S E D A R

Southeast Data, Assessment, and Review

SEDAR 19-AW04

Assessment Workshop Working Paper

Red Grouper: Predecisional Surplus-production Model Results

Prepared by

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The Caribbean Fishery Management Council

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3.2 Surplus–Production Model

The logistic model for population growth is the simplest form of a differential equation which satisfies a number of ecologically realistic constraints, such as a carrying capacity (due to limited resources, for instance). When written in terms of stock biomass, this model specifies that

$$\frac{dB_t}{dt} = rB_t - \frac{r}{K}B_t^2,$$

where B_t is biomass at time t, r is the intrinsic rate of increase in absence of density dependence, and K is population carrying capacity (Schaefer 1954; 1957). This equation may be rewritten to account for the effects of fishing by introducing an instantaneous fishing mortality term, F_t:

$$\frac{dB_t}{dt} = (r - F_t)B_t - \frac{r}{K}B_t^2.$$

By writing the term F_t as a function of catchability coefficients and effort expended by fishermen in different fisheries, Prager (1994) showed how to estimate model parameters from time series of yields and effort. These parameters can be estimated numerically using maximum likelihood, as with program ASPIC (Prager 1994; 1995).

3.2.1 Methods

A surplus production model was used as a supplement to the primary age-structured model. Production modeling used the ASPIC formulation and software of Prager (1994; 1995). This is an observation-error estimator of the continuous-time form of the Schaefer (logistic) production model (Schaefer 1954; 1957).

Data included total landings in weight and a combined index based on three fishery–dependent sources and two fishery–independent sources. Several of the indices were developed in numbers for input into the age-structured model. We converted indices in number to weight as required by the model. Recreational landings and discards time series in weight were also developed from the SEDAR 19 DW time series in numbers. The methods for converting data are described in the Data Sources section below.

3.2.1.1 Overview The base run was structured to allow B_1/K to be estimated, using maximum likelihood as the objective function. A sensitivity run was made using a combined index adjusted to reflect the assumption of catchability increasing linearly at 2%/yr starting in 1978, the first year relative abundance estimates were available. Annual increases in catchability were assumed to cease in 2003, and constant catchability was applied thereafter. This is consistent with the recommendations from fishermen at the DW about when the effects of GPS were saturated.

The model was tested for the ability to converge on similar results at varying starting values for initial biomass (B_1/K estimated by the model). Additional runs were made with B_1/K at values (0.05,0.4) bracketing the freely estimated B_1/K, to evaluate the strength of information in the likelihood for estimating this parameter. Confidence intervals for the preliminary base model were estimated using bootstrap methods. No projections were run using production model methods. Age-structured projections are considered more realistic and meaningful for management decisions.

3.2.1.2 Data Sources

Landings Headboat and MRFSS recreational landings in numbers and whole pounds were developed at the SEDAR 19–DW. The MRFSS landings in number were subsequently smoothed for input into the age–structured model. The MRFSS landings in weight were not smoothed and were converted to pounds for the MRFSS survey by multiplying by the average annual mean weight, calculated as landings in weight/landings in number, by the smoothed MRFSS landings series from 1981–2008. The unsmoothed MRFSS data was used to determine average size. The 1978–1980 MRFSS landings were calculated as the average of 1981–1983.

Commercial landings were reported by the DW in gutted pounds and were converted to whole pounds using the whole weight–gutted weight conversion supplied by the life history group.

Dead Discards Discard estimates were provided in numbers for commercial and recreational data sources. We assumed the discarded weight of individual fish as the average weight of fish age 0 and 1 prior to the 1992 20–inch size limit and the average of fish age 0,1, and 2 since the 20–inch size limit. The prior 12–inch size limit did not effect the length compositions and was not considered. The recommended constant discard mortality of 20% was applied to the discarded numbers and then multiplied by the average weight.

Commercial discards were reported in gutted pounds and were converted to whole pounds using the whole weight–gutted weight conversion supplied by the life history group.

Relative abundance The indices for red grouper were developed in numbers of landed fish with the exceptions of MRFSS and commercial logbook. MRFSS was developed as numbers of landed and discarded fish and commercial logbook was developed in pounds. The surplus–production model requires input in pounds and therefore the MARMAP, headboat, and RVC indices were converted by multiplying the annual index for each series by an annual mean weight for each gear. There was considerable noise in the MARMAP index in pounds, and was therefore smoothed using a cubic spline weighted by the inverse of the CV's. MRFSS had the additional step of proportioning the index into landed and discarded fish and applying a mean weight for each. The mean weight for discarded fish was calculated as the mean weight of age 0 and 1 fish prior to the 20–inch size limit in 1992 and the mean weight of age 0,1, and 2 year old fish after the 20–inch size limit. The mean weight of the landed fish was calculated using the length compositions and the associated estimate of weight at length. The annual mean weight was then calculated as $\sum P_i \; w_i$ where (P_i) is the proportion for each length bin(i). The length–weight equation provided by the SEDAR 19 DW was used to estimate the weight in whole pounds at each length bin (w_i).

These individual indices were combined into a single index using hierarchical analysis (See SEDAR19-AW01). An additional combined index was generated that incorporates a 2% catchability increase per year until 2003 for use in sensitivity runs.

3.2.2 Model Results

3.2.2.1 Parameter Estimates and Associated Measures of Uncertainty

Parameter estimates for the base run (base) and sensitivity run are presented in the ASPIC output, which is included as Appendix A, and in table 2. The model was insensitive to different starting values of B_1/K and converged to nearly identical results with B_1/K estimated (Table 1). Strong improvements in the likelihood value function approaching the estimated B_1/K value of 0.188 from the higher fixed values of B_1/K (0.4) and weaker improvement at lower fixed values of B_1/K (0.05) . The sensitivity run gave similar estimates of relative fishing rate compared to the base run (Figures 1). However, the estimates of relative biomass differed between the two runs (Figure 2). Both runs fit the combined index reasonably well except that they had difficulty fitting the first few years (Figure 4). As expected, both runs fit the landings exactly since they are conditioned on catch(Figure 3). Attempts were made to run the model with individual indices or groups of indices, but these runs failed to converge and are not presented here.

