Assessment Working Paper 4

DEVELOPMENT AND APPLICATION OF SIMPLE PRODUCTION MODELS TO THE CHESAPEAKE BAY BLUE CRAB FISHERY

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Introduction

Surplus production models are simple, computationally-efficient methods to fit an observed time series of indices of population biomass to a population dynamics model to estimate key population dynamic parameters (Schnute and Richards 2002). Production is simply the change in biomass (*B*) from one year to the next. Surplus production (*SP*) arises through compensatory population processes that occur as a result of mortality, in fisheries applications due to harvest. Thus, surplus production specifically incorporates biomass lost to fishing through yearly catch (*C*) estimates as:

$$ASP(t)=B(t+1)-B(t)+C(t) \qquad \text{Eq. 1.}$$

When direct estimates of *B*(*t*) are lacking, an index of biomass, *b*(*t*) is used, which is related to *B*(*t*) by a catchability coefficient *q*. Hence an estimate of A*SP*(t) is given by

$$\frac{b(t+1)-b(t)}{q} = (b(t+1)-b(t))q^{-1} \qquad \text{Eq. 2}$$

A simple population dynamics model can then be used to relate annual surplus production to stock biomass. If the underlying population dynamics are presumed to follow from a simple function, often a logistic model or a variant thereof, then annual surplus production may be related to stock biomass by:

A $ASP(t) = rB(t)\left(1-\frac{B(t)}{K}\right)$ Eq. 3

where *r* is the intrinsic rate of population increase and *K* the population carrying capacity. Estimation can now proceed, given assumptions regarding observation and process error. For example, we may write:

$$\left(b(t+1)-b(t)\right)q^{-1} + C(t) = rb(t)q^{-1}\left(1-\frac{b(t)}{qK}\right)+\varepsilon(t) \qquad \text{Eq. 4}$$

where $\varepsilon(t)$ is normally distributed with mean 0 and standard deviation σ. Estimation involves finding the parameter values for *q*, *r*, *K* and σ that maximize the appropriate likelihood function. Standard errors of the parameter estimates are calculated numerically by inverting the Hessian matrix.

Although this simple approach to modeling the dynamics of fish stocks has fallen out of favor as the principal approach to developing reference points, the use of simple production models is still widespread as an independent approach to verify the results of more complex models. For example Meuter and Megrey (2006) used simple production models to estimate yields in several principal fisheries in Alaska and to assess the role of abiotic and biotic covariates on yield. More recently, Link et al . (2010) have used these models to compare production dynamics among different species across 11 major northern hemisphere temperate marine ecosystems.

For this assessment we explored the application of a simple non-equilibrium production model to the Chesapeake Bay blue crab stock. The model follows the approach of Mueter and Megrey (2006) and assumes that a time series of absolute biomass or abundance is available.

Methods

We fit two different production models: Model 1 was fit to age-1+ abundance only, Model 2 was fit to total abundance. To fit both models we used the winter dredge survey estimated abundance in number (Miller et al. 2011). The winter dredge survey is believed to provide a reliable estimate of absolute abundance for age-1+ crabs. However, Miller et al. 2011 report a constant of proportionality of q_0=0.4 between winter dredge survey estimates of the abundance of age-0 crabs and total abundance. We used this estimate of q_0 and estimates of age-1+ crabs to estimate a time series of total abundance for model 2 as:

$$N_t = \frac{N_{0,t}}{q_0} + N_{1,t} \qquad \text{Eq. 5}$$

We assembled a parallel time series of reported catches of blue crab in the Chesapeake Bay. We followed Miller et al. 2011 in correcting reported landings from Maryland for a reporting change in 1981 and correcting reported landings from Virginia for a reporting change in 1993. These catch time series were converted to estimates of catch by number using estimates of average size in fishery-independent surveys and an sex-specific allometric relationships (Miller et al. 2011). In addition, we assumed that the recreational catch was a constant additional 8% of the commercial catch.

We calculated time series of annual surplus production (ASP – Eq 1). These estimates of ASP were then fit to time series of abundance of either age-1+ crabs (Model 1) or total abundance (Model 2) and catch in numbers using the gls method in the NLME library in R (R Core Development Team 2007).

