Assessing the Goliath Grouper Stock off the Southeast U.S.A Using an Age–Structured Production Model (ASPM)

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BACKGROUND

- ICES (2012) classifies Population Dynamics Models as (criteria: structure/complexity & “realism”):
- Catch Only Methods (e.g., DCAC) < Time Series Models (e.g., AIM) < Production (Age-aggregated) Models (PMs) < Delay-Difference (a.k.a. Stage–structured) Models < **Age–Structured Production Models (ASPMs)** < VPA-based Approaches < Statistical Catch-at-Age Models (SCAM) < Integrated Analysis Models

- ASPM Characteristics:
- 1 – Replace the estimation of PM parameters by stock–recruit parameters, the recruitment being functionally dependent on spawner stock size

BACKGROUND

ASPM Characteristics:

- 2 – Take into account age structure of the population
- 3 – Project the population forward in time via internal age-structured simulations accounting for time-lags, fleets' selectivity and age schedules of biological parameters
- 4 – Tuned with (age-aggregated or age-structured) abundance indices, each with its unique age-selection
- 5 – Do not incorporate age and/or size composition of catch; and age schedules must be specified by the user (i.e., **ARE KNOWN ON THE BASIS OF EXTERNAL ESTIMATIONS**).

ASPM structure: Similar to that of a SCAM

Including the SEPARABILITY ASSUMPTION

Selectivity				
0.1	0.3	0.5	...	1.0

F multiplier
0.2
0.8
0.5
...
0.6

	Age 1	Age 2	Age 3	...	Age A
Year 1					
Year 2					
Year 3		0.15			
...					
Year T					

Key data
C_1 & I_1
C_2 & I_2
C_3 & I_3
...
C_T & I_T

BUT: No Catch and Length Compositions

$$F_{a,y} = Fmult_t * Sel_a$$

$$Z_{a,t} = F_{a,t} + M_a$$

BACKGROUND

ASPMs vs. (Stochastic) Stock Reduction Analysis (SRA):

- ASPMs = a class of models for fisheries without age and size compositions (e.g., Hilborn, 1990).
- Stochastic versions through Bayesian approaches led to referring to ASPMs as Stock Reduction Analyses, SRAs (e.g., Walters et al., 2006), although original SRAs were based on delay–difference models (e.g., Kimura, 1985).
- Either way, an ASPM or SRA is a removal method asking how large the stock (including recruitment) needed to be to have produced the time series of observed catches (landings + discards) and observed changes in relative abundance
- In this context, the historical catches and abundance indices are the key inputs to ASPM/SRA.

BACKGROUND

For Goliath Grouper

- An ASPM version developed by Martell et al. (2008) was used (Timeframe: 1950–2014)
- Objectives:
- 1 – To reconstruct the possible trajectories of abundance and fishing mortality (F) in light of the estimated time series of fishery removals and abundance indices.
- 2 – To determine the current (2014) stock status.
- The MSY and F_{MSY} are the ASPM parameters and could serve as BRPs, the status could be judged gainst. However, consistent with the species management prescriptions (GMFMC, 2015), SPR analyses were conducted and their results compared with the MFMT and MSST.

Materials and Methods: 1 – ASPM Description

- A population dynamics model with age–structured representations of growth, survival, and recruitment.
- Simulations are carried forward in time.
- Parameterized in terms of MSY and F_{MSY} assuming that:
- 1 – MSY is proportional to the unfished biomass (B_0);
- 2 – F_{MSY} is a function of a population productivity metric called Goodyear recruitment compensation ratio (κ).

- **IN OTHER WORDS,**

MSY and F_{MSY} are estimated; B_0 and κ values consistent with the (MSY, F_{MSY}) hypothesis are derived, given (KNOWN) life-history parameters and selectivity schedules.

Materials and Methods: 1 - ASPM Description

- The model runs using an ADMB code.
- The model was originally tuned with a single (age-aggregated) index and used that index age composition.

- Dr. Wade Cooper modified the code to accommodate multiple indices.
- The main likelihood component relates to indices.

- However, the total LL may or may not include the likelihood components associated with priors for F_{MSY}, MSY, κ, fishing mortality"-observations", and the penalty for κ being negative.

Materials and Methods: 2 – Model Configuration

- Calculations made for age-0 through age-37 (1950–2014)
- No harvest and index age and length composition data
- Age schedules included:
- 1 – Mean length (mm); mean weight (kg)
- 2 – Selectivity:
- 2 blocks for the fishery (logistic for the1950–1989 block as in SEDAR 6 and quasi-logistic for the 1990–2014 block);
- A single block for each index; assumptions:

➔ Dome-shaped selectivity for juvenile indices;

➔ Logistic selectivity for the dive reef index;

➔ Quasi-logistic selectivity of the fishery during 1990–2014 was applied to the MRFSS/MRIP offshore index;

