A Data-Poor Assessment of the US Wreckfish Fishery

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Introduction

The wreckfish (*Polyprion americanus*) fishery off the southeast US has resisted attempts at stock assessment (e.g., Vaughan et al., 2001). However, the fishery data are well-suited to treatment by methods such as Depletion-Based Stock Reduction Analysis (DB-SRA), a data-poor method developed by Dick and MacCall (2010, 2011) to support ACL determinations for unassessed groundfish stocks on the US west coast. DB-SRA was identified by the ORCS Working Group (Berkson et al., 2011) as being a promising approach to determining Acceptable Biological Catch (ABC) and related management quantities. This application of Stock Reduction Analyses (SRA) to the wreckfish fishery is intended to explore use of a different production function than appears in Dick and MacCall (2011), and to include a fit to fishery CPUE data. It also serves as an independent basis for evaluating the wreckfish ACL recently adopted by the SAFMC.

Technical Issues

Natural mortality rate: Previous analyses have tended to use M = 0.1/year, with sensitivity analyses based on M = 0.05 and M = 0.15. The maximum age of wreckfish reported by Peres and Haimovici (2004) is 76 years (n = 337), which gives an estimated M = 0.06/year according to the maximum age method of Hoenig (1983). Using the same growth parameters used by Butterworth and Rademeyer (2012), which were also based on Peres and Haimovici (2004), the wreckfish somatic growth rate (G) is approximately 5%/year when they are at a weight of 32 pounds, the average size taken by the fishery. In the biomass-based model proposed in this paper the natural mortality rate corresponds to M-G, which would be 0.06-0.05=0.01. This is implausibly low, so I have used an *ad-hoc* mean of 0.03 (one-half the Hoenig-based M) for the prior on M-G, with large imprecision, $\sigma ln(M\text{-}G) = 0.5$. For simplicity, the quantity M-G is referred to as M in the model.

Stock Structure: The resource available off the southeastern US is a segment of what is believed to be an extensive meta-population comprising a circular chain inhabiting the rim of the North Atlantic Ocean. This has been raised as a problem for stock assessment and management. This problem is resolved by adopting a strategy where each local population segment is managed independently to a target value of relative abundance or equivalently SPR (see recruitment discussion below). Choice of the target abundance is a management decision, and ideally would involve international cooperation. Until that decision is made, a target abundance of 35% to 40% of unfished abundance would be consistent with many or most management programs. Most importantly, this policy avoids local overfishing (overfishing of any individual segment of link in the chain potentially jeopardizes the entire Atlantic-wide resource), and allows the local fishery to be managed rationally without explicit knowledge of the full Atlantic-wide stock, its catches and management elsewhere.

Recruitment: Because a substantial proportion (perhaps nearly all) of the local recruitment is assumed to be produced by other upstream segments of the meta-population, I assume that local recruitment is not influenced by local stock size. This would correspond to a steepness of h=1 in a Beverton-Holt SRR, but recruitment is more simply treated as a constant value. I also consider the evidence for a time-trend in recruitment by introducing a slope parameter in recruitment vs. year. Although this h=1 model has a nominal Bmsy = 0 and MSY = recruitment, this fishing intensity would not ultimately be sustainable because it would result in downstream recruitment failure, ultimately collapsing the circular chain of population segments.

Age and length compositions: This model does not attempt to fit data on the age or length composition of the catches. There has been very little historical change in those compositions, and hence, very little apparent response to fishing pressure. I hypothesize that the fishery has a dome-shaped selectivity so that the larger fish predicted to exist in the population do not appear in the catches. Even when correctly specified, a dome-shaped pattern reduces the information content in length compositions. When it is mis-specified it causes model bias, especially with regard to estimation of M. For example, when asymptotic selectivity is assumed, the model may favor higher values of M in order to reduce the predicted abundance of those larger fish that are underrepresented in the catches.

Catch per unit Effort: I digitized a time series of CPUE (and standard errors) for the years 1991 to 2010 from a figure in an addendum to the document SERO-LAPP-2011-07 updated November 4, 2011. The CPUEs are a mean of three values for individual vessels. No authorship is given, but I presume Andy Strelcheck (NMFS-SERO) was a major contributor. Annual catches were provided by NMFS, but are not tabulated here due to confidentiality restrictions.

A Bayesian Stock Reduction Analysis of Wreckfish

Because the annual catches are known from the beginning of the fishery, wreckfish is a good candidate for SRA. However, the local stock is not self-generating, and the dome-shaped production function described by Dick and MacCall (2011) is inappropriate, as are all conventional stock-recruitment models where expected recruitment varies with parental stock abundance. Here I develop an alternative SRA model based on recruitment that is independent of local stock abundance.

