BAYESIAN SURPLUS PRODUCTION MODEL APPLIED TO PORBAGLE CATCH, CPUE AND EFFORT DATA

Elizabeth A. Babcock[1], Enric Cortes[2]

SUMMARY

The Bayesian Surplus Production (BSP) model that was used in the ICCAT assessments of blue and shortfin mako shark in 2004 and 2008 was applied to northwest Atlantic porbeagle. An informative prior was developed for the rate of population increase (r) based on demographic data. Catch and catch per unit effort data were taken from the literature. We compared the results of the surplus production model to the age structured stock assessment results for the northwest Atlantic population. Catch and CPUE data were not available from the literature for the northeast and southern Atlantic populations. To use the BSP model for this population, it will be necessary to develop at least one CPUE index of abundance for each population, as well as a time series of catches. If catch data are not available for the entire history of the fishery, the BSP model can be fitted to a series of longline effort data rather than catch in the early years of the fishery.

RÉSUMÉ

Le modèle de production excédentaire bayésien (BSP), qui a été utilisé dans les évaluations de l'ICCAT du requin peau bleue et du requin taupe bleu en 2004 et en 2008, a été appliqué au requin-taupe commun de l'Atlantique Nord-Ouest. Un prior informatif a été développé pour le taux de croissance de la population (r) fondé sur des données démographiques. Les données de capture et de capture par unité d'effort proviennent de la documentation existante. Les résultats du modèle de production excédentaire ont été comparés aux résultats de l'évaluation de stock structurée par âge pour la population de l'Atlantique du Nord-Ouest. Les données de capture et de la CPUE n'étaient pas disponibles dans la documentation pour les populations de l'Atlantique du Nord-Est et du Sud. Pour utiliser le modèle BSP pour cette population, il conviendra de développer au moins un indice d'abondance basé sur la CPUE pour chaque population, ainsi qu'une série temporelle de captures. Si les données de capture ne sont pas disponibles pour l'ensemble de l'historique de la pêcherie, le modèle BSP peut être ajusté à une série de données d'effort palangrier au lieu d'être ajusté à la capture des premières années de la pêcherie.

RESUMEN

El modelo de producción excedente bayesiano (BSP) que se utilizó en las evaluaciones de ICCAT de tintorera y marrajo dientuso en 2004 y 2008 se aplicó al marrajo sardinero del Atlántico noroccidental. Se desarrolló una distribución previa informativa para la tasa de incremento de la población (r) basada en datos demográficos. Los datos de captura y de captura por unidad de esfuerzo se tomaron de la bibliografía existente. Se compararon los resultados del modelo de producción excedente con los resultados de la evaluación de stock estructurada por edad para la población del Atlántico noroccidental. Los datos de captura y de CPUE no estaban disponibles en la bibliografía para las poblaciones del Atlántico nororiental y meridional. Para utilizar el modelo BSP para esta población, sería necesario desarrollar al menos un índice de abundancia de CPUE para cada población, así como una serie temporal de capturas. Si no están disponibles los datos de captura para toda la historia de la pesquería, el modelo BSP puede ajustarse a una serie de datos de esfuerzo de palangre en lugar de a la captura en los primeros años de la pesquería.

KEYWORDS

Catch/effort, mathematical models, stochastic models
stock assessment, population dynamics

[1] Marine Biology and Fisheries Division, Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Cswy., Miami, FL 33149. USA. ebabcock@rsmas.miami.edu
[2] National Marine Fisheries Service, Southeast Fisheries Science Center, Panama City Laboratory, 3500 Delwood Beach Road, Panama City, Florida 32408 USA.

1. Introduction

Porbeagle sharks are thought to form several distinct stocks in the Atlantic, one in the Northwest, one in the Northeast and at least one in the southern hemisphere. Of these, only the Northwest Atlantic stock has been the subject of a stock assessment (Gibson and Campana 2005). For the other stocks, a limited amount of catch and abundance data are available, but no assessments have been conducted (Anonymous 2008).

The Bayesian Surplus Production (BSP) model has been used by the ICCAT shark working group for assessments of blue and shortfin mako sharks, along with age structured production models, because these models are not as data intensive as fully age structured models. The BSP model, which requires only catch and catch per unit of effort (CPUE) data, can also incorporate demographic information into an informative prior distribution for the intrinsic rate of population increase (*r*) (McAllister *et al*. 2001, 2003, Babcock and Cortes 2004, 2009). This approach is appropriate for porbeagle sharks because their life history is relatively well studied (e.g. Gibson and Campana 2005, Francis *et al.* 2008). The BSP model can be fitted to effort data instead of catch data for part of the history of the fishery if catch data are lacking in some years (Babcock and Cortes 2009).