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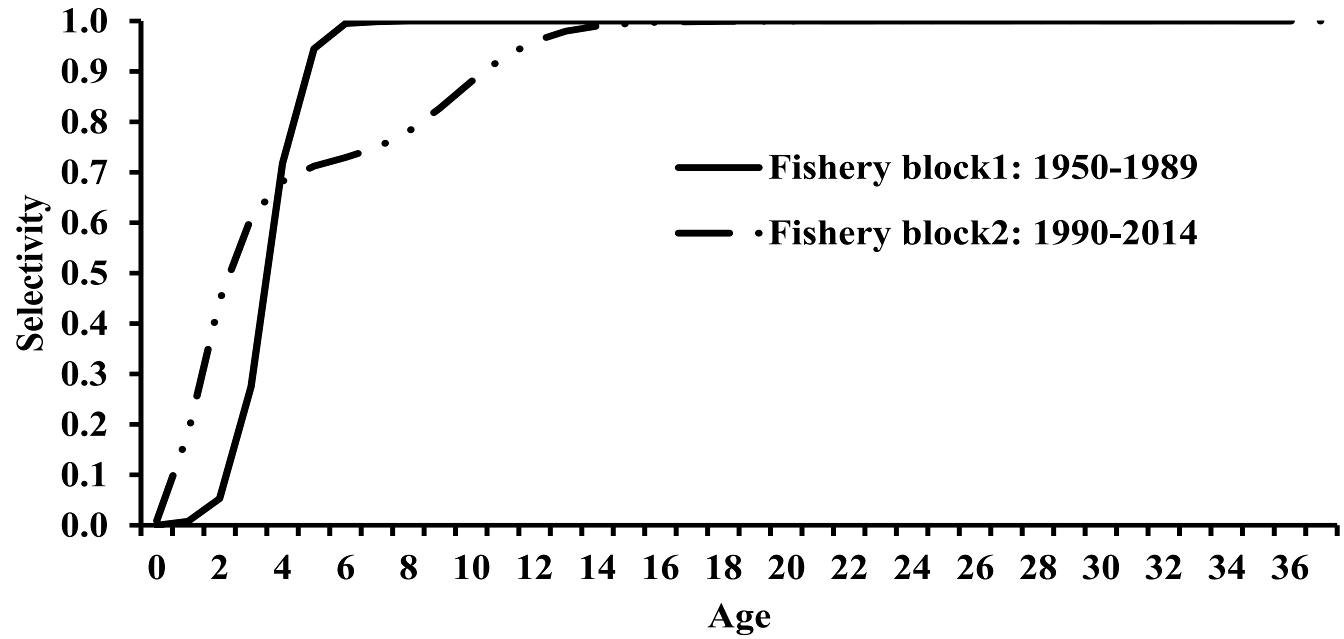
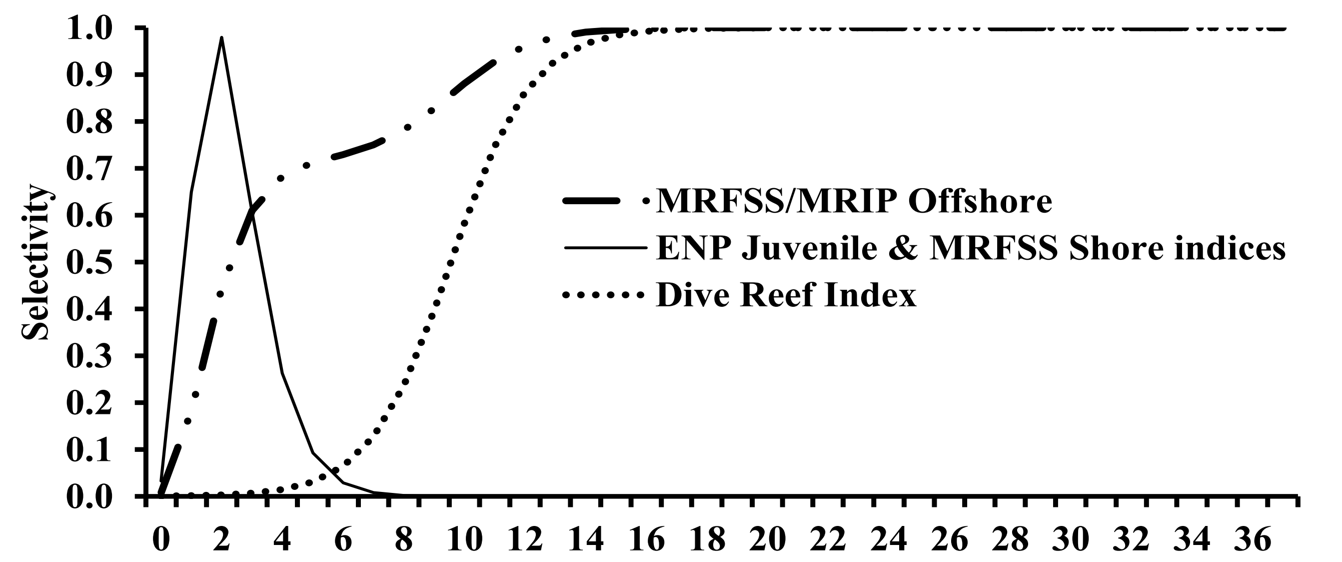
Materials and Methods: 2 – Selectivity schedules





Materials and Methods: 2 – Model Configuration

- Age schedules included:
- 3 – Proportion mature: 0 for age-0 to age-5; 1 otherwise;
- 4 – Natural and fished survivorships to various ages
- NOTE:

➔ Constant $M = 0.18$; from $M = 4.899(T_{max})^{-0.916}$ (Then et al. 2015) where T_{max} is longevity (i.e. 37 years)

➔ M-at-age (M_a): Lorezen (1996) for ocean populations ($M_a = 3.69(W_a)^{-0.305}$, such that constant M was target (i.e., average M of all fully selected ages, 4–37).

- 5 – Fecundity at age approximated by $W_{a+\pi} \times m_a$; $W_{a+\pi}$ = mean weight at age a+π, π = fraction of the year elapsed at the time of spawning, and m_a = proportion mature.