We implemented the base run using 1000 bootstrap runs to generate 80% confidence intervals (Figure 5) and evaluate the shape of the distribution (Figure 6) of the current relative fishing mortality rate F/F_{MSY} and biomass relative to the minimum spawning stock threshold B/MSST.

3.2.3 Discussion

The ASPIC model fit the data and estimated B_1/K at 0.188 in 1978. Combining the indices allowed the model to fit the data without the added difficulty of resolving conflicts among the indices. The production model estimates that current stock size is slightly below MSST and that the current level of fishing is slightly above the limit reference point F_{MSY}. The surplus production model, because it omits population age and size structure, does not make use of data on those characteristics. Because such data are available for red grouper, a model that uses them would normally be preferred for a detailed assessment

3.2.4 Tables

Table 1. Sensitivity of model to specification of B_1/K initial guess. Biomass quantities (MSY, F_{MSY},B_{MSY},K) are in units of pounds whole weight.

Run	B_1/K guess	B_1/K	MSY	F_{MSY}	B_{MSY}	K	r	q	B/B_{MSY}	F/F_{MSY}	like.val
bk.1	0.1	0.188	1.46E+06	0.256	5.73E+06	1.15E+07	0.511	4.07E-07	0.689	1.695	3.394
bk.2	0.2	0.189	1.46E+06	0.256	5.69E+06	1.14E+07	0.513	4.08E-07	0.690	1.696	3.394
bk.4	0.4	0.188	1.46E+06	0.256	5.72E+06	1.14E+07	0.511	4.07E-07	0.689	1.695	3.394
bk.6	0.6	0.188	1.46E+06	0.256	5.73E+06	1.15E+07	0.511	4.07E-07	0.689	1.695	3.394
bk.8	0.8	0.188	1.46E+06	0.256	5.72E+06	1.14E+07	0.511	4.07E-07	0.689	1.695	3.394

Table 2. ASPIC model results with B_1/K estimated and with combined index (base) and with a combined index that incorporates a 2% catchability increase per year (q2pct). Biomass quantities (MSY, F_{MSY},B_{MSY},K) are in units of pounds whole weight.

Run	B_1/K	MSY	F_{MSY}	B_{MSY}	K	r	q	B/B_{MSY}	F/F_{MSY}	like.val
base	0.188	1.47E+06	0.255	5.74E+06	1.15E+07	0.511	4.06E-07	0.689	1.694	3.394
q2pct	0.069	3.50E+06	0.240	1.46E+07	2.91E+07	0.480	4.65E-07	0.213	2.274	3.958

3.2.5 Figures

Figure 1. Red Grouper in Atlantic: Production model estimates of relative fishing mortality rate. Base run (base) and a 2% catchability increase since 1978 (q2pct).

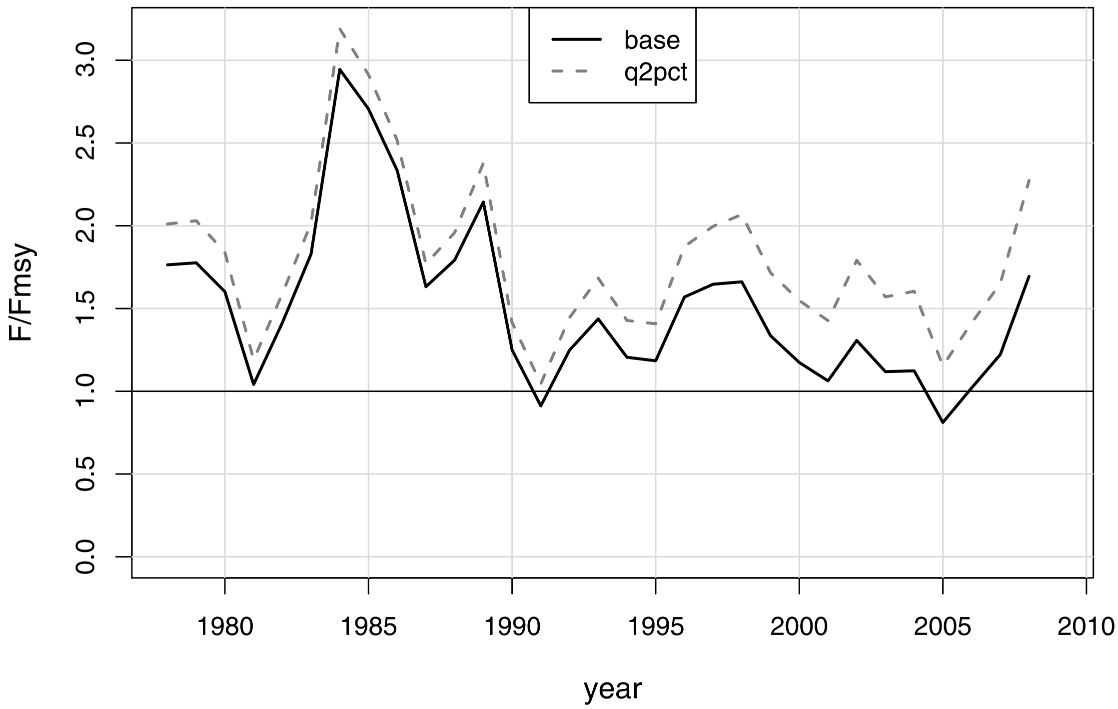


Figure 2. Red Grouper in Atlantic: Production model estimates of relative biomass. Base run (base) and a 2% catchability increase since 1978 (q2pct).

