SEFSC

SEDAR 39

HMS Gulf of Mexico Smoothhound Complex

Assessment Process Report

SEDAR 39 Review Workshop

February 10-12, 2015, Panama City, FL

Outline

- Rationale
- Data inputs
- Model description
- Base model and results
- Retrospective analysis
- Uncertainty analysis (sensitivities)
- Projections
- Conclusions

Why assess a complex *vs.* individual species?

- Inability to differentiate among species due to difficulty of correct identification. This made it necessary to conduct the analyses on the complex of three species of GOM *Mustelus*

Why use surplus production models?

- Inability to differentiate among species precluded use of an age-structured model

- Use of a production model still allowed us to carry out quantitative projections

Why use Bayesian methods?

- Bayesian methods combine the *likelihood* with the *prior* distributions of each parameter to calculate a *posterior* distribution including both sources of information

- Demographic information allows us to develop an informative prior for *r* for smoothhound sharks

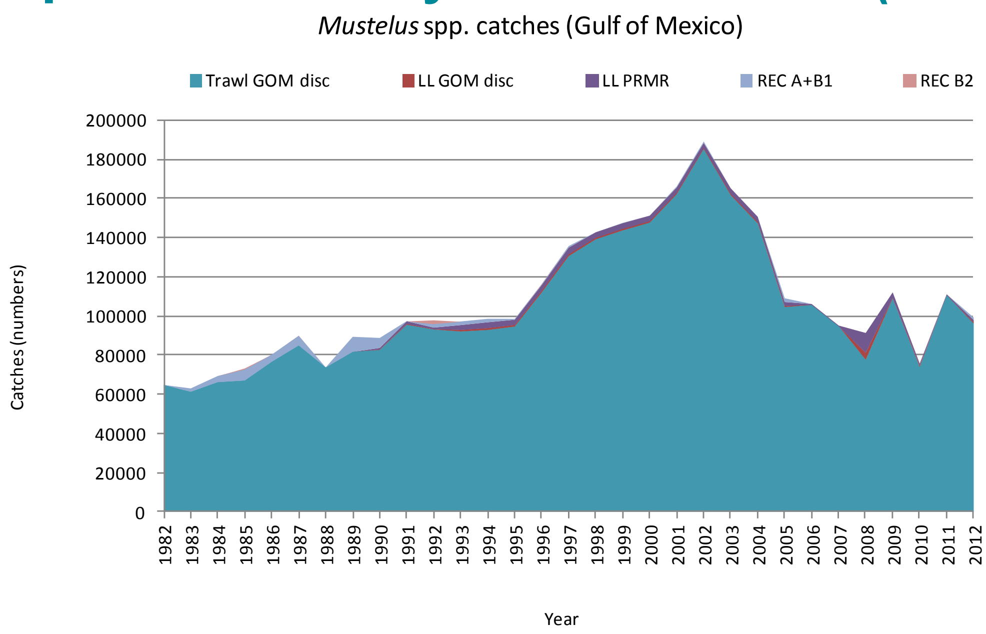
Why use state-space Bayesian surplus production model (SS-SPM) (Meyer and Millar 1999)?

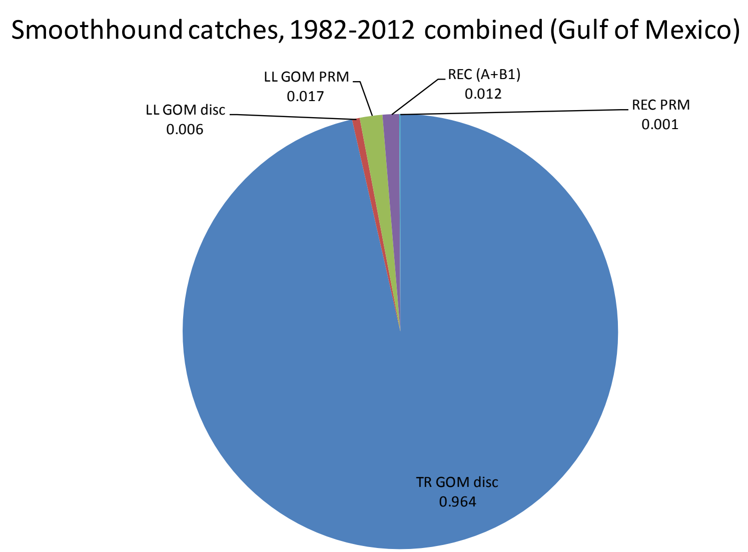
We initially attempted to use the Bayesian Surplus Production (BSP) model (McAllister and Babcock 2006), but the model was not able to fit the indices of abundance adequately (it showed flat trends) and the Assessment Panel (AP) recommended using an alternative approach. We thus decided to use a state-space Bayesian surplus production model (Meyer and Millar 1999), which in addition to considering observation error (like the BSP), also considers process error.

Data inputs

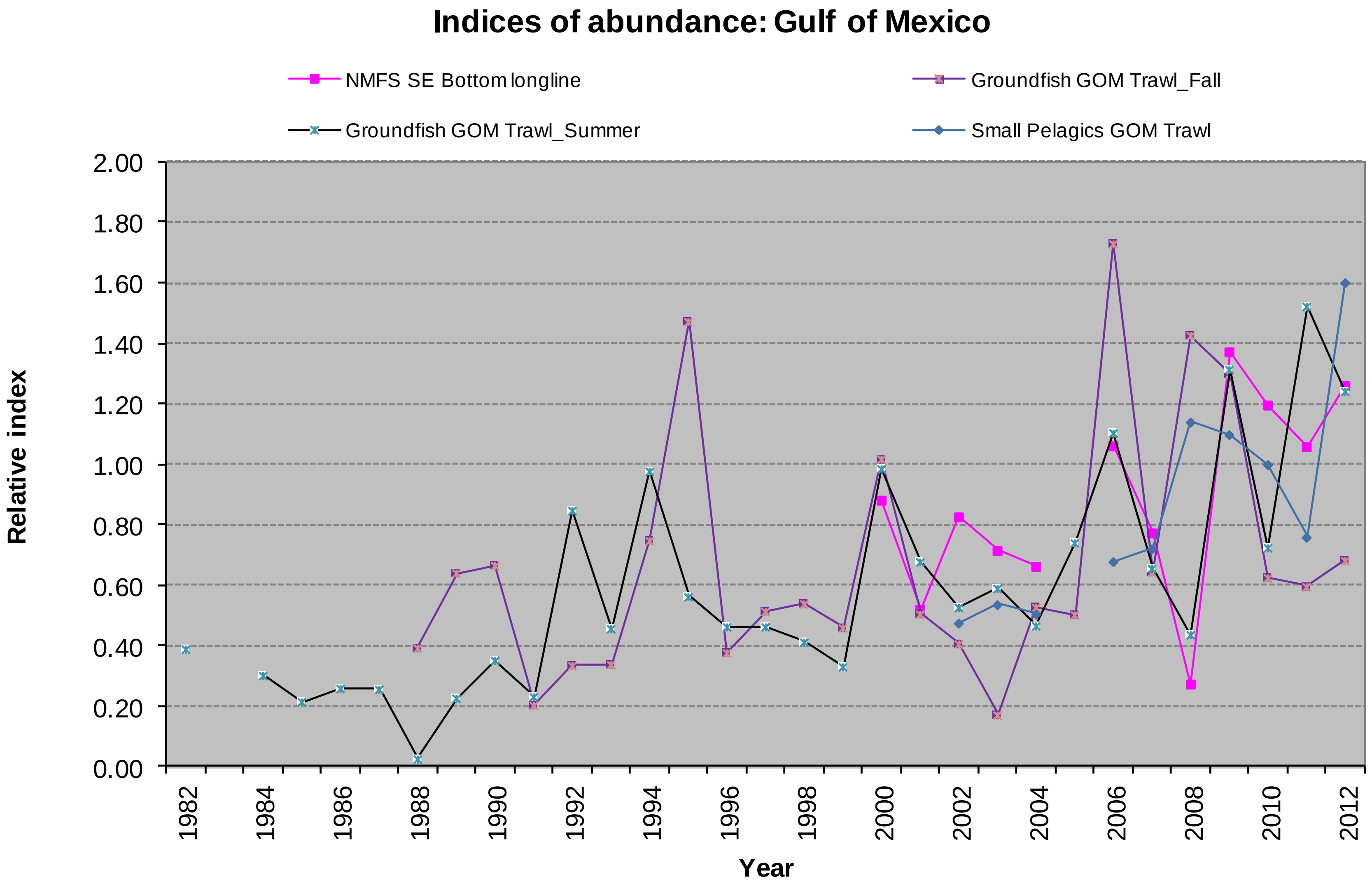
- Catch (one single series)
- Indices of abundance:
  1. NMFS SE Bottom Longline (NMFSSEBLL)
  2. Groundfish Trawl_Fall (GROUNDTRF)
  3. Groundfish Trawl_Summer (GROUNDTRS)
  4. Small Pelagics Trawl (SMALLPELTR)
- Priors for r, K, $P_{82}=N_{82}/K$ (initial depletion), observation error process error variances, proportions of carrying capacity ($P_t=N_t/K$, $t>=2$)

Catches of smoothhounds in the Gulf of Mexico, 1982-2012 (top) and as a proportion for all years combined (bottom)

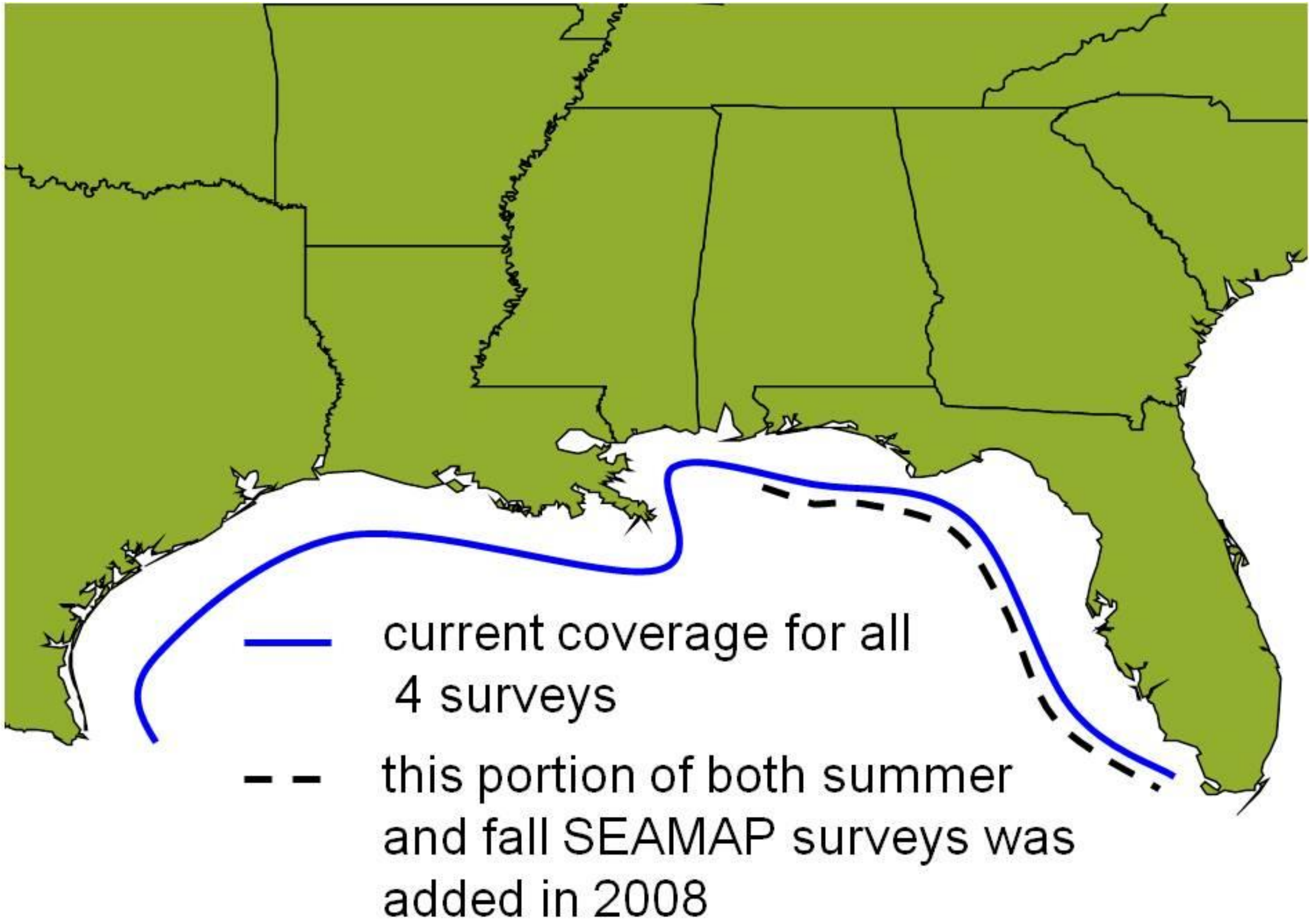




Indices of abundance



Approximate linear coverage of specific abundance indices for *Mustelus* spp. in the Gulf of Mexico



Model configuration

- Model started in 1982 and ended in 2012
- The first year in which both CPUE and catch data were available was 1982
- In the base run, each individual index of abundance value was weighted equally
- Model is fitted to the CPUEs and catch is treated as a known constant

Estimated parameters

Parameters to be estimated: K, r, P_{82} (initial depletion at the start of the model, $t=1$), P_t ($t>=2$), σ^2 for P_t (process error variance) and τ^2 for each CPUE index (observation error variance)

State-space Bayesian surplus production model (SS-SPM) (Meyer and Millar 1999)

Surplus production model is reparameterized by expressing the annual abundance as a proportion of carrying capacity:

$$P_{initial} = (P_{mean\_initial})e^{\sigma_{initial}^2} \qquad P_1 = (P_{initial})e^{\sigma^2}$$

Hierarchical for the initial year

$$P_t = (P_{t-1} + rP_{t-1}(1 - P_{t-1}) - \frac{C_{t-1}}{K})e^{\sigma^2}$$

$$P_t = \left(\frac{N_t}{K}\right)$$

Observed catch rates ($I_{j,t}$) relate to unobserved states (P_t) through a stochastic observation model for $I_{j,t}$ given P_t

$$I_{j,t} = q_j K P_t e^{\tau^2}$$

State-space Bayesian surplus production model (SS-SPM)

The catchability coefficient for each index of abundance (q_j) is taken as the MLE (closed form):

$$q_j = e^{\left(\frac{\sum_{t=1}^{t=y} \left(\ln(I_{j,t}) - \ln(N_t) \right)}{n_j} \right)}$$

r (*intrinsic rate of growth*)

- *r* obtained from life tables
- Life History WG recommended using values for *Mustelus canis* + *Mustelus sinusmexicanus* and *M. norrisi* to bound the range of biologically plausible values
- Life tables were used to calculate r_{max} for these 2 groupings based on values listed in the DW report

Biological Inputs: *M. canis-M. sinusmexicanus*

- Von Bertalanffy growth curve:
  L_∞ = 113.8 cm FL, K = 0.130 yr^{-1}, t_0 = -3.87 yr
- Lifespan = 14 yr; a_{50} = 3.6 yr
- Length-weight relationship: $W = 2x10^{-6}L^{3.258}$
- Pup-production: pups = 10 (midpoint of 15 and 5)
- Parturition frequency: annual (1 yr)
- Natural Mortality = 0.30 (age-0) → 0.17 (a_{max})
- r = 0.28 yr^{-1}