Materials and Methods: 2 – Derived quantities and data

- Combination of age schedules produces: Incidence functions on a per-recruit basis (e.g. SSB, Eggs, Yield)
- Leading parameters: MSY and F_{MSY} ; but annual recruitment deviations also estimated
- Given (i) MSY and F_{MSY}, (ii) incidence functions, and (iii) an assumed Beverton–Holt Stock–Recruit model, the derived quantities included:
- κ , h, B_0, E_0, $R_e(F)$, $Y_e(F)$, and stock–recruit parameters

- NOTE :
- 1 – F_{MSY}: bounded between 0.01 and 0.5; guess: 0.1.
- 2 – MSY: bounded between 1,000 and 200,000 kg; guess: 70,000 kg (i.e. Average of the estimated harvests)
- 3 – “Prior” for κ : 17; assumed to be normally distributed; SD of 0.6 (Rose et al.’s (2001) meta-analysis results for periodic species)
- 4 – Weights of one (1) used for various likelihood components

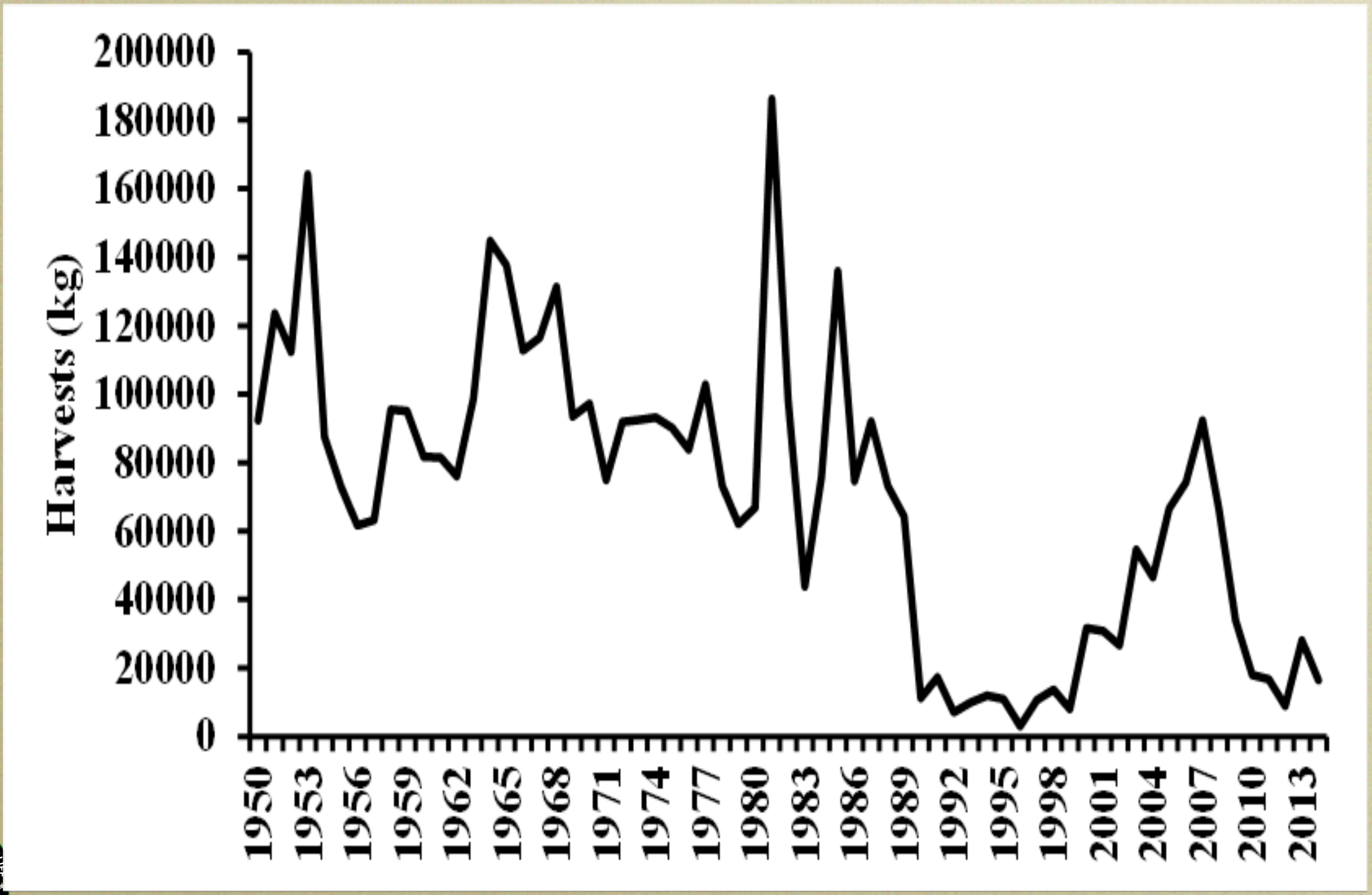
Materials and Methods: 2 – Data

- 1 – C_t (1950–20014) = com landings (1950–1989), rec landings, Type AB1 (1981–1989), and rec dead discards, Type B2 (1981–2014) with an assumed release mortality of 5%. **KNOWN W/O ERROR**

