Ben Moffat
MBE 716 – Bayesian Statistics
Final Project

A Bayesian Analysis and Stock Assessment of North Atlantic Swordfish (Xiphias gladius)

Background

The North Atlantic Swordfish fishery began as a harpoon subsistence fishery off the coast of New England in the 1800s. It transitioned to a primarily commercial pelagic longline fishery in the late 1900s. The advancement in gear and increased fishing effort led to severe overfishing of the Swordfish population resulting in a sharp decrease in estimated abundance observed in 1985. A management plan was put in place that implemented regulations to reduce the total allowable catch and imposed minimum size limits. Eventually, the fishery is rebuilt and is currently regarded as sustainable, meaning it is not being overfished or undergoing overfishing. This has been considered a great success story that illustrates the effectiveness of appropriate resource management (Neilson et al., 2013).

Methods and Data

Data analysis was performed using the GitHub package JABBA "Just Another Bayesian Biomass Analysis" Package that creates a user-friendly wrapper of JAGS in R. It requires three separate inputs for catch, catch per unit effort (CPUE), and standard error (SE) (Winker et al.,2018). The package gives several options for the model type, referring to how the parameters are calculated, including the Pella-Tomlinson, Schaefer, and Fox models. The Pella-Tomlinson model is used here as it was used in similar JABBA assessments on highly migratory species (Figure 1). It's important to note that this model type requires the user to define the Bmsy/K ratio. Here, the default and commonly utilized value of 0.4 is used.

As the North Atlantic Swordfish fishery is international and has many fleets, it complicates data collection. The 2017 ICCAT North Atlantic Swordfish Stock Assessment had compiled data for catch, CPUE, and SE across all fleets (Anon., 2017). For catch, the data was years 1950 to 2017 and total aggregate catch by weight for all fleets with no missing values. The CPUE data was combined CPUE across fleets and had missing values for several years. Lastly, the SE data was available as the CV of the standardized CPUE.

$$SP_t = \frac{r}{m-1} B_t \left(1 - \left(\frac{B_t}{K}\right)^{m-1}\right)$$

Figure 1. Pella-Tomlinson surplus production formula (Pella and Tomlinson, 1969)

Prior Selection

A logical place to find a suitable informative prior is with other stock assessments on the same species, in this case, Pacific Swordfish. The International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean conducted the 2014 North Pacific Swordfish Stock Assessment from a Bayesian production model (Anon., 2014). From this output, I created an informative prior for r (intrinsic population growth rate) using a mean of 0.578 with a standard deviation of 0.217 from Table 1. As K (carrying capacity) is a function of the habitat quality, total habitat available, prey availability, and because dynamics are different between ocean basins, it is not justifiable to use an informative prior. Instead, an uninformative lognormal prior or weakly informative is appropriate. In this case, a mean of 125,000 tons and a CV of 3 is used.

Table 1. Estimated parameters from a Pacific swordfish stock assessment (Anon., 2014)

Table 5.1. Estimated mean and standard deviation model parameter values for a Bayesian state-space production model for swordfish in the Western and Central North Pacific Ocean.

Parameter	**Mean**	**SD**
Intrinsic rate of pop. growth (r)	0.578	0.217
Carrying capacity (K; 1000 mt)	123.700	24.630
Production shape parameter (M)	0.978	0.453
Process error variance (σ^2)	0.017	0.005
JPN longline CPUE obs. error variance (τ^2_{JPN})	0.035	0.008
TWN longline CPUE obs. error variance (τ^2_{TWN})	0.094	0.040
HW longline CPUE obs. error variance (τ^2_{HW})	0.093	0.038
P_1 (B_{1951}/K)	0.848	0.086
JPN longline CPUE catchability (q_{JPN})	2.82x10^{-3}	6.18x10^{-4}
TWN longline CPUE catchability (q_{TWN})	2.67x10^{-3}	6.21x10^{-4}
HW longline CPUE catchability (q_{HW})	0.169	0.040
Max surplus production (MSY; 1000 tons)	14.920	1.816
Biomass giving MSY (B_{MSY}; 1000 tons)	60.720	11.790
Harvest rate giving MSY (H_{MSY})	0.255	0.057

