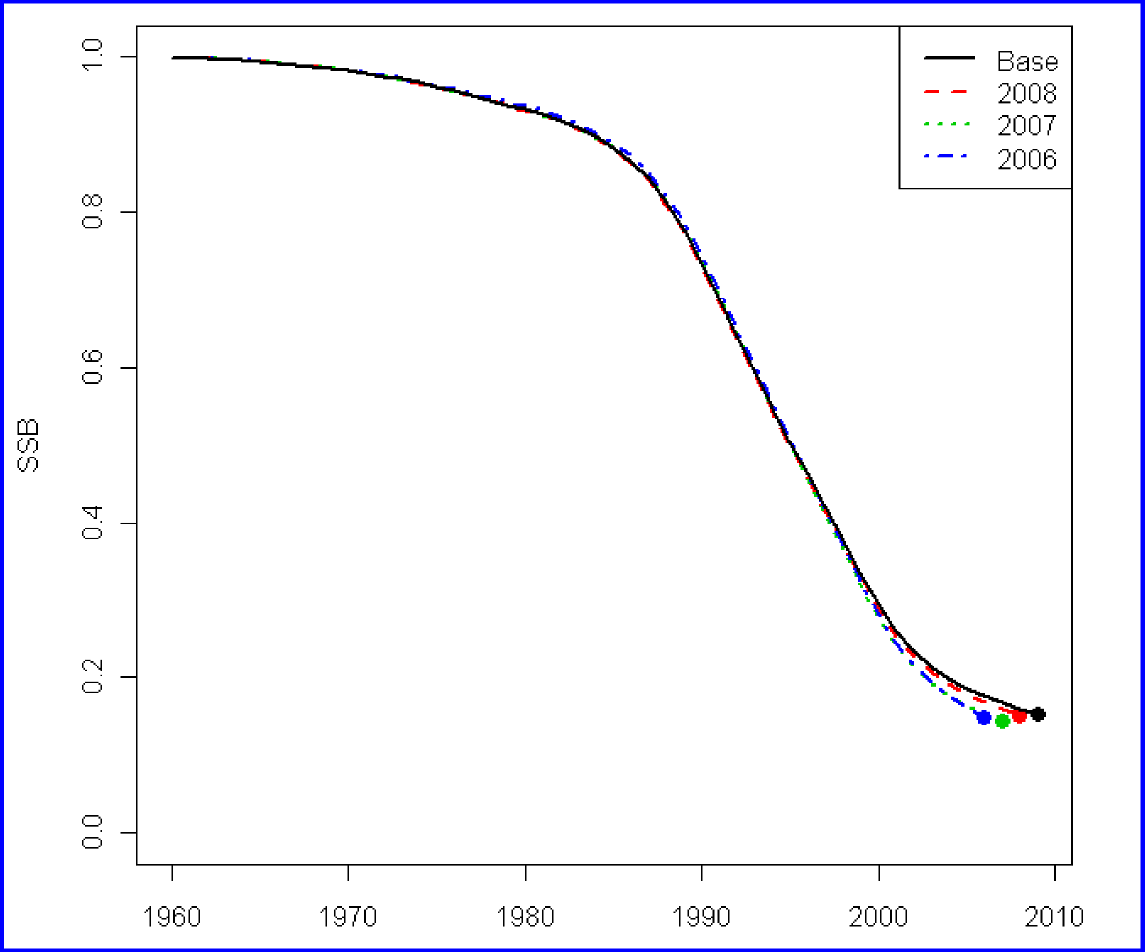
Posterior distributions for stock status