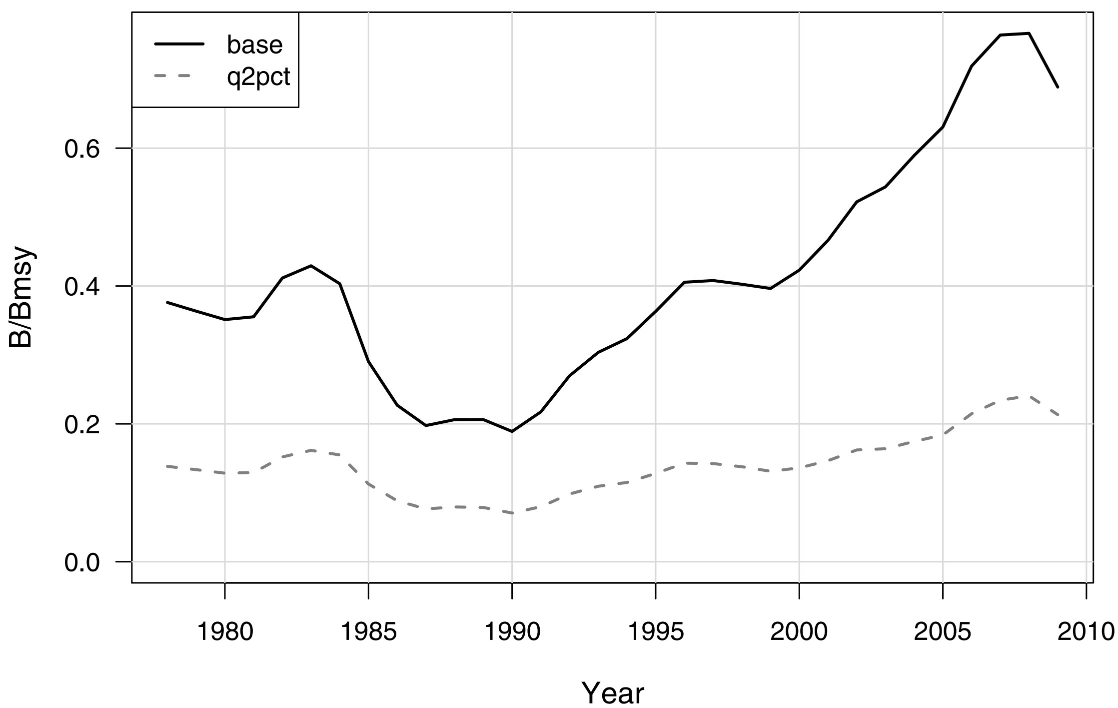


Figure 3. Red Grouper in Atlantic: Production model fit estimate of landings. The base run and q2pct run identically fit the landings exactly.

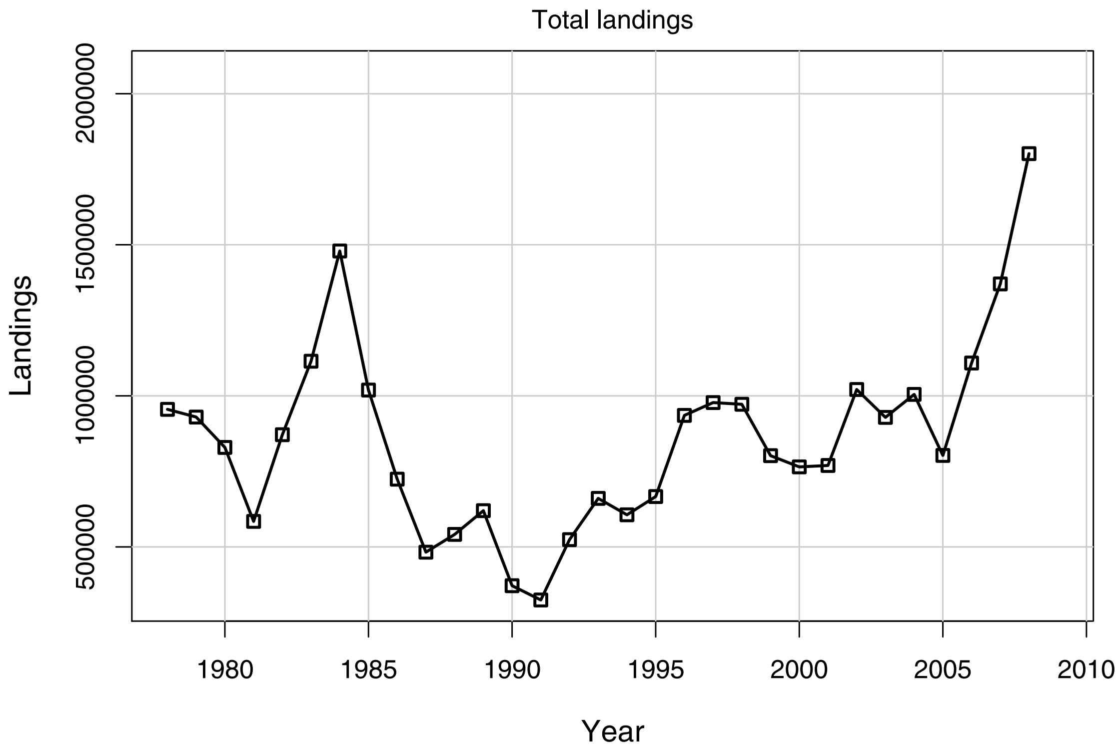
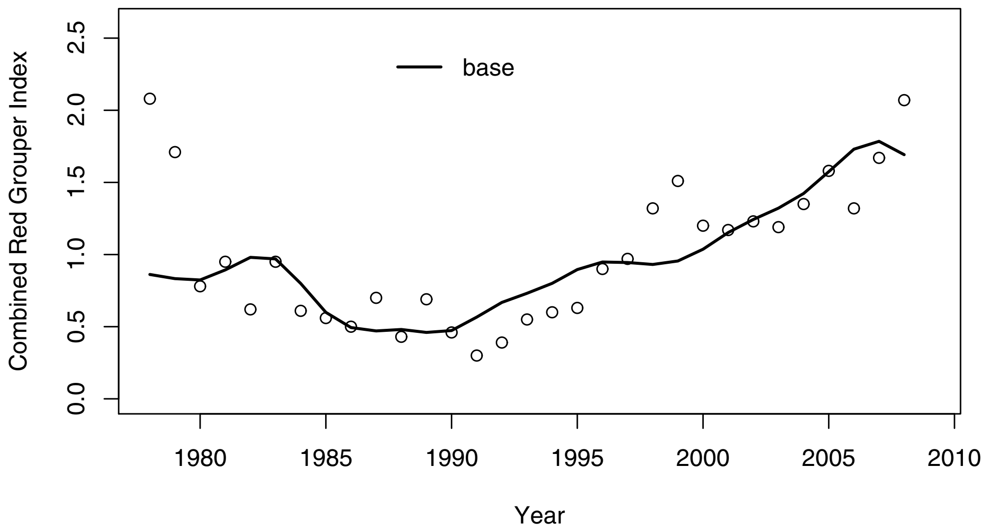


Figure 4. Red Grouper in Atlantic: Fit of production models to combined index. Base run (base) and a 2% catchability increase since 1978 (q2pct).