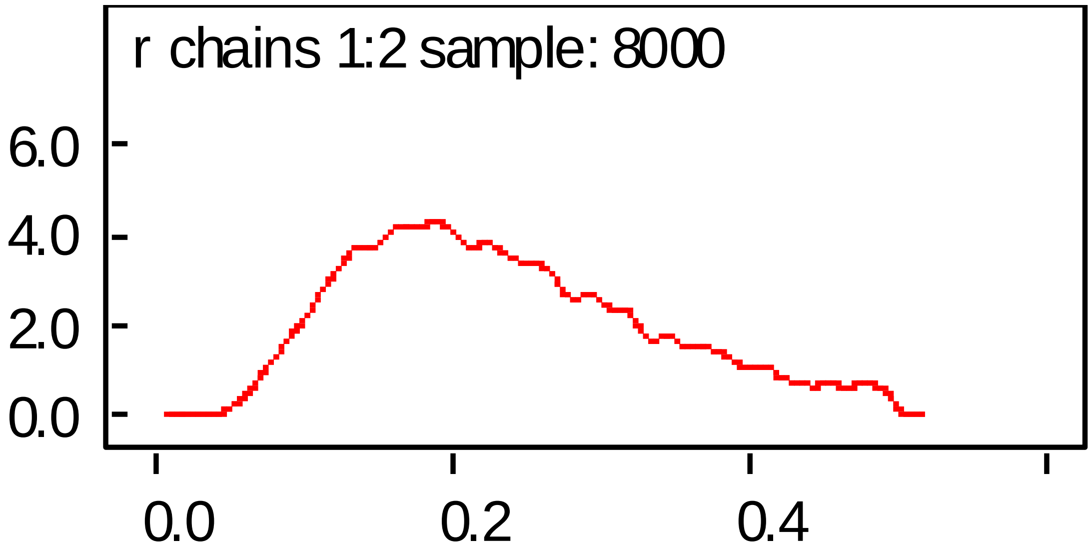
Biological Inputs: *M. norrisi*

- Von Bertalanffy growth curve:
  L_∞ = 95.05 cm FL, K = 0.250 yr^{-1}, t_0 = -2.03 yr
- Lifespan = 9 yr; a_{50} = 3.6 yr
- Length-weight relationship: $W = 2x10^{-6}L^{3.2486}$
- Pup-production: pups = 11.3
- Parturition frequency: annual (1 yr)
- Natural Mortality = 0.47 (age-0) → 0.24 (a_{max})
- r = 0.18 yr^{-1}

Prior for r

An informative prior for r=0.23 yr^{-1}, equivalent to a log(r)=-1.470, was used as the mean of a lognormal distribution with a precision=4, which corresponds to a CV of 0.5 on the arithmetic scale

r ~ dlnorm(-1.470,4.0)I(0.01,0.5)

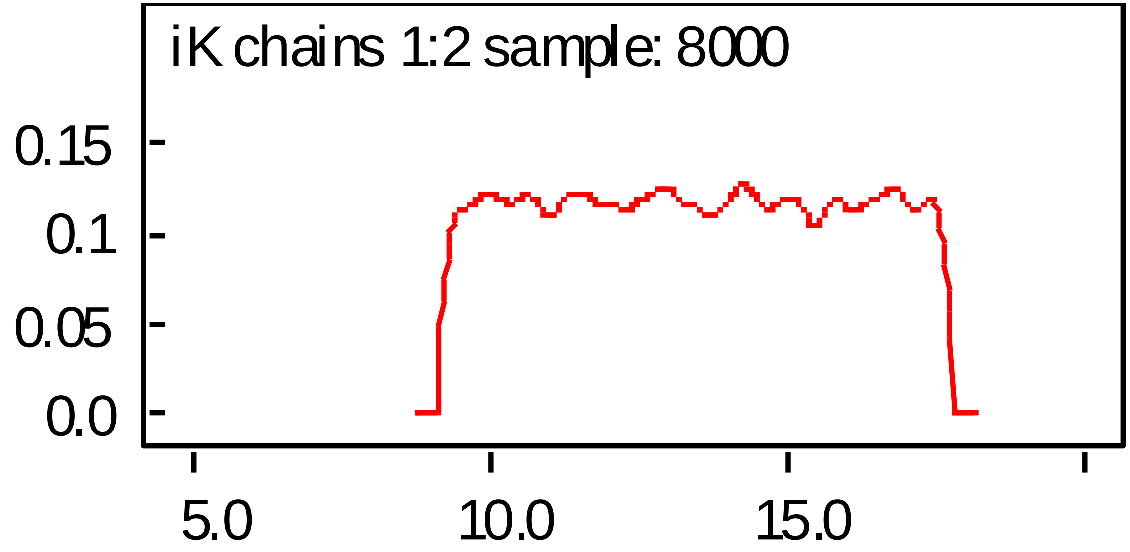


node	mean	sd	MC error	2.5%	median	97.5%	start	sample
r	0.236	0.09876	0.001084	0.08492	0.2215	0.4596	50001	8000

Prior for K (*carrying capacity*)

Uniform on log(K), with a range of 10^4 to $50x10^6$ (ca. 250 times the maximum observed catch) individuals on the arithmetic scale

iK ~ dunif(9.21,17.73);   K=exp(iK)

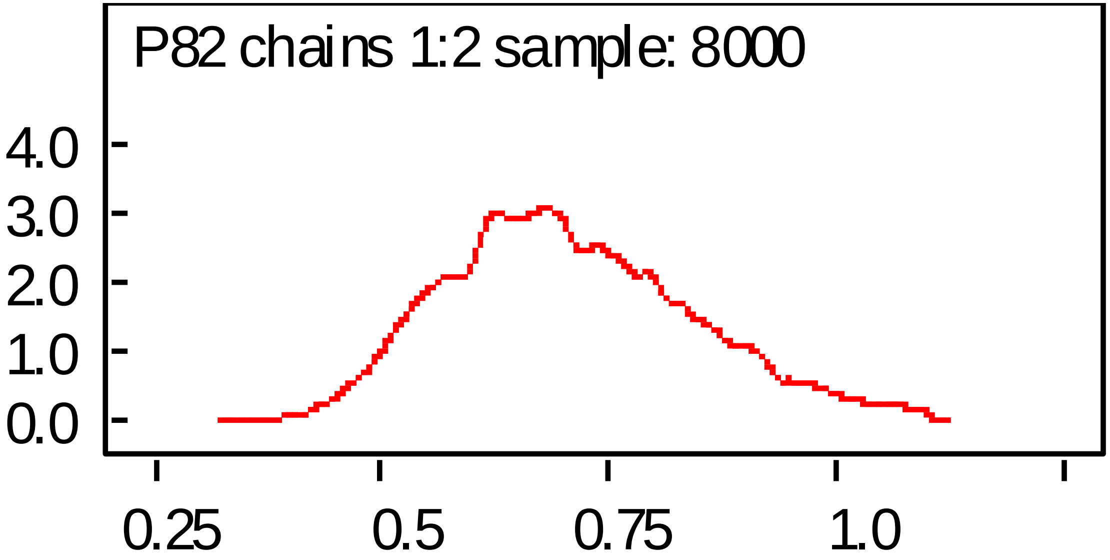


node	mean	sd	MC error	2.5%	median	97.5%	start	sample
iK	13.47	2.462	0.02572	9.406	13.45	17.53	50001	8000

Prior for $P_{82} = N_{82}/K$ (*initial depletion*)

An informative prior for P_{82}=0.7, equivalent to a log(P_{82})=-0.357, was used as the mean of a lognormal distribution with the precision=25, which corresponds to a CV of 0.2 on the arithmetic scale

$$P_{82} \sim \text{dlnorm}(-0.357,25.0)I(0.2,1.1)$$



node	mean	sd	MC error	2.5%	median	97.5%	start	sample
P82	0.708	0.1359	0.001381	0.4762	0.6945	1.005	50001	8000

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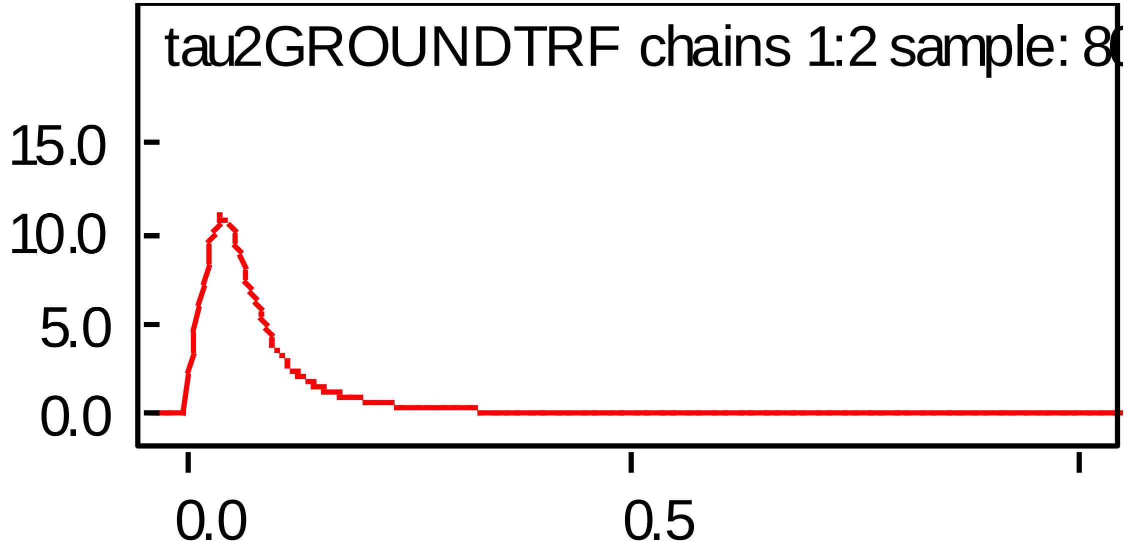
Prior for observation error variance (inverse gamma)

- Same for each CPUE index
- itau2GROUNDTRF ~ dgamma(2.0,0.1) Precision
- tau2GROUNDTRF <- 1/itau2GROUNDTRF Variance
- $IGROUNDTRF_{[i]}$ ~ dlnorm($ImeanGROUNDTRF_{[i]}$, itau2GROUNDTRF)



node	mean	sd	MC error	2.5%	median	97.5%	start	sample
tau2GROUNDTRF	0.09917	0.2513	0.002924	0.01795	0.05974	0.3957	50001	8000

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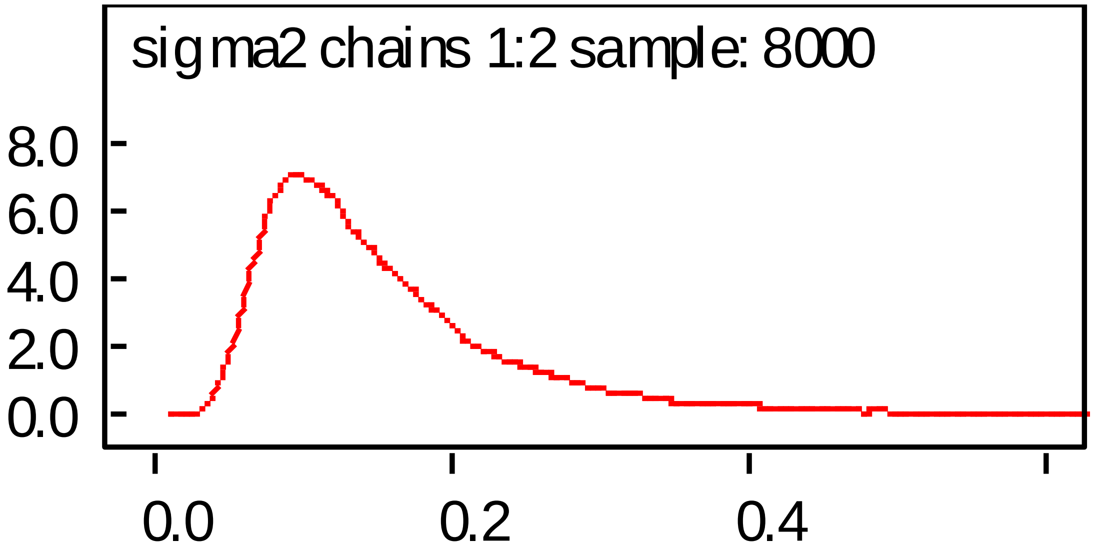
Prior for process error variance (inverse gamma)

- $P_{[i]}$ = $N_{[i]}$/K
- isigma2~ dgamma(4.0,0.5)
- sigma2 <- 1/isigma2
- $Pmean_{[i]}$ <- log(max($P_{[i-1]}$+r*$P_{[i-1]}$*(1-$P_{[i-1]}$)-$C_{[i-1]}$/K,0.0001))
- $P_{[i]}$ ~ dlnorm($Pmean_{[i]}$, isigma2)I(0.0001,1.1)



node	mean	sd	MC error	2.5%	median	97.5%	start	sample
sigma2	0.167	0.1221	0.001461	0.0572	0.1357	0.4626	50001	8000

MCMC simulation

- Two chains

- A thinning interval of 5 was used to minimize parameter autocorrelation

- Initial 50,000 iterations were discarded

- Another 20,000 iterations with a thinning interval of 5 were run to generate the posterior distributions and DIC (sample size: 2*20,000/5=8,000)

Posterior distribution

Joint posterior distribution of the unobservable states given the data, which is equal to the product of the joint prior distribution and the sampling distribution (likelihood of the CPUE data) by Bayes' theorem

$$p(K, r, P_{82}, \sigma^2, \tau^2, P_2, \ldots, P_n \mid I_1, \ldots, I_n) =$$

$$p(K)\, p(r)\, p(P_{82})\, p(\sigma^2)\, p(\tau^2)\, p(P_1 \mid P_{82}, \sigma^2)$$

$$\times \prod_{i=2}^{i=n} p(P_t \mid P_{t-1}, K, r, \sigma^2) \prod_{t=1}^{t=n} p(I_t \mid P_t, \tau^2)$$

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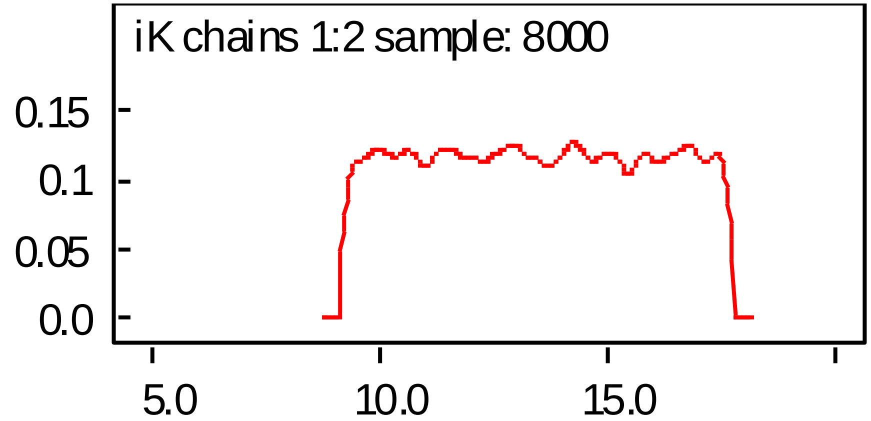
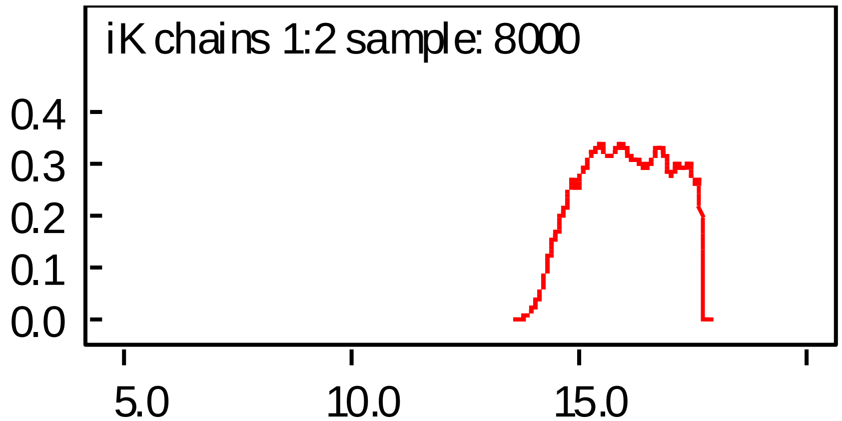
Prior and posterior distribution for carrying capacity (*K=exp(iK)*) in the base run