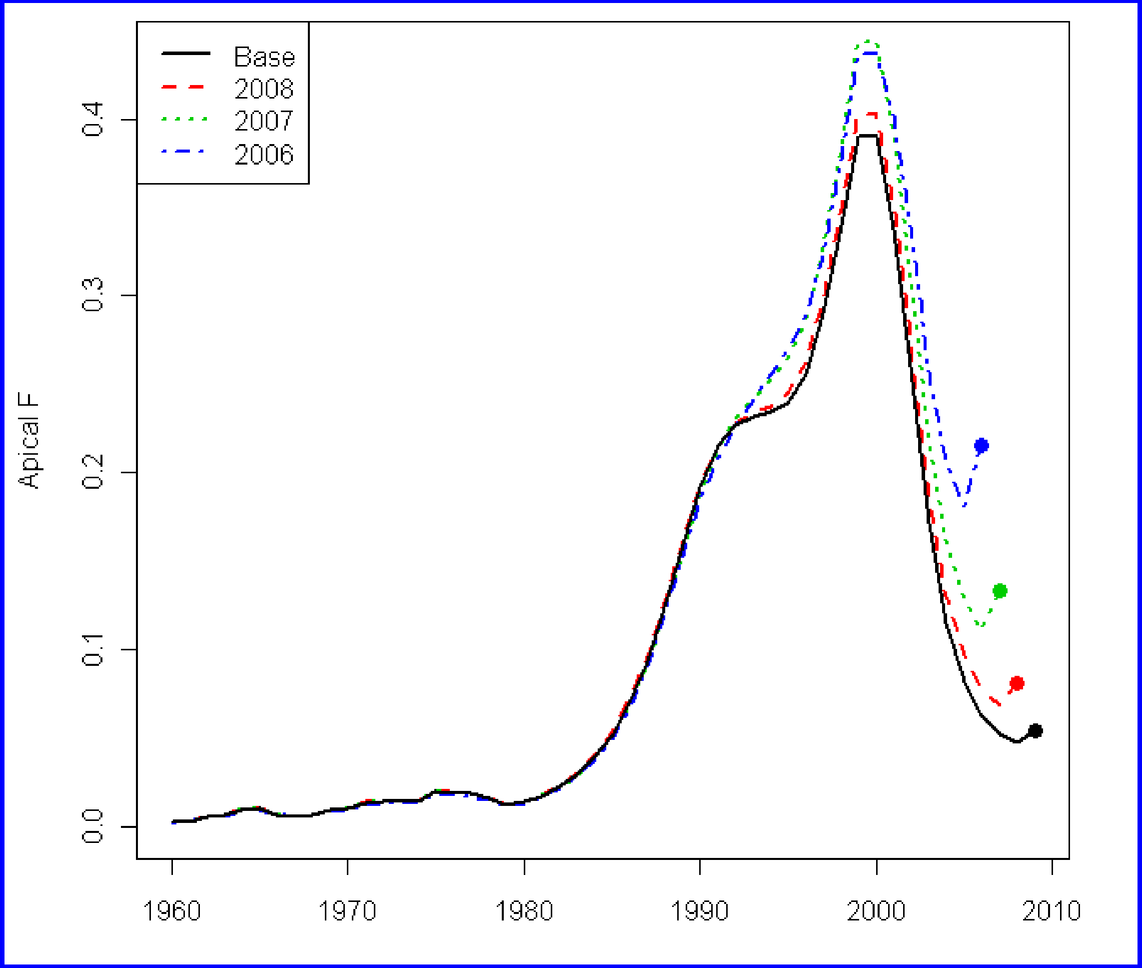
Results: base run

Quantity	Est	CV
SSB_{2009}/SSB_{MSY}	**0.44**	0.56
SSB_{2009}/SSB_{MSST}	**0.47**	0.56
F_{2009}/F_{MSY}	**1.59**	0.72
SPR_{MSY}	0.51	0.04
F_{MSY}	0.035	0.06
SSB_{MSY}/SSB_0	0.35	0.18
SSB_{MSST}/SSB_0	0.33	0.18
F_{2009}	0.055	0.73
N_{2009}	0.28	0.34
SSB_{2009}	0.15	0.51
B_{2009}	0.20	0.40
Pup-survival	0.89	0.28
Alpha	4.18	0.29
$F_{20\%}$	0.085	0.07
$F_{30\%}$	0.063	0.06
$F_{40\%}$	0.048	0.06
$F_{50\%}$	0.036	0.06
$F_{60\%}$	0.026	0.06