We applied the BSP software to the catch and CPUE data available for the Northwest Atlantic porbeagle, from the 2005 assessment (Gibson and Campana 2005). We compare the BSP results to the results of the age structured population dynamics model used by Gibson and Campana (2005).

2. Methods

For porbeagle sharks, we used the discrete time version of the Schaefer surplus production model:

$$B_{t+1} = rB_t - \frac{r}{K}B_t^2 - C_t \quad (1)$$

where B_t= biomass at the beginning of year *t*, *r* is the intrinsic rate of population increase, *K* is carrying capacity and C_t is the catch in year *t*. The log-likelihood was:

$$\ln L = -\sum_j \sum_y \frac{\left[\ln(I_{j,y}) - \ln(\hat{q}_j \hat{B}_y)\right]^2}{2\sigma_{j,y}^{\ 2}} \quad (2)$$

were $I_{j,y}$ is the CPUE in year *y* for series *j*, $\hat{q}_j$ is the constant of proportionality for series *j*, $\hat{B}_y$ is the estimated biomass in year *y*, and $\sigma_{j,y}^{\ 2}$ is the variance (=1/weight) applied to series *j* in year *y*. We gave equal weights to each point in each data series.

The model can also calculate estimated catches if effort data E_y is supplied, as follows:

$$C_y = q_C E_y \hat{B}_y \quad (3)$$

The constant of proportionality for the catch data q_C can be estimated by adding the following term to the likelihood:

$$\ln L = -\sum_j \sum_y \frac{\left[\ln(I_{j,y}) - \ln(\hat{q}_j \hat{B}_y)\right]^2}{2\sigma_{j,y}^{\ 2}} - \sum_y \frac{\left[\ln(C_y) - \ln(q_C E_y \hat{B}_y)\right]^2}{2\sigma_C^{\ 2}} \quad (4)$$

where $\sigma_C^{\ 2}$ is the variance of the catch residuals.

For Northwest Atlantic porbeagle sharks, catch data were available from 1961 through 2004, and CPUE data were available from three spatial areas from 1961 through 2004 (Gibson and Campana 2005, **Figure 1**). We used the CPUE series for mature sharks in all three regions (Basin, NF Gulf and Shelf Edge) digitized from Gibson and Campana (2005, Figure 8) as indices of abundance (**Figure 1**). The prior for *r* was informative and was

lognormally distributed with a mean of 0.048 and a log standard deviation of 0.1 (Cortez *et al.* 2008). The starting biomass relative to *K* (*alphaBo*) was given an informative prior centered on 1.0 with a CV of 0.2. The prior for *K* was uniform on log *K*. The posterior distribution of was found by Sampling Importance Resampling (SIR), using the priors as an importance function. As a sensitivity analysis, we also used a somewhat less informative prior for *r* with mean of 0.048 and log standard deviation of 0.2.

3. Results and discussion

The northwest Atlantic porbeagle population was heavily fished in the early 1960s, lightly fished in the 1970s and 1980s and then heavily fished in the 1990s (**Figure 1**, Gibson and Campana 2005). The BSP model, with either a high CV prior for *r* or a low CV prior for *r* was able to fit the CPUE series (**Figure 2a, Figure 3a**) with good convergence diagnostics. With either prior for *r*, the model estimated that the population was severely depleted, with a current (2004) biomass at 3% of the biomass in 1961 (**Table 1**). Because the CPUE data series only covered the later history of the fishery when the population abundance was declining, the data were not informative with respect to the value of *r*. Thus, the posterior distribution of *r* was very similar to the prior. In contrast, the posterior distribution of *K* was much more concentrated than the prior. The population had a less than 50% probability of rebuilding in 50 years, even without fishing (**Table 2**).

The BSP model's estimate of depletion was more pessimistic than the results of Gibson and Campana (2005), who found that current biomass was between 10% and 24% of 1961 biomass depending on the assessment model. The trend in biomass was similar between the BSP model and the age structured model in the 1960s through the 1980s, but the BSP model fit a much steeper decline in the 1990s than the age structured model. The differences between the surplus production model results and the age structured model results may be caused by the lack of selectivity information in the BSP model, and the fact that the BSP model was fitted to the CPUE data for mature sharks only. The surplus production model assumes that each CPUE series is proportional to total abundance. Thus, it would be more appropriate to fit the model to a CPUE series that combined regions and included both mature and immature sharks.

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Table 1. Results (expected value of the mean and CV in parentheses) for shortfin mako sharks. HR refers to harvest rate and repY is replacement yield. Current year (cur) is 2004.