RESULTS AND DISCUSSION

The results for Model 1 are shown in Figs 1 and 2. The production modeling results are presented in Table 1. MSY estimates for Model 1 are at the extreme values of observed abundances, indicating that reference points are extrapolations of the data rather than interpolations. However, this simple production model predicts an MSY yield of 356 million crabs (~118 million lbs) at an abundance of 511 million age-1+ crabs. The overfished reference point for this model is 255 million age-1+ crabs.

The results from Model 2 are shown in Figs 1 and 2. The production modeling results are presented in Table 1. In contrast to Model 1, MSY estimates for Model 2 are at the extreme values of observed abundances, indicating that reference points are extrapolations of the data rather than interpolations. Model 2 production model predicts an MSY yield of 803 million crabs (~89 million lbs) at an abundance of 1,331 million crabs. The overfished reference point for this model is 665 million crabs.

Both Model 1 and Model 2 provide credible yield-based reference points. The yields predicted by both models are comparable to observed values and comparable with results of a sex-specific catch, multiple survey analysis (SSCMSA - Miller et al. 2011). Abundance-based reference points, however, are more variable. Model 1 predicts an overfished definition of 255 million age-1+ crabs. The SSCMSA analysis predicts an overfished definition of 70 million age-1+ female crabs. If we assume a ratio of sex-specific exploitation rates of unity, the SSCMSA reference point translates to an overfished abundance of 135 million age-1+ crabs. In contrast Model 2 predicts an overfished abundance of 410 million crabs of all ages. The equivalent value from the SSCMSA is 142.47 million age 0+ crabs. Thus in both cases, production model estimates, whether from Model 1 or Model 2 are greater than those predicted by the SSCMSA.

LITERATURE CITED

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Table 1. Results of production modeling based on the abundance of age-1+ crabs for 1990-2009. Shown are A) results of linear regression of trends in abundance, catch and annual surplus production, B) Production model fit and C) Estimated Reference Points

A) Linear Fits

Variable	Intercept	SE	Slope	SE	Adj R^2
Abundance	2.27E+10	5.52E+09	-1.13E+07	2.76E+06	0.451
Catch	2.46E+10	2.91E+09	-1.22E+07	1.45E+06	0.785
Annual Surplus Production	2.09E+10	7.54E+09	-1.04E+07	3.78E+06	0.266

B) Production Model

	AIC	Log Likelihood
Model Diagnostic	783.67	-389.33

Variable	Value	SE
AvgB	1.393	0.1136
$AvgB^2$	-1.36E-09	0

C) Estimated Reference Points

Reference Point	Value	SE
MSY	356,023,340.00	8.34E+07
N_{MSY}	511,132,673.00	4.17E+07
$0.5*N_{MSY}$	255,566,336.50	2.09E+07

Table 2. Results of production modeling based on the total abundance of crabs for 1990-2009. Shown are A) results of linear regression of trends in abundance, catch and annual surplus production, B) Production model fit and C) Estimated Reference Points

A) Linear Fits

Variable	Intercept	SE	Slope	SE	Adj R^2
Abundance	4.65E+10	1.28E+10	-2.30E+07	6.42E+06	0.397
Catch	1.76E+10	2.74E+09	-8.70E+06	1.37E+06	0.673
Annual Surplus Production	5.61E+09	1.59E+06	-2.70E+06	7.93E+06	-0.049

B) Production Model

	AIC	Log Likelihood
Model Diagnostic	868.8	-430.4

Variable	Value	SE
AvgB	0.662	0.248
$AvgB^2$	-4.03E-10	0

C) Estimated Reference Points

Reference Point	Value	SE
MSY	271867526	6.15E+08
N_{MSY}	821087613.5	3.08E+08
$0.5*N_{MSY}$	410543806.8	1.54E+08

Figure 1 Time series of estimated abundance (upper panel), catch (middle panel) and annual surplus production (bottom) panel for the blue crab population in Chesapeake Bay. Analyses are based on the abundance of age-1+ crabs only. Annual surplus productions were calculated from Eq. 1. The red line on the plot is the linear least squares fit to the data.

