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SURPLUS PRODUCTION MODEL APPLIED TO THE DATA FOR BLUE AND MAKO SHARKS AVAILABLE AT THE 2001 ICCAT BY-CATCH WORKING GROUP AND OTHER PUBLISHED DATA

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SUMMARY

There are few data available on trends in abundance over time for blue and shortfin mako sharks in the Atlantic Ocean. However, demographic information is available, which can give some indication of the resilience of each population to fishing pressure. We developed a surplus production model applied to the data for blue and mako sharks available at the 2001 ICCAT bycatch working group and other published data. The available catch rate indices of abundance were not very informative for estimating the intrinsic rate of increase (r) and carrying capacity (K) for these species. Therefore, we developed informative Bayesian prior distributions for r, based on published demographic information. The Bayesian surplus production (BSP) model was used to explore potential contradictions in the available abundance index data. Bayesian decision analysis was used to examine the sustainability of various levels of future catch.

RÉSUMÉ

On dispose de peu de données sur les tendances de l'abondance dans le temps pour le requin peau bleue et le requin taupe bleue dans l'océan Atlantique. Toutefois, les informations démographiques sont disponibles et peuvent fournir une certaine indication de la résistance de chaque population face à la pression de la pêche. Nous avons élaboré un modèle de production excédentaire appliqué aux données pour le requin peau bleue et le requin taupe bleue disponible pour le groupe de travail de l'ICCAT sur les prises accessoires de 2001, ainsi qu'à d'autres données publiées. Les indices d'abondance disponibles basés sur le taux de capture n'ont pas été très utiles pour estimer le taux d'augmentation intrinsèque (r) et la capacité de transport (K) de ces espèces. C'est pourquoi nous avons conçu des distributions bayésiennes à priori informatives pour r, basées sur les informations démographiques publiées. Le modèle de production excédentaire bayésienne (BSP) a été utilisé pour explorer des contradictions potentielles dans les données disponibles de l'indice d'abondance. On a eu recours à l'analyse de décision bayésienne pour examiner la viabilité des divers niveaux des futures captures.

RESUMEN

Hay pocos datos disponibles sobre las tendencias de abundancia en el tiempo para la tintorera y el marrajo dientuso en el océano Atlántico. Sin embargo, sí se dispone de información demográfica que puede proporcionar alguna indicación sobre la elasticidad de cada población frente a la presión pesquera. Hemos desarrollado un modelo de producción excedente aplicado a los datos de tintorera y marrajo dientuso disponibles durante la reunión Grupo de trabajo ICCAT sobre capturas fortuitas de 2001 y a otros datos publicados. Los índices de abundancia disponibles basados en las tasas de captura no aportan mucha información a la hora de estimar la tasa intrínseca de incremento (r) y la capacidad de carga (K) para estas especies. Por consiguiente, hemos desarrollado distribuciones a priori bayesianas informativas para r, basadas en la información demográfica publicada. Se utilizó el modelo de producción excedente bayesiano (BSP) para explorar las contradicciones potenciales en los datos

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disponibles sobre índices de abundancia. Se utilizó el análisis de decisión bayesiano para examinar la sostenibilidad de diferentes niveles de captura en el futuro.

KEYWORDS

Catch/effort, Mathematical models, Stochastic models, Stock assessment, Population dynamics

1. Introduction

For blue (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*) in the Atlantic, the only available indices of abundance are catch-per-unit-of-effort data from commercial and recreational fisheries. Information about total catches of blue and mako sharks are available for the last decade, but not for the early years of the fishery, when sharks were not recorded or were not identified to species. Demographic information is available for both species. Thus, a Bayesian surplus production model that can incorporate demographic information into an informative prior distribution for the intrinsic rate of population increase (r) is an appropriate assessment method. A similar model has been applied to large coastal sharks in the U.S. Atlantic (McAllister *et al.* 2001, Cortes *et al.* 2002).

2. Methods

The Bayesian surplus production model (BSP) software available in the ICCAT catalog of methods (McAllister and Babcock 2003) was used to fit a surplus production model to the data available at the ICCAT bycatch working group meeting in 2001 (Anon. 2002). The discrete-time version of the model was used, so that:

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

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

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

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.