Prior



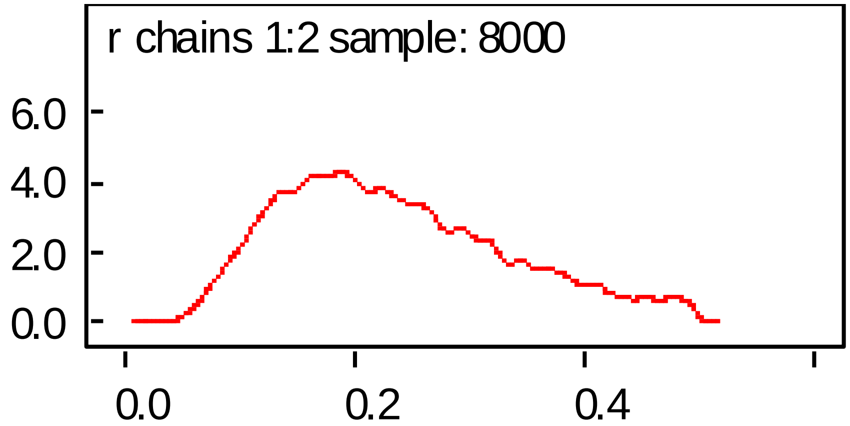
Posterior



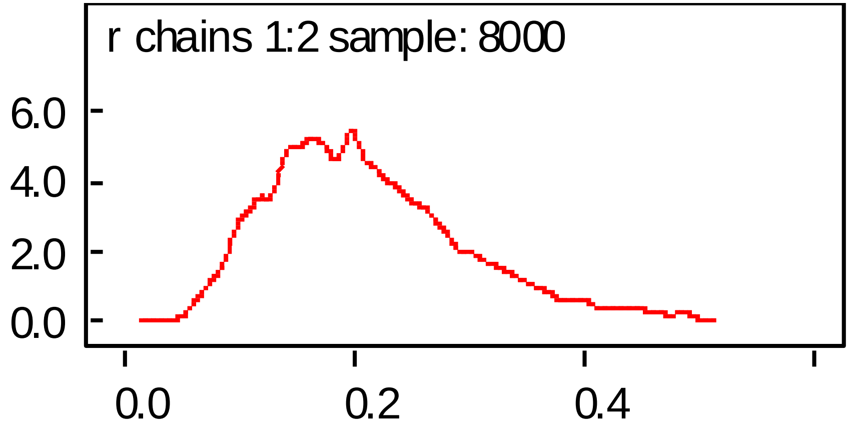
	node	mean	sd	MC error	2.5%	median	97.5%	start	sample
Prior	iK	13.47	2.462	0.02572	9.406	13.45	17.53	50001	8000
Posterior	iK	16.07	0.9529	0.01097	14.36	16.07	17.64	50001	8000

Prior and posterior distribution for the intrinsic rate of increase (*r*) in the base run

Prior



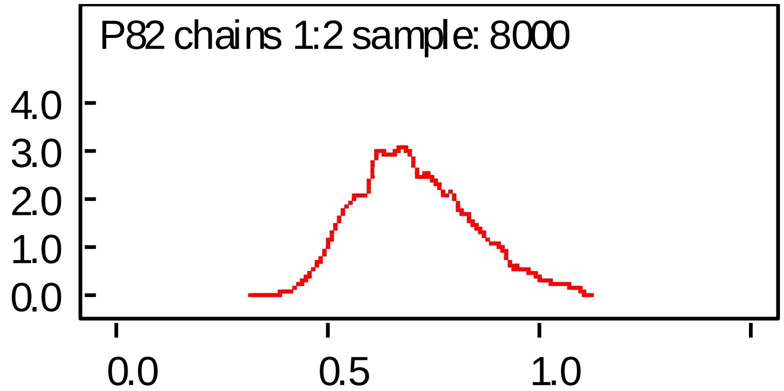
Posterior



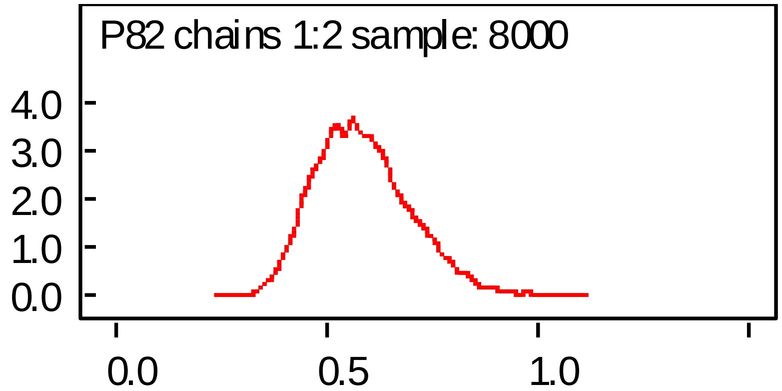
	node	mean	sd	MC error	2.5%	median	97.5%	start	sample
Prior	r	0.236	0.09876	0.001084	0.08492	0.2215	0.4596	50001	8000
Posterior	r	0.2115	0.08397	9.921E-4	0.08319	0.1993	0.4118	50001	8000

Prior and posterior distribution for initial depletion (P_{82}) in the base run

Prior



Posterior

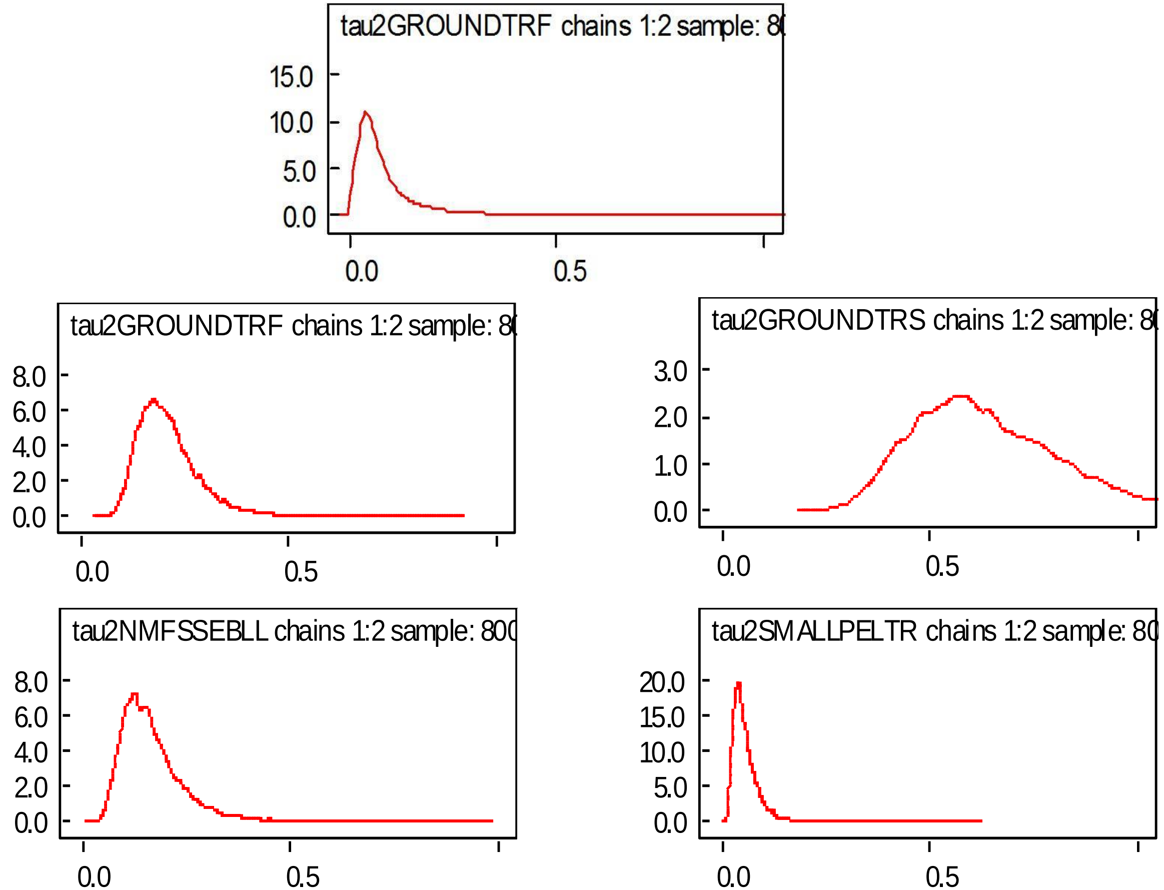


	node	mean	sd	MC error	2.5%	median	97.5%	start	sample
Prior	P82	0.708	0.1359	0.001381	0.4762	0.6945	1.005	50001	8000
Posterior	P82	0.5886	0.115	0.001462	0.3957	0.5777	0.8397	50001	8000

Prior and posterior distribution for the observation error variance (τ^2) in the base run

Prior

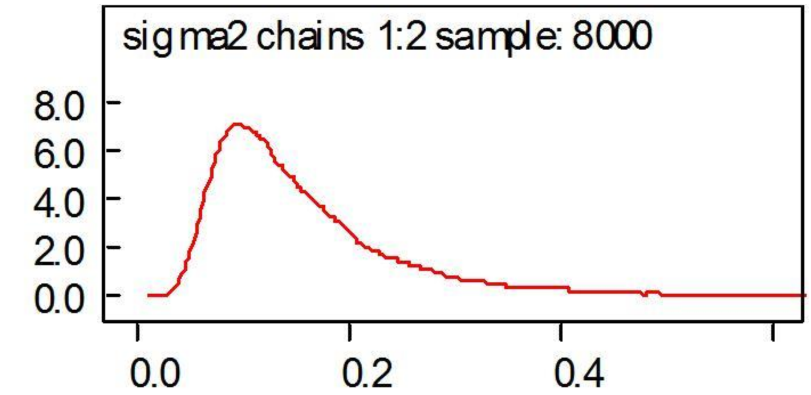
Posterior



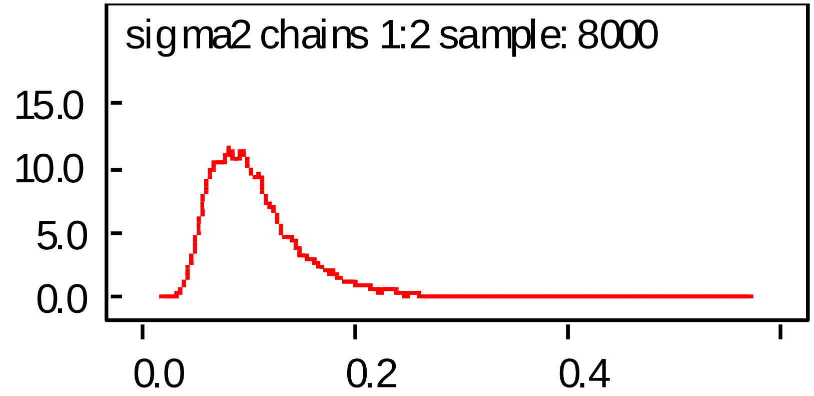
The prior (top panel) was the same for the four indices, but posteriors (four lower panels) differed.

Prior and posterior distribution for the process error variance (σ^2) in the base run

Prior



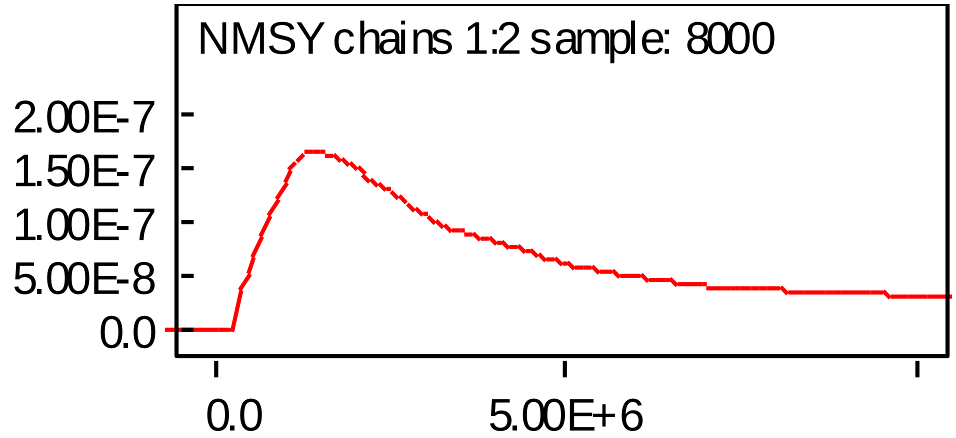
Posterior



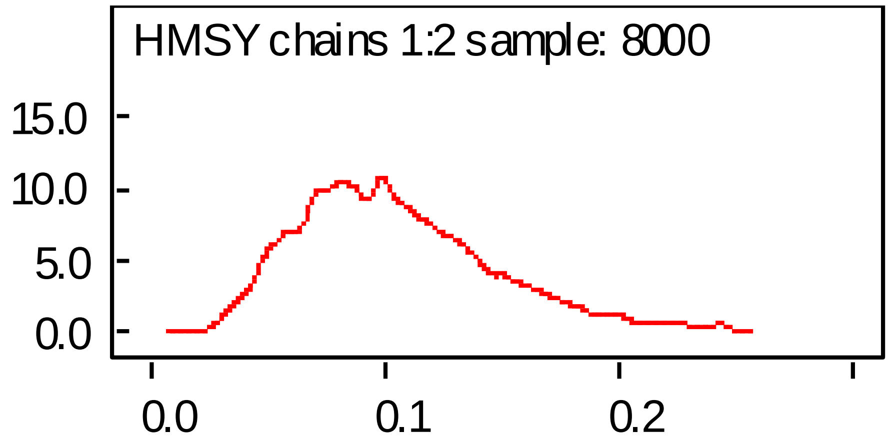
	node	mean	sd	MC error	2.5%	median	97.5%	start	sample
Prior	sigma2	0.167	0.1221	0.001461	0.0572	0.1357	0.4626	50001	8000
Posterior	sigma2	0.1092	0.04772	7.778E-4	0.04947	0.09912	0.2293	50001	8000

Posterior distribution for the predicted exploitable number at MSY (N_{msy}) and exploitation rate at MSY(H_{msy}) in the base run