Model

```
#Load Libraries/Packages
library(devtools)
library(JABBA)
library(gplots)
library(coda)
library(rjags)
library(R2jags)
library("fitdistrplus")
library(reshape)

#read in data
catch<-read.csv("swordfishcatch.csv")
cpue<-read.csv("swordfishCPUE.csv")
```

```r
se<-read.csv("swordfishse.csv")

# MCMC settings
ni <- 30000 # Number of iterations
nt <- 5 # Steps saved
nb <- 5000 # Burn-in
nc <- 2 # number of chains

# Compile JABBA JAGS model and input object
jbinput = build_jabba(catch=catch,cpue=cpue,se=se,
                      model.type = "Pella", #Pella, Fox, or Schafer
                      r.prior=c(0.578,0.217), #Informative
                      K.prior = c(125000,3), #Uninformative Lognormal
                      add.catch.CV = TRUE,
                      )

# fit JABBA (in JAGS) ... Initialization took 1 min 3 sec
swordfish = fit_jabba(jbinput)

#Posteriors Summary Table with credible intervals
print(swordfish$estimates)

# Prior/Posterior Density Distribution Plot
jbplot_ppdist(swordfish)

#Output Plots
jbplot_catcherror(swordfish)
jbplot_cpuefits(swordfish)
jbplot_logfits(swordfish)
jbplot_trj(swordfish,type="B",add=T)
jbplot_trj(swordfish,type="F",add=T)
jbplot_trj(swordfish,type="BBmsy",add=T)
jbplot_trj(swordfish,type="FFmsy",add=T)
jbplot_spphase(swordfish,add=T)
jbplot_kobe(swordfish)
jbplot_summary(swordfish)

#Export all plots
jabba_plots(jabba=swordfish)

#Convergence Diagnostics (Trace)
jbplot_mcmc(swordfish)
```

Convergence Diagnostics

The model took 1 minute and 3 seconds to initialize and run. The model successfully converged. The MCMC trace plots showed no signs of convergence issues within the model as traces were uniform and in a consistent range (Figure 2).

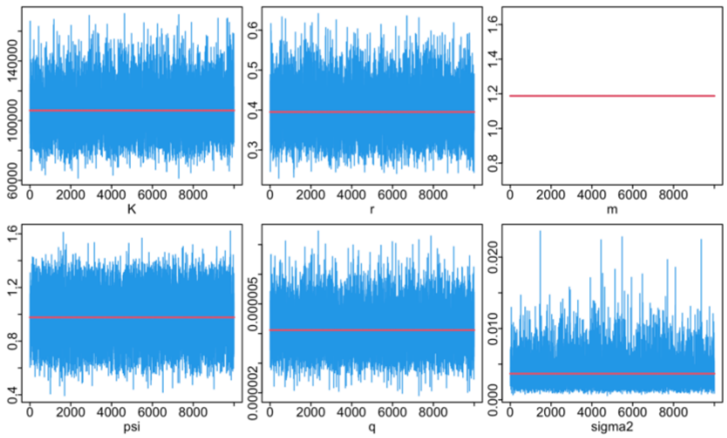

Figure 2. Convergence diagnostics (MCMC Trace)

Process error assumes biomass is normally distributed around surplus production model prediction values. It treats biomass as a random variable which makes it more biologically realistic and improves model fit. The process error was not fixed in this time series (Figure 3).

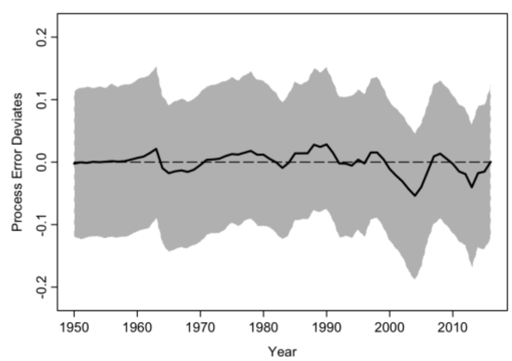

Figure 3. Process Error deviation plot from model

Results

The estimated carrying capacity for North Atlantic Swordfish is 105,543 tons with an intrinsic population growth rate of 0.39 and an initial depletion rate of 0.97 (Table 2). Both the intrinsic population growth rate and carrying capacity are smaller in comparison to the Pacific stock of swordfish. Other notable estimates include the values for the maximum sustainable yield (MSY), which is 13,866 tons.