CPUE data were available from 1971 for both species, and catch data were available from 1986 for blue sharks (**Table 1**) and 1990 for mako sharks (**Table 2**). Some of the CPUE series provided at the 2001 meeting were multiple analyses of the same data sets. Thus, for both blue and mako sharks we arbitrarily excluded the North and South Atlantic Japanese longline series (duplicated by the JLL total Atlantic series) and the US longline logbook series SCRS/01/72 (duplicated by the series from SCRS/01/60).

The fishery was assumed to begin in 1971, which was the first year for which CPUE data were available. The catches in the years 1971-1985 (for blue sharks) and 1971-1989 (for mako sharks) were assumed to be constant and equal to the model estimated parameter *cat0*. Other estimated parameters were r, K and the biomass in 1971 relative to K (B_{71}/K). The constant of proportionality between each abundance index and the biomass trend was calculated using the numerical shortcut of Walters and Ludwig (1994). The variance of the residuals $\sigma^2_{j,y}$ was set equal to 1.0 for all data points in all series, for the base case analysis. The prior for K was uniform on log(K), weakly favoring smaller values, and was allowed to vary between 0.001 and 500000 t. Informative priors were used for *cat0*, B_{71}/K and r, all with a lognormal distribution. For *cat0*, because the catches were increasing over the time series, the prior was given a mean equal to the mean of the catches in the first five years of the catch data series (blue shark mean=710 t, mako shark mean = 580 t), and a log-standard deviation equal to 1.0 implying a wide distribution. For B_{71}/K, the mean was set equal to 1, and the log-sd was 0.2. For r, the mean and log-sd were calculated based on demographic data. This was done by fitting a lognormal distribution to

10,000 *r* values obtained through Monte Carlo simulation of Leslie matrices (Cortés, in press). Mean and log-sd *r* values for blue shark were 0.28 yr^{-1} and 0.20, and 0.05 yr^{-1} and 0.81 for shortfin mako, respectively.

The marginal posterior distributions were calculated using the sampling-importance resampling algorithm (SIR), using the diagnostics of convergence described in McAllister and Babcock (2003). The importance function used was either a multivariate *t* distribution, or simply the priors of the parameters, depending on which function produced better convergence diagnostics. To evaluate the potential consequences of future management actions, the populations were projected forward in time 30 years, with the harvest levels set equal to zero, the current catch, the highest catch ever recorded, and *Fmsy*. For each harvest level the probability of the population remaining above *Bmsy* and other reference points were calculated.

Sensitivity analyses were done to examine the impact of the priors on the results. The method used to weight the CPUE data points ($\sigma^2_{j,y}$) was also considered. Alternative weighting methods used included the MLE estimate of σ^2, two inverse variance methods, input variance method, additional variance, and equal weighting(McAllister and Babcock 2003).

3. Results

3.1 Blue sharks

For blue sharks, the CPUE series are quite variable, and show little trend over time (**Figure 1**). The biomass trajectory at the mode of the posterior distribution (**Figure 1**) showed a slight increasing trend, followed by a decrease in the late 1990s. For the importance sampling, a multivariate *t*-distribution was used as an importance function. The SIR algorithm converged in 150,000 draws with good diagnostics of convergence (maximum weight on any draw <<1%, CV(weights) approximately equal CV(likelihood * priors)). The posterior distribution of *r* was very similar to the prior distribution (**Figure 2**, **Table 3**). The posterior of *cat0* was also similar to the prior (**Table 3**). The data supported relatively high values of *K* (**Figure 2**) and a lower value of B_{71}/K than the priors (**Table 3**). Current status of the population was above *Bmsy*, and the current catch was below the replacement yield (**Table 3**). Population projections showed that the population would be expected to remain above *Bmsy* unless catches remained at the highest level ever recorded or when applying a policy based on *Fmsy*(**Table 4**).

The sensitivity analyses were all consistent with the base case analysis (**Table 5**). The model would not converge to a solution with no informative priors, but did converge with the baseline priors except for an uninformative prior on *r*. All the sensitivity analyses were optimistic about the current status of blue sharks. The BR Santos series, which was not standardized, appear to contradict the other series. A sensitivity analysis with the BR Santos series excluded was similar to the base case, but slightly more optimistic.