The model (Table 1) is implemented in OpenBUGS, and is unusually simple. Let Binit[t] be the available biomass at the beginning of year t. By using "available biomass" I refer to the portion of the stock that is available to fishing without having to specify the details (this simplification is further strengthened by the invariance of the catch compositions). In order to have the CPUE prediction coincide with mid-fishery, I remove half of the catches (C[t]) and add half of the recruitment to give a mid-fishery biomass. Then the year is completed by removing the other half of the catch and adding the other half of the recruitment, and finally by multiplying the result by the biomass survival rate (surv) where surv = exp(-M), where M is the net natural mortality rate of biomass, formally represented by M-G. For given values of recruitment (R) and mortality rate, the initial unfished biomass is given by the sum of an infinite series Binit[1] = R*surv/(1-surv).

The catchability coefficient is a nuisance parameter, but was given an uninformative prior distribution and was treated as estimable (in the future it may be possible to remove this parameter from the model by integration). Similarly, an added-variance parameter was specified by an uninformative prior to address the potential problem where the reported CPUE standard errors are too precise for the model to duplicate—this is a common problem in stock assessments

This model produces catch-based time series of available biomasses from the beginning of the fishery to the beginning of the year following the most recent year for which catches are specified. The historical catch series allows an abundance estimate as of the beginning of 2011. Projections of the next 20 years assume annual catches equal to an ACL of 106.6 tons. A possible trend in recruitment was specified as an annual change in recruitment with a prior of N(0,1) tons per year.

The OpenBUGS chain was thinned to 1/5000, which produced a negligibly small serial correlation (Figure 1). The model started from near the maximum likelihood solution, and the burn-in was 5000 iterations. In most cases 1000 samples were retained after thinning, requiring 1 to 2 hours of computing time on a PC. In the many million iterations, the model produced no instances of negative biomass, which is technically possible because the catch is directly subtracted from the modeled abundance.

Results

The Bayesian posteriors show strong differences from the priors, indicating an informative model and data (Table 2). The model, evaluated at the posterior parameter means, fits the CPUE data quite well given the unusual simplicity of the model (Figure 2). Note that because the CPUE is the mean of three values, the fit is based a Student's-t distribution (2 df) after logarithmic transform, so the error structure is symmetrical about the line showing model predictions. No additional variance appears to be needed to explain the variability in ln(CPUE), but this feature remains included during model development

The net biomass mortality rate (M-G) is estimated at 0.0231/yr, and the error variability in ln(M-G) decreases from a prior of 0.5 to a posterior of 0.23, indicating an unusually strong ability to estimate this important parameter. Recruitment is estimated with a mean of 183.5 tons/year, 95%CI is 116-299 tons/yr (Figure 3). The model and data provide no information on a potential time trend in recruitment, with the posterior distribution being nearly identical to the prior distribution (Figure 4). Although the prior is *ad-hoc*, this feature remains in the model for future projection.

Estimated unfished biomass is a function of recruitment and M, giving a mean of 7683 tons, 95%CI is 6306-10580 tons. Current relative abundance (B2011/Bunfished) has a mean of 0.37, 95%CI is 0.24-0.56. An interesting technical detail is that although relative biomass is not assigned a prior distribution, it is a quantity derived from parameters that do have prior distributions, and it therefore has an implicit prior distribution that is somewhat peculiar in shape (Figure 5). Fortunately, 95% of the mass of the posterior distribution lies between 0.24 and 0.56, which is a region in which the implicit prior is well-behaved (Figure 6). The problematic region of the implicit prior (ca. 0.75) has a negligibly low probability in the posterior, so it doesn't influence the results.

The model includes a 20-year projection under an assumed catch equal to the ACL (106.6 tons/year), assuming that the entire ACL is taken each year. Uncertainty includes the potential time trend shown in Figure 4. In 2031, the relative abundance is estimated to be 0.38, 95%CI is 0.18-0.60. Thus ACL is expected to result in very little change in resource abundance over the next 20 years, indicating that it is sustainable. The probability of overfishing is low: Based on the CI for recruitment, there is a less than 2.5% probability that the ACL is larger than the recruitment, indicating low risk of overfishing. A larger ACL would result in a decline in biomass, up to a "nominal" maximum of 183 tons which would eventually reduce the biomass to near-zero under continuing constant recruitment. This maximum would be sustainable only in the short-term. Reduced export of reproduction would cause declines in downstream adult abundance, and eventually declines in those downstream segments of the chain that are upstream producers of recruitment to this segment. It is unknown how long this process would take.