Posterior

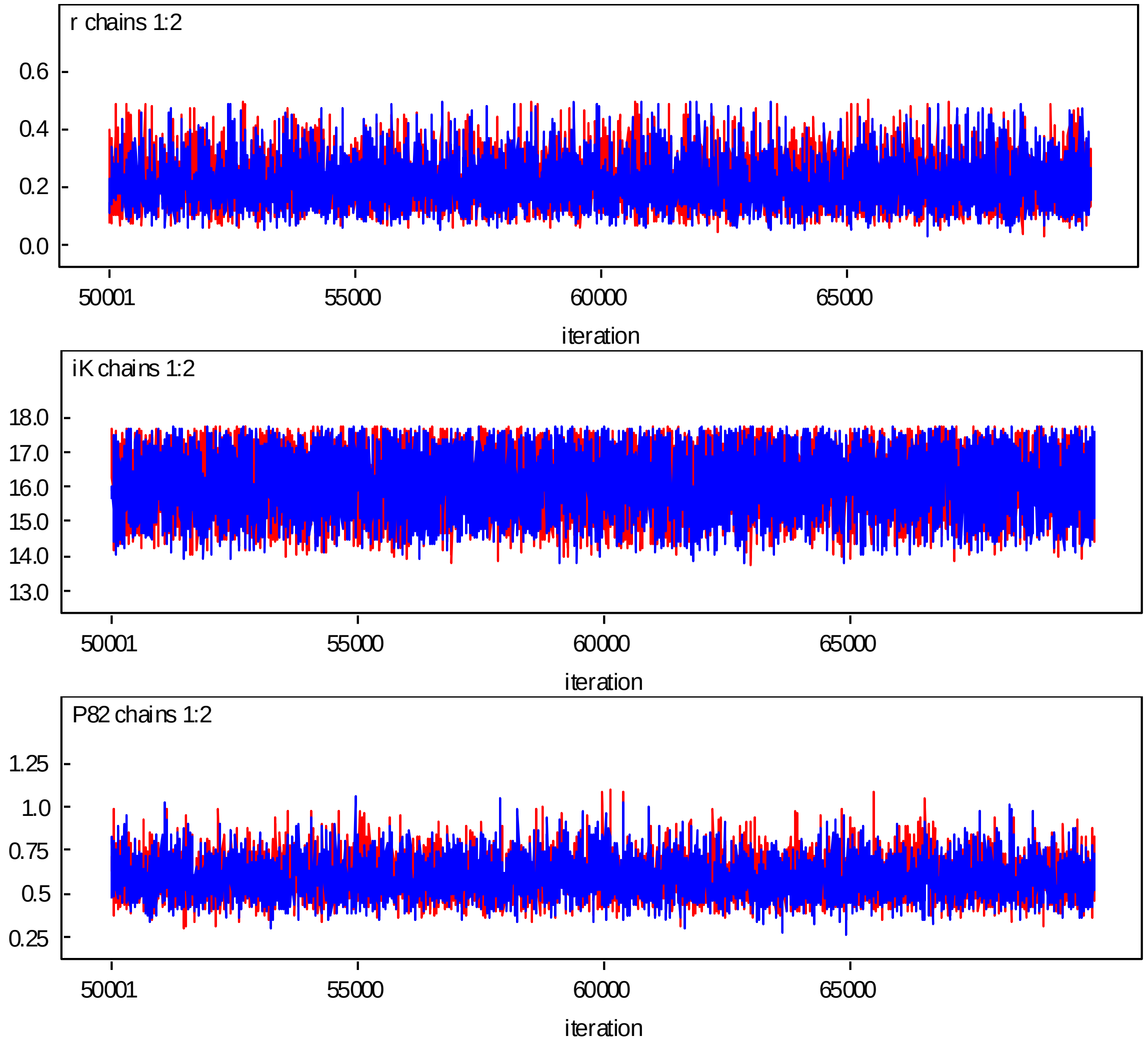


Posterior

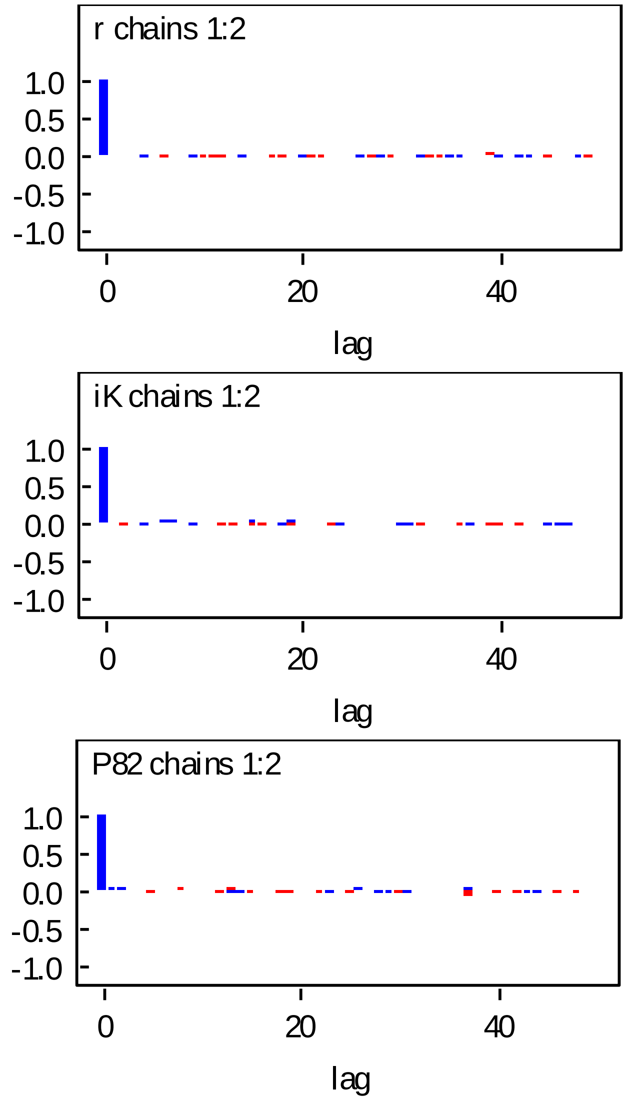


	node	mean	sd	MC error	2.5%	median	97.5%	start	sample
Prior	N_{MSY}	7.188E+6	6.3E+6	69280.0	859400.0	4.746E+6	2.297E+7	50001	8000
Posterior	H_{MSY}	0.1057	0.04198	4.961E-4	0.0416	0.09967	0.2059	50001	8000

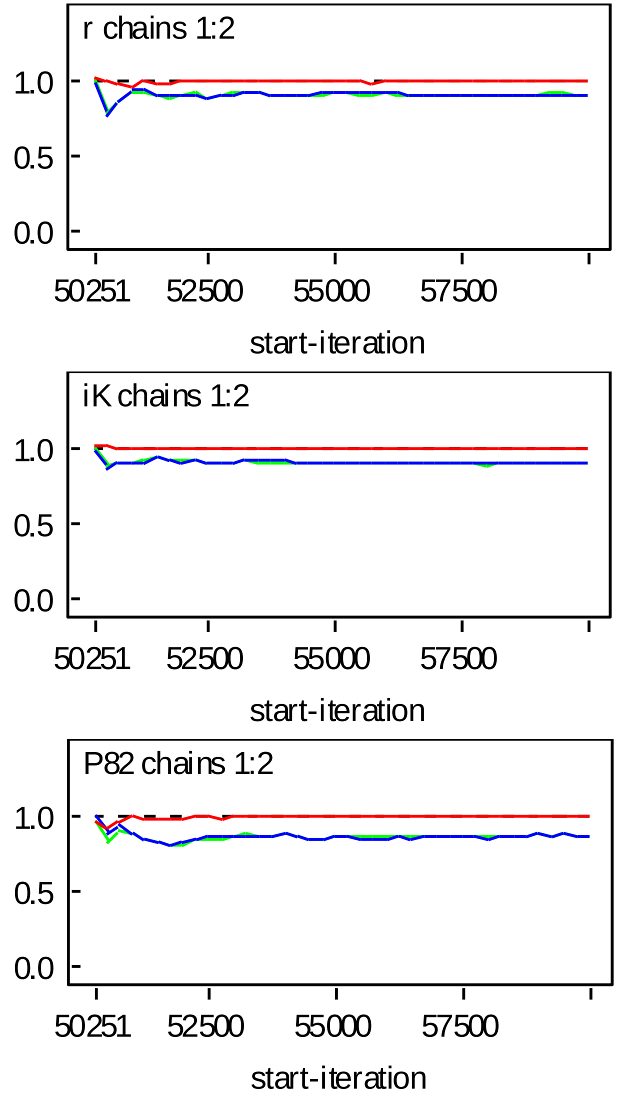
Convergence diagnostic for the base run showing the time series history of mixing for the two chains for the key model parameters



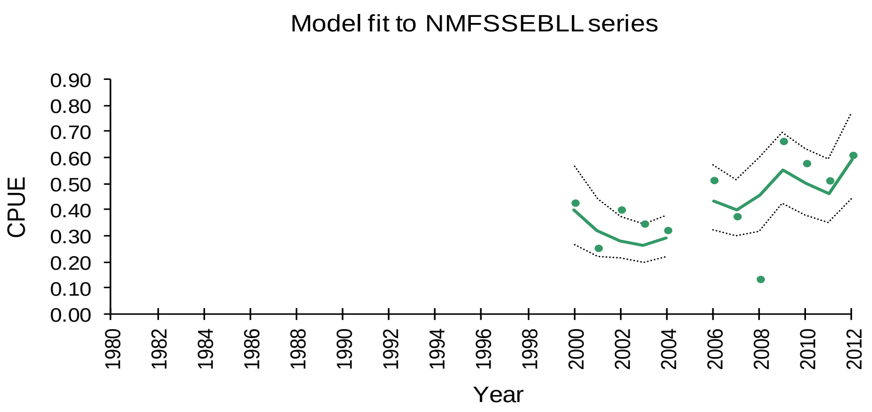
Convergence diagnostic for the base run showing the autocorrelation for the two chains for the key model parameters

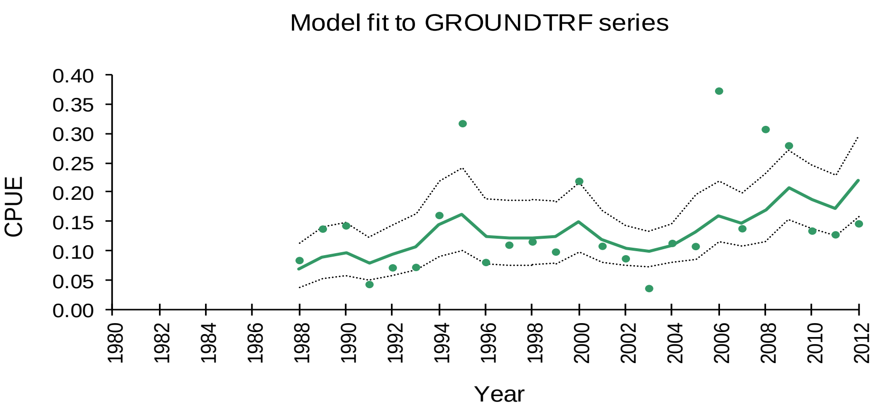


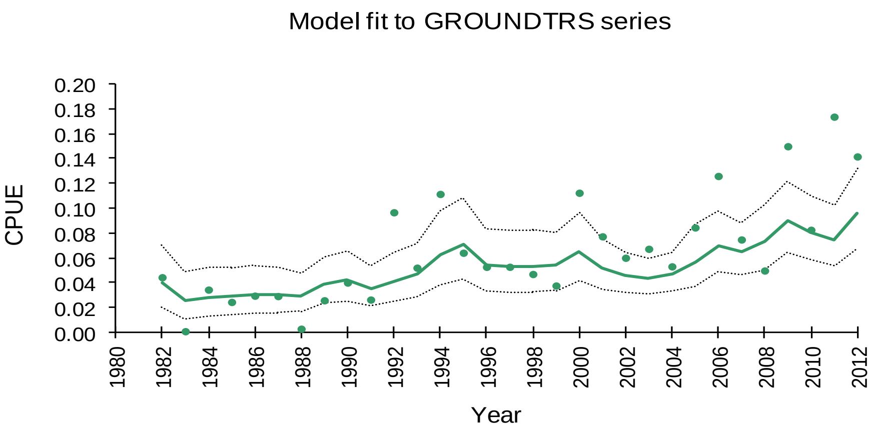
Convergence diagnostic for the base run showing the Gelman-Rubin statistic for the two chains for the key model parameters

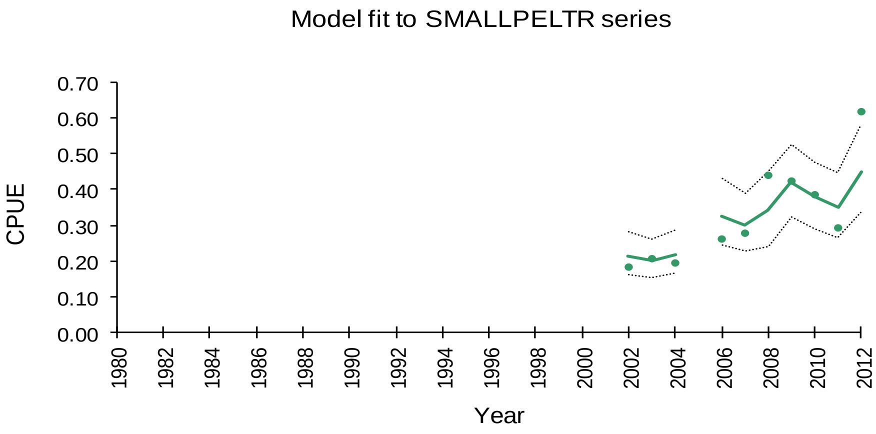


Predicted fits to the four indices of abundance in the base run









Solid circles are observed CPUEs, solid lines are mean predicted CPUEs, and dotted lines are 95% credible intervals.

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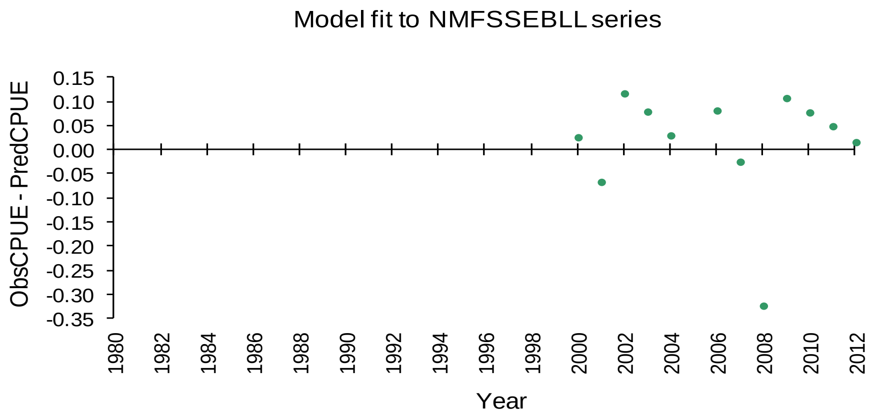
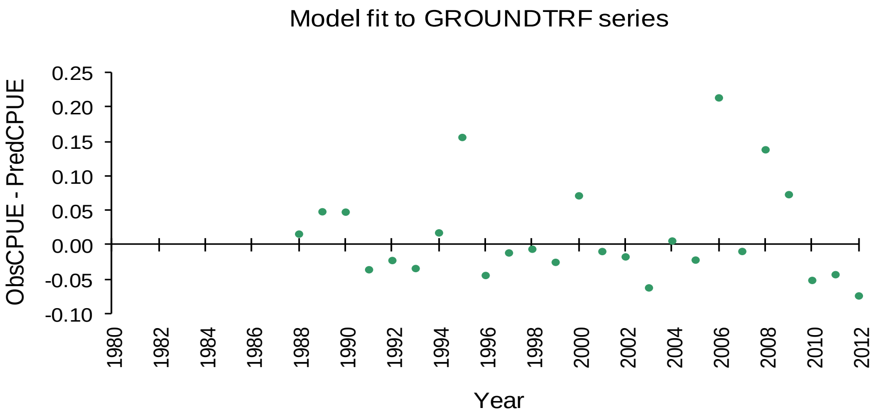
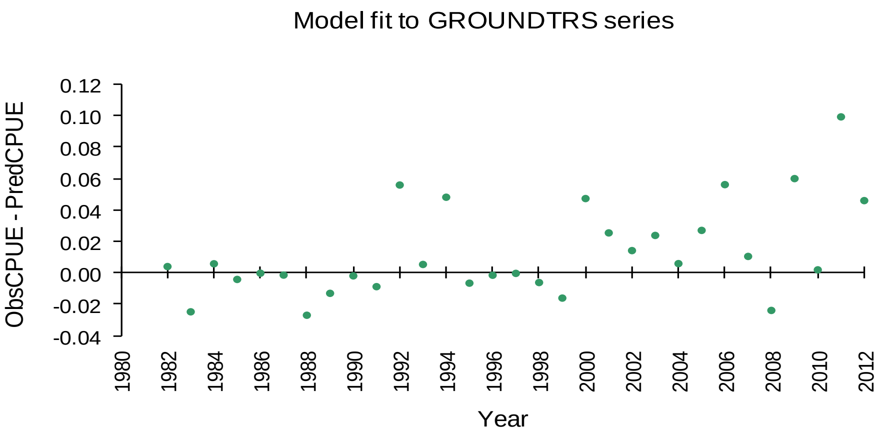
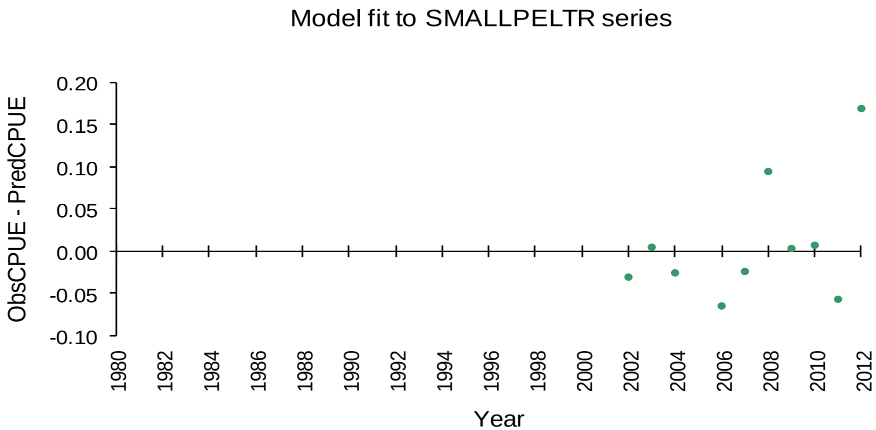
Residual plots (normal scale) of the CPUE fits for the base run