3.2 Mako sharks

For mako sharks, the CPUE series, while variable, appear to show a downward trend in the 1990s (**Figure 3**). The biomass trajectory at the mode of the posterior distribution (**Figure 3**) showed a decrease throughout the time series with a sharp decline in the late 1990s. For the importance sampling, the prior distributions were used as an importance function. The SIR algorithm converged in 140,000 draws with good diagnostics of convergence. The posterior distribution of *r* favored somewhat lower values than the prior distribution (**Figure 4, Table 6**). Current status of the population was 20% above *Bmsy*, but the current catch was above both MSY and the replacement yield (**Table 6**). Population projections showed that the population would be expected to continue to decline at current catch levels, so that there would be a 50% probability of the population dropping below Bmsy in 10 years (**Table 7**).

The sensitivity analyses with different weightings of the CPUE data were all consistent with the base case analysis (**Table 8**). The model would not converge to a solution with no informative priors. With the baseline priors except for an uninformative prior on *r,* the mean of the posterior for *r* was 0.81, a value that is biologically impossible for mako sharks. A sensitivity analysis excluding the unstandardized BR Santos series was similar to the base case, but slightly more pessimistic.

4. Discussion

The catch and CPUE data available for blue and mako sharks are not sufficiently informative to estimate all the parameters of a surplus production model without at least some informative priors. In particular, for mako sharks the informative prior for r is necessary to ensure that the estimated values of r are consistent with the known biology of the species. The relative weights applied to the data points in the CPUE series do not greatly influence the results for the series used in this analysis.

This implementation of the model assumed that the unreported catches were constant between 1971 and the first year for which catches were reported. It was also assumed that the catch data were complete. In fact, catch data are missing for many years for some fleets (Anon. 2002). Thus, a more nuanced estimation process for the missing data should be attempted.

5. Acknowledgements

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Table 1. Catch and CPUE data (Anonymous 2002) used for blue sharks.

	JLL-all	*US obs-JLL*	*US-LL-log*	*US-rec*	*US-obs*	*BR Santos*	*Catch (t)*
1971	0.9837					0.08	
1972	1.0835					0.017	
1973	1.2029					0.093	
1974	1.9328					0.025	
1975	1.1607					0.132	
1976	0.8946					0.335	
1977	2.9867					0.486	
1978	2.1851	2.43				0.476	
1979	6.4575	1.77				0.977	
1980	4.8394	1.55				0.8	
1981	1.788	1.09				1.579	
1982	2.4455	0.45				0.965	
1983	1.8589	1.08				1.162	
1984	1.8502	1.89				1.472	
1985	1.6211	1.62				1.893	
1986	2.0612	1.34	9.6554	0.5153		1.609	1
1987	2.4365	1	5.1532	0.3003		2.068	526
1988	1.5515	0.4	3.5649	0.5977		1.869	421
1989	1.816		2.2731	0.3354		1.424	480
1990	2.0479		3.1226	0.3907		1.879	2129
1991	1.8101		2.3492	0.7871		1.659	3029
1992	2.0927		1.9529	0.983	0.512		1768
1993	2.4169		2.0085	0.8782	0.596		6886
1994	2.4544		1.872	1.0646	0.866		7845
1995	2.0871		1.5945	0.9369	1.426		8134
1996	1.9672		2.1524	2.8766	0.958		8116
1997	1.8715		2.123	2.0534	1.033		11247
1998	1.8038		1.5395	1.2809	1.598		32313
1999	1.6618		1.0246		0.93		32654
2000	1.5328				0.68		3652

Table 2. Catch and CPUE data (Anonymous 2002) used for mako sharks.