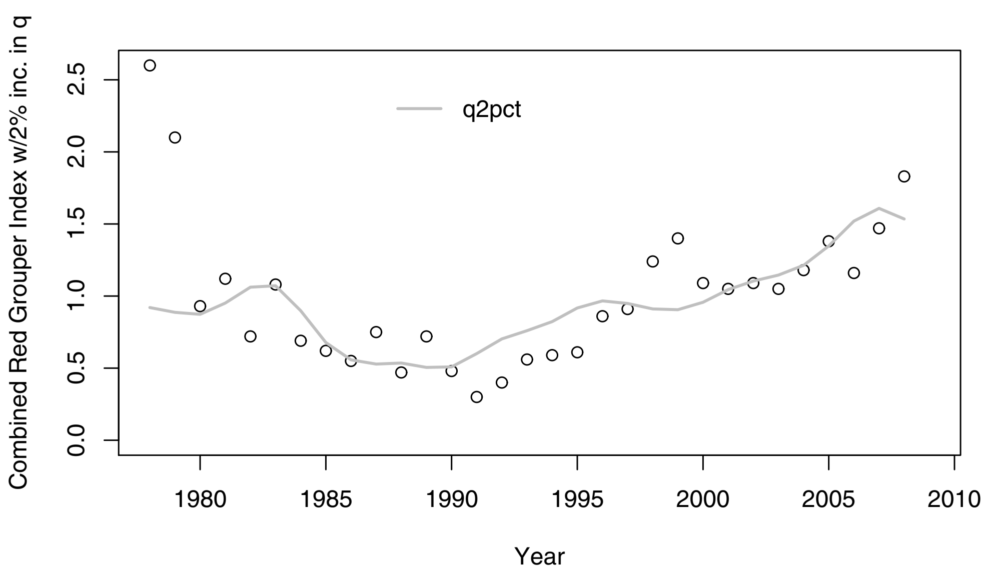


Figure 5. Red Grouper in Atlantic: Production model estimates of biomass/MSST and F/Fmsy for the base run with B_1/K estimated. The 80% confidence interval is represented by the dotted line.