Parameter	*Low CV in r prior*		*High CV in r prior*	
	Expected value	*CV*	*Expected Value*	*CV*
K	43105.25	0.12	43101.31	0.13
r	0.05	0.10	0.05	0.21
Binit	36814.24	0.03	36987.26	0.06
MSY	515.01	0.14	510.14	0.20
repY	53.3	0.32	52.92	0.35
Bmsy	21552.63	0.12	21550.66	0.13
Bcur	983.63	0.40	986.6	0.41
Bcur/K	0.02	0.41	0.02	0.41
Bcur/Bmsy	0.05	0.41	0.05	0.41
Bcur/Binit	0.03	0.39	0.03	0.40
Ccur/MSY	0.43	0.13	0.44	0.19
Ccur/repY	4.49	0.30	4.63	0.35
Fcur/Fmsy	10.73	0.38	11.07	0.43

Table 2. Decision table for the Northwest Atlantic porbeagle with a low CV prior for *r*. Policies are harvest rates as a percentage of total biomass.

Horizon	*Policy*	*E(Bfin/ K)*	*E(Bfin/ Bmsy)*	*P(Bfin< 0.2K)*	*P(Bfin> Bmsy)*	*P(Bfin> Bcur)*	*P(Ffin< Fcur)*	*P(Bfin< 0.01K)*
10 -year	HR= 0	0.04	0.07	1.00	0.00	1.00	1.00	0.00
	HR= 0.02	0.03	0.06	1.00	0.00	1.00	1.00	0.00
	HR= 0.04	0.02	0.05	1.00	0.00	0.94	1.00	0.00
	HR= 0.07	0.02	0.04	1.00	0.00	0.00	0.90	0.10
20 -year	HR= 0	0.06	0.11	1.00	0.00	1.00	1.00	0.00
	HR= 0.02	0.04	0.08	1.00	0.00	1.00	1.00	0.00
	HR= 0.04	0.03	0.05	1.00	0.00	0.94	1.00	0.00
	HR= 0.07	0.01	0.03	1.00	0.00	0.00	0.75	0.25
50 -year	HR= 0	0.20	0.39	0.55	0.00	1.00	1.00	0.00
	HR= 0.02	0.08	0.17	0.99	0.00	1.00	1.00	0.00
	HR= 0.04	0.03	0.07	1.00	0.00	0.94	1.00	0.00
	HR= 0.07	0.01	0.02	1.00	0.00	0.00	0.19	0.80