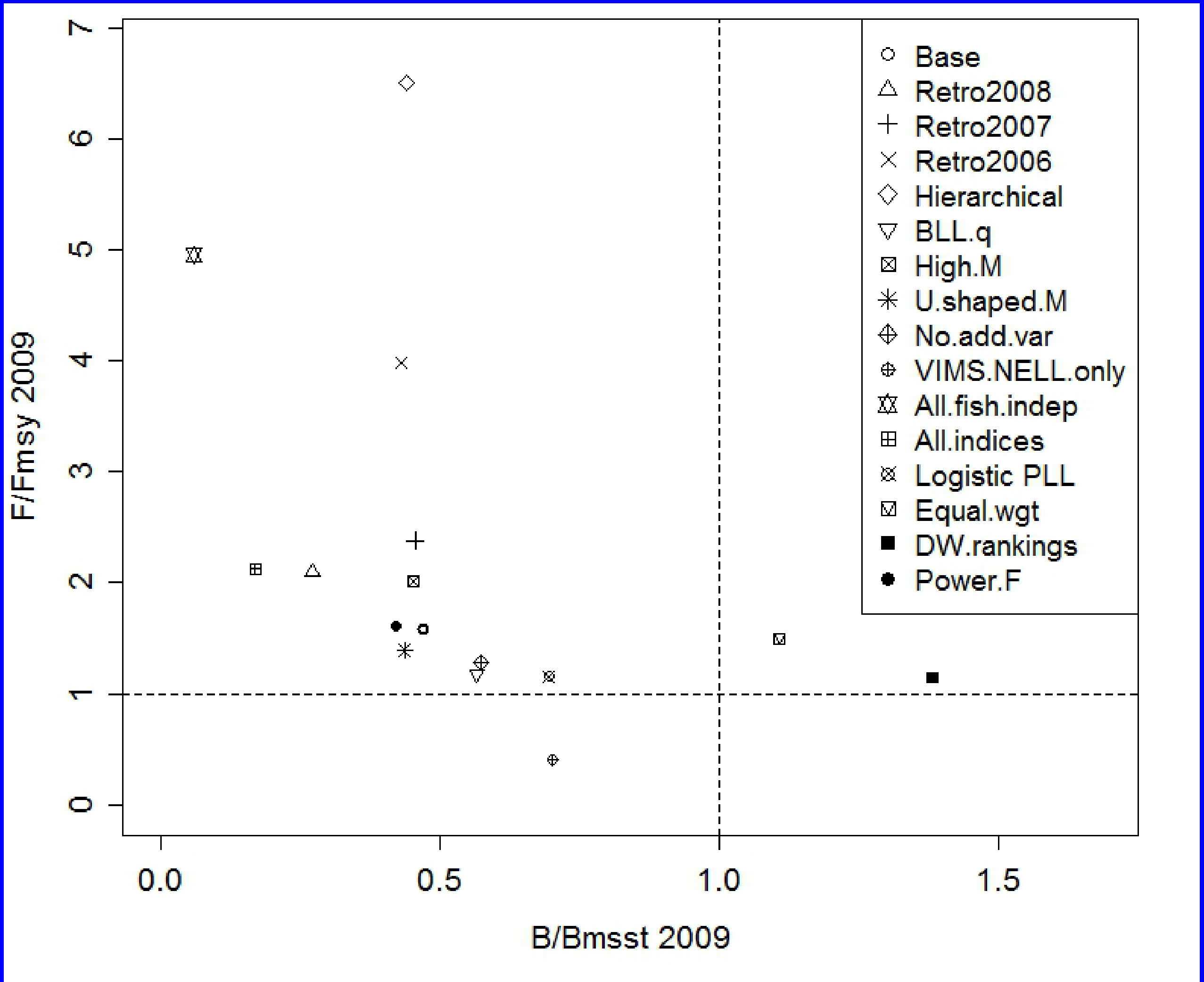
Results: retrospective runs



Results: retrospective runs

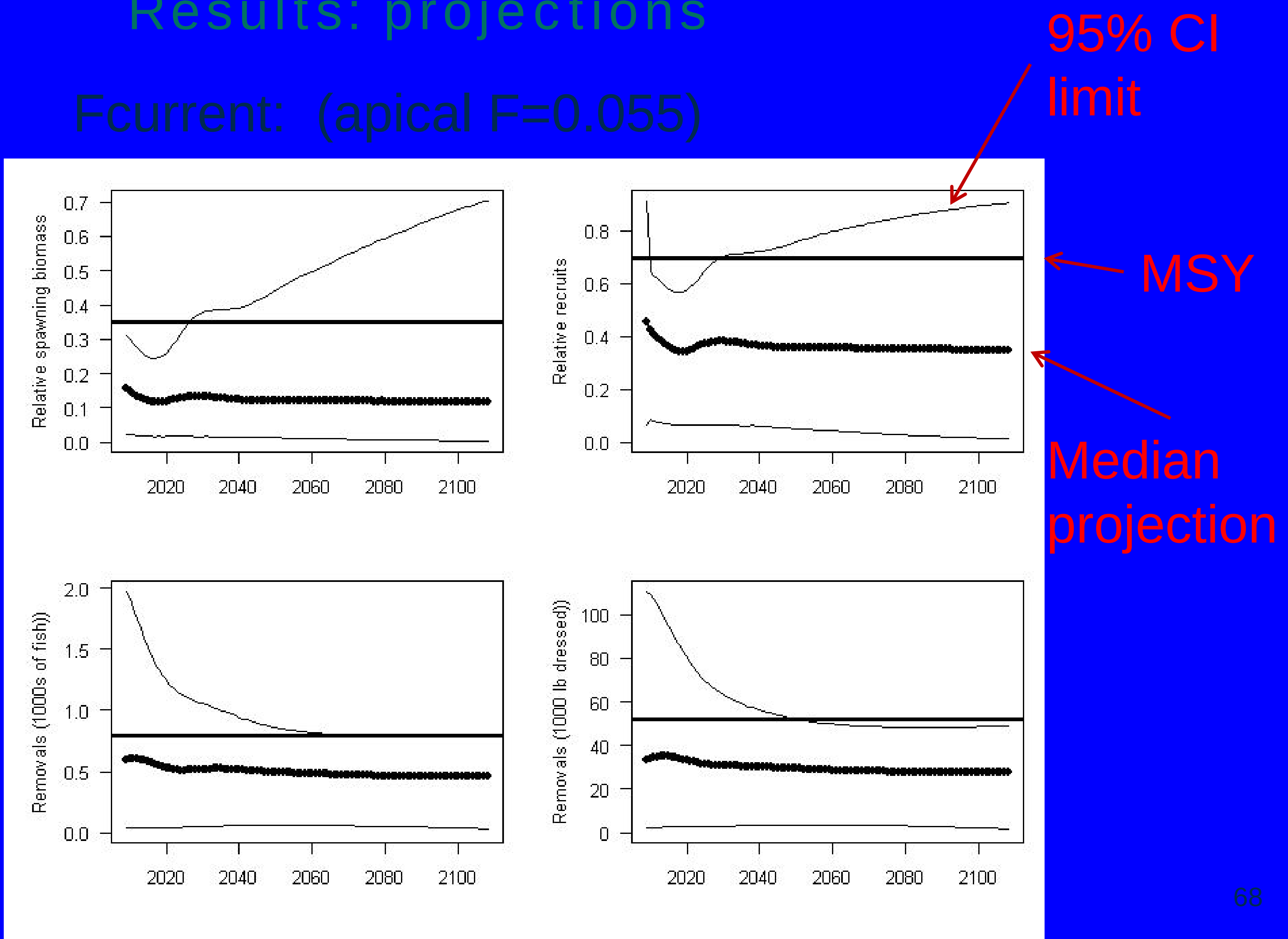