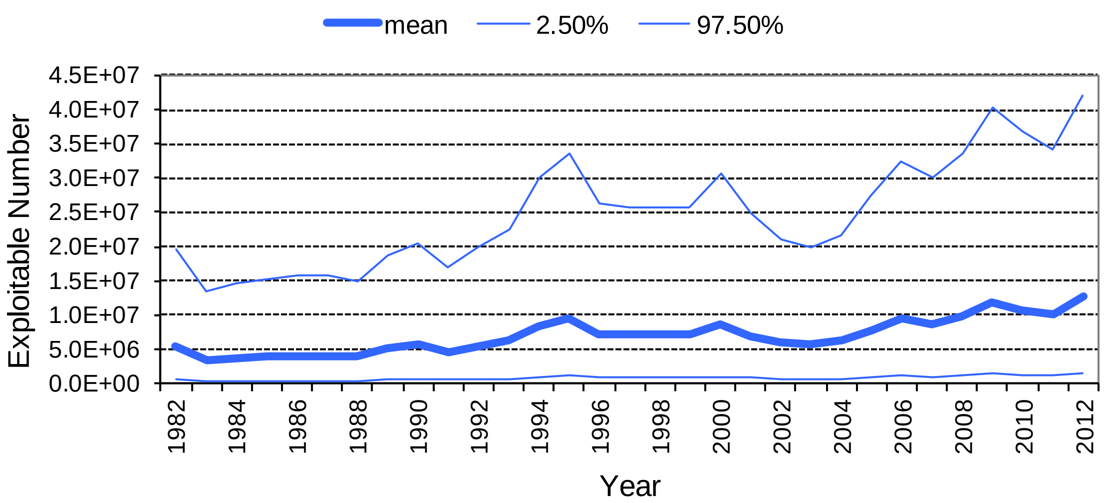


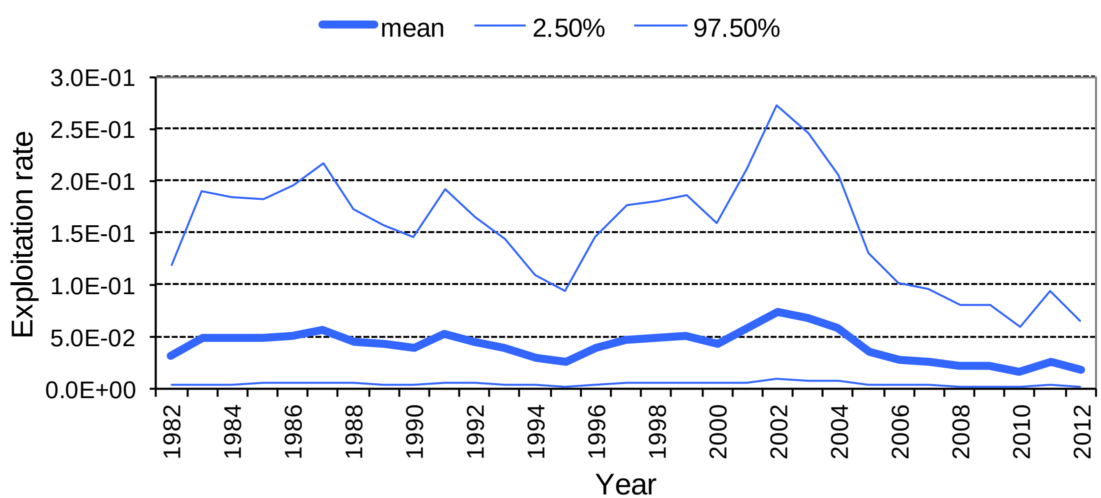




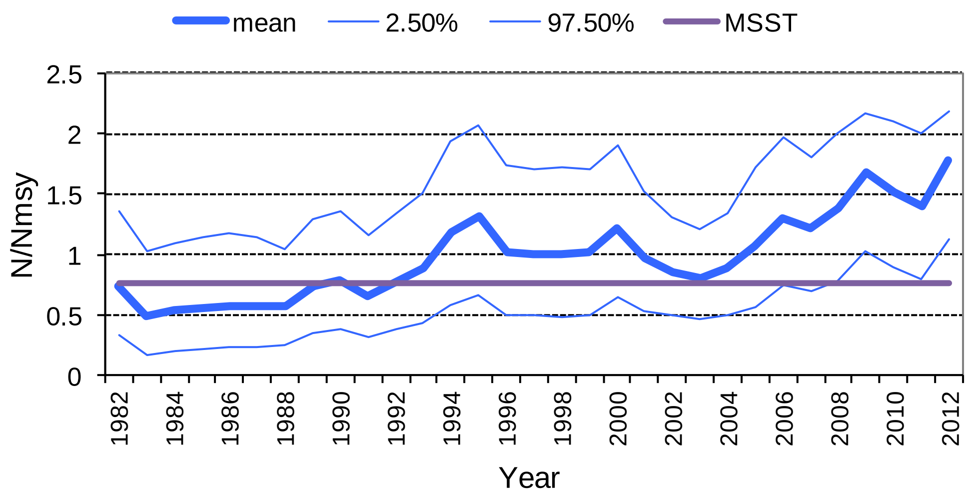


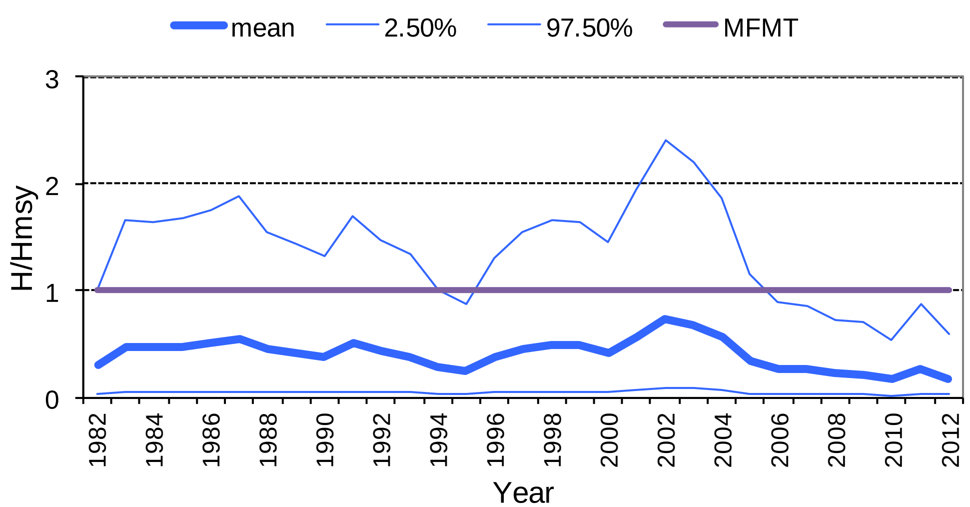
Predicted exploitable number (top) and exploitation rate (bottom) trajectories (with 95% credible intervals) for the base run





Predicted relative exploitable number (top) and relative exploitation rate (bottom) trajectories (with 95% credible intervals) for the base





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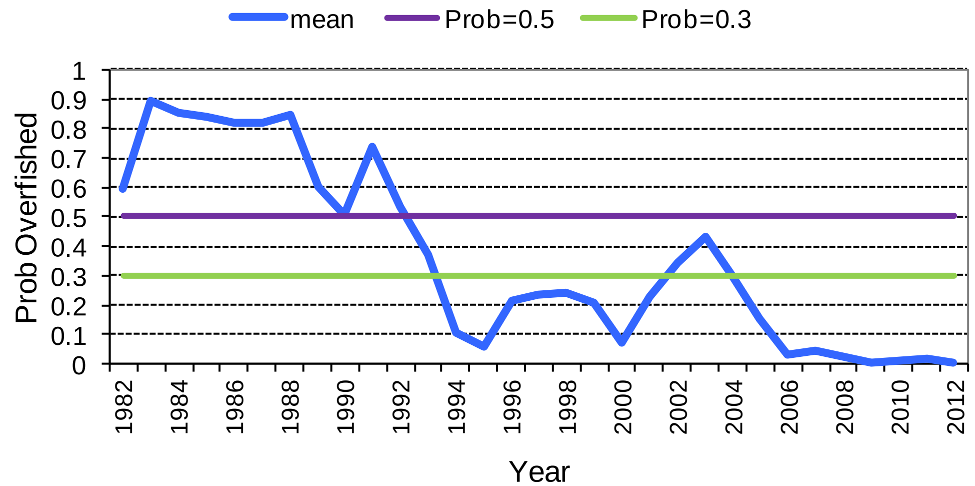
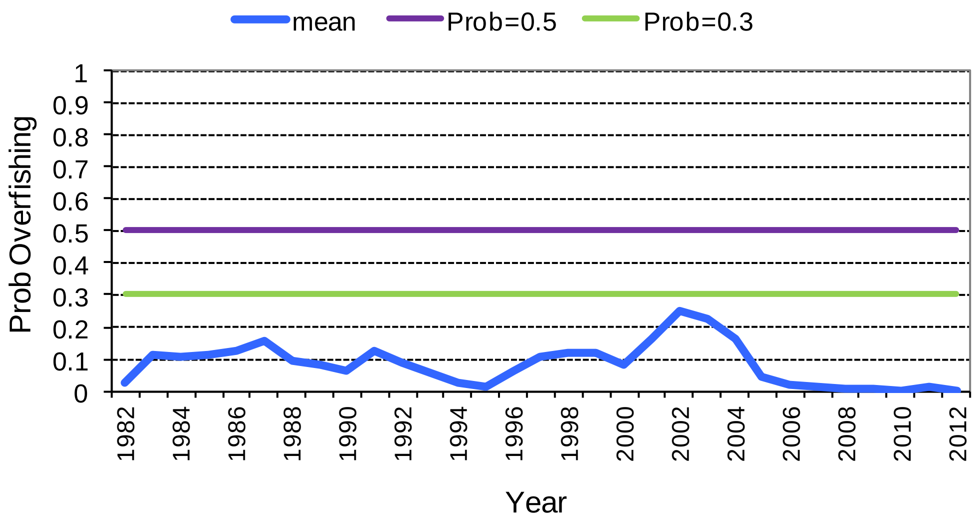
Probability of exploitable number being smaller than MSST (overfished condition; top) and probability of exploitation rate being larger than H_{MSY} (overfishing condition; bottom) for the base run





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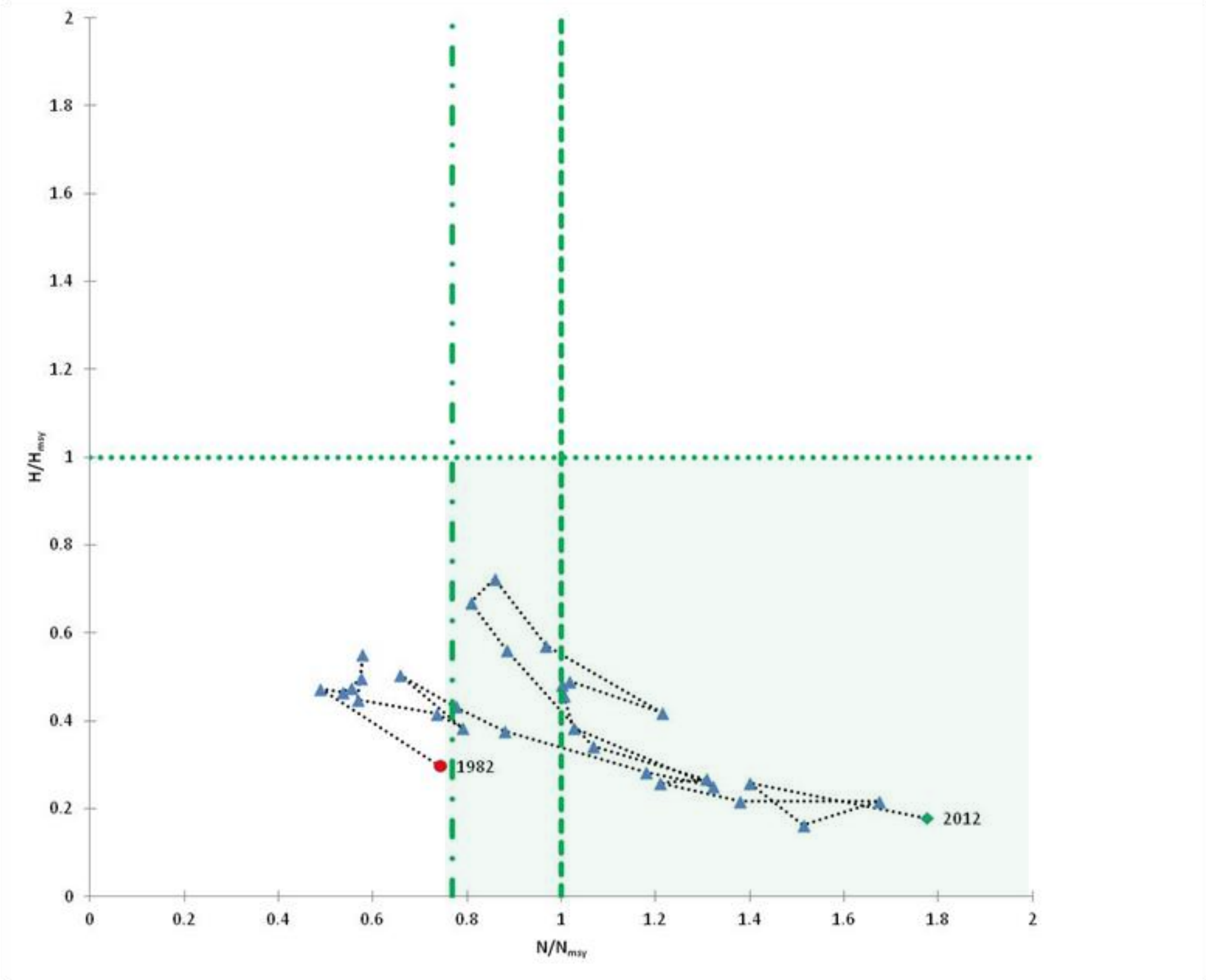
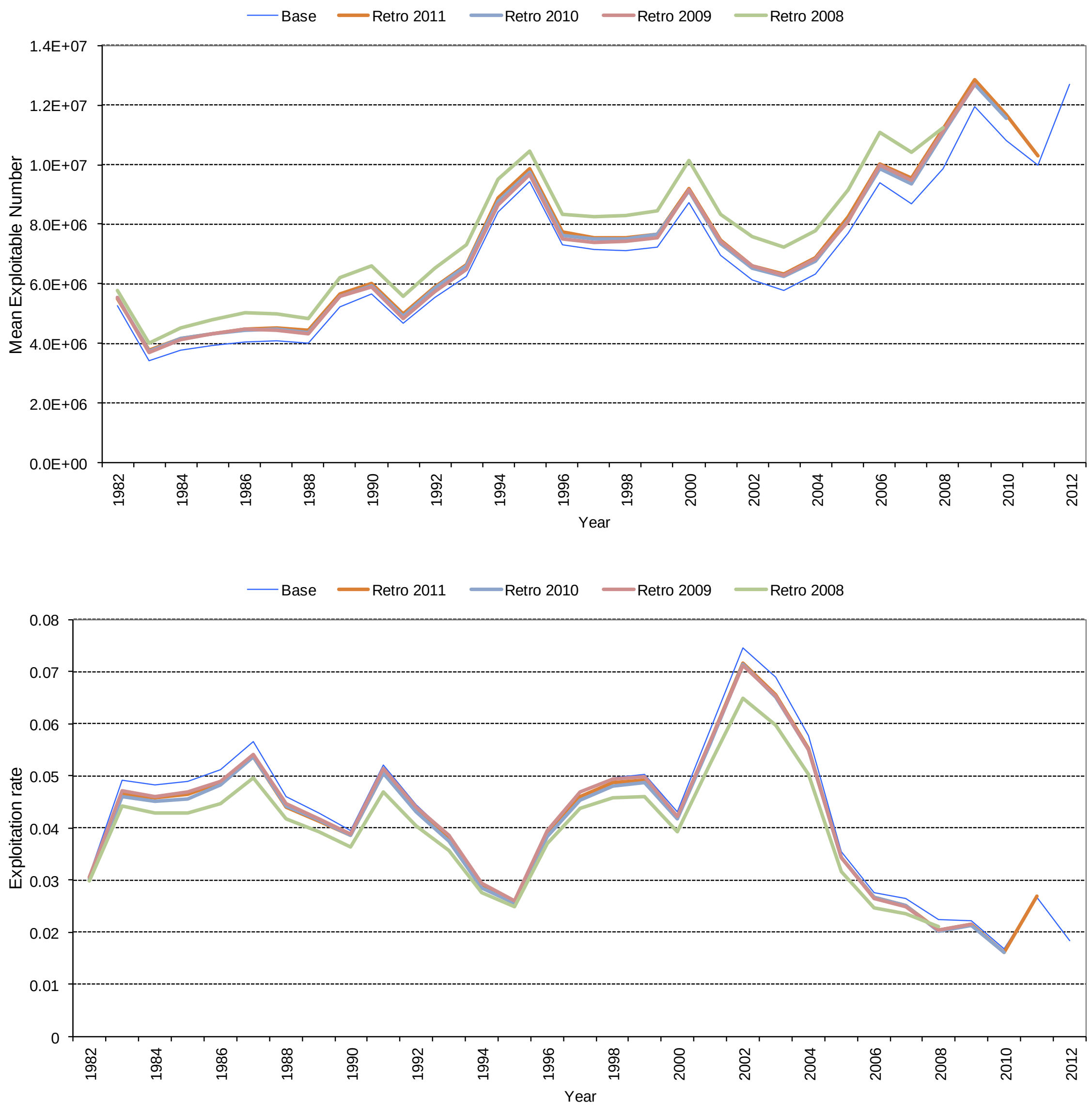
Combined relative exploitable number and relative exploitation rate trajectory for the base run