Table 2. Estimated parameters from posterior probabilities

	mu	lci	uci
K	105543.3536385	79033.7338929	140533.6316361
r	0.3902387	0.2923409	0.5245198
psi	0.9739229	0.6248178	1.3348351
sigma.proc	0.0560000	0.0360000	0.0960000
m	1.1880000	1.1880000	1.1880000
Hmsy	0.3280000	0.2460000	0.4420000
SBmsy	42215.4190000	31612.0540000	56210.8920000
MSY	13866.5270000	12811.5000000	15296.3000000
bmsyk	0.4000000	0.4000000	0.4000000
P1950	0.9750000	0.6160000	1.3200000
P2016	0.5060000	0.3860000	0.6400000
B_Bmsy.cur	1.2660000	0.9660000	1.6000000
H_Hmsy.cur	0.6440000	0.4790000	0.8800000

The prior and posterior distributions are compared in Figure 4 for each parameter. The model has a seemingly small variance in the K posterior (although the large x-axis scale makes it look more so). The weakly informative prior is evident, as is the informative prior of r (Figure 4).

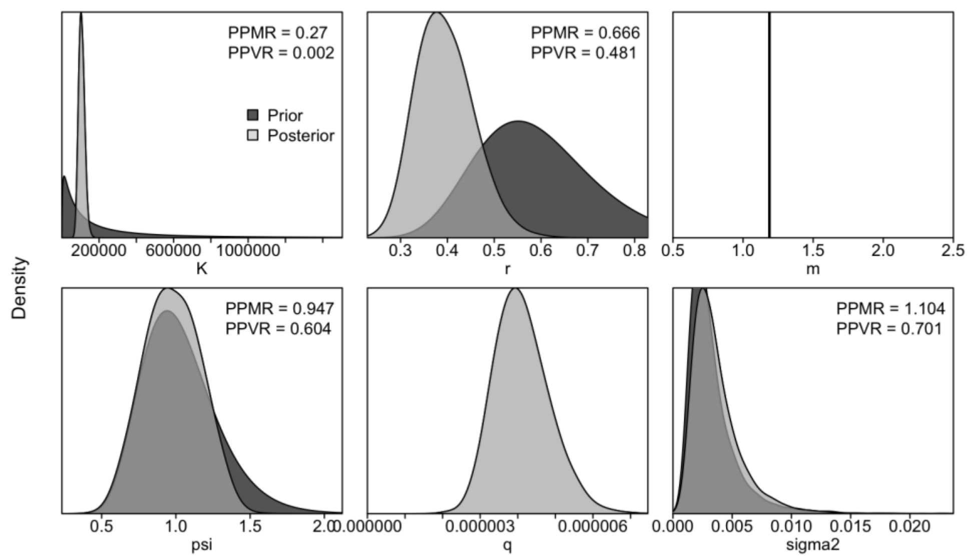

Figure 4. Density plots showing prior and posterior distributions of parameters

Output

The model fits the estimated catch to the observed values well, although the credible intervals seem to increase with time (Figure 5).

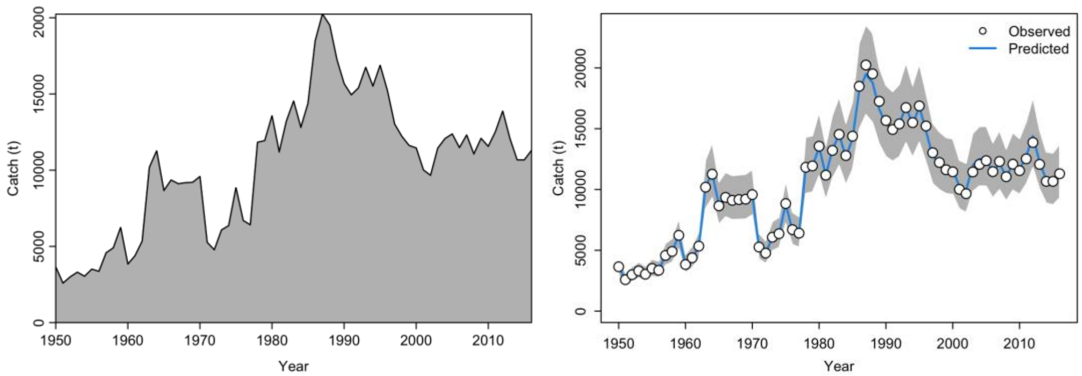

Figure 5. Landings and Catch with observed and predicted values plotted with credible intervals

The first CPUE data point is much higher with a large credible interval than the rest making it an outlier and influencing the early CPUE trend (Figure 6). The loess fit and small credible intervals in the more recent years (1980 forward) should particularly good fit. The CPUE decreases slowly and steadily until it stabilizes in the mid-1990s.