Results: sensitivity analyses



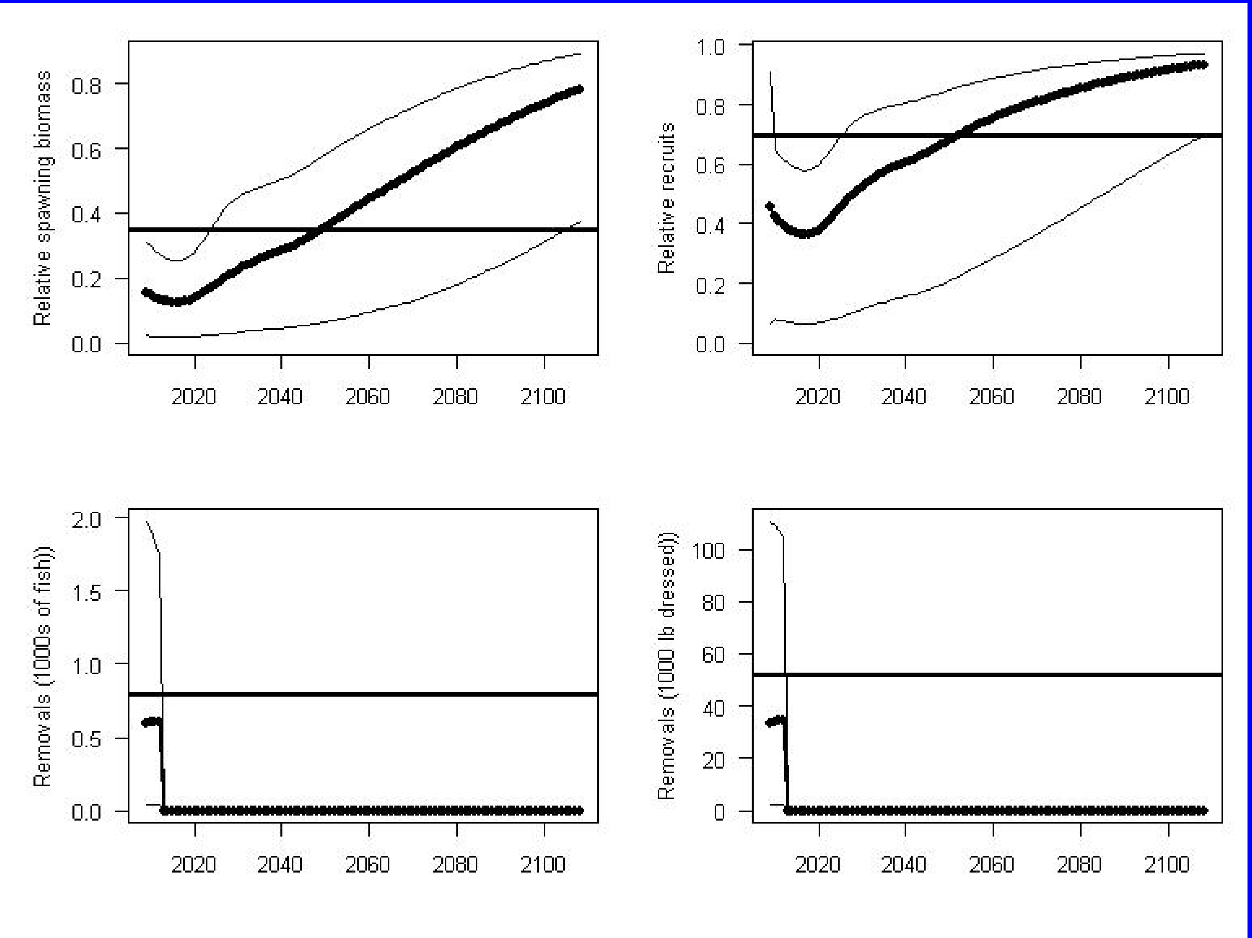
Results: projections

Fcurrent: (apical F=0.055)