Summary of results (mean and CV) for base model

Run	Base	
	Mean	CV
K	1.44E+07	0.88
r	0.212	0.40
MSY	6.89E+05	0.95
N_{2012}	1.27E+07	0.90
H_{2012}	0.018	0.96
N_{2013}ratio	0.787	0.24
N_{1982}	5.28E+06	0.98
H_{2012}/H_{MSY}	**0.179**	**0.89**
N_{2012}/N_{MSY}	**1.776**	**0.16**
N_{MSY}	7.19E+06	0.88
H_{MSY}	0.106	0.40
P_{1982}	0.589	0.20
MSST ((1-M)*N_{msy}	5.53E+06	
Convergence diagnostics		
Chain mixing	Good	
Autocorrelations	Low	
Gelman-Rubin	Good	
(MC error)/(posterior sd)	<5%	
Abundance index	**RMSE/(Index Mean)**	
NMFS SE Bottom LL	0.269	
NMFS SEAMAP Gr Tr (F)	0.487	
NMFS SEAMAP Gr Tr (S)	0.487	
NMFS Small Pel Tr	0.210	

Predicted exploitable number (top) and exploitation rate (bottom) trajectories for the base model retrospective analysis



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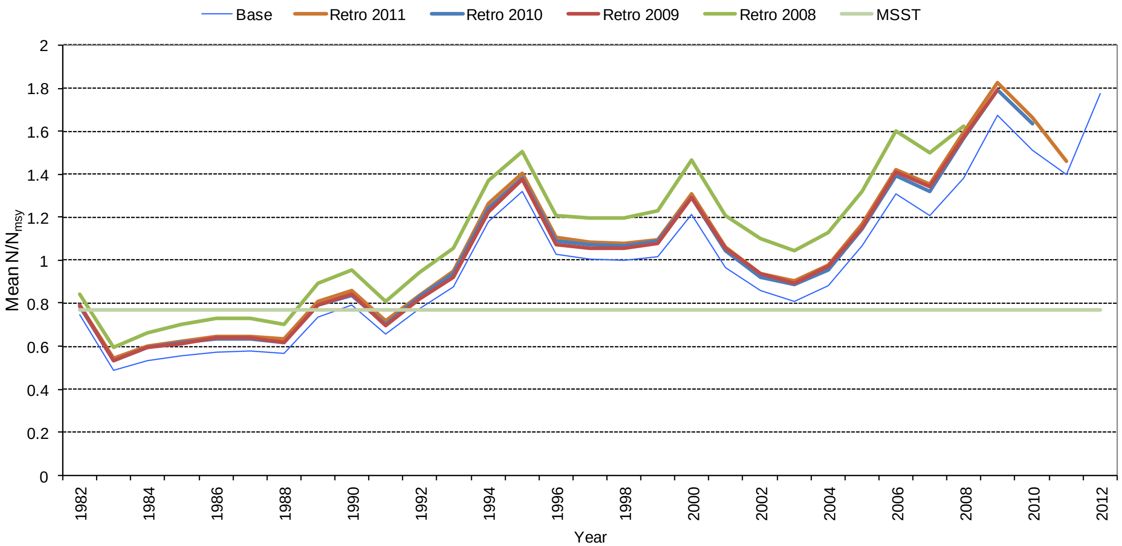
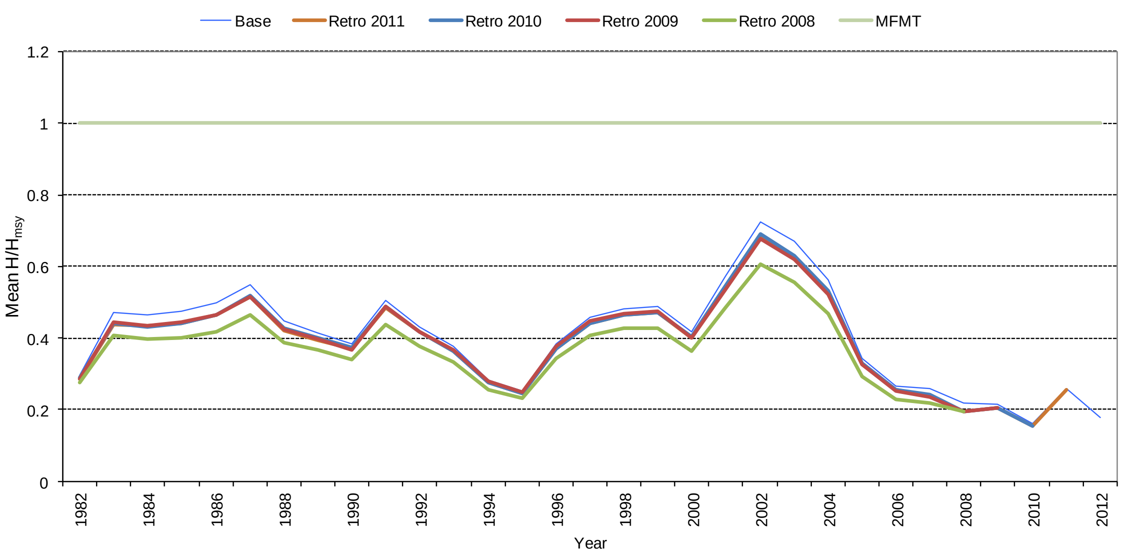
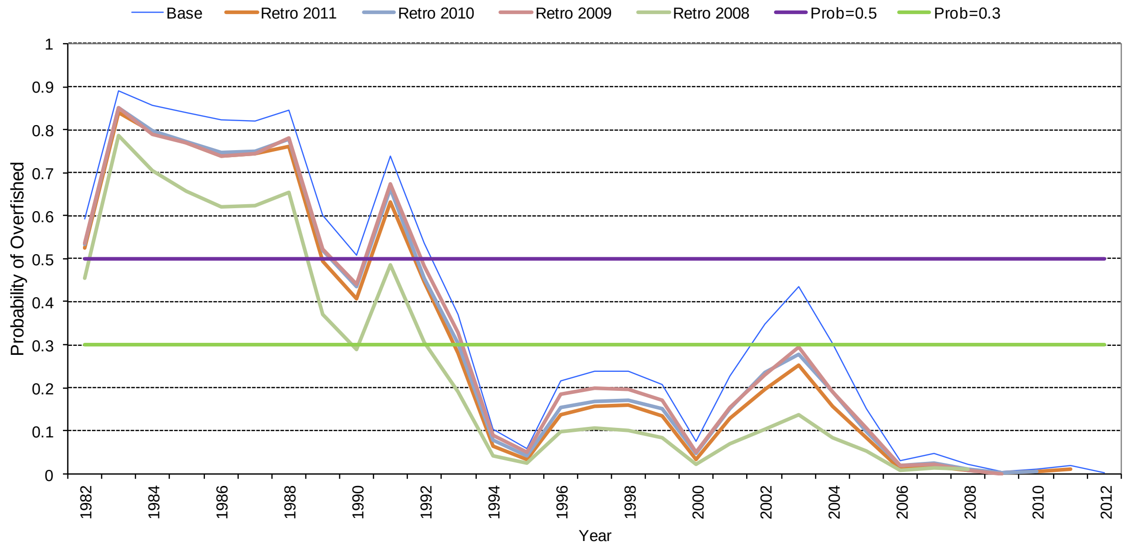
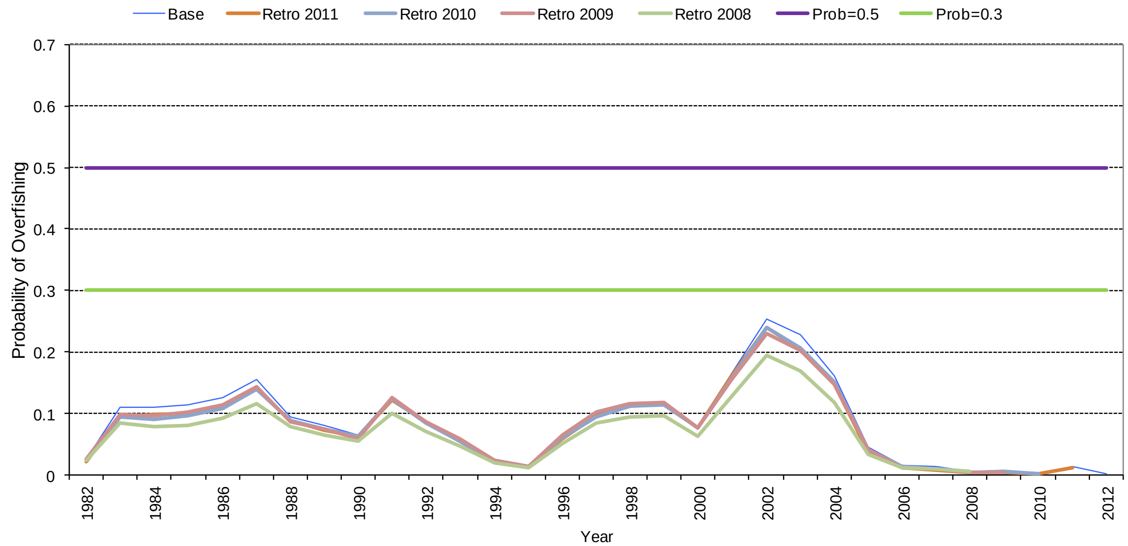
Predicted relative exploitable number (top) and relative exploitation rate (bottom) trajectories for the base model retrospective analysis





Probability of exploitable number being smaller than MSST (overfished condition) (top) and probability of exploitation rate being larger than H_{MSY} (bottom) for the base model retrospective analysis





Summary of results (mean and CV) for the base model retrospective runs

Run	Base		Retro2011		Retro2010		Retro2009		Retro2008	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
K	1.44E+07	0.88	1.41E+07	0.90	1.42E+07	0.89	1.42E+07	0.90	1.39E+07	0.91
r	0.212	0.40	0.214	0.39	0.213	0.40	0.216	0.39	0.224	0.40
MSY	6.89E+05	0.95	6.84E+05	0.98	6.88E+05	0.97	7.00E+05	0.98	7.16E+05	1.00
N_{cur}	1.27E+07	0.90	1.03E+07	0.93	1.16E+07	0.92	1.27E+07	0.92	1.12E+07	0.95
$H_{2012cur}$	0.018	0.96	0.027	0.99	0.016	1.00	0.022	0.98	0.021	1.04
N_{cur+1}ratio	0.787	0.24	0.715	0.27	0.762	0.25	0.787	0.24	0.753	0.26
N_{1982}	5.28E+06	0.98	5.52E+06	0.99	5.55E+06	1.00	5.53E+06	1.02	5.76E+06	1.01
H_{cur}/H_{MSY}	**0.179**	**0.89**	**0.257**	**0.91**	**0.155**	**0.89**	**0.204**	**0.89**	**0.196**	**0.99**
$Ncur/N_{MSY}$	**1.776**	**0.16**	**1.462**	**0.20**	**1.635**	**0.19**	**1.794**	**0.16**	**1.622**	**0.21**
N_{MSY}	7.19E+06	0.88	7.06E+06	0.90	7.10E+06	0.89	7.09E+06	0.90	6.95E+06	0.91
H_{MSY}	0.106	0.40	0.107	0.39	0.106	0.40	0.108	0.39	0.112	0.40
P_{1982}	0.589	0.20	0.594	0.19	0.594	0.19	0.599	0.20	0.607	0.19
MSST $((1-M)*N_{msy}$	5.53E+06		5.43E+06		5.46E+06		5.45E+06		5.35E+06	
Convergence diagnostics										
Chain mixing	Good		Good		Good		Good		Good	
Autocorrelations	Low		Low		Low		Low		Low	
Gelman-Rubin	Good		Good		Good		Good		Good	
(MC error)/(posterior sd)	<5%		<5%		<5%		<5%		<5%	
Abundance index	**RMSE/(Index Mean)**									
NMFS SE Bottom LL	0.269		0.311		0.330		0.358		0.355	
NMFS SEAMAP Gr Tr (F)	0.487		0.479		0.481		0.474		0.518	
NMFS SEAMAP Gr Tr (S)	0.487		0.513		0.463		0.477		0.467	
NMFS Small Pel Tr	0.210		0.131		0.132		0.150		0.217	

cur = 2012 for base, 2011 for Retro2011, 2010 for Retro2010, 2009 for Reto2009, and 2008 for Retro2008