Discussion

I believe that this simple SRA model gives us a view of the fishery that is more plausible and robust than the VPA approach used by Vaughan (2001) or the age structured model of Butterworth and Redemeyer (2012). This SRA model's assumption of constant recruitment is difficult to accommodate in a VPA, and does not require the selectivity assumptions needed to link cohorts in VPA. It also avoids addressing the issue of a nearly invariant length composition, the cause of which (and hence the proper model specification) is not well understood. Despite its simplicity, this model is a complete stock assessment, with fully-estimated parameters, and providing information on current status with regard to fishing rates and relative abundance as well as future potential under alternative management actions. Unlike most stock assessments, the model includes meaningful precision estimates for all quantities including risk of overfishing.

It is worth addressing the difference between the magnitude of the catches in the early fishery (peaking at about 1700 tons) and the seemingly low ACL of 106.6 tons. Given an estimated unfished abundance of 7683 tons, there is a one-time (not sustainable) total harvest of about 4600 tons from the resource that is a "mining" of the stock from 100% down to 40% of unexploited abundance. Another way to view this is to realize that this 4600 tons is a windfall, once-only harvest equivalent to 25 years of recruitment. This initial bonanza is a common feature of stocks with low natural mortality rates, and many fish stocks have been overfished because science and management have failed to distinguish between initial once-only and sustainable contributions to production.

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Table 1. OpenBUGS SRA model of wreckfish

```
#simple wreckfish model for OpenBUGS
#Uses students t distribution and log CPUE, with trend in R

model{
#parameter draws (no additional variance for now)
	R ~ dunif(50,500) # draw recruitment from uniform dist
	AnnChangeR ~ dnorm(0,1)
	lnM ~ dnorm(-3.506,4) #mu is ln(M=0.03), tau of 4 is sigmalnM of 0.5
		surv<-exp(-exp(lnM)) #convert to annual survival rate
	q ~ dunif(0.0001, 0.001) #uninformative catchability
	addvar ~ dunif(0.001,1)

#run population model -- year 1 is 1987, first year of fishery
	Binit[1]<-R*surv/(1-surv) #unfished abundance based on infinite series
for(i in 2:4){
	years[i]<-i-1
	Binit[i] <- (Binit[i-1]-C[i]+R+years[i]*AnnChangeR)*surv
#natural mort after recruitment
}
# We have CPUEs from 1991 to 2010, or model years 5 to 24, project 25 on.
# Calc CPUE at mid-catch and mid-R
for(i in 5:24){
	years[i]<-i-1
	Bmid[i] <- max(0.01, Binit[i-1]-0.5*C[i]+0.5*(R+years[i]*AnnChangeR))
#abundance at mid-season, at half catch and half R
#avoids crashes due to taking logarithm of negative biomass—in hindsight not needed
	lnCPUEpred[i]<-log(q*Bmid[i]) #use log CPUE
	totCPUEtau[i]<-1/((1/lnCPUEtau[i])+addvar)
	lnCPUE[i]~dt(lnCPUEpred[i], totCPUEtau[i],2) #use students t dist with 2 df
	Binit[i] <- (Bmid[i]-0.5*C[i]+0.5*(R+years[i]*AnnChangeR))*surv
#catch remaining fish, add remaining recruitment and do survival
}
for(i in 25:45){
	years[i]<-i-1
	Binit[i] <- (Binit[i-1]-C[i]+R+years[i]*AnnChangeR)*surv
}
deplnow<-Binit[24]/Binit[1]
deplfuture<-Binit[45]/Binit[1]
}
```

Table 2. Estimated parameters.

	Prior	Posterior					
	distribution	mean	std dev	MC error	2.50%	median	97.50%
ln(M)	N(ln(0.03),0.5)	ln(0.0231)	0.230	0.009	0.015	0.023	0.036
Recruitment	U(50, 500)	183.5	46.1	2.4	115.7	174.1	298.7
q	U(0.0001,0.001)	0.000387	0.000124	6.30E-06	0.000169	0.000384	0.000649
AddVar	U(0.001,1)	0.0093	0.0086	0.00038	0.0012	0.0068	0.031
AnChnginR	N(0,1)	-0.071	11	0.046	-2	-0.04	1.9
Bunfished	derived	7683	1128	67	6306	7387	10580
Rel B 2011	derived	0.370	0.083	0.0046	0.24	0.35	0.56
20-year projection at ACL:							
Rel B 2031	derived	0.378	0.110	0.0055	0.18	0.37	0.6

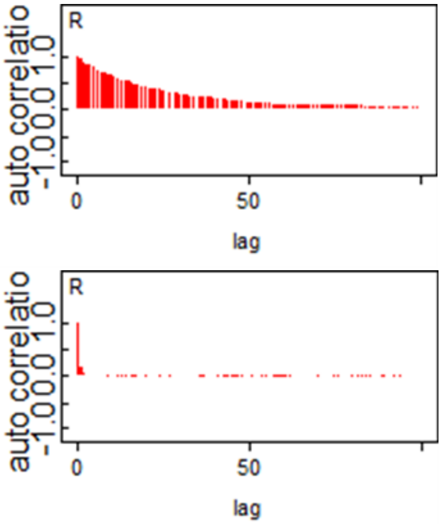

Figure 1. Autocorrelation spectrum of the MCMC chain of OpenBUGS samples. Upper is every 100 samples; Lower shows every 5000 samples (used for analysis).