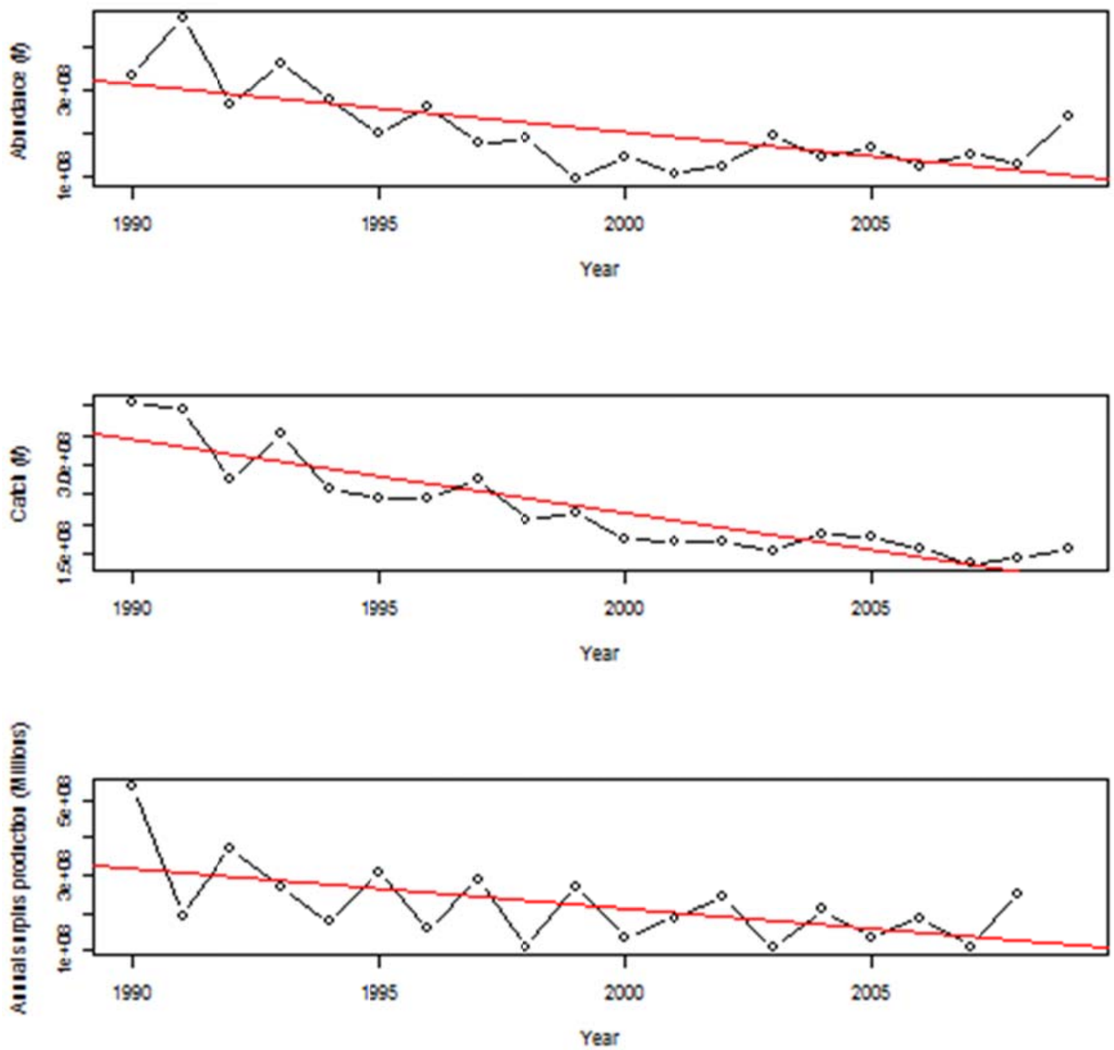

Figure 2. Surplus production model fit to blue crab annual surplus production as a function of the abundance of age-1+ crabs in the Chesapeake Bay. Symbols indicate the last two years of the estimate of annual surplus production. The red line is the fitted Graham Schaefer production model. The horizontal black line is the maximum surplus production estimate (356 million) .