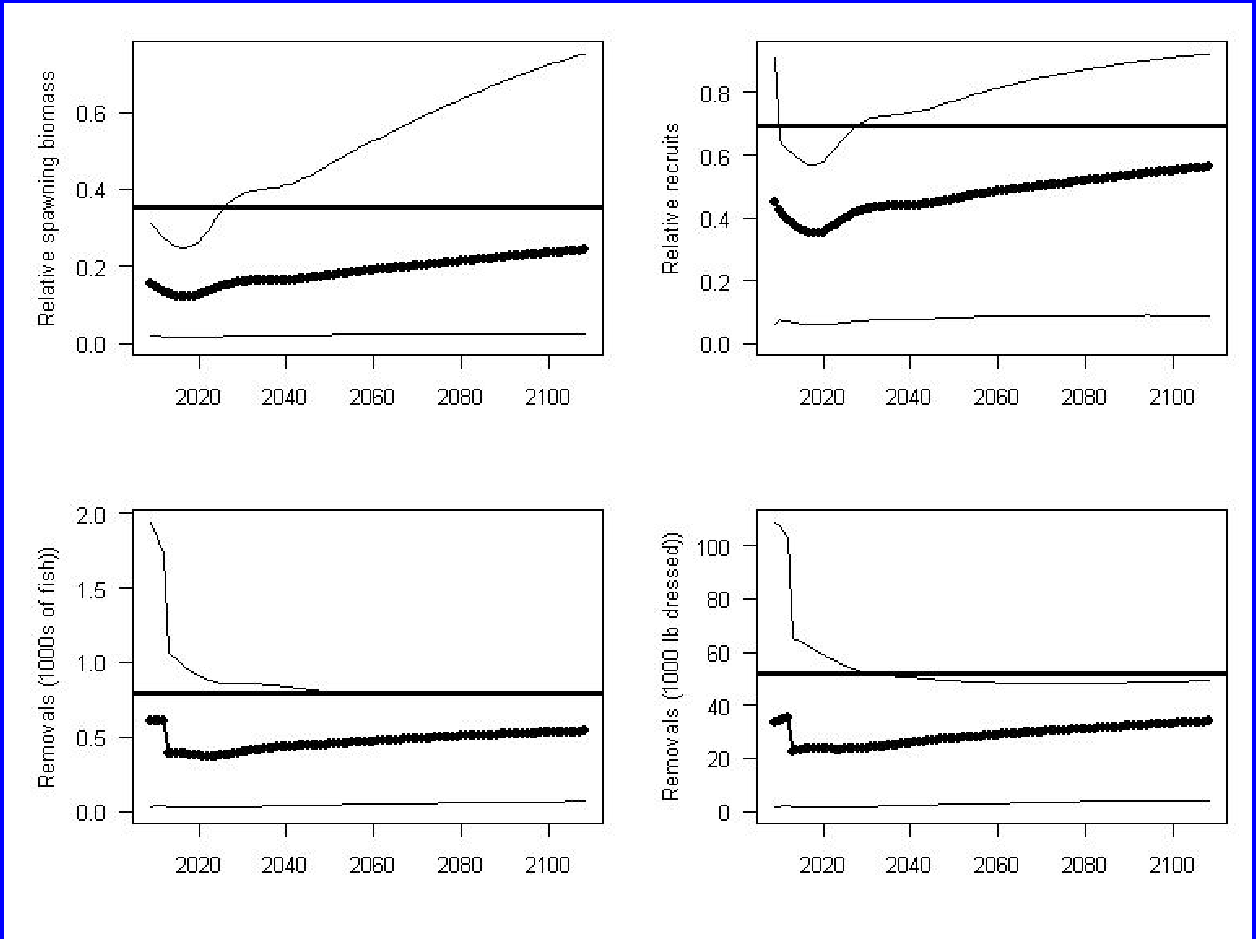
Results: projections

F=0 scenario:



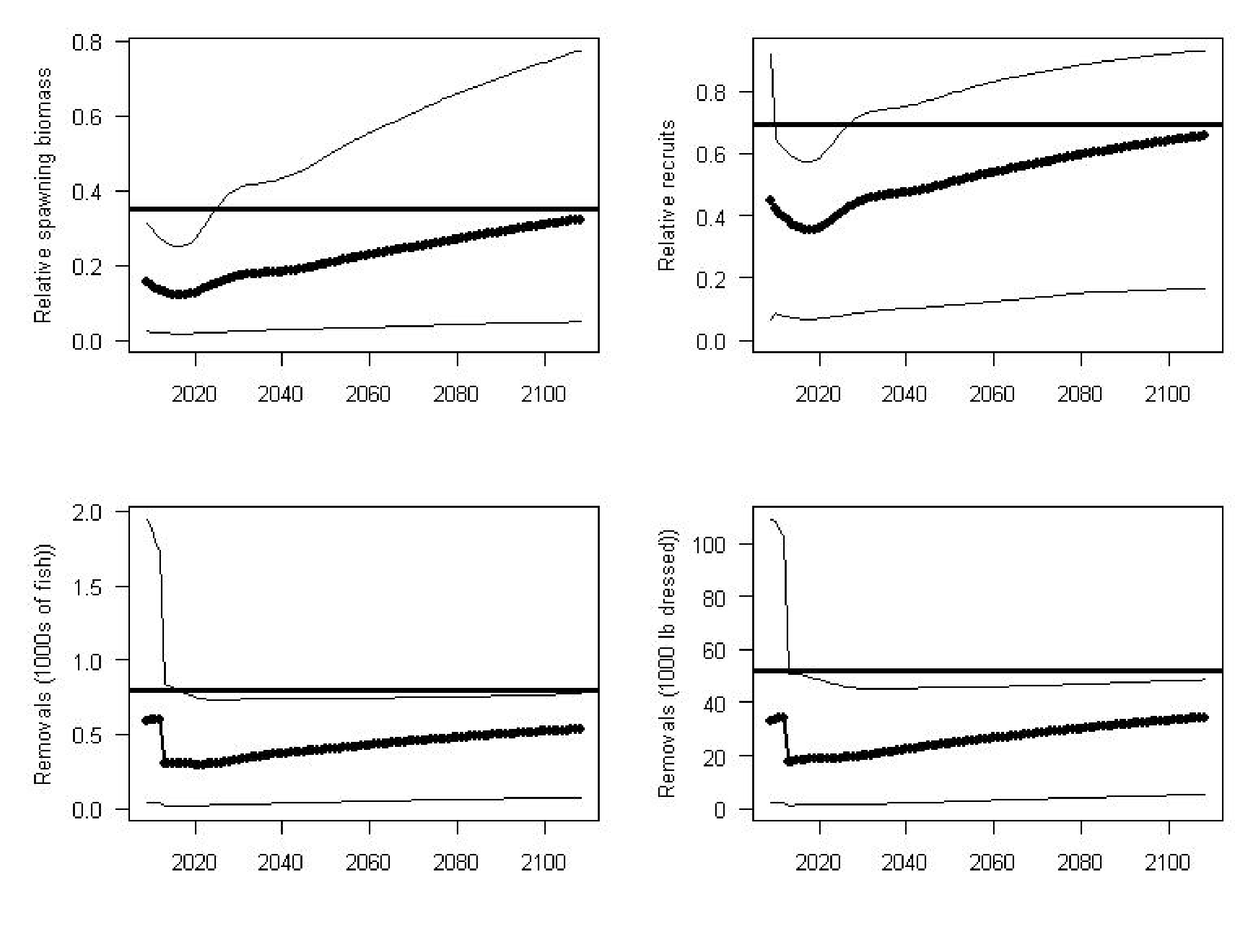
Results: projections

Fmsy scenario (apical F=0.035)