Year	*JLL-all*	*US obs-JLL*	*US-LL-log*	*US dealer (wt)*	*US-rec*	*US-obs*	*BR Santos*	*Catch (t)*
1971	0.025						0.901	
1972	0.0184						1.224	
1973	0.0221						0.906	
1974	0.02						1.084	
1975	0.0213						0.215	
1976	0.023						0.959	
1977	0.0214						0.805	
1978	0.0194	0.6					0.942	
1979	0.0143	0.42					0.867	
1980	0.018	0.36					0.938	
1981	0.0204	0.3					1.687	
1982	0.0161	0.16					0.674	
1983	0.0184	0.22					0.957	
1984	0.017	0.3					0.787	
1985	0.0158	0.23		60.84			0.784	
1986	0.0155	0.27	1.343	76.87	1.328		0.773	
1987	0.0193	0.26	0.752	55.63	0.876		1.167	
1988	0.0174	0.17	0.533	53.03	0.365		2.11	
1989	0.0158		0.643	49.57	0.59		0.939	
1990	0.0145		0.434	41.7	0.675		1.279	193
1991	0.0151		0.343	38.12	1.094			314
1992	0.0137		0.421	24.47	1.046	0.481		246
1993	0.0123		0.284	32.73	1.086	0.251		1111
1994	0.0103		0.281		0.972	0.234		1023
1995	0.0097		0.302		0.897	0.326		1113
1996	0.0101		0.279		1.042	0.164		1343
1997	0.0108		0.3		1.373	0.245		5057
1998	0.0086		0.217		1.655	0.065		3901
1999	0.0095		0.223			0.131		3573
2000	0.008					0.213		863

Table 3. Results of SIR for blue sharks. HR refers to harvest rate and repy is replacement yield.

	Expected value	*CV*
K	300145	0.34
r	0.26	0.19
MSY	19664	0.39
B_{2001}	242835	0.44
B_{2001}/K	0.78	0.15
B_{1971}	186972	0.39
B_{2001}/ B_{1971}	1.28	0.22
C_{2001}/MSY	0.22	0.42
$HR_{2001}/HRmsy$	0.16	0.71
$B_{2001}/Bmsy$	1.55	0.15
$C_{2001}/repy$	0.30	0.19
Bmsy	150073	0.34
repy	12593	0.15
cat0	674	1.13

Table 4. Blue shark decision table. TAC quota policies include the current catch (3652 t) and the highest catch ever recorded (32654 t).

Horizon	*Policy*	*E(Bfin/K)*	*P(Bfin<0.2K)*	*P(Bfin>Bmsy)*
10 -year	TAC= 0	0.98	0.00	1.00
	TAC= 3652	0.92	0.00	1.00
	TAC= 32654	0.28	0.47	0.30
	HRmsy (=0.162)	0.46	0.00	0.24
20 -year	TAC= 0	1.00	0.00	1.00
	TAC= 3652	0.94	0.00	1.00
	TAC= 32654	0.15	0.70	0.14
	HRmsy (=0.162)	0.40	0.01	0.13
30 -year	TAC= 0	1.00	0.00	1.00
	TAC= 3652	0.94	0.00	1.00
	TAC= 32654	0.11	0.81	0.09
	HRmsy (=0.162)	0.38	0.03	0.12

Table 5. Sensitivity analysis for blue sharks. The model would not converge with no informative priors, or with the additional variance weighting method. CVs are given in parentheses. Numbers in headings correspond to methods to weight CPUE data points as described in McAllister and Babcock (2003).

		Weighting methods				
	Uninformative prior for r	*2-MLE by series*	*3-average by series = MLE, years within series weighted by input CV*	*5-Input variance multiplied by one scale parameter*	*8-Input variance*	*10-constant estimated variance*
K	303556 (0.36)	313519 (0.31)	307377 (0.33)	302272 (0.34)	234007 (0.44)	296860 (0.35)
r	0.33 (0.61)	0.28 (0.2)	0.29 (0.22)	0.27 (0.2)	0.29 (0.22)	0.27 (0.2)
MSY	24023 (0.65)	22043 (0.36)	21840 (0.38)	20000 (0.39)	16557 (0.44)	19678 (0.4)
B_{2001}	249976 (0.44)	260524 (0.38)	254354 (0.41)	245473 (0.44)	176529 (0.6)	239863 (0.45)
B_{2001}/K	0.8 (0.16)	0.81 (0.11)	0.8 (0.12)	0.78 (0.15)	0.7 (0.2)	0.77 (0.16)
B_{1971}	204391 (0.41)	233412 (0.35)	229865 (0.37)	198091 (0.39)	177644 (0.46)	196863 (0.4)
B_{2001}/ B_{1971}	1.22 (0.24)	1.11 (0.18)	1.1 (0.18)	1.23 (0.23)	0.95 (0.25)	1.2 (0.24)
C_{2001}/MSY	0.22 (0.81)	0.19 (0.38)	0.19 (0.4)	0.21 (0.42)	0.26 (0.38)	0.22 (0.43)
sigma	NA	NA	NA	0.57 (0.16)	NA	0.59 (0.16)
$HR_{2001}/HRmsy$	0.16 (1.35)	0.12 (0.54)	0.13 (0.59)	0.15 (0.74)	0.21 (0.65)	0.16 (0.76)
$B_{2001}/Bmsy$	1.59 (0.16)	1.62 (0.11)	1.6 (0.12)	1.56 (0.15)	1.4 (0.2)	1.54 (0.16)
$C_{2001}/repy$	0.29 (2.41)	0.28 (0.14)	0.28 (0.16)	0.3 (0.2)	0.31 (0.22)	0.3 (0.21)
Bmsy	151778 (0.36)	156759 (0.31)	153689 (0.33)	151136 (0.34)	117004 (0.44)	148430 (0.35)
repy	12704 (0.29)	13352 (0.12)	13315 (0.13)	12671 (0.15)	12157 (0.18)	12607 (0.16)
cat0	873 (1.03)	678 (1.16)	916 (1.12)	692 (1.15)	807 (1.13)	684 (1.15)