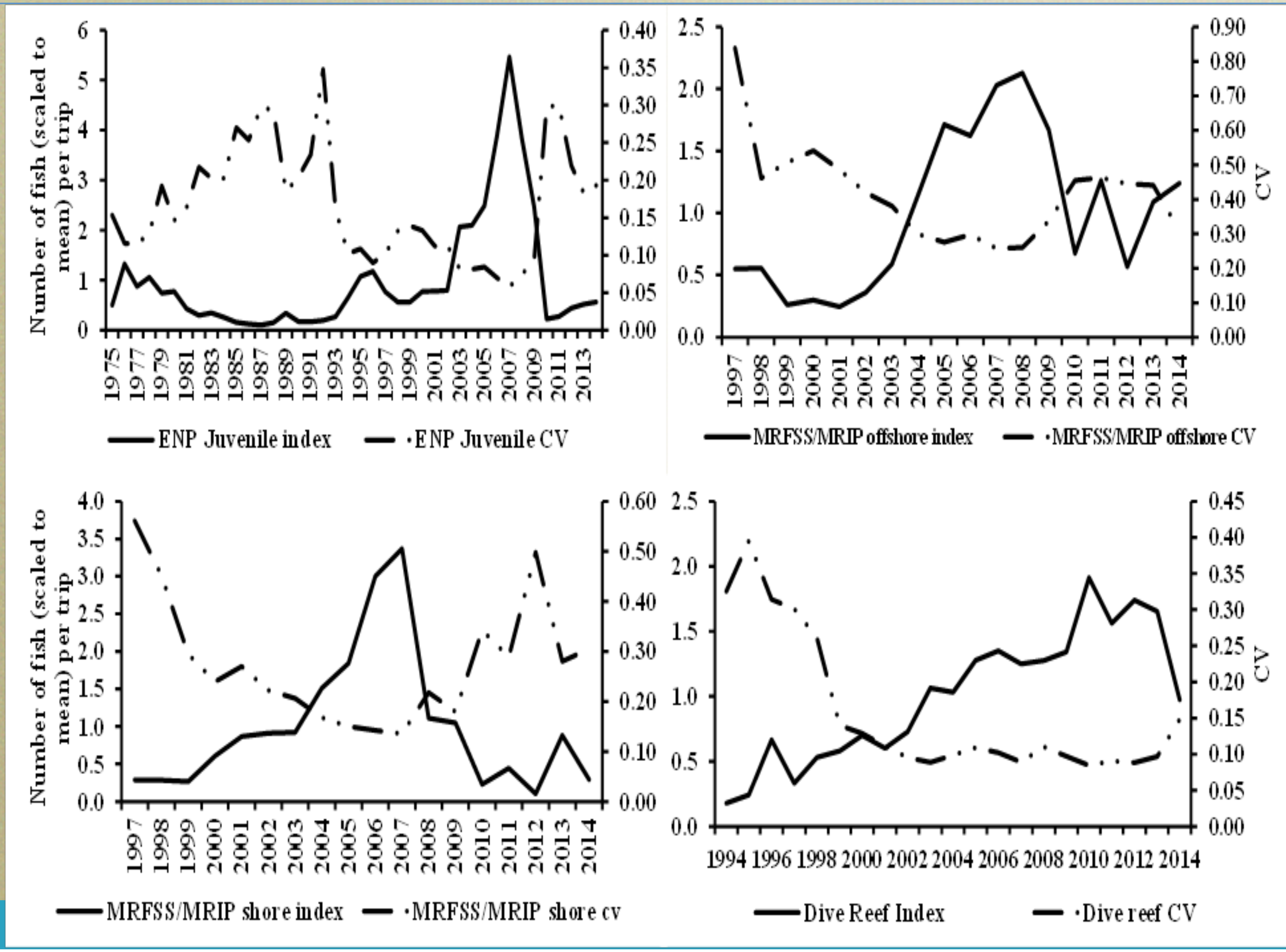
- 2 – I_t and CVs: ENP Juveniles (1975–2014), MRFSS/MRIP offshore for adults (1997–2014), MRFSS/MRIP offshore for Juveniles (1997–2014), and Diver Survey (1994–2014)

- Martell et al.'s ASPM is conditioned on the Baranov catch equation predicting the fishery removals: F_t is initialized as $F_t = C_t / B_t$; then, using Newton's root finding method, F_t values are iteratively updated until the difference between the predicted removals ($c\downarrow t$) and the observed removals is minimal, following this equation (where i indexed iteration):
- $F\downarrow ti+1 = F\downarrow ti - C\downarrow t - C\downarrow t / C\downarrow t\uparrow'$
- RUNING THE MODEL IN THE MCMC MODE MAKE IT "STOCHASTIC".

Materials and Methods: 2 – Data (Trajectory of Fishery Removals)



Materials and Methods: 2 –Data (Trajectory of Indices of abundance and CVs)



Materials and Methods: 2 – Calculation of the NLL

- Year-specific index is predicted as:

$I_t = W_a S_a^{(I)} \mathbf{N}^T / \frac{1}{n}\sum_a W_a S_a^{(I)} \mathbf{N}^T$ (biomass); $I_t = S_a^{(I)} \mathbf{N}^T / \frac{1}{n}\sum_a S_a^{(I)} \mathbf{N}^T$ (numbers) where $\mathbf{N}^\mathbf{T}$ is a transpose matrix of $N_{a,t}$ predicted over an index period.

- The log-likelihood for each index is given by:

$LI_t = \lambda_I \{0.5\log(2\pi) + 0.5\log(\sigma_{I,t}^2) + [\log(I_t) - \log(I_t)]^2 / \sigma_{I,t}^2\}$ where λ_I is the index weight and $\sigma_{I,t}^2$ is the index variance by year

- The total log-likelihood may or may not include the likelihood components associated with priors for F_{MSY}, MSY, κ, fishing mortality"-observations", and the penalty for κ being negative.

- E.G., the Log-likelihood for F_{MSY} prior (F_{MSY}P), LF_{MSY}, is given by: $LF_{MSY} = \lambda_{F_{MSY}} \{0.5\log(2\pi) + 0.5\log(\sigma_{F_{MSY}P}^2) + [\log(F_{MSY}P) - \log(F_{MSY})]^2 / \sigma_{F_{MSY}P}^2\}$ where $\lambda_{F_{MSY}}$ is weight and $\sigma_{F_{MSY}P}^2$ is variance.

Materials and Methods: 2 – Uncertainty in model Results

- MCMC simulations ➔ uncertainty in quantities of interest (provided the chains converge).
- 6 chains were run (1,000,000 draws, a saving of every 1,000th) ➔ 1,000 draws were saved ("accepted").
- Convergence diagnostics were checked through traces, density and autocorrelation plots.
- Uncertainty was characterized by summarizing the marginal posterior probability density functions in terms of the means, percentiles and standard deviations

- In addiction to MCMC simulations, a retrospective analysis was carried out by removing successive years of data from the model for 5 years ➔ to inspect retrospective patterns and to evaluate the retrospective error in model results (i.e., the rho statistic of Mohn (1999))

Materials and Methods: 2 – Stock Status/Miscellaneous

- Management Prescriptions (GMFC, 2015):
- 1 – The maximum *F* threshold (MFMT) equivalent to 50%SPR as F_{MSY} proxy ➔ to determine whether overfishing is or is not occurring
- 2 – The minimum stock size threshold (MSST) at or below which the stock is considered to be overfished:
- **MSST = (1–M)×B_{MSY} (or proxy, which here is the SSB associated with the MFMT) or MSST = 0.5 B_{MSY} (or proxy), whichever is greater.**
- To this end, various per-recruit analyses were developed; *F* @ 50%SPR determined; a BH SRR (1975 – 2014) fitted; its parameters and the SSBR combined to calculate MSST.
- Overfishing status employed the ratio Fcur/MFMT (if > 1 Overfishing!
- Overfished status employedthe ratio SSBcur/MSST (if <1 Overfished!!)
- sSPR and tSPR plots and comparisons with the management threshol of 50%SPR
- Sensitivity analyses & Projections: not made.