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Evaluation of uncertainty

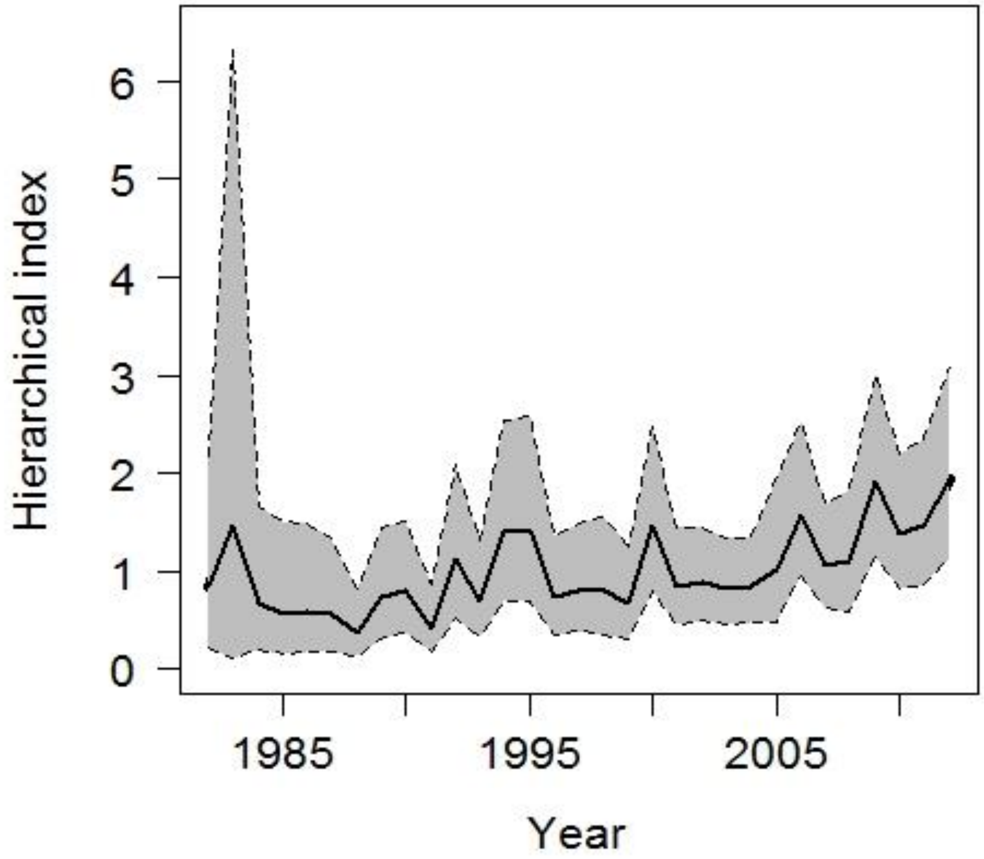
Different data inputs

- *Sensitivity run 1 (Hierarchical index)*
- *Sensitivity run 2 (Inverse CV weighting)*
- *Sensitivity runs 3 and 4 (Low and high catch)*

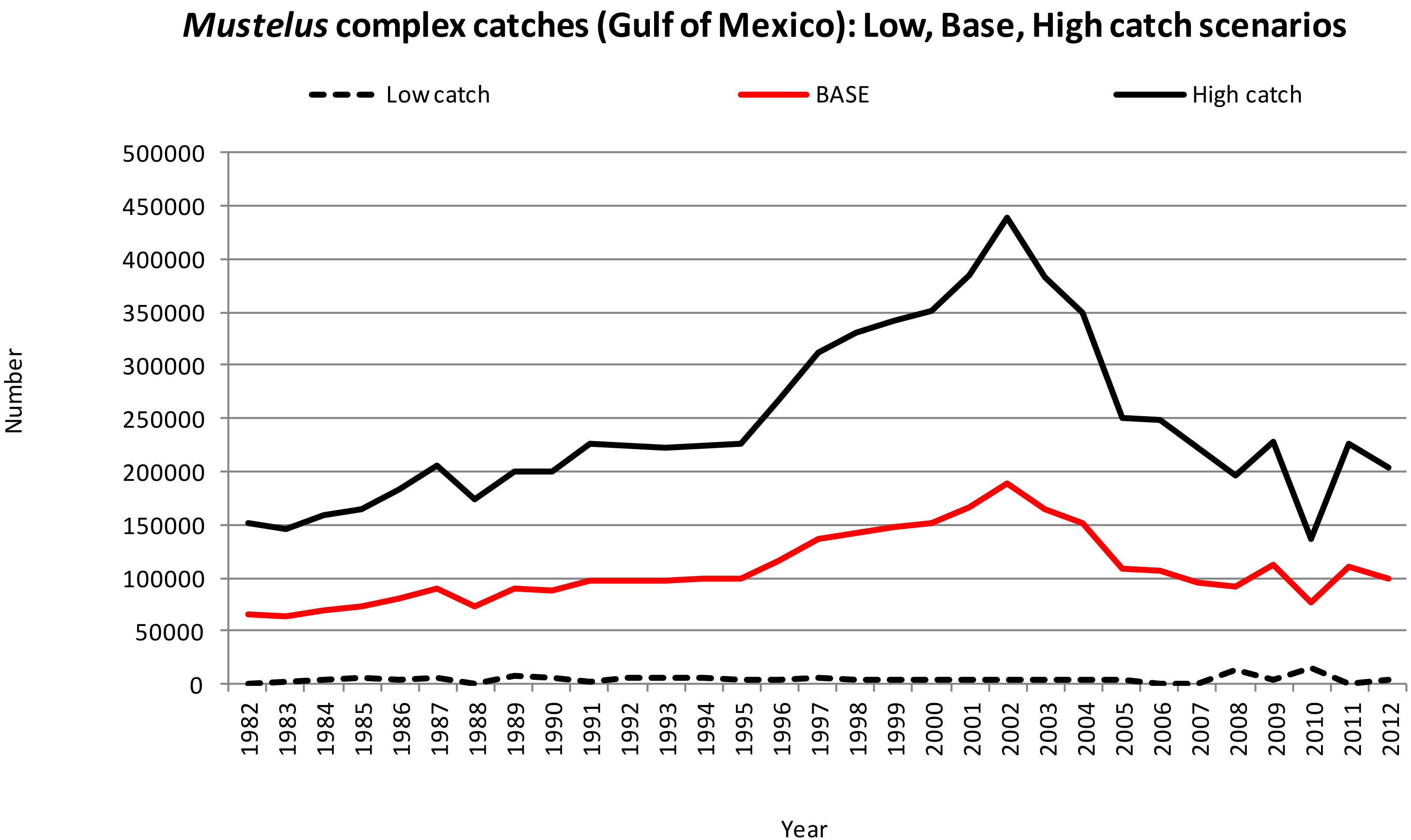
Same data inputs

- *Sensitivity runs 5 and 6 (Low and high productivity)*
- *Sensitivity runs 7, 8, and 9 (Large process error variance, large observation error variance, and both simultaneously)*
- *Sensitivity runs 10 and 11 (High and low initial depletion)*
- *Sensitivity runs 12 and 13 (High and low carrying capacity)*

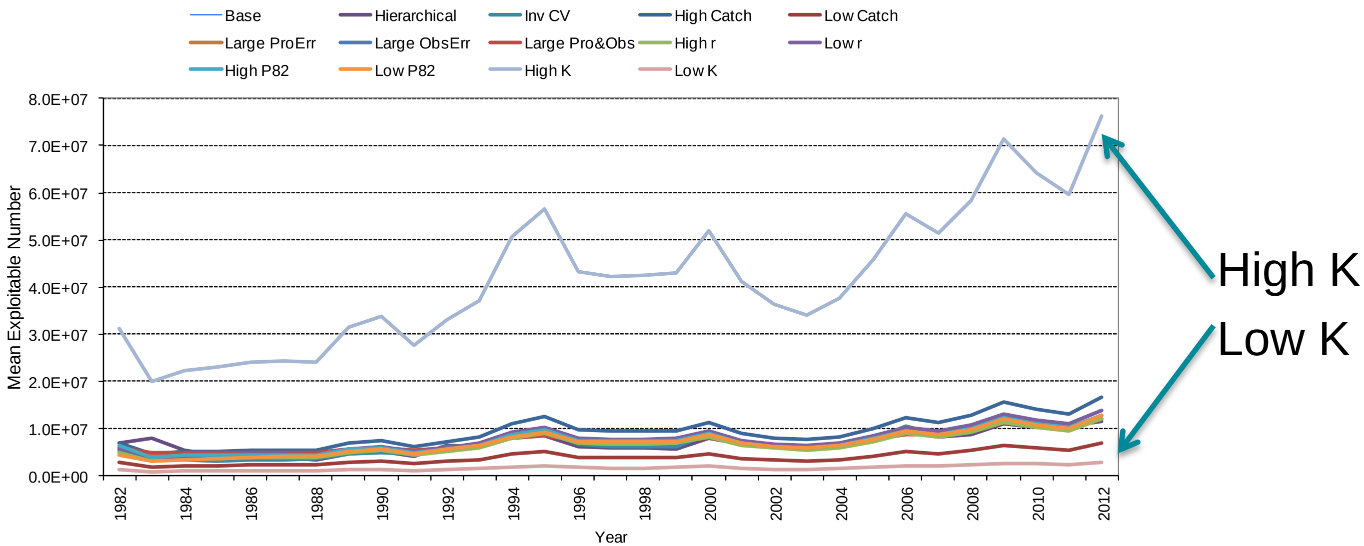
Hierarchical index of abundance used in sensitivity run 1

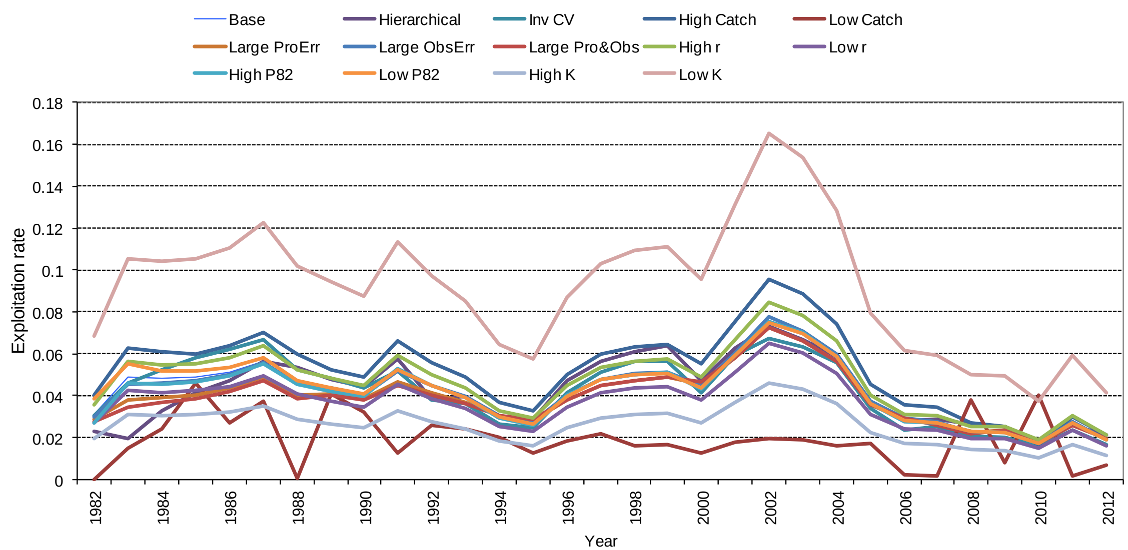


Low and high catches used in the low and high catch sensitivity runs (3 and 4)

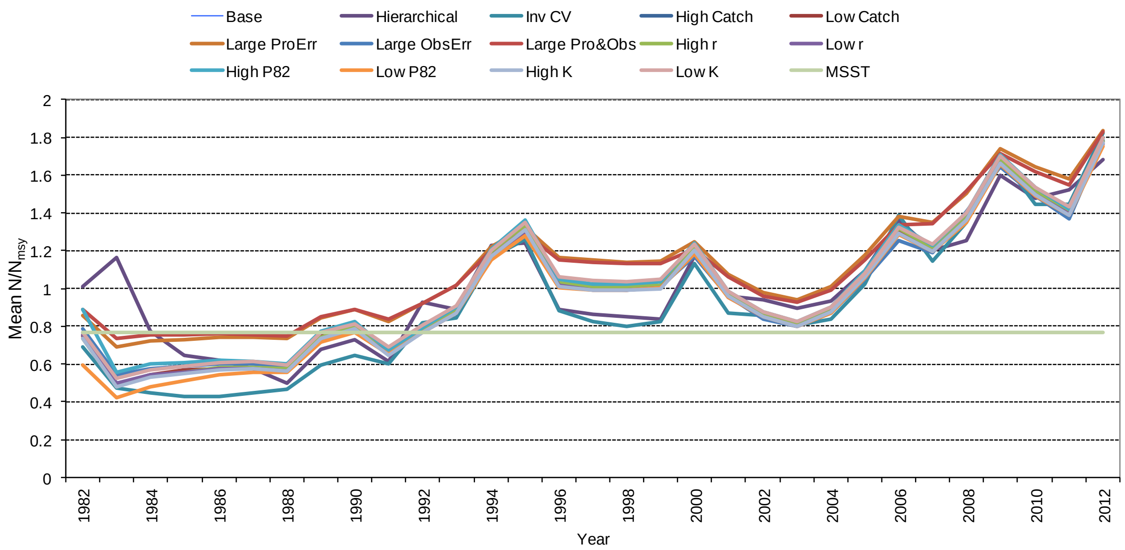


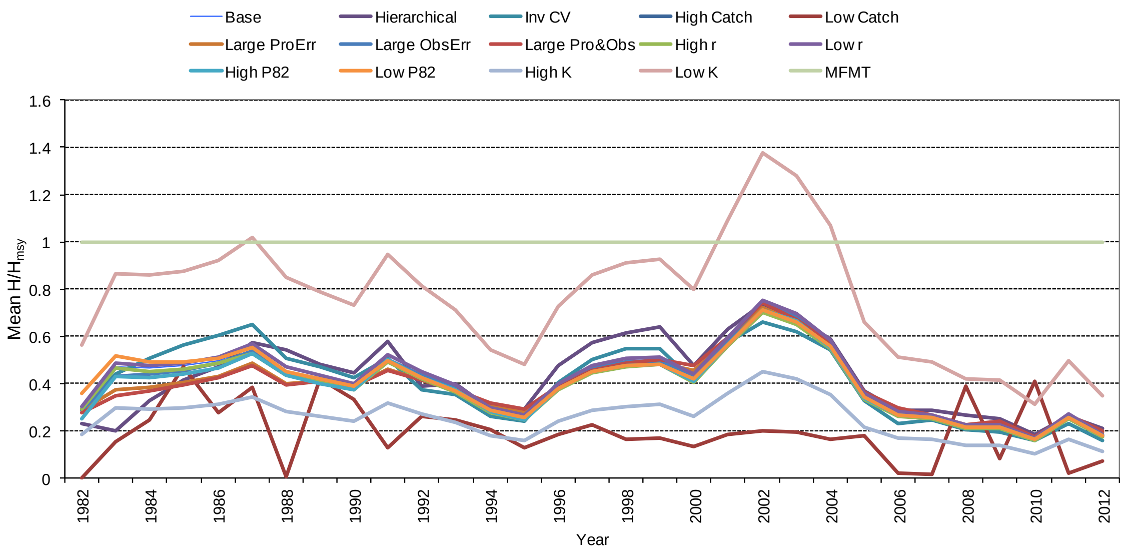
Predicted exploitable number (top) and exploitation rate (bottom) trajectories for each of the 13 sensitivity runs