Table 6. Results of SIR for mako sharks. HR refers to harvest rate and repy is replacement yield.

	Expected value	*CV*
K	85862	0.96
r	0.04	1.02
MSY	926	1.72
B_{2001}	63473	1.30
B_{2001}/K	0.59	0.38
B_{1971}	88932	0.98
B_{2001}/ B_{1971}	0.58	0.36
C_{2001}/MSY	2.69	1.15
HR_{2001}/HRmsy	3.36	1.64
B_{2001}/Bmsy	1.19	0.38
C_{2001}/repy	2.06	169.19
Bmsy	42931	0.96
repy	487	0.87
cat0	492	1.02

Table 7. Mako shark decision table. TAC quota policies include current catch (863 t) and the highest catch ever recorded (5057 t).

Horizon	*Policy*	*E(Bfin/K)*	*P(Bfin<0.2K)*	*P(Bfin>Bmsy)*
10 -year	TAC= 0	0.66	0.01	0.74
	TAC= 863	0.50	0.19	0.50
	TAC= 5057	0.17	0.73	0.17
	HRmsy=0.07	0.62	0.01	0.69
20 -year	TAC= 0	0.72	0.01	0.82
	TAC= 863	0.43	0.33	0.45
	TAC= 5057	0.11	0.83	0.11
	HRmsy=0.07	0.65	0.01	0.75
30 -year	TAC= 0	0.77	0.00	0.88
	TAC= 863	0.39	0.41	0.41
	TAC= 5057	0.08	0.87	0.08
	HRmsy=0.07	0.67	0.01	0.78

Table 8. Sensitivity analysis for mako sharks. Model runs with uninformative priors for all parameters, with input variance weighting, and with additional variance weighting did not converge. CVs are given in parentheses. Numbers in headings correspond to methods to weight CPUE data points as described in McAllister and Babcock (2003).

		Weighting methods			
	Uninformative prior for r	*2-MLE by series*	*3-average seriew weight = MLE, years within series weighted by input CV*	*5-Input variance multiplied by one scale parameter*	*10-constant estimated variance*
K	85873 (1.06)	57256 (0.26)	58990 (0.26)	54302 (0.6)	67408 (0.85)
r	0.81 (0.72)	0.02 (0.68)	0.01 (0.67)	0.03 (0.89)	0.04 (1.08)
MSY	19172 (1.56)	208 (0.56)	206 (0.58)	409 (1.17)	522 (1.39)
B_{2001}	79920 (1.16)	19518 (0.25)	19915 (0.26)	28623 (1.11)	40964 (1.4)
B_{2001}/K	0.85 (0.22)	0.35 (0.22)	0.35 (0.23)	0.49 (0.33)	0.52 (0.38)
B_{1971}	84576 (1.07)	59787 (0.18)	61290 (0.17)	58054 (0.66)	70468 (0.91)
B_{2001}/B_{1971}	0.9 (0.3)	0.32 (0.12)	0.32 (0.12)	0.45 (0.26)	0.49 (0.31)
C_{2001}/MSY	0.51 (4.97)	5.86 (0.69)	6.05 (0.7)	3.83 (0.9)	3.52 (1.04)
sigma				0.15 (0.15)	0.14 (0.16)
HR_{2001}/HRmsy	0.57 (6.78)	8.68 (0.69)	9.05 (0.71)	4.7 (1.07)	4.41 (1.25)
B_{2001}/Bmsy	1.7 (0.22)	0.7 (0.22)	0.69 (0.23)	0.98 (0.33)	1.03 (0.38)
C_{2001}/repy	0.64 (26.94)	6.53 (0.68)	6.77 (0.7)	4.32 (11.86)	3.86 (3.87)
Bmsy	42936 (1.06)	28628 (0.26)	29495 (0.26)	27151 (0.6)	33704 (0.85)
repy	1003 (1.62)	187 (0.57)	183 (0.58)	331 (0.75)	366 (0.83)
cat0	441 (1.08)	1330 (0.3)	1396 (0.29)	633 (0.82)	642 (0.93)