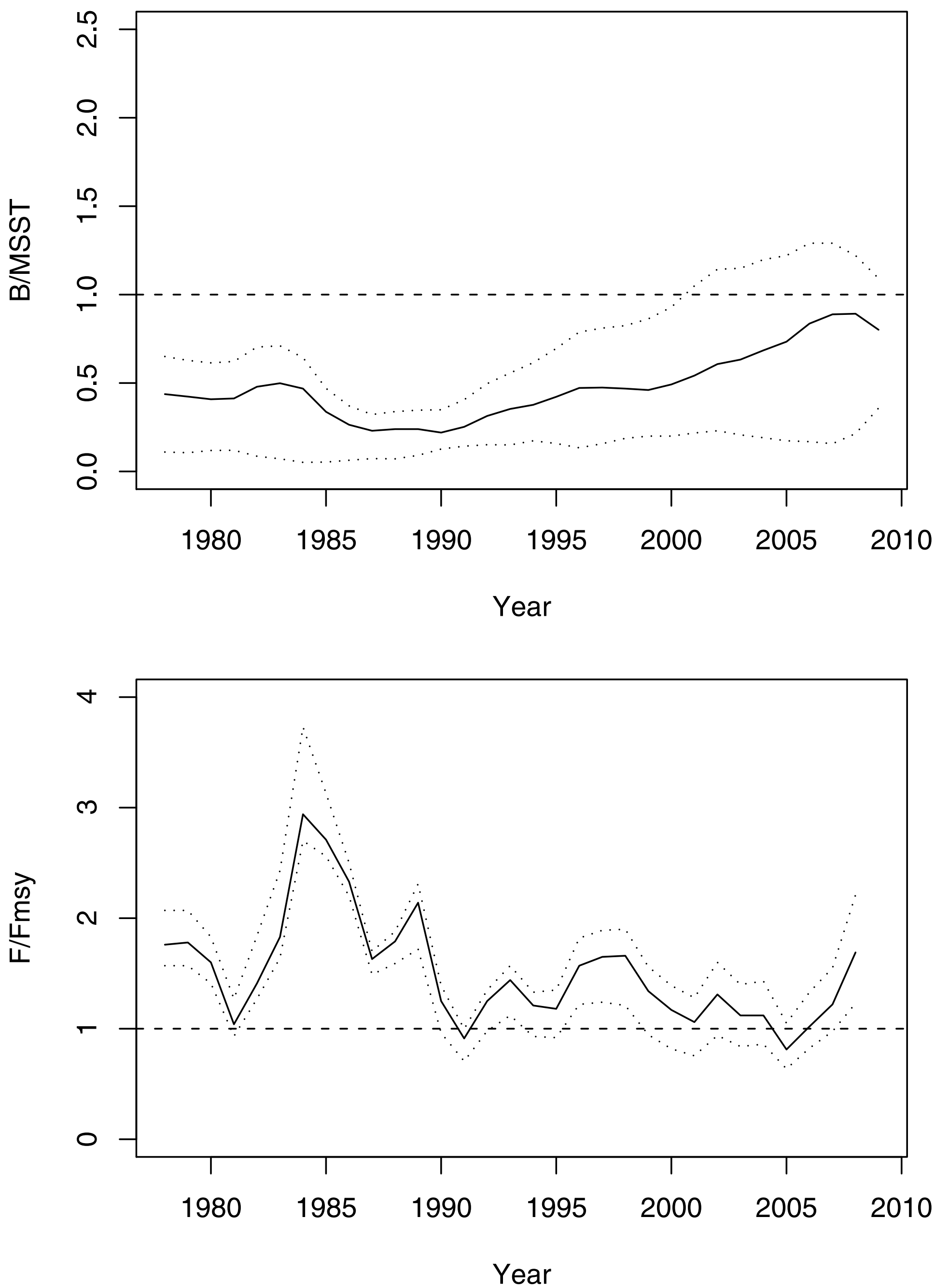
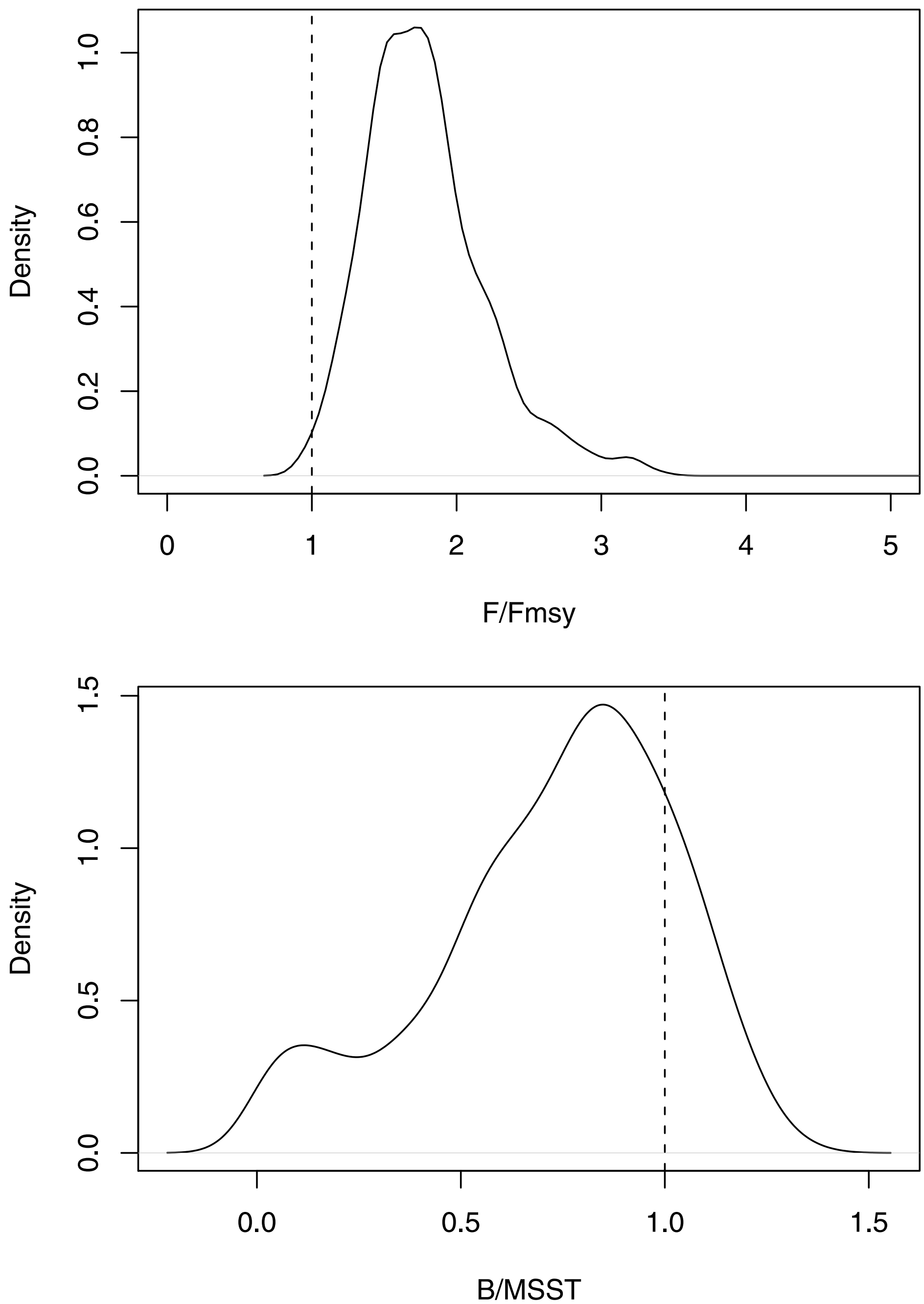


Figure 6. Red Grouper in Atlantic: Kernel density plots of 1000 bootstrap runs of the base model for B/MSST and F/F_{MSY} with B_1/K estimated.



References

Prager, M. H. 1994. A suite of extensions to a nonequilibrium surplus–production model. Fishery Bulletin 92: 374–389.

Prager, M. H. 1995. User's manual for ASPIC: A stock-production model incorporating covariates, program version 3.6x. NMFS Southeast Fisheries Science Center, Miami Laboratory Document MIA–2/93–55, 4th ed.

Schaefer, M. B. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Bulletin of the Inter-American Tropical Tuna Commission 1(2): 27–56.

Schaefer, M. B. 1957. A study of the dynamics of the fishery for yellowfin tuna in the eastern tropical Pacific Ocean. Bulletin of the Inter-American Tropical Tuna Commission 2: 247–268.

Appendix A ASPIC (Production Model) Input – Output

A.1 Aspic Input – base run

```
BOT                        Run Mode
'SAFMC Red Grouper (2009) Landings and Indices'
LOGISTIC YLD SSE           Modeltype, conditioning, loss fn
112                        Verbosity
600                        N Bootstraps
0  100000                  Monte Carlo
1d-8                       Conv (fit)
3d-8  8                    Conv (restart), N restarts
1d-4  6                    Conv (F), steps/yr for generalized
8d0                        Max F allowed
1                          Weight for B1>K
1                          Number of series
1d0                        Series weights
0.5d0                      B1/K guess
9.0e5                      MSY guess
9.0e6                      K guess
5d-8                       q guess
1 1 1 1                    Estimate flags
2e4  2e8                   MSY bounds
1e5  1e9                  K bounds
82184571                   Random seed
31                         Number of years
"Combined Index (1978-2006), Total Ldgs whole pounds"
"CC"

1978 2.08   955335
1979 1.71   929805
1980 0.78   829313
1981 0.95   584541
1982 0.62   871342
1983 0.95   1114579
1984 0.61   1479356
1985 0.56   1019164
1986 0.5    724227
1987 0.7    482606
1988 0.43   541470
1989 0.69   619986
1990 0.46   371613
1991 0.3    324400
1992 0.39   524100
1993 0.55   660620
1994 0.6    606320
1995 0.63   666670
1996 0.9    935242
1997 0.97   977674
1998 1.32   972103
1999 1.51   802000
2000 1.2    764920
2001 1.17   769534
2002 1.23   1020978
2003 1.19   928720
2004 1.35   1004767
2005 1.58   802822
2006 1.32   1108620
2007    1.67   1370379
```

```
2008    2.07   1801590


Note: Source of data is file "RG_INPUT_ASPIC.xls" dated 15 SEP 2009, prepared by RTC
```