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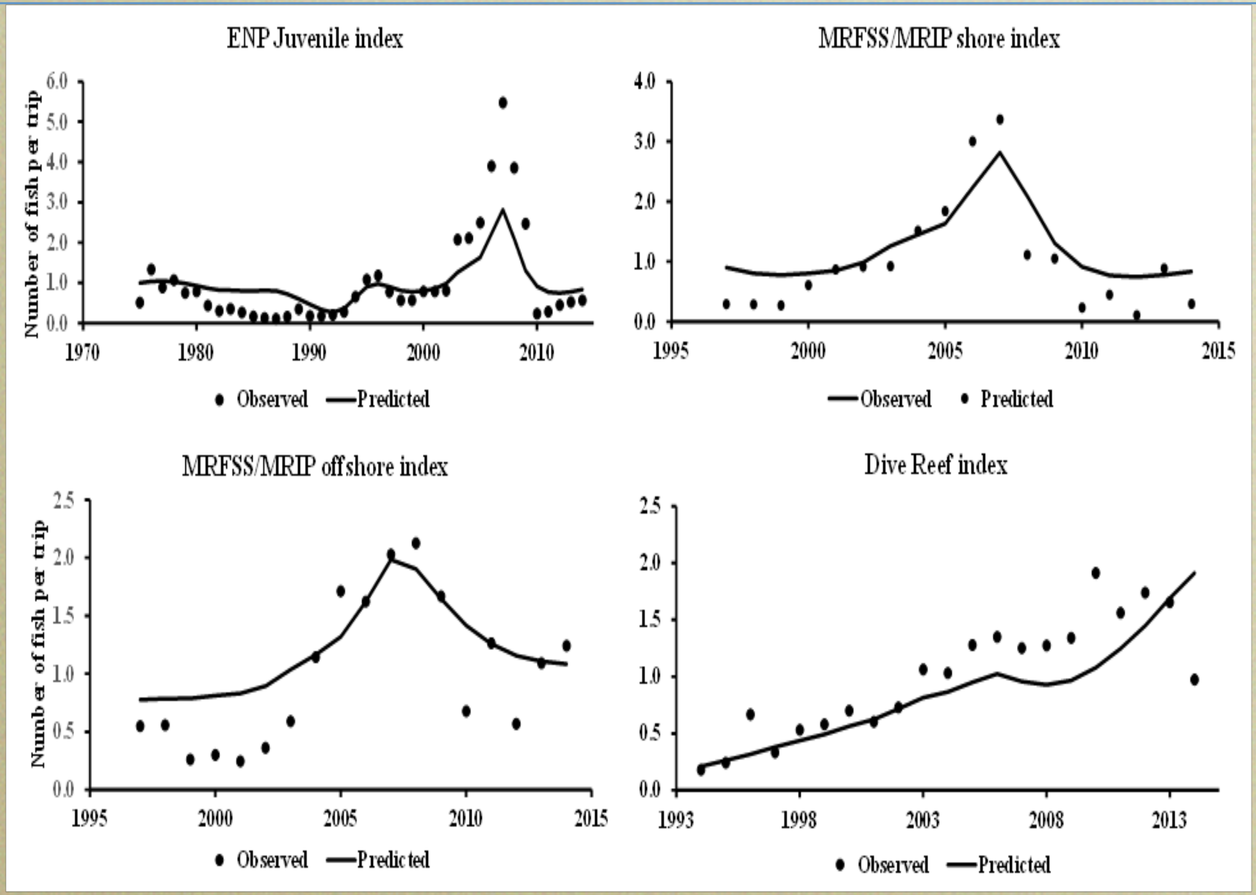
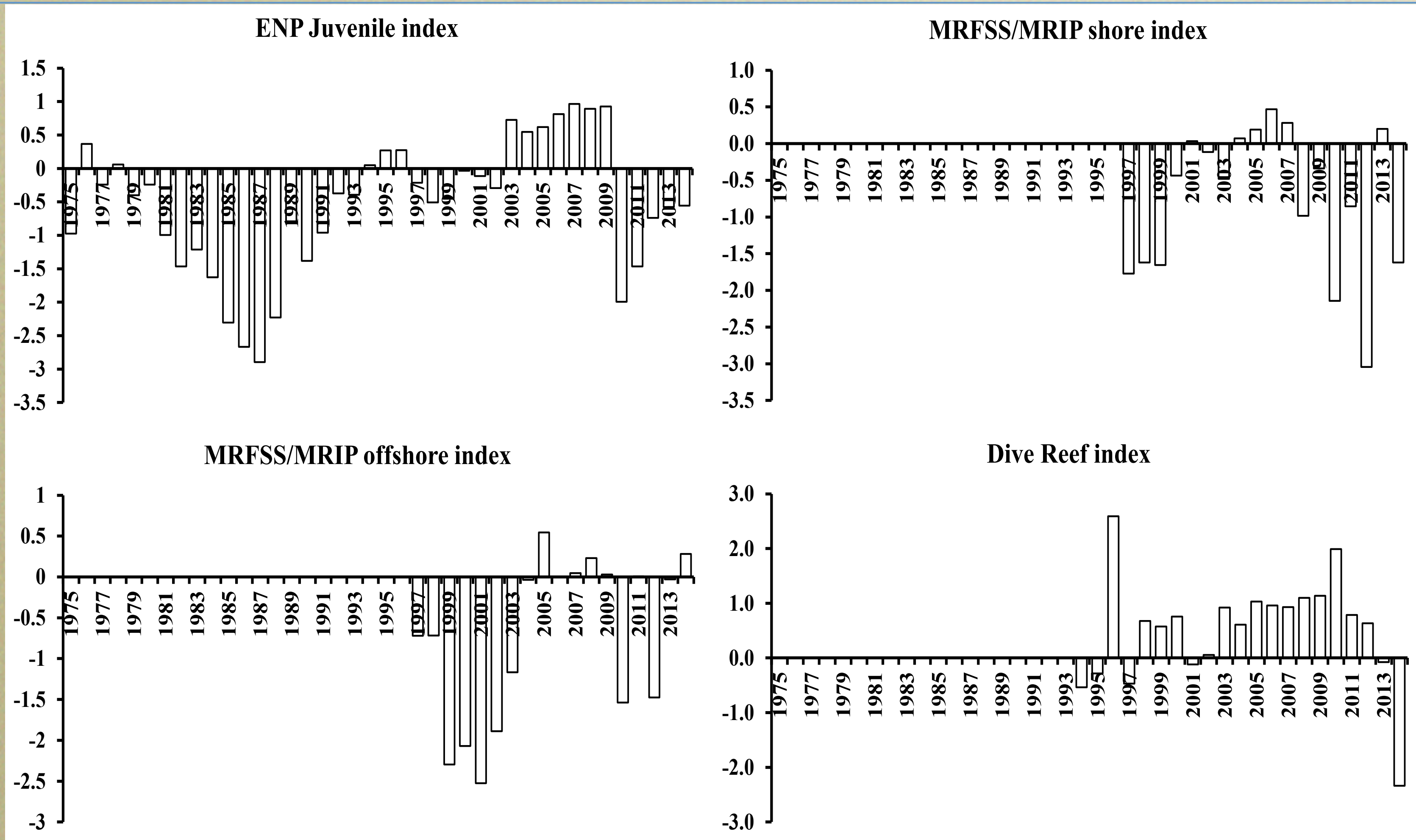
Results: Goodness-of-Fit