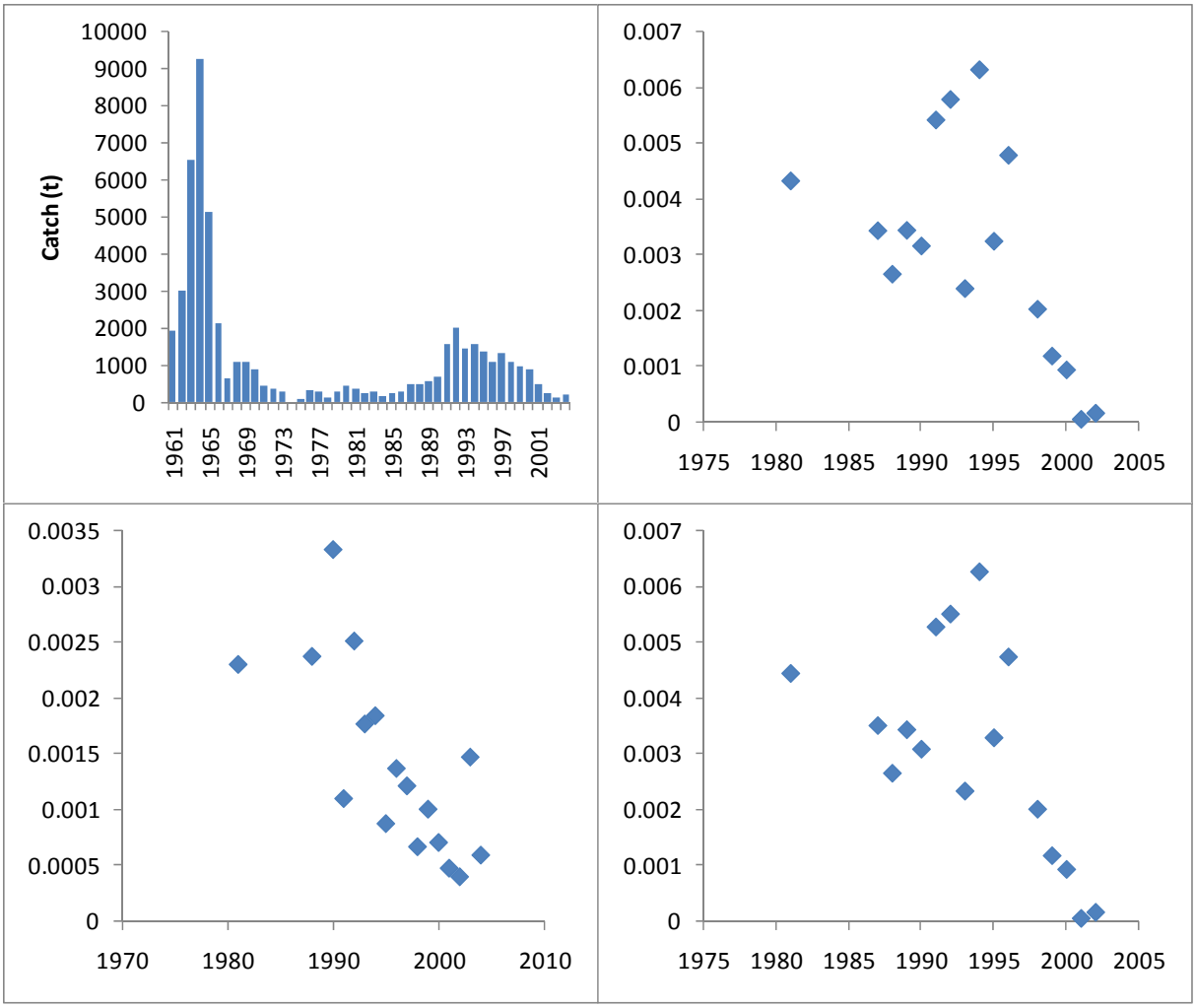


Figure 1. Northwest Atlantic porbeagle shark catches (a) and three CPUE series for mature sharks (b-d), from Gibson and Campana (2005).