A.2 Aspic Output – base run

```
SAFMC Red Grouper (2009) Landings and Indices                                                         Page 1
                                                                          Wednesday, 16 Sep 2009 at 22:09:37
ASPIC -- A Surplus-Production Model Including Covariates (Ver. 5.31)
                                                                                            BOT program mode
Author:     Michael H. Prager; NOAA Center for Coastal Fisheries and Habitat Research    LOGISTIC model mode
            101 Pivers Island Road; Beaufort, North Carolina  28516  USA                   YLD conditioning
            Mike.Prager@noaa.gov                                                           SSE optimization

Reference:  Prager, M. H. 1994. A suite of extensions to a nonequilibrium           ASPIC User's Manual is available
            surplus-production model.  Fishery Bulletin 92: 374-389.                      gratis from the author.

CONTROL PARAMETERS (FROM INPUT FILE)                          Input file: e:\rg\assessment\aspic\rg2009_007_bot.inp
------------------------------------------------------------------------------------------------------------------------
Operation of ASPIC:  Fit logistic (Schaefer) model by direct optimization with bootstrap.
Number of years analyzed:                        31            Number of bootstrap trials:                        600
Number of data series:                            1            Bounds on MSY (min, max):       2.000E+04     2.000E+08
Objective function:                   Least squares            Bounds on K (min, max):         1.000E+05     1.000E+09
Relative conv. criterion (simplex):       1.000E-08            Monte Carlo search mode, trials:        0        100000
Relative conv. criterion (restart):       3.000E-08            Random number seed:                              82184571
Relative conv. criterion (effort):        1.000E-04            Identical convergences required in fitting:            8
Maximum F allowed in fitting:                 8.000


PROGRAM STATUS INFORMATION (NON-BOOTSTRAPPED ANALYSIS)                                               error code   0
------------------------------------------------------------------------------------------------------------------------
Normal convergence


GOODNESS-OF-FIT AND WEIGHTING (NON-BOOTSTRAPPED ANALYSIS)
------------------------------------------------------------------------------------------------------------------------
                                                    Weighted            Weighted      Current    Inv. var.    R-squared
Loss component number and title                          SSE      N          MSE       weight       weight      in CPUE

Loss(-1)  SSE in yield                             0.000E+00
Loss(0)   Penalty for B1 > K                       0.000E+00      1          N/A    1.000E+00          N/A
Loss(1)   Combined Index (1978-2006), Total Ldgs   3.394E+00     31    1.170E-01    1.000E+00    1.000E+00        0.499
.............................................................................................
TOTAL OBJECTIVE FUNCTION, MSE, RMSE:          3.39357160E+00           1.257E-01    3.545E-01
Estimated contrast index (ideal = 1.0):               0.2888           C* = (Bmax-Bmin)/K
Estimated nearness index (ideal = 1.0):               0.8833           N* = 1 - |min(B-Bmsy)|/K


MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)
------------------------------------------------------------------------------------------------------------------------
Parameter                                           Estimate    User/pgm guess    2nd guess    Estimated   User guess

B1/K      Starting relative biomass (in 1978)      1.880E-01         5.000E-01    9.000E-01            1            1
MSY       Maximum sustainable yield                1.465E+06         9.000E+05    7.284E+05            1            1
K         Maximum population size                  1.148E+07         9.000E+06    4.370E+06            1            1
phi       Shape of production curve (Bmsy/K)       0.5000            0.5000            ----            0            1

--------- Catchability Coefficients by Data Series ---------------
q(1)      Combined Index (1978-2006), Total Ldgs   4.063E-07         5.000E-08    4.750E-06            1            1


MANAGEMENT and DERIVED PARAMETER ESTIMATES (NON-BOOTSTRAPPED)
------------------------------------------------------------------------------------------------------------------------
Parameter                                           Estimate              Logistic formula          General formula
```

MSY	Maximum sustainable yield	1.465E+06	----	----
Bmsy	Stock biomass giving MSY	5.739E+06	K/2	K*n**(1/(1-n))
Fmsy	Fishing mortality rate at MSY	2.553E-01	MSY/Bmsy	MSY/Bmsy
n	Exponent in production function	2.0000	----	----
g	Fletcher's gamma	4.000E+00	----	[n**(n/(n-1))]/[n-1]
B./Bmsy	Ratio: B(2009)/Bmsy	6.886E-01	----	----
F./Fmsy	Ratio: F(2008)/Fmsy	1.694E+00	----	----
Fmsy/F.	Ratio: Fmsy/F(2008)	5.902E-01	----	----
Y.(Fmsy)	Approx. yield available at Fmsy in 2009	1.009E+06	MSY*B./Bmsy	MSY*B./Bmsy
	...as proportion of MSY	6.886E-01	----	----
Ye.	Equilibrium yield available in 2009	1.323E+06	4*MSY*(B/K-(B/K)**2)	g*MSY*(B/K-(B/K)**n)
	...as proportion of MSY	9.030E-01	----	----

--------- Fishing effort rate at MSY in units of each CE or CC series ---------

fmsy(1)	Combined Index (1978-2006), Total Ldgs	6.284E+05	Fmsy/q(1)	Fmsy/q(1)

ESTIMATED POPULATION TRAJECTORY (NON-BOOTSTRAPPED)