The predicted indices of abundance mimicked the overall trends of observed values, especially for juveniles, BUT….

Results: Goodness-of-Fit



The standardized residuals indicated periods when the observed values were overestimated and underestimated during consecutive years

Results: Parameters (measures of central tendency and variability)

a

	Mean	SD	Naive SE	Time-series SE
negLL	1468.00	5.84	0.18	0.19
Fmsy	0.1822	0.0035	0.0001	0.0001
MSY	85650	1206	38	45
h	0.93	0.01	0.00	0.00

b

	2.50%	25%	50%	75%	97.50%
negLL	1457.00	1464.00	1467.00	1471.00	1480.21
Fmsy	0.1753	0.1799	0.1821	0.1846	0.1890
MSY	83460	84840	85630	86420	88047
h	0.910	0.921	0.927	0.932	0.942

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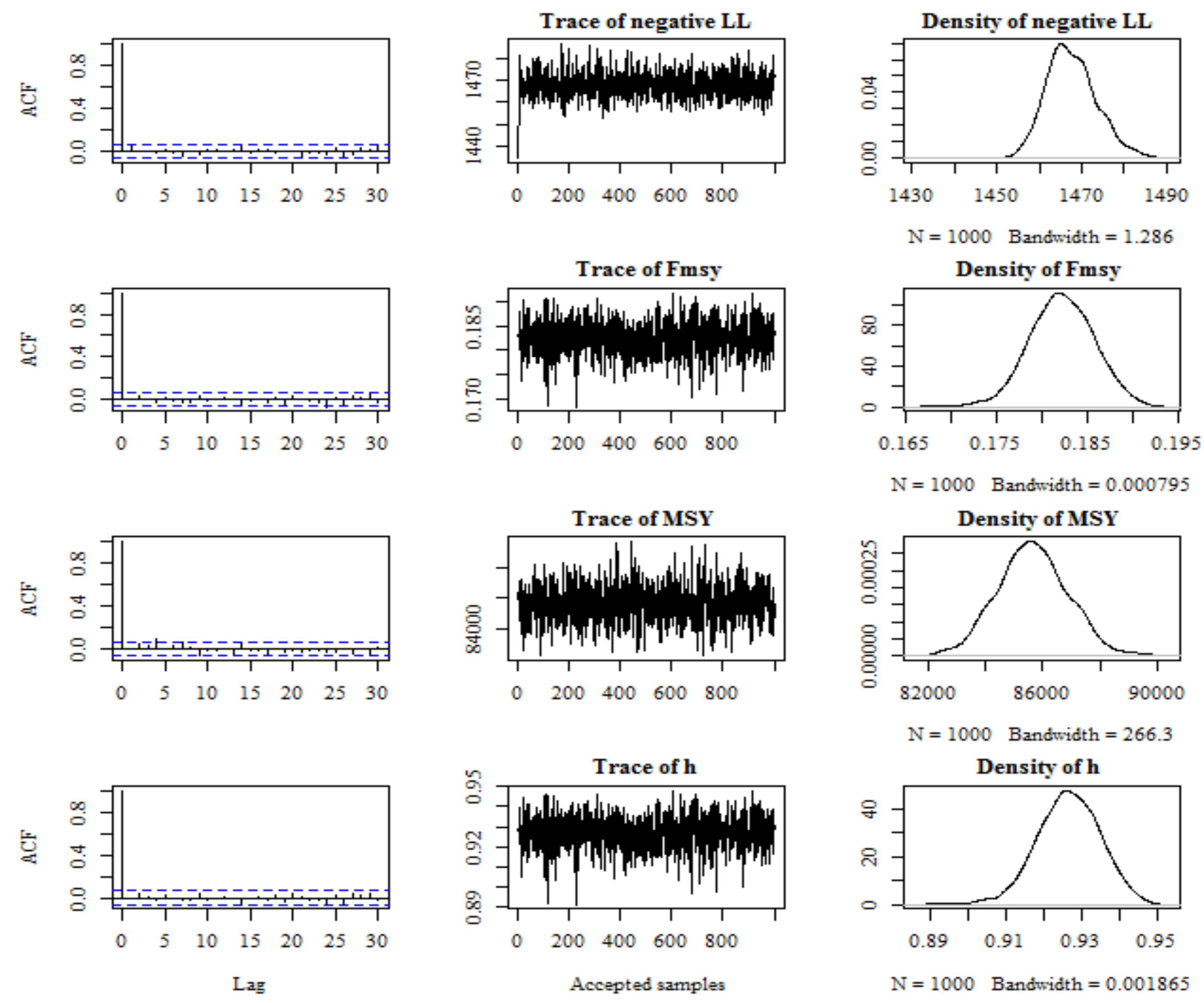
Results: Parameters (diagnostic plots on estimation)