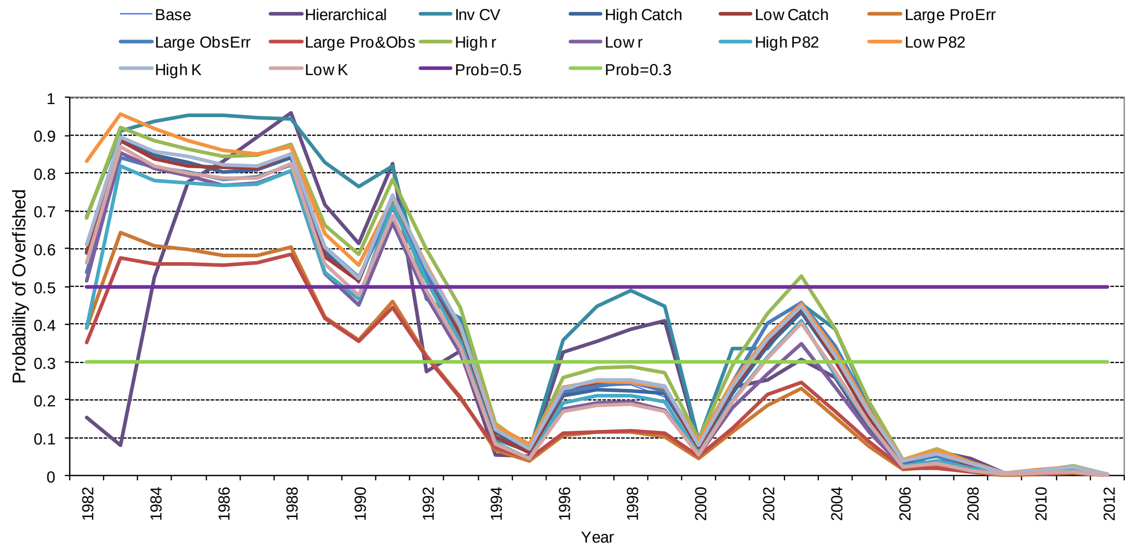


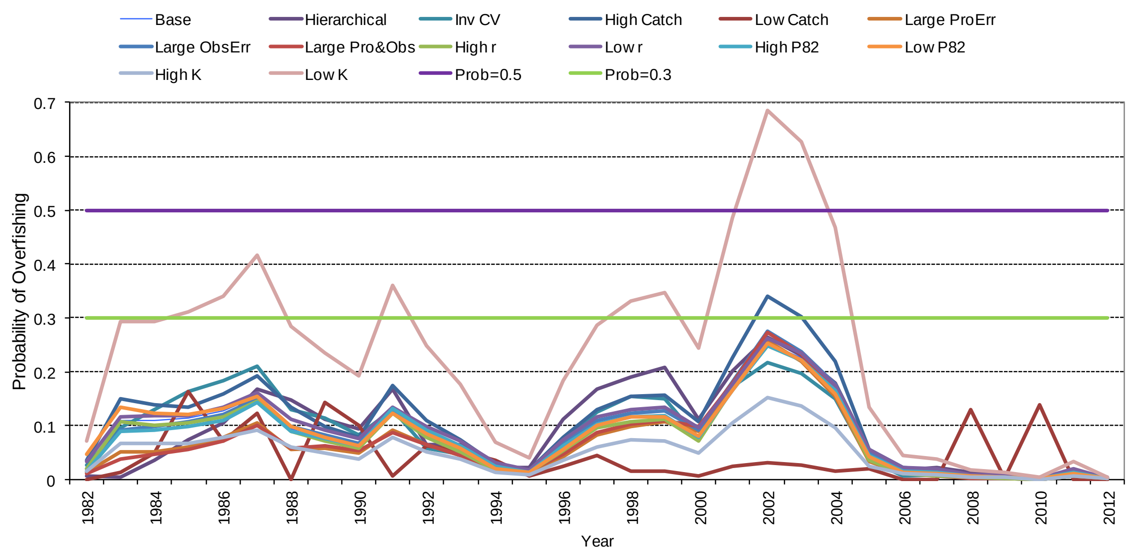
Predicted relative exploitable number (top) and relative exploitation rate (bottom) trajectories for each of the 13 sensitivity runs





Probability of exploitable number being smaller than MSST (overfished condition; top) and probability of exploitation rate being larger than H_{MSY} (overfishing condition; bottom) for each of the 13 sensitivity runs





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Summary of results (mean and CV) for sensitivity runs 1-4

Run	Base		Hierarchical		Inv CV		Low Catch		High Catch	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
K	1.44E+07	0.88	1.37E+07	0.90	1.52E+07	0.84	7.65E+06	1.50	1.88E+07	0.67
r	0.212	0.40	0.204	0.40	0.210	0.39	0.195	0.39	0.223	0.39
MSY	6.89E+05	0.95	6.27E+05	0.98	7.21E+05	0.90	3.48E+05	1.64	9.61E+05	0.74
N_{2012}	1.27E+07	0.90	1.15E+07	0.94	1.38E+07	0.86	6.77E+06	1.54	1.67E+07	0.70
H_{2012}	0.018	0.96	0.021	0.97	0.016	0.97	0.007	1.60	0.021	0.81
N_{2013}ratio	0.787	0.24	0.767	0.24	0.789	0.23	0.790	0.24	0.785	0.24
N_{1982}	5.28E+06	0.98	6.84E+06	0.95	5.16E+06	0.95	2.77E+06	1.61	6.95E+06	0.79
H_{2012}/H_{MSY}	**0.179**	**0.89**	**0.211**	**0.89**	**0.159**	**0.87**	**0.071**	**1.51**	**0.196**	**0.73**
N_{2012}/N_{MSY}	**1.776**	**0.16**	**1.680**	**0.19**	**1.826**	**0.15**	**1.776**	**0.17**	**1.778**	**0.16**
N_{MSY}	7.19E+06	0.88	6.84E+06	0.90	7.60E+06	0.84	3.82E+06	1.50	9.42E+06	0.67
H_{MSY}	0.106	0.40	0.102	0.40	0.105	0.39	0.098	0.39	0.112	0.39
P_{1982}	0.589	0.20	0.638	0.18	0.584	0.20	0.590	0.20	0.588	0.20
MSST ((1-M)*N_{msy}	5.53E+06		5.26E+06		5.84E+06		2.94E+06		7.24E+06	
Convergence diagnostics										
Chain mixing	Good		Good		Good		Good		Good	
Autocorrelations	Low		Low		Low		Low		Low	
Gelman-Rubin	Good		Good		Good		Good		Good	
(MC error)/(posterior sd)	<5%		<5%		<5%		<5%		<5%	
Abundance Index	**RMSE/(Index Mean)**		**RMSE/(Index Mean)**		**RMSE/(Index Mean)**		**RMSE/(Index Mean)**		**RMSE/(Index Mean)**	
NMFS SE Bottom LL	0.269				0.260		0.272		0.268	
NMFS SEAMAP Gr Tr (F)	0.487				0.478		0.485		0.488	
NMFS SEAMAP Gr Tr (S)	0.487				0.431		0.488		0.489	
NMFS Small Pel Tr	0.210				0.212		0.207		0.210	
Hierarchical			0.099							

Summary of results (mean and CV) for sensitivity runs 5-13

Run	Base		Low r		High r		Large ProErr		Large ObsErr		Large Pro&Obs	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
K	1.44E+07	0.88	1.58E+07	0.82	1.34E+07	0.93	1.30E+07	0.93	1.44E+07	0.89	1.31E+07	0.93
r	0.212	0.40	0.182	0.42	0.241	0.37	0.199	0.40	0.210	0.39	0.195	0.40
MSY	6.89E+05	0.95	6.59E+05	0.92	7.28E+05	1.00	5.70E+05	0.98	6.80E+05	0.96	5.61E+05	0.98
N_{2012}	1.27E+07	0.90	1.39E+07	0.85	1.19E+07	0.96	1.20E+07	0.95	1.27E+07	0.91	1.20E+07	0.95
H_{2012}	0.018	0.96	0.016	0.99	0.021	0.97	0.020	0.93	0.019	0.97	0.020	0.92
N_{2013}ratio	0.787	0.24	0.785	0.24	0.736	0.35	0.848	0.19	0.793	0.23	0.847	0.19
N_{1982}	5.28E+06	0.98	5.85E+06	0.93	4.85E+06	1.04	5.48E+06	1.00	5.56E+06	0.99	5.72E+06	1.00
H_{2012}/H_{MSY}	**0.179**	**0.89**	**0.186**	**0.92**	**0.175**	**0.86**	**0.196**	**0.79**	**0.180**	**0.87**	**0.198**	**0.77**
N_{2012}/N_{MSY}	**1.776**	**0.16**	**1.768**	**0.17**	**1.777**	**0.16**	**1.834**	**0.14**	**1.782**	**0.16**	**1.828**	**0.14**
N_{MSY}	7.19E+06	0.88	7.90E+06	0.82	6.71E+06	0.93	6.51E+06	0.93	7.19E+06	0.89	6.57E+06	0.93
H_{MSY}	0.106	0.40	0.091	0.42	0.120	0.37	0.099	0.40	0.105	0.39	0.097	0.40
P_{1982}	0.589	0.20	0.588	0.19	0.587	0.20	0.562	0.20	0.593	0.19	0.568	0.20
MSST ((1-M)*N_{msy}	5.53E+06		6.08E+06		5.16E+06		5.01E+06		5.53E+06		5.05E+06	
Convergence diagnostics												
Chain mixing	Good		Good		Good		Good		Good		Good	
Autocorrelations	Low		Low		Low		Low		Low		Low	
Gelman-Rubin	Good		Good		Good		Good		Good		Good	
(MC error)/(posterior sd)	<5%		<5%		<5%		<5%		<5%		<5%	
Abundance index	**RMSE/(Index Mean)**		**RMSE/(Index Mean)**		**RMSE/(Index Mean)**		**RMSE/(Index Mean)**		**RMSE/(Index Mean)**		**RMSE/(Index Mean)**	
NMFS SE Bottom LL	0.269		0.268		0.268		0.275		0.282		0.284	
NMFS SEAMAP Gr Tr (F)	0.487		0.487		0.485		0.514		0.494		0.517	
NMFS SEAMAP Gr Tr (S)	0.487		0.487		0.486		0.525		0.501		0.535	
NMFS Small Pel Tr	0.210		0.209		0.211		0.235		0.194		0.226	
DIC for model comparison	-197.906		-197.973		-197.571		-196.532		-195.252		-194.221	

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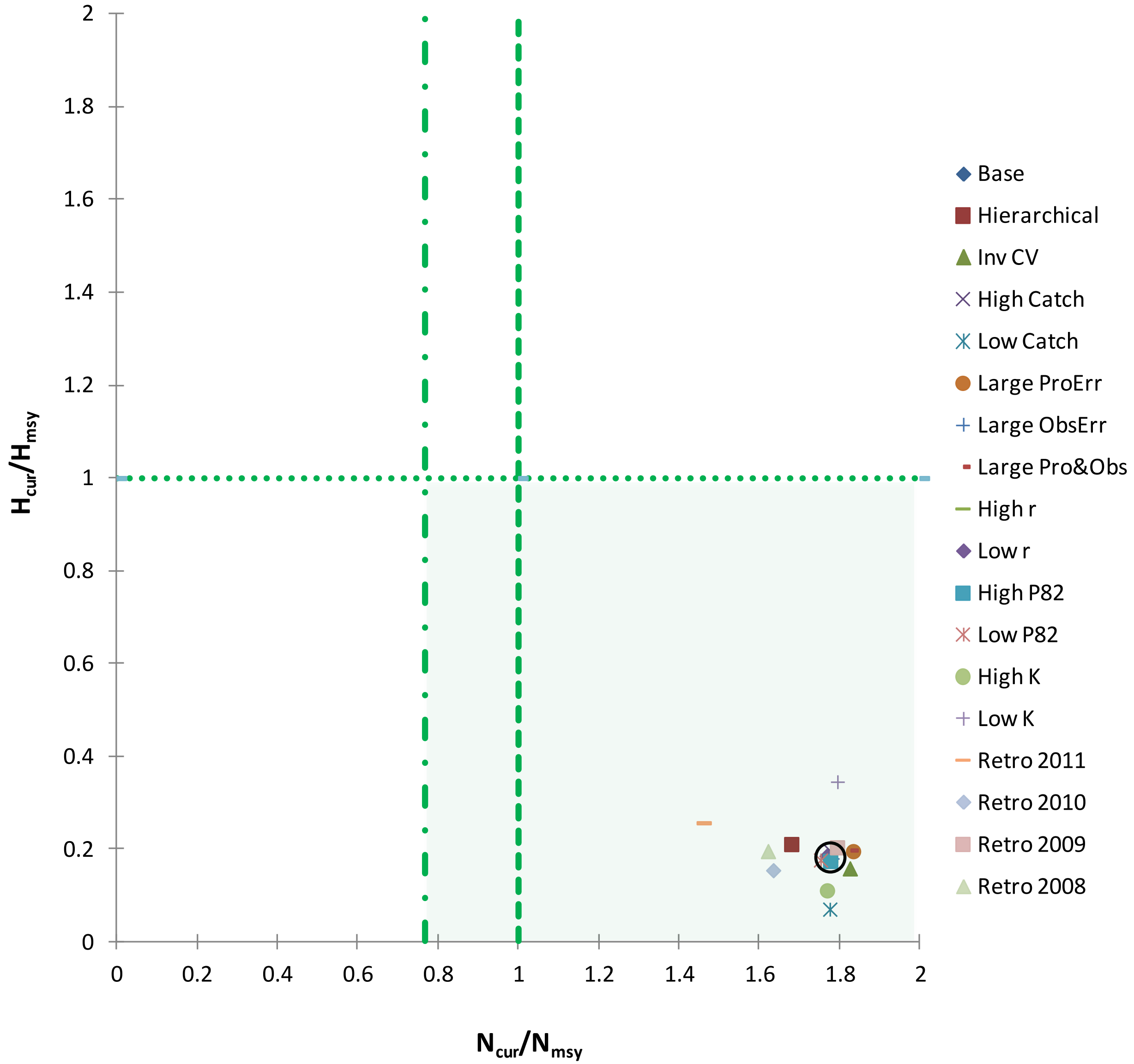
Summary of results (mean and CV) for sensitivity runs 5-13 (Continued)

Run	Base		High P_{82}		Low P_{82}		High K		Low K	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
K	1.44E+07	0.88	1.43E+07	0.88	1.45E+07	0.88	8.61E+07	1.38	3.11E+06	0.33
r	0.212	0.40	0.215	0.40	0.214	0.39	0.201	0.40	0.260	0.35
MSY	6.89E+05	0.95	6.97E+05	0.96	7.03E+05	0.94	3.96E+06	1.51	1.93E+05	0.40
N_{2012}	1.27E+07	0.90	1.29E+07	0.91	1.27E+07	0.90	7.62E+07	1.42	2.78E+06	0.36
H_{2012}	0.018	0.96	0.019	1.00	0.019	0.97	0.012	1.44	0.042	0.44
N_{2013}ratio	0.787	0.24	0.786	0.24	0.789	0.23	0.786	0.24	0.786	0.23
N_{1982}	5.28E+06	0.98	6.25E+06	0.99	4.25E+06	0.97	3.11E+07	1.51	1.19E+06	0.47
H_{2012}/H_{MSY}	**0.179**	**0.89**	**0.179**	**0.91**	**0.177**	**0.88**	**0.111**	**1.31**	**0.345**	**0.47**
N_{2012}/N_{MSY}	**1.776**	**0.16**	**1.796**	**0.15**	**1.753**	**0.17**	**1.769**	**0.17**	**1.795**	**0.15**
N_{MSY}	7.19E+06	0.88	7.17E+06	0.89	7.26E+06	0.88	4.30E+07	1.38	1.56E+06	0.33
H_{MSY}	0.106	0.40	0.107	0.40	0.107	0.39	0.101	0.40	0.130	0.35
P_{1982}	0.589	0.20	0.740	0.18	0.430	0.20	0.588	0.20	0.590	0.20
MSST ((1-M)*N_{msy}	5.53E+06		5.51E+06		5.58E+06		3.31E+07		1.20E+06	
Convergence diagnostics										
Chain mixing	Good		Good		Good		Good		Good	
Autocorrelations	Low		Low		Low		Low		Low	
Gelman-Rubin	Good		Good		Good		Good		Good	
(MC error)/(posterior sd)	<5%		<5%		<5%		<5%		<5%	
Abundance index	**RMSE/(Index Mean)**		**RMSE/(Index Mean)**		**RMSE/(Index Mean)**		**RMSE/(Index Mean)**		**RMSE/(Index Mean)**	
NMFS SE Bottom LL	0.269		0.269		0.268		0.268		0.269	
NMFS SEAMAP Gr Tr (F)	0.487		0.485		0.487		0.487		0.490	
NMFS SEAMAP Gr Tr (S)	0.487		0.498		0.485		0.485		0.495	
NMFS Small Pel Tr	0.210		0.213		0.208		0.208		0.213	
DIC for model comparison	-197.906		-195.799		-199.297		-197.855		-197.843	

Phase plot of Gulf of Mexico *Mustelus* spp. complex stock status for all runs



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Probability of exploitable number being smaller than MSST (overfished condition) (top) and probability of exploitation rate being larger than H_{MSY} (bottom) for all runs