Obs	Year or ID	Estimated total F mort	Estimated starting biomass	Estimated average biomass	Observed total yield	Model total yield	Estimated surplus production	Ratio of F mort to Fmsy	Ratio of biomass to Bmsy
1	1978	0.450	2.158E+06	2.122E+06	9.553E+05	9.553E+05	8.830E+05	1.764E+00	3.761E-01
2	1979	0.453	2.086E+06	2.050E+06	9.298E+05	9.298E+05	8.599E+05	1.776E+00	3.635E-01
3	1980	0.409	2.016E+06	2.028E+06	8.293E+05	8.293E+05	8.525E+05	1.602E+00	3.513E-01
4	1981	0.266	2.039E+06	2.199E+06	5.845E+05	5.845E+05	9.074E+05	1.041E+00	3.553E-01
5	1982	0.361	2.362E+06	2.414E+06	8.713E+05	8.713E+05	9.732E+05	1.414E+00	4.116E-01
6	1983	0.467	2.464E+06	2.387E+06	1.115E+06	1.115E+06	9.653E+05	1.829E+00	4.293E-01
7	1984	0.752	2.315E+06	1.968E+06	1.479E+06	1.479E+06	8.310E+05	2.944E+00	4.033E-01
8	1985	0.691	1.666E+06	1.475E+06	1.019E+06	1.019E+06	6.560E+05	2.706E+00	2.904E-01
9	1986	0.596	1.303E+06	1.216E+06	7.242E+05	7.242E+05	5.549E+05	2.333E+00	2.271E-01
10	1987	0.417	1.134E+06	1.158E+06	4.826E+05	4.826E+05	5.318E+05	1.632E+00	1.976E-01
11	1988	0.458	1.183E+06	1.183E+06	5.415E+05	5.415E+05	5.418E+05	1.793E+00	2.061E-01
12	1989	0.547	1.183E+06	1.133E+06	6.200E+05	6.200E+05	5.213E+05	2.144E+00	2.062E-01
13	1990	0.319	1.085E+06	1.165E+06	3.716E+05	3.716E+05	5.343E+05	1.250E+00	1.890E-01
14	1991	0.233	1.247E+06	1.394E+06	3.244E+05	3.244E+05	6.249E+05	9.117E-01	2.173E-01
15	1992	0.319	1.548E+06	1.645E+06	5.241E+05	5.241E+05	7.193E+05	1.248E+00	2.697E-01
16	1993	0.367	1.743E+06	1.800E+06	6.606E+05	6.606E+05	7.750E+05	1.437E+00	3.037E-01
17	1994	0.308	1.857E+06	1.970E+06	6.063E+05	6.063E+05	8.331E+05	1.205E+00	3.236E-01
18	1995	0.302	2.084E+06	2.205E+06	6.667E+05	6.667E+05	9.095E+05	1.184E+00	3.632E-01
19	1996	0.401	2.327E+06	2.334E+06	9.352E+05	9.352E+05	9.494E+05	1.569E+00	4.055E-01
20	1997	0.420	2.341E+06	2.326E+06	9.777E+05	9.777E+05	9.468E+05	1.647E+00	4.079E-01
21	1998	0.424	2.310E+06	2.292E+06	9.721E+05	9.721E+05	9.367E+05	1.661E+00	4.026E-01
22	1999	0.341	2.275E+06	2.352E+06	8.020E+05	8.020E+05	9.547E+05	1.336E+00	3.964E-01
23	2000	0.300	2.428E+06	2.552E+06	7.649E+05	7.649E+05	1.013E+06	1.174E+00	4.230E-01
24	2001	0.271	2.676E+06	2.836E+06	7.695E+05	7.695E+05	1.090E+06	1.063E+00	4.662E-01
25	2002	0.334	2.996E+06	3.060E+06	1.021E+06	1.021E+06	1.146E+06	1.307E+00	5.221E-01
26	2003	0.286	3.121E+06	3.253E+06	9.287E+05	9.287E+05	1.190E+06	1.118E+00	5.438E-01
27	2004	0.287	3.382E+06	3.503E+06	1.005E+06	1.005E+06	1.242E+06	1.124E+00	5.893E-01
28	2005	0.207	3.620E+06	3.875E+06	8.028E+05	8.028E+05	1.310E+06	8.116E-01	6.307E-01
29	2006	0.260	4.127E+06	4.259E+06	1.109E+06	1.109E+06	1.367E+06	1.020E+00	7.190E-01
30	2007	0.312	4.385E+06	4.393E+06	1.370E+06	1.370E+06	1.384E+06	1.222E+00	7.641E-01
31	2008	0.433	4.399E+06	4.165E+06	1.802E+06	1.802E+06	1.354E+06	1.694E+00	7.666E-01
32	2009		3.952E+06						6.886E-01

RESULTS FOR DATA SERIES # 1 (NON-BOOTSTRAPPED) Combined Index (1978-2006), Total Ldgs w