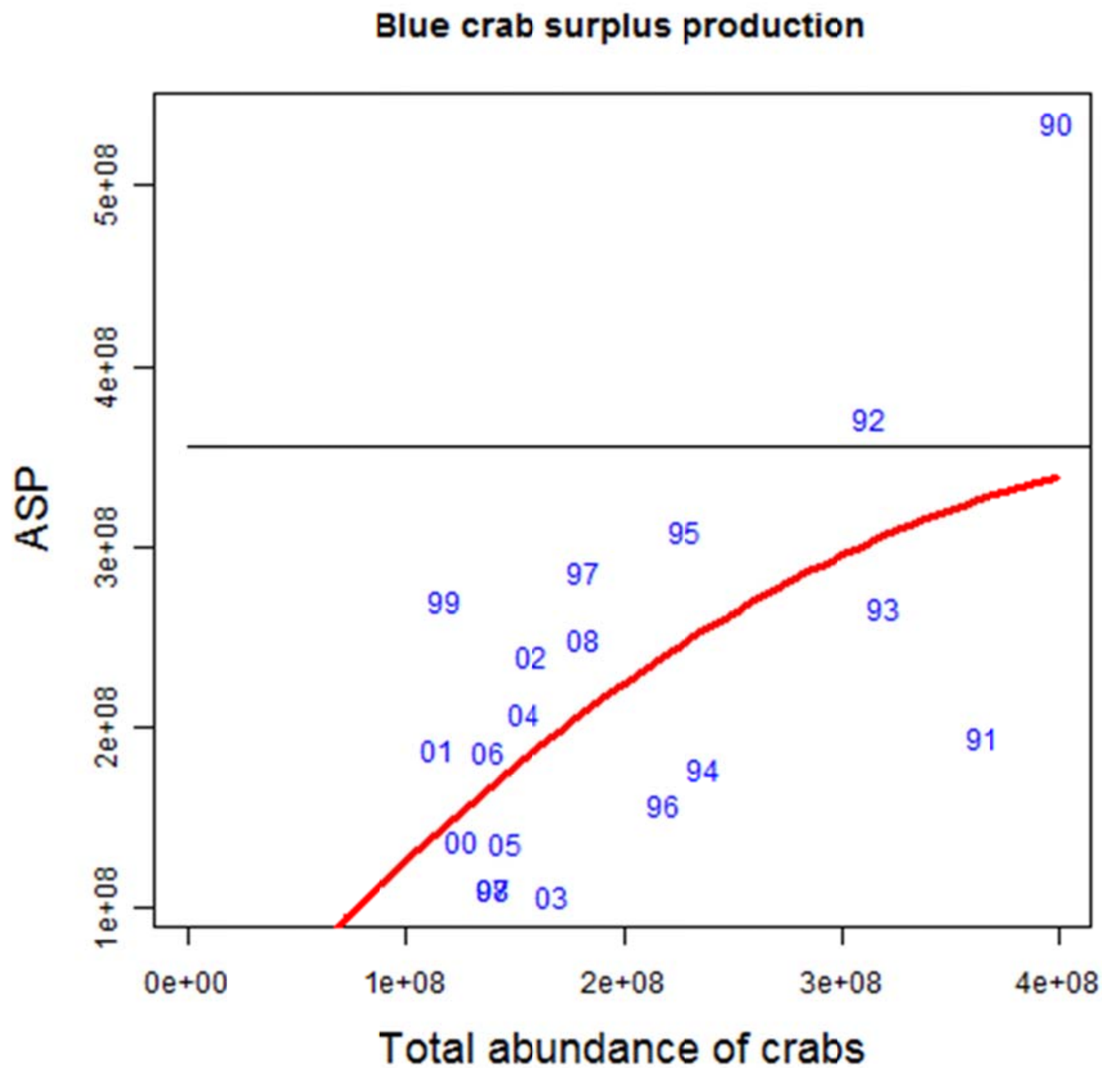

Figure 3. Time series of estimated abundance (upper panel), catch (middle panel) and annual surplus production (bottom) panel for the blue crab population in Chesapeake Bay. Analyses are based on the total abundance of crabs. Annual surplus productions were calculated from Eq. 1. The red line on the plot is the linear least squares fit to the data.