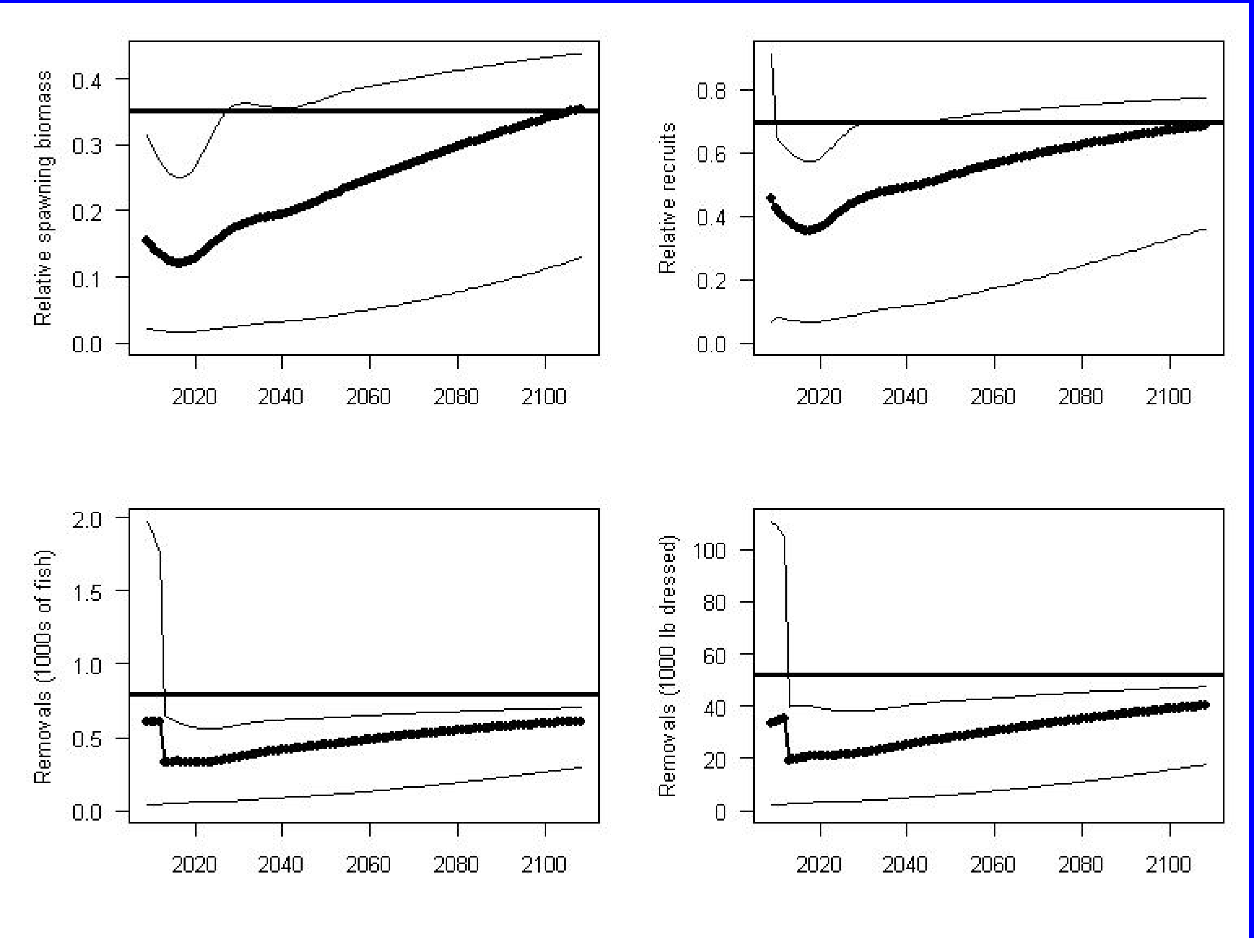
Results: projections

Ftarget scenario (apical F=0.028)