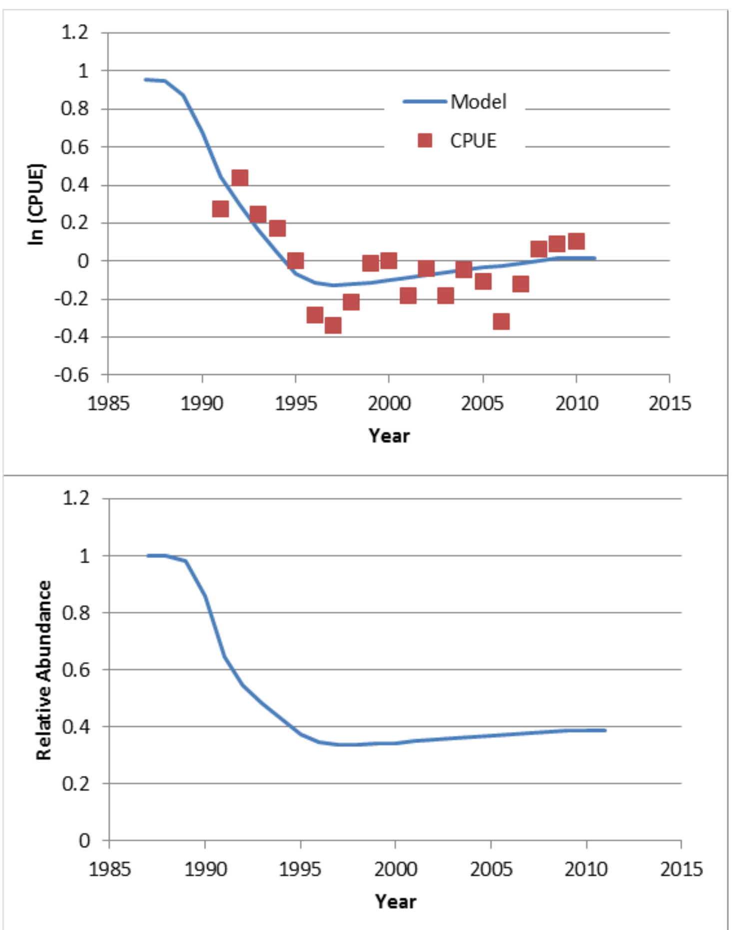

Figure 2. Upper: Model fit (at parameter means) to CPUE on logarithmic scale; Lower: History of abundance relative to unfished abundance.

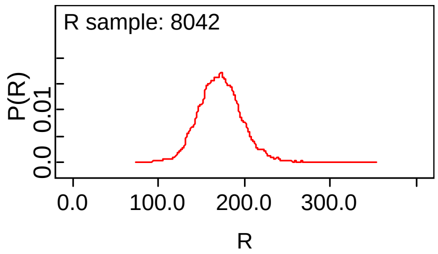

Figure 3. Posterior distribution of annual recruitment (tons).

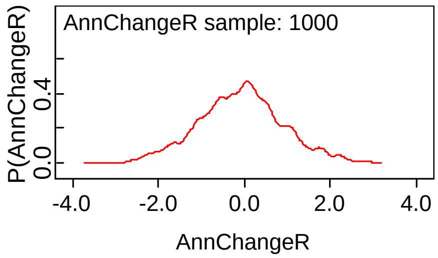

Figure 4. Posterior distribution of annual trend in recruitment (tons/year).

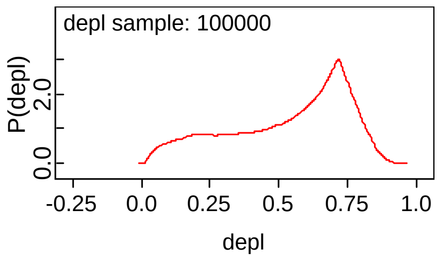

Figure 5. Implicit prior distribution of relative biomass in 2011 (wrongly labeled "depl").

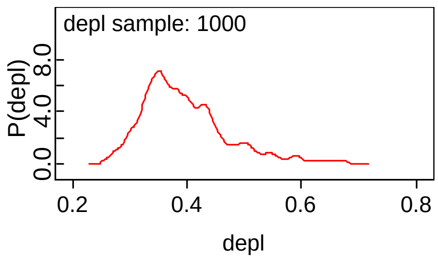

Figure 6. Posterior distribution of relative biomass in 2011 (wrongly labeled "depl").