Data type CC: CPUE-catch series Series weight: 1.000

Obs	Year	Observed CPUE	Estimated CPUE	Estim F	Observed yield	Model yield	Resid in log scale	Statist weight
1	1978	2.080E+00	8.619E-01	0.4503	9.553E+05	9.553E+05	-0.88097	1.000E+00
2	1979	1.710E+00	8.330E-01	0.4535	9.298E+05	9.298E+05	-0.71918	1.000E+00
3	1980	7.800E-01	8.239E-01	0.4090	8.293E+05	8.293E+05	0.05471	1.000E+00
4	1981	9.500E-01	8.936E-01	0.2658	5.845E+05	5.845E+05	-0.06124	1.000E+00
5	1982	6.200E-01	9.806E-01	0.3610	8.713E+05	8.713E+05	0.45843	1.000E+00
6	1983	9.500E-01	9.699E-01	0.4669	1.115E+06	1.115E+06	0.02070	1.000E+00
7	1984	6.100E-01	7.996E-01	0.7517	1.479E+06	1.479E+06	0.27062	1.000E+00
8	1985	5.600E-01	5.994E-01	0.6908	1.019E+06	1.019E+06	0.06796	1.000E+00
9	1986	5.000E-01	4.939E-01	0.5957	7.242E+05	7.242E+05	-0.01220	1.000E+00
10	1987	7.000E-01	4.707E-01	0.4166	4.826E+05	4.826E+05	-0.39695	1.000E+00
11	1988	4.300E-01	4.807E-01	0.4576	5.415E+05	5.415E+05	0.11144	1.000E+00
12	1989	6.900E-01	4.603E-01	0.5472	6.200E+05	6.200E+05	-0.40486	1.000E+00
13	1990	4.600E-01	4.732E-01	0.3190	3.716E+05	3.716E+05	0.02837	1.000E+00
14	1991	3.000E-01	5.663E-01	0.2328	3.244E+05	3.244E+05	0.63526	1.000E+00
15	1992	3.900E-01	6.682E-01	0.3187	5.241E+05	5.241E+05	0.53844	1.000E+00
16	1993	5.500E-01	7.314E-01	0.3669	6.606E+05	6.606E+05	0.28511	1.000E+00
17	1994	6.000E-01	8.005E-01	0.3077	6.063E+05	6.063E+05	0.28829	1.000E+00
18	1995	6.300E-01	8.960E-01	0.3023	6.667E+05	6.667E+05	0.35221	1.000E+00
19	1996	9.000E-01	9.483E-01	0.4007	9.352E+05	9.352E+05	0.05231	1.000E+00
20	1997	9.700E-01	9.448E-01	0.4204	9.777E+05	9.777E+05	-0.02633	1.000E+00
21	1998	1.320E+00	9.313E-01	0.4241	9.721E+05	9.721E+05	-0.34878	1.000E+00
22	1999	1.510E+00	9.555E-01	0.3410	8.020E+05	8.020E+05	-0.45766	1.000E+00
23	2000	1.200E+00	1.037E+00	0.2997	7.649E+05	7.649E+05	-0.14615	1.000E+00
24	2001	1.170E+00	1.152E+00	0.2713	7.695E+05	7.695E+05	-0.01521	1.000E+00
25	2002	1.230E+00	1.243E+00	0.3337	1.021E+06	1.021E+06	0.01052	1.000E+00
26	2003	1.190E+00	1.322E+00	0.2855	9.287E+05	9.287E+05	0.10486	1.000E+00
27	2004	1.350E+00	1.423E+00	0.2869	1.005E+06	1.005E+06	0.05270	1.000E+00
28	2005	1.580E+00	1.574E+00	0.2072	8.028E+05	8.028E+05	-0.00362	1.000E+00
29	2006	1.320E+00	1.730E+00	0.2603	1.109E+06	1.109E+06	0.27061	1.000E+00
30	2007	1.670E+00	1.785E+00	0.3120	1.370E+06	1.370E+06	0.06637	1.000E+00
31	2008	2.070E+00	1.692E+00	0.4326	1.802E+06	1.802E+06	-0.20158	1.000E+00

ESTIMATES FROM BOOTSTRAPPED ANALYSIS

Param name	Point estimate	Estimated bias in pt estimate	Estimated relative bias	Bias-corrected approximate confidence limits 80% lower	80% upper	50% lower	50% upper	Inter-quartile range	Relative IQ range
B1/K	1.880E-01	-3.314E-03	-1.76%	4.722E-02	2.795E-01	1.414E-01	2.316E-01	9.023E-02	0.480
K	1.148E+07	2.304E+07	200.76%	7.646E+06	1.578E+08	9.467E+06	2.817E+07	1.871E+07	1.630
q(1)	4.063E-07	1.544E-08	3.80%	2.492E-07	5.659E-07	3.144E-07	4.988E-07	1.845E-07	0.454
MSY	1.465E+06	1.449E+06	98.88%	1.102E+06	4.479E+06	1.242E+06	1.795E+06	5.530E+05	0.377
Ye(2009)	1.323E+06	2.290E+04	1.73%	1.047E+06	2.121E+06	1.178E+06	1.636E+06	4.585E+05	0.347
Y.@Fmsy	1.009E+06	-8.706E+03	-0.86%	7.273E+05	1.418E+06	8.697E+05	1.208E+06	3.379E+05	0.335
Bmsy	5.739E+06	1.152E+07	200.76%	3.823E+06	7.889E+07	4.733E+06	1.409E+07	9.354E+06	1.630
Fmsy	2.553E-01	1.510E-02	5.91%	1.344E-01	3.358E-01	1.748E-01	2.934E-01	1.186E-01	0.465
fmsy(1)	6.284E+05	1.458E+04	2.32%	5.361E+05	7.442E+05	5.711E+05	6.820E+05	1.109E+05	0.177

B./Bmsy	6.886E-01	-6.022E-02	-8.74%	3.082E-01	9.394E-01	5.172E-01	8.345E-01	3.173E-01	0.461
F./Fmsy	1.694E+00	1.280E-01	7.55%	1.232E+00	2.211E+00	1.435E+00	1.887E+00	4.519E-01	0.267
Ye./MSY	9.030E-01	-1.051E-01	-11.63%	5.214E-01	9.956E-01	7.669E-01	9.726E-01	2.057E-01	0.228

INFORMATION FOR REPAST (Prager, Porch, Shertzer, & Caddy. 2003. NAJFM 23: 349-361)

Unitless limit reference point in F (Fmsy/F.): 0.5902
CV of above (from bootstrap distribution): 0.2249

NOTES ON BOOTSTRAPPED ESTIMATES:

- Bootstrap results were computed from 600 trials.
- Results are conditional on bounds set on MSY and K in the input file.
- All bootstrapped intervals are approximate. The statistical literature recommends using at least 1000 trials for accurate 95% intervals. The default 80% intervals used by ASPIC should require fewer trials for equivalent accuracy. Using at least 500 trials is recommended.
- Bias estimates are typically of high variance and therefore may be misleading.

Trials replaced for lack of convergence: 0
Trials replaced for q out-of-bounds: 0
Trials replaced for K out-of-bounds: 7
Trials replaced for MSY out of bounds: 0
Residual-adjustment factor: 1.0715

Elapsed time: 0 hours, 19 minutes, 48 seconds.