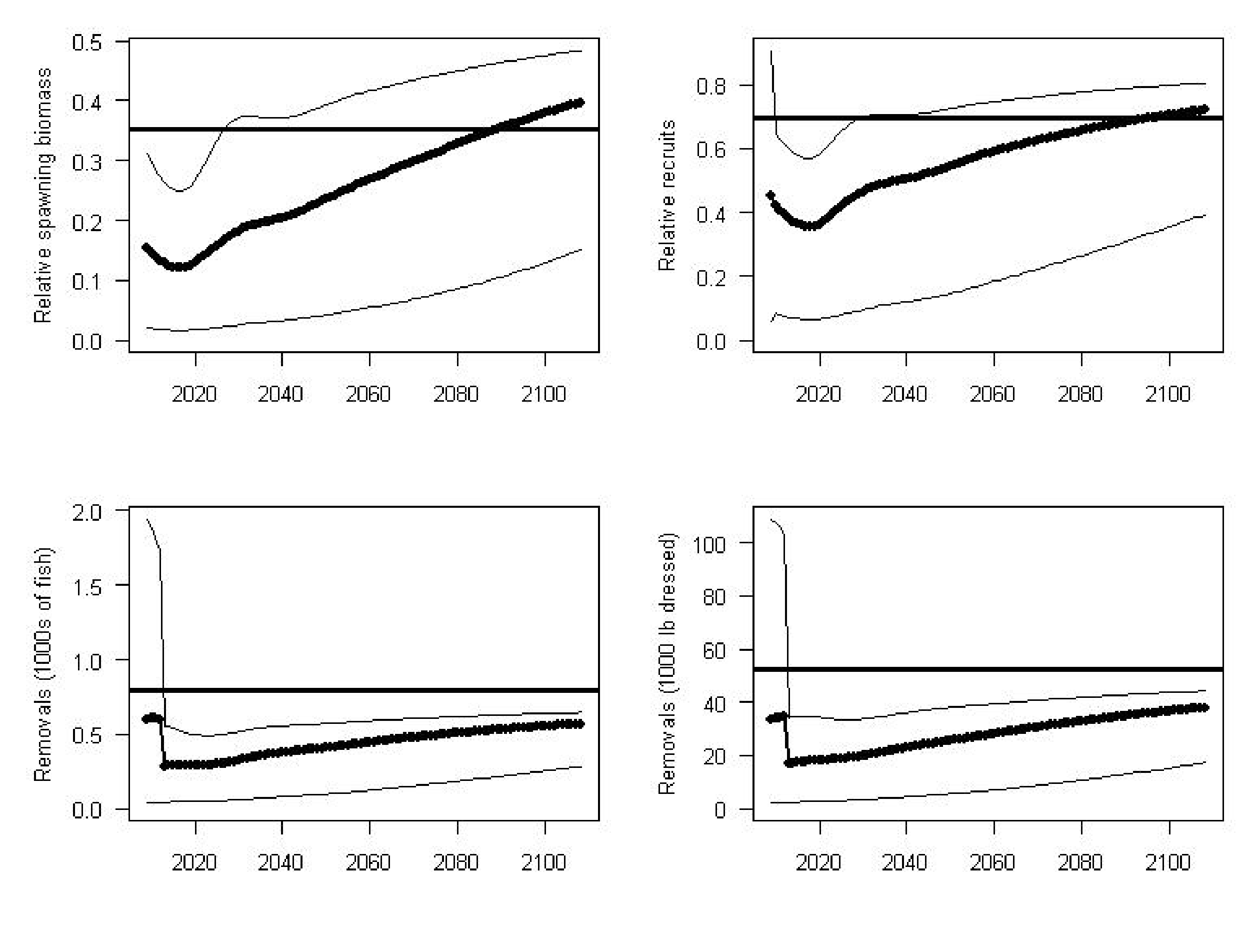
Results: projections

Frebuild50 scenario (apical F=0.027)



Results: projections

Frebuild70 scenario (apical F=0.023)



Results: projections

Fixed removals (21,200 lbs. gutted):