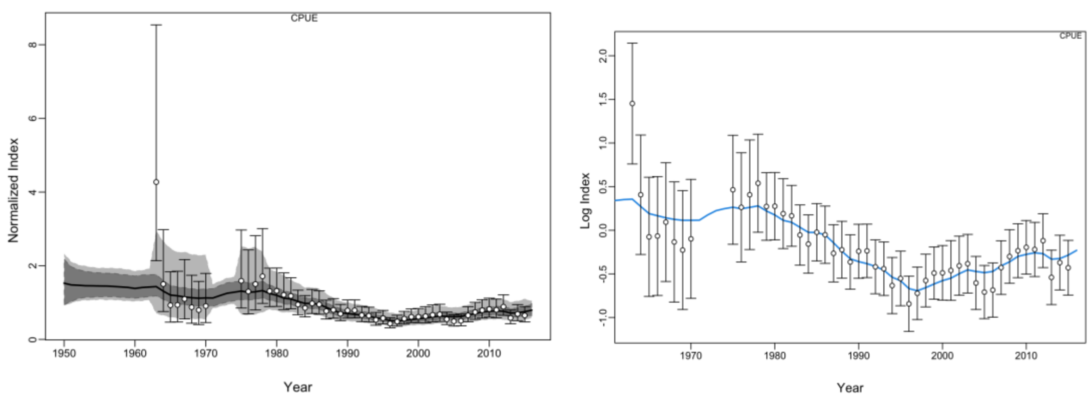

Figure 6. The normalized and log index of CPUE with observed and predicted values plotted with credible intervals

Aside from the first outlier mark, the residuals from the CPUE show an okay fit (Figure 7).

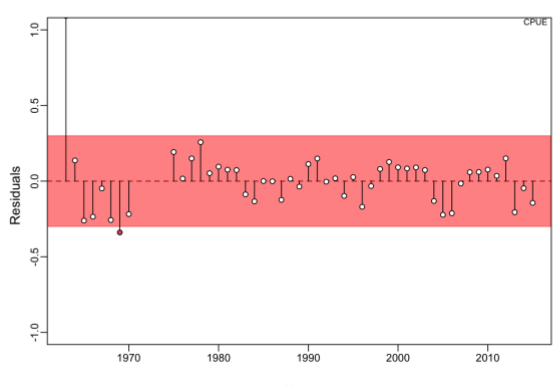

Figure 7. Residuals from the CPUE fit

The effects of advancement in gear and effort in the data throughout the 1900s until the stock plummeted and regulations were put into place in the late 1990s is well illustrated in the biomass and fishing mortality plots (Figure 8). It is clear that when the fishing mortality (or effort) was beyond Fmsy (overfishing) the biomass then followed suit by dipping below Bmsy (overfished).

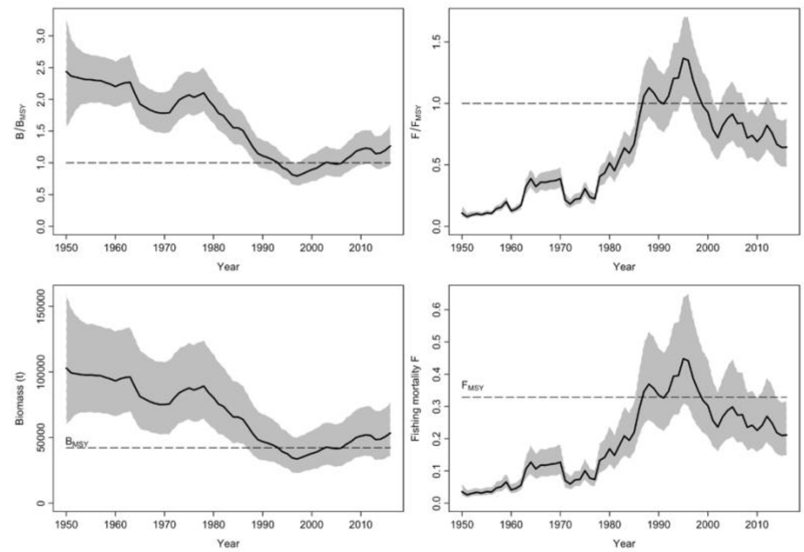

Figure 8. Biomass and Effort plots with MSY reference points and as ratios to MSY value

