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Pacific Ocean Perch off Washington and Oregon: Rebuilding Prospects as Assessed in 1998

by

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BACKGROUND

In 1981 the Pacific Fishery Management Council (PFMC) adopted a 20-year plan to rebuild the depleted Pacific ocean perch (*Sebastes alutus*) resource in waters off the Washington and Oregon coast. This plan was based on the results of two studies. The first study employed a cohort analysis of 1966-76 catch and age composition data as a basis for examining various schedules of rebuilding (Gunderson 1979). This report was later updated with four additional years of catch and age information (Gunderson 1981). The second study provided an evaluation of alternative trip limits as a management tool for the Pacific ocean perch fishery (Tagart et al. 1980). Trip limits have been used by the Council (and NMFS) as a means of curbing directed Pacific ocean perch fishing but have had little effect on rebuilding the POP stock in this area. This failure appears to be due to the lack of strong year-classes in recent history.

In this paper, we abstract part of the assessment conducted in 1998 (Ianelli and Zimmermann, 1998) for closer examination of rebuilding strategies for this stock. The 1998 assessment used a stock-recruitment relationship as an integrated part of the age-structured model. This provided estimates of the fishing mortality rate that achieves maximum yield to evaluate compared to the commonly used proxy SPR (spawning biomass per recruit) rates (e.g., $F_{40\%}$). While analyses involving stock-recruitment relationships typically require many assumptions, the integrated model addresses many of the problems (e.g., errors in the estimate of both stock size and recruitment values) and hence may be preferred over other proxy values for F_{msy}.

In the assessment we developed a model that encompasses a greater acknowledgement of uncertainty. For example, we allowed for uncertainty in natural mortality, total catch (by weight) estimates, and in the survey catchability coefficients. We concluded that the reference case adequately envelops the range of uncertainty. This reference case is used for assessing rebuilding strategies.

MODEL DESCRIPTION

As mentioned above, we selected a prior distribution for natural mortality instead of assuming a constant fixed value. Also, we allow selectivity to be a smooth function of age and to vary over time. We assume further that the catchability coefficient for NMFS area-swept biomass estimates may be different than 1.0. Finally, we implement a way to allow uncertainty in the stock-recruitment relationship using an integrated form. We begin with a re-parameterized form of the Beverton-Holt stock recruitment model so that the critical shape parameter has a straightforward biological interpretation.

RESULTS

For perspective, the overall assessment result is reproduced here in Fig. 1. A value of 0.73 was estimated for stock-recruitment steepness. The level of uncertainty about the 1998 stock size is expressed in Fig. 2. The 10th and 90th percentiles occur at about 13,000 and 28,000 tons respectively. This represents a stock size that is very likely to be below the target B_{msy} level (Fig. 3). This figure shows that there is only about 10% chance that the current stock size is above the target level. Further details are discussed in Ianelli and Zimmerman (1998).

Harvest projections

To evaluate the properties of the yield computations we plotted the yield curve relative to values obtained under different spawning biomass-per-recruit (SPR) harvest rates (e.g., $F_{35\%}$). This suggests that for west coast POP, the F_{msy} value is closest to the $F_{35\%}$ level. The actual estimate of uncertainty in the F_{msy} value suggests that the 10th and 90th percentiles are approximately between 0.05 and 0.09 (Fig 4). Since measures of uncertainty are available under the methods developed above, we evaluated the uncertainty in these harvest rates and stock size to project the level of 1999 harvests. These indicate a relatively broad overlap between these values (Fig. 5).

Harvest rates, and associated yields over the next 3 years are presented in the middle part of Table 1. These show some effect of different harvest levels and future stock sizes but only represent the "point estimates" of these outcomes. In our analyses, we performed a Markov-chain Monte Carlo integration scheme to encapsulate the uncertainty in the multivariate parameter space. The values reported from the integration are based on expected values, while the other "point estimates" represent the "modes" or maximum likelihood estimate from the joint probability distributions.

Analyses projecting forward for 11 years (to 2009) showing alternative current stock sizes and outcomes under different harvest policies is presented in Table 2. **This shows that under most policies, the expected value indicates that the target (B_{msy}) will be attained by the year 2009**. I.e., the expected value of the ratio of female spawning biomass in 2009 over B_{msy} is close to 1 (note that these ratios are expressed as percents: $F_{35\%}$ = 98%; $F_{40\%}$ = 104%; F_{msy} = 99%). This is tempered somewhat by displays of the uncertainty in future stock sizes (Figs. 6 and 7). If our harvest proceeds at these levels and the true "state of nature" is a low stock size (rather than the expected value) then the ratio of the 2009 stock size over B_{msy} would only be 63% under F_{msy} harvest levels. This pessimistic view of the stock condition would still result in an expected increase in stock size from the 1998 level of about 54% by the year 2009 (see Table 2).

Over the entire model time period, the reference-case model gave a distribution of spawning biomass estimates expressed in the following figure (with projections assuming F_{msy} harvest rate; with 95% confidence bands):

Let

$$R_i = \frac{S_{i-3}e^{\varepsilon_i}}{\alpha + \beta S_{i-3}}$$

where

R_i is recruitment at age 3 in year i,
S_i is the biomass of female spawners in year i,
ε_i is the "recruitment anomaly" for year i,
α, β are stock-recruitment function parameters.

Values for the stock-recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the "steepness" of the stock-recruit relationship (h). The "steepness" is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992), so that:

$$\alpha = \tilde{B}_0 \frac{1-h}{4h}$$

$$\beta = \frac{5h-1}{4hR_0}$$

where

$\tilde{B}_0$ is the total egg production (or proxy, e.g., female spawning biomass) in the absence of exploitation (and recruitment variability) expressed as a fraction of R_0.