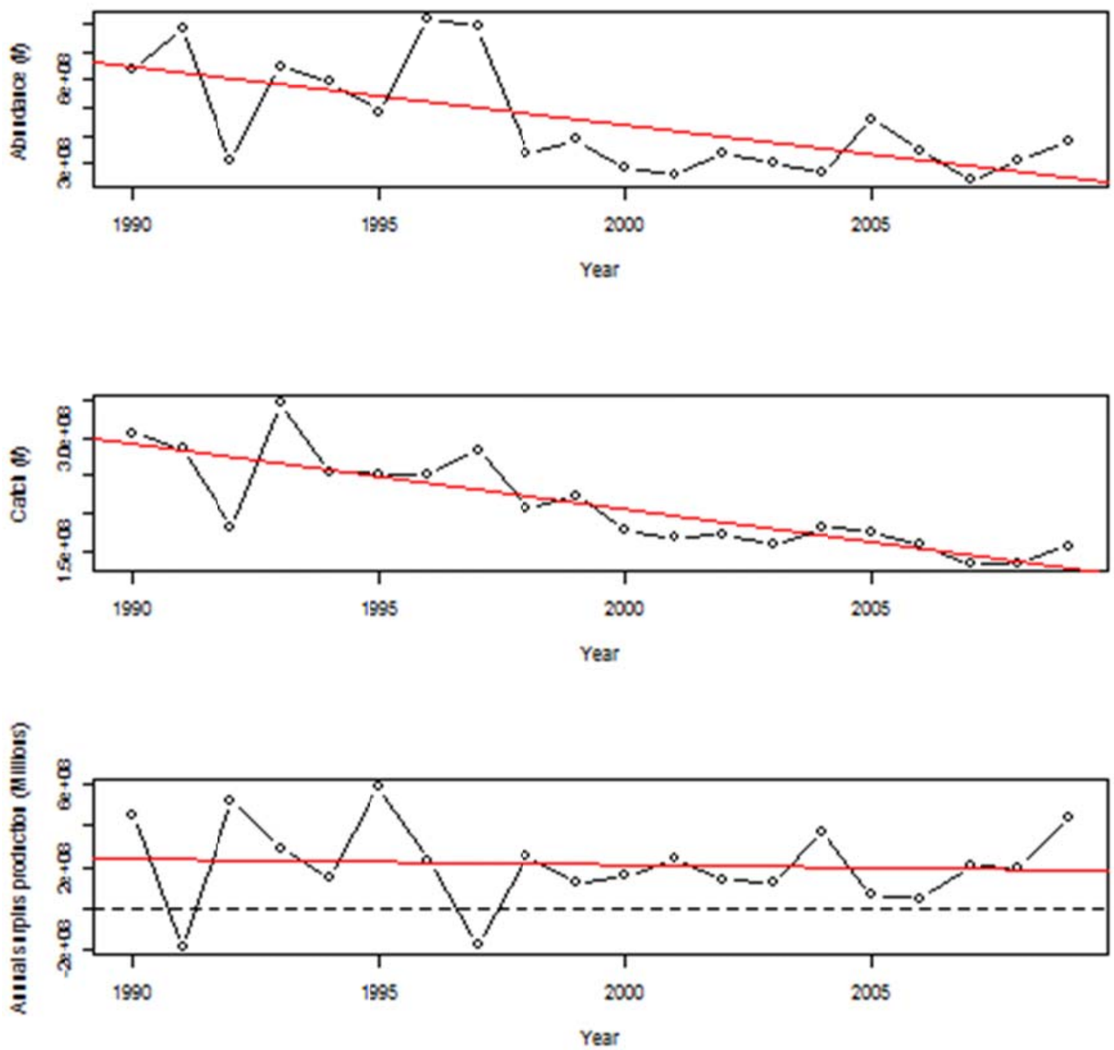

Figure 4.   Surplus production model fit to blue crab annual surplus production as a function of the total abundance of crabs in the Chesapeake Bay. Symbols indicate the last two years of the estimate of annual surplus production. The red line is the fitted Graham Schaefer production model. The horizontal black line is the maximum surplus production estimate (271.8 million) and the vertical black line is the abundance at MSY (821 million crabs)