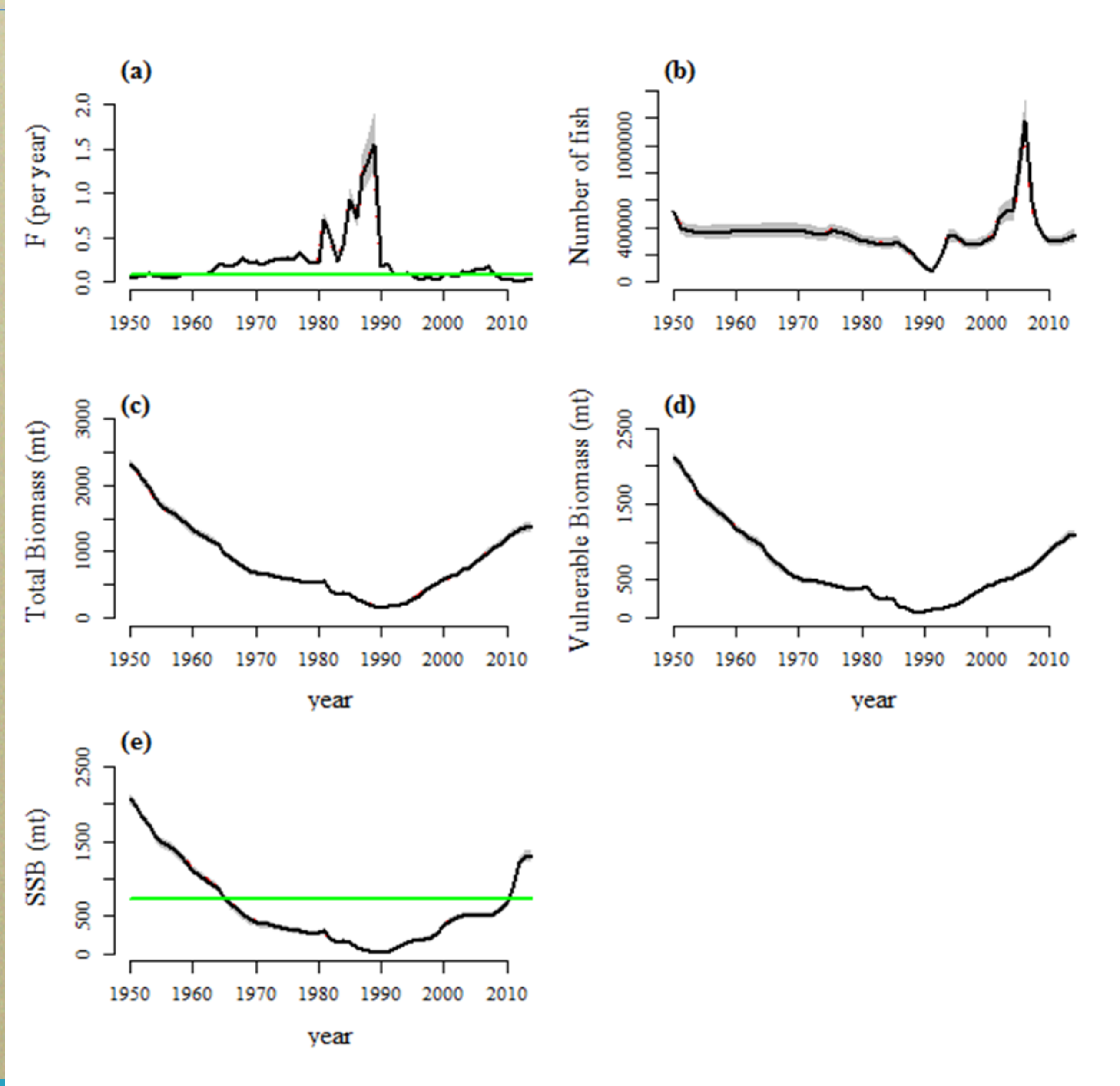
MCMC simulations converged fairly well;

Various chains produced similar plots



Results: Trajectories (F, Numbers, biomass

- *F* increased (1950–1989); low thereafter
- *F* > MFMT during 1963–1989 & 2003–2008)
- N varied smoothly during 1950 – 2005 and then tracked the trend of the ENP juvenile index
- Total B, vulnerable B and SSB declined steadily between 1950 and 1991, then trended up
- SSB < MSST: Mid-1960s –late 2000s.