Some interpretation and further explanation follows. For steepness equal 0.2, then recruits are a linear function of spawning biomass (implying no surplus production). For steepness equal to 1.0, then recruitment is constant for all levels of spawning stock size. A value of 0.9 implies that 90% drop in the unfished spawning stock size will result in a 20% drop in the expected value of recruitment. Steepness of 0.9 is a commonly assumed default value for the Beverton-Holt form. Here we assume the expected value of steepness is 0.9 with a 10% coefficient of variation. The prior distribution was assumed to be lognormal within the range 0.2-1.0. Clearly, alternative values could be applied, particularly in the sense of taking the experience among other fish stocks (e.g., Lierman and Hilborn 1997). Since we include a stock-recruitment curve as an integrated part of the assessment, assumptions about prior parameter values are critical, particularly if the data are non-informative. This feature also allows for computation of F_{msy} values and related quantities such as MSY, Bmsy etc. The method we develop for this is described in the appendix.

Analyses of model uncertainty were done three ways. First, for all parameters of interest, approximate variances were computed through the propagation-of-error techniques also known as the Delta method. This method provides an easily computed measure of relative uncertainty among different model parameters but requires assumptions about the shape of the likelihood surface that may be inappropriate. Namely, for the Delta method variance estimates (and those derived from inversion of the Hessian matrix) require that the likelihood surface is quadratic—a condition that holds when the parameters can be shown to be multivariate normally-distributed. To avoid these problems, we performed a Markov-Chain Monte Carlo integration procedure to sample from the "true" posterior probability distribution. This accounts for possible curvature in the likelihood surface amongst parameters and integrates out uncertainty in all dimensions (as opposed to conditional upon, say, maximum likelihood estimates of other so-called "nuisance" parameters). These methods are described in Gilks *et al.* 1996 and in Gelman *et al.* (1996).

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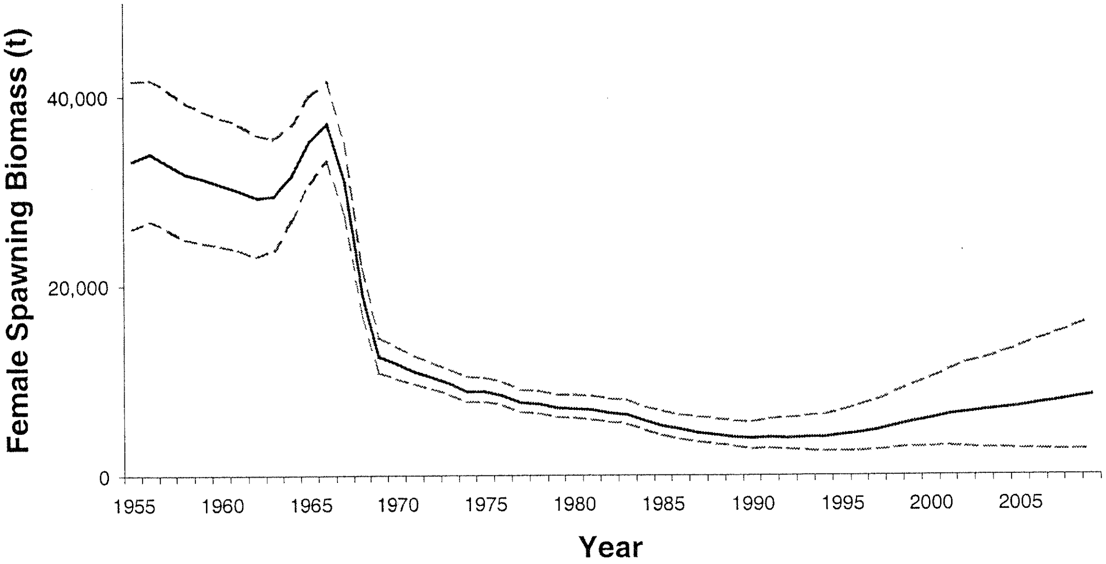
TABLES

Table 1. Summary point estimates of 10-year and 3-year projections presented in Ianelli and Zimmermann (1998).

Stock Condition	Model 1
Projections (based on point estimates)	
2009 Spawning biomass @ $F=0$	11,391
2009 Spawning biomass @ F_{msy}	7,242
2009 Spawning biomass @ $F_{30\%}$	6,427
2009 Spawning biomass @ $F_{40\%}$	7,656
1999 Harvest @ F_{msy}	800
2000 Harvest @ F_{msy}	834
2001 Harvest @ F_{msy}	860
1999 Harvest @ $F_{40\%}$	700
2000 Harvest @ $F_{40\%}$	735
2001 Harvest @ $F_{40\%}$	764



DISCUSSION

We introduced a procedure for estimating F_{msy} and associated yields directly within the larger model. This was included with the other SPR rates for contrast. Importantly, we evaluate our ability to estimate F_{msy} and provide associated levels of uncertainty. We found that the value for F_{msy} occurred at slightly higher values than the normal SPR values (e.g., $F_{35\%}$). However, the trade-off of lower fishing mortality rates represent only small reductions in overall sustainable yields.

Our findings suggest that the current stock level remains low and is about 44% of the target (B_{msy}) stock size. Based on these results, we recommend harvests should remain at minimal levels until substantive stock increases are observed.

For the reference-case model specification we expressed the uncertainty in the form of a decision table (Table 2). The low-mod-high columns of this table represent different hypotheses about the current level of stock size being at low, moderate, or high levels. What seems clear from this is that even with zero fishing mortality, we expect the stock to reach of the target B_{msy} level. Examinations of the probability distributions about this target we conclude that there is a high degree of uncertainty about future stock conditions (e.g., Ianelli and Heifetz 1995).

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FIGURES

Model 1