The Kobe plot and surplus production plots illustrate the journey of the fishery crashing and rebuilding (Figures 8 and 9). Remarkably, the most recent status point (2017, triangle point) shows a 95.7% probability that the stock is sustainable (not being overfished and not undergoing overfishing). This is impressive seeing as how in 1996 (white circle point) the stock was being both overfished and undergoing overfishing at a high rate.

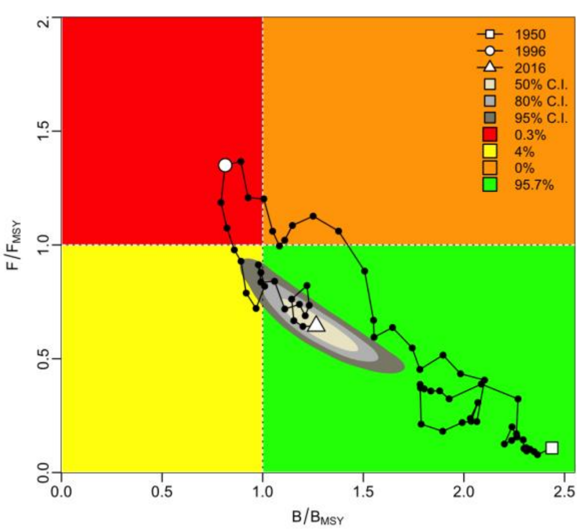

Figure 9. Kobe Plot

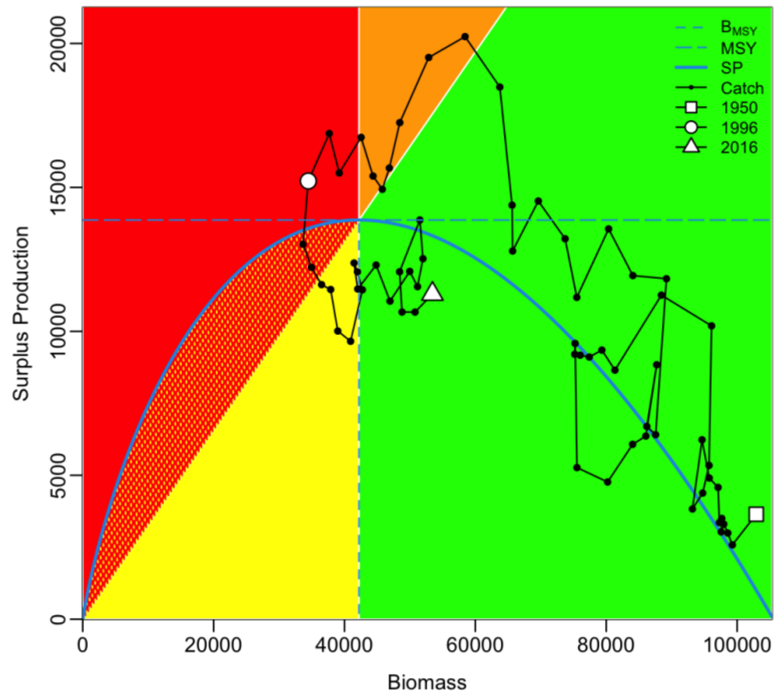

Figure 10. Surplus Production vs. Biomass Plot

The JABBA package allows for a user-friendly method to produce Bayesian stock assessments and useful plots for fisheries management. The most important aspect when using JABBA is to always be aware of the underlying default settings and ensure the prior selection is sound. The analysis of the North Atlantic Swordfish data converged well and quickly, and the output seems to agree with other assessments performed on the fishery. With the analysis package is easy to identify if and by how much a stock is being overfished or undergoing overfishing.

References

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NORTH PACIFIC SWORDFISH (Xiphiaus gladius) STOCK ASSESSMENT IN 2014

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