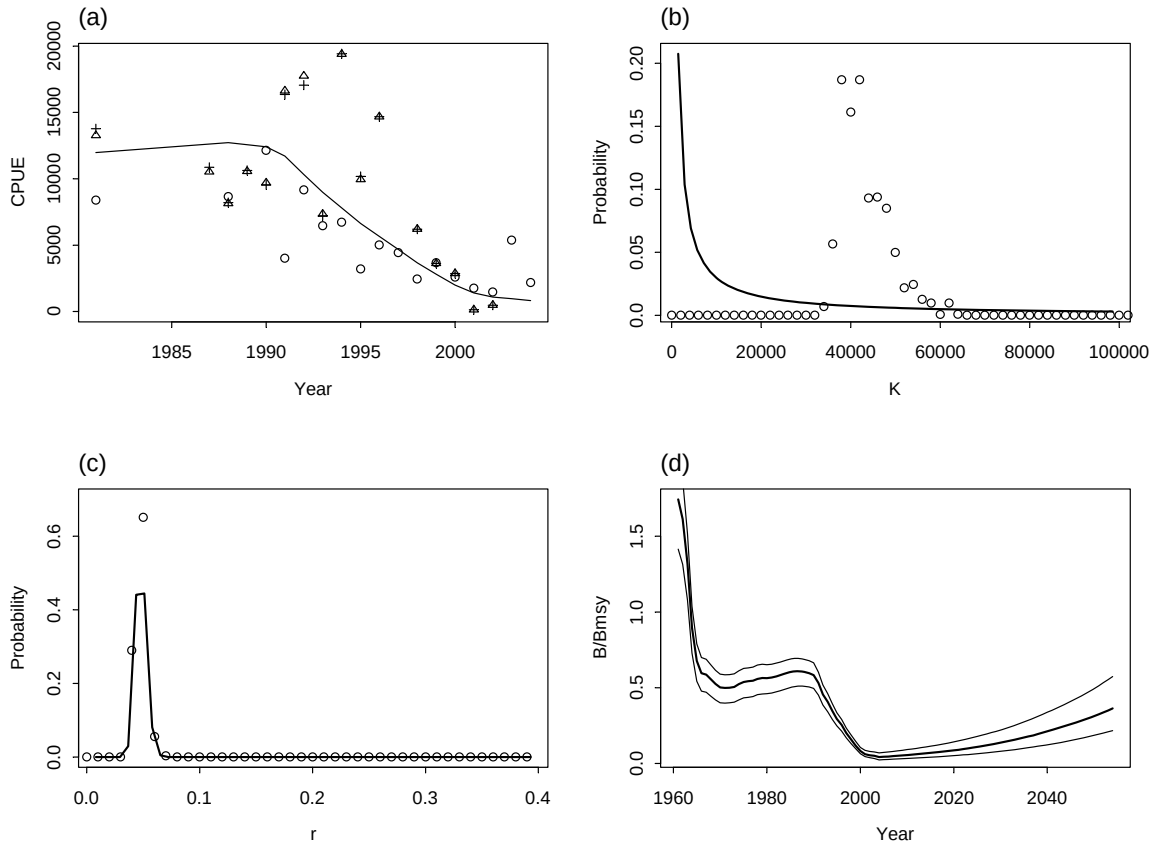


Figure 2. For Northwest Atlantic porbeagle BSP model run with a low CV in the prior for *r*, (a) fitted biomass trend (line) and CPUE series (points), (b) prior (line) and posterior (points) distributions of *r*, (c) prior and posterior distributions of *K*, and (d) the median and 80% credibility interval for biomass relative to B_{MSY} with no fishing after 2004.

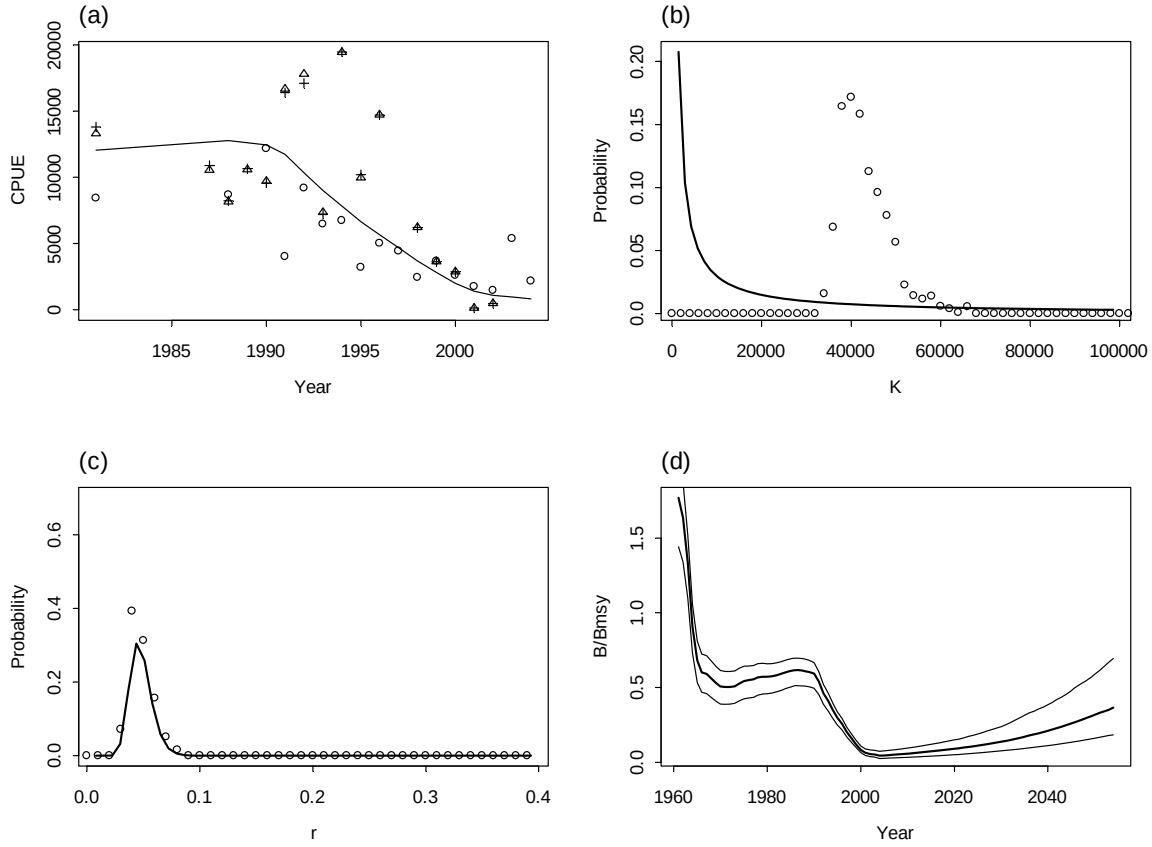


Figure 3. For Northwest Atlantic porbeagle BSP model run with a higher CV in the prior for *r*, (a) fitted biomass trend (line) and CPUE series (points), (b) prior (line) and posterior (points) distributions of *r*, (c) prior and posterior distributions of *K*, and (d) the median and 80% credibility interval for biomass relative to B_{MSY} with no fishing after 2004.