Results: Uncertainty in model results

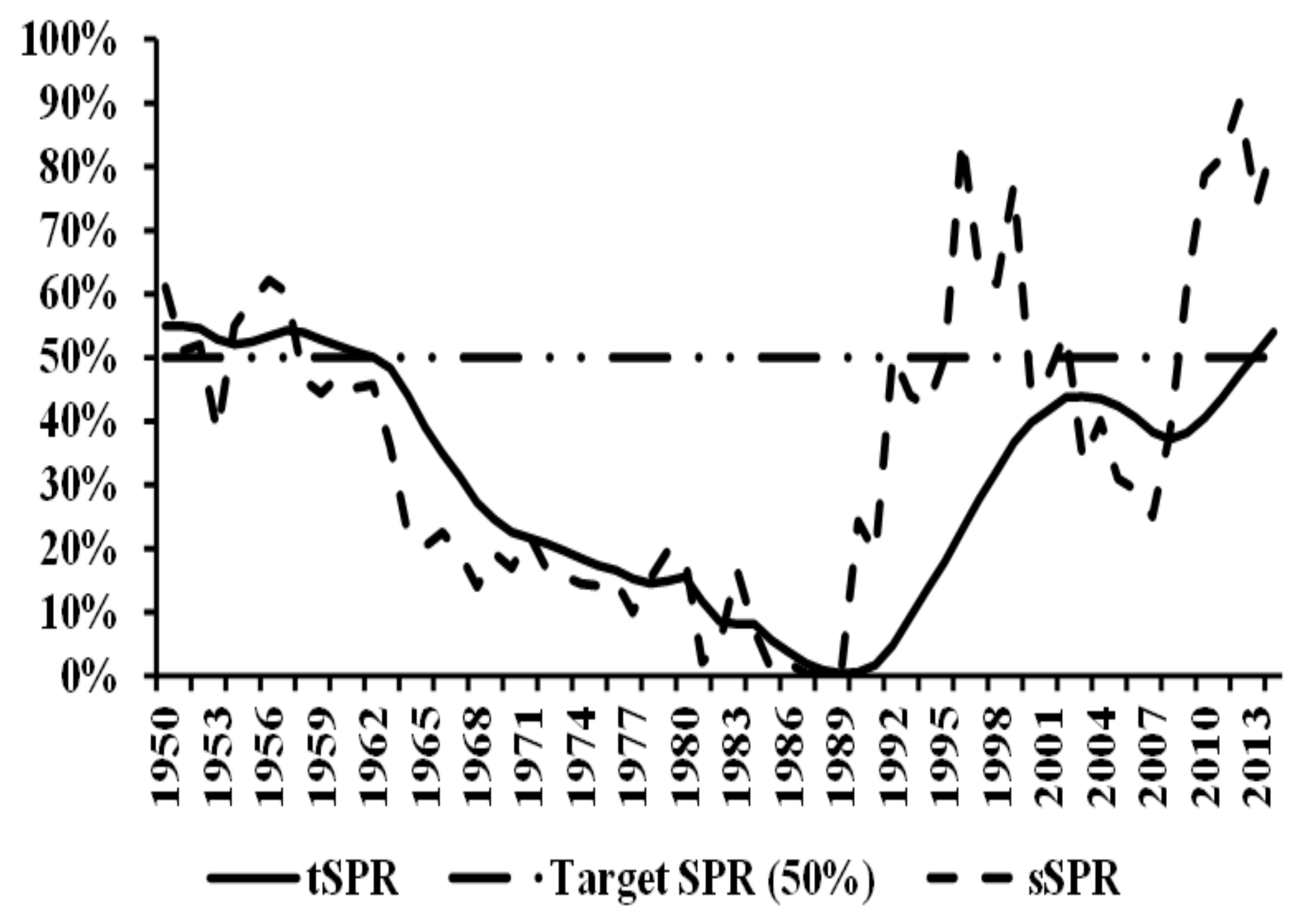
- Uncertainty appeared small as reflected in narrow 95%BCIs
- Such precise results may largely be due to fishery data and life history inputs that were assumed to be known without error.

Results: Stock Status

- Mean Fcur = 0.017year^{-1} (95%BCI = 0.016–0.018year^{-1})
- Mean SSBcur = 324 MT (95%BCI = 284–371 MT)
- Per-recruit analyses (YPR, SBPR, SPR), the fitting of the BH– SRR (1975–2014) indicated:
- 1) F @ 50%SPR = 0.08year^{-1}; hence, MFMT = 0.08year^{-1}.
- 2) The SSB @ F50%SPR = 890,508 kg (B_{MSY} proxy); for M = 0.18, the MSST = 730,216 kg;
- otherwise, the MSST could be 890,508 kg/2 = 445,254 kg.
- Since, 730,216 kg > 445,254 kg, the retained MSST = 730,216 kg.

- Because Fcur/MFMT = 0.22 and the SSBcur/MSST = 1.48, overfishing was not occurring and the stock of goliath grouper was not overfished in most recent years.

Results: Stock Status --- for the sSPR and tSPR:



Results: Stock Status --- for the sSPR and tSPR:

- The sSPR indicated that overfishing was not occurring since 1995, except perhaps during 2003–2008 when $F >$ the MFMT and sSPR < 50%SPR.

- The tSPR trended similarly as biomasses: the age structure of goliath grouper may have been expanding since the mid-1990s, after a long period of continual contraction, from 1963 (tSPR = 48.3%) through the late 1980s–early 1990s (tSPR = 0.4–9%).
- However, the tSPR did not exceed the management target of 50%, except in 2013 and 2014.

Concluding Remarks

- The ASPM relied heavily on indices of abundance, landings + discards, life history and selectivity (assumed to be known and free of error).
- There may have been improvement in the development of indices of abundance, but the related selectivity schedules were problematic.
- Other issues related to:
- (i) possible higher *M* for a species that may live longer;
- (ii) lack of reproduction data; and
- (iii) apparent inability for the ASPM to fit adequately indices

- Keeping in mind that the stock of goliath grouper is data-poor, the inputs used and assumptions made to run the ASPM were the best tools at hand to reconstruct the plausible historical population size, and determine the current stock status of the species.

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THANKS

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