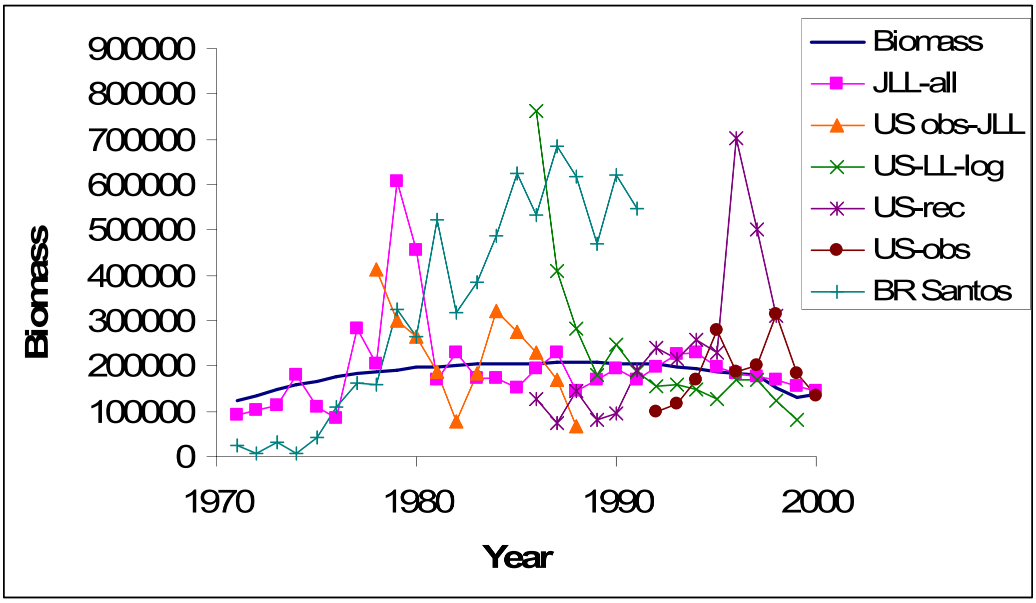

Figure 1. Blue shark best fit biomass trend compared to CPUE series divided by catchability.

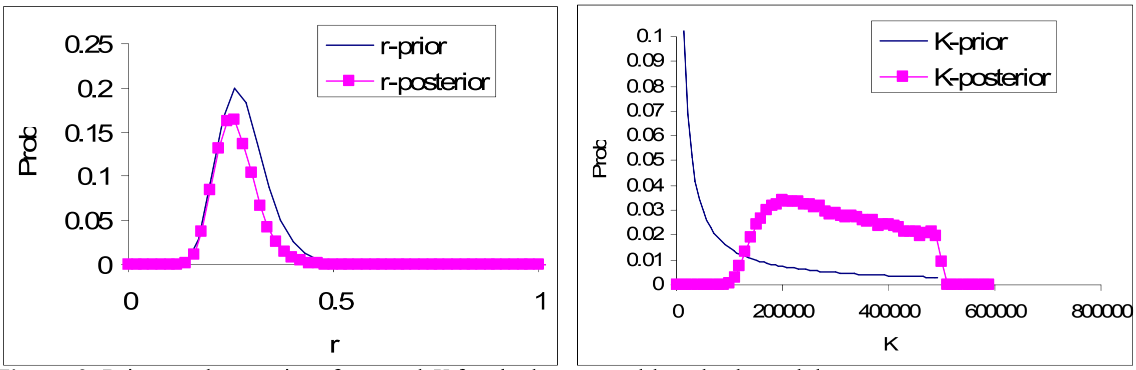

Figure 2. Priors and posteriors for *r* and *K* for the base case blue shark model.

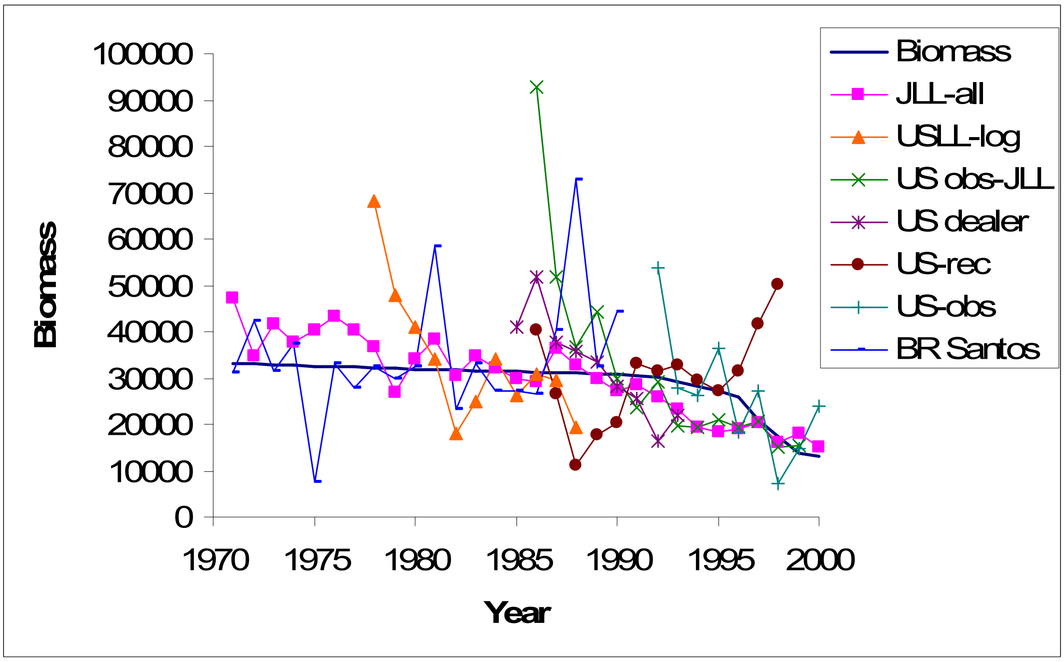

Figure 3. Mako base case CPUE series with best fit biomass trend.

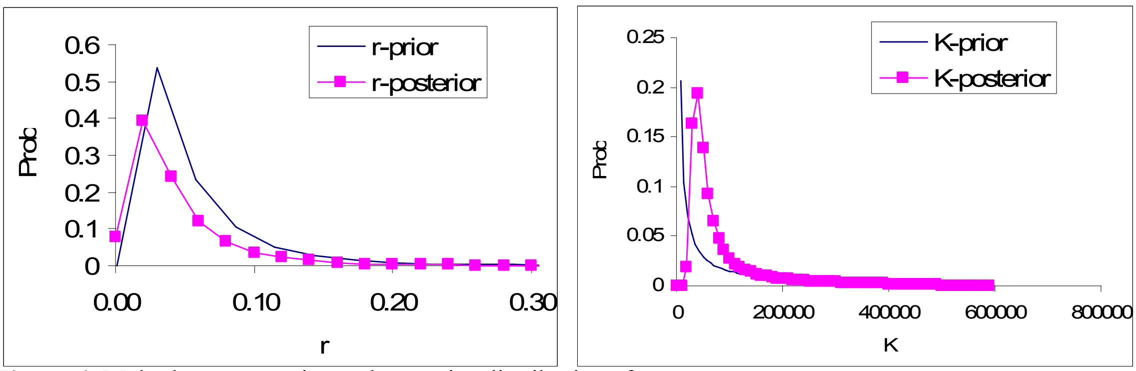

Figure 4. Mako base case prior and posterior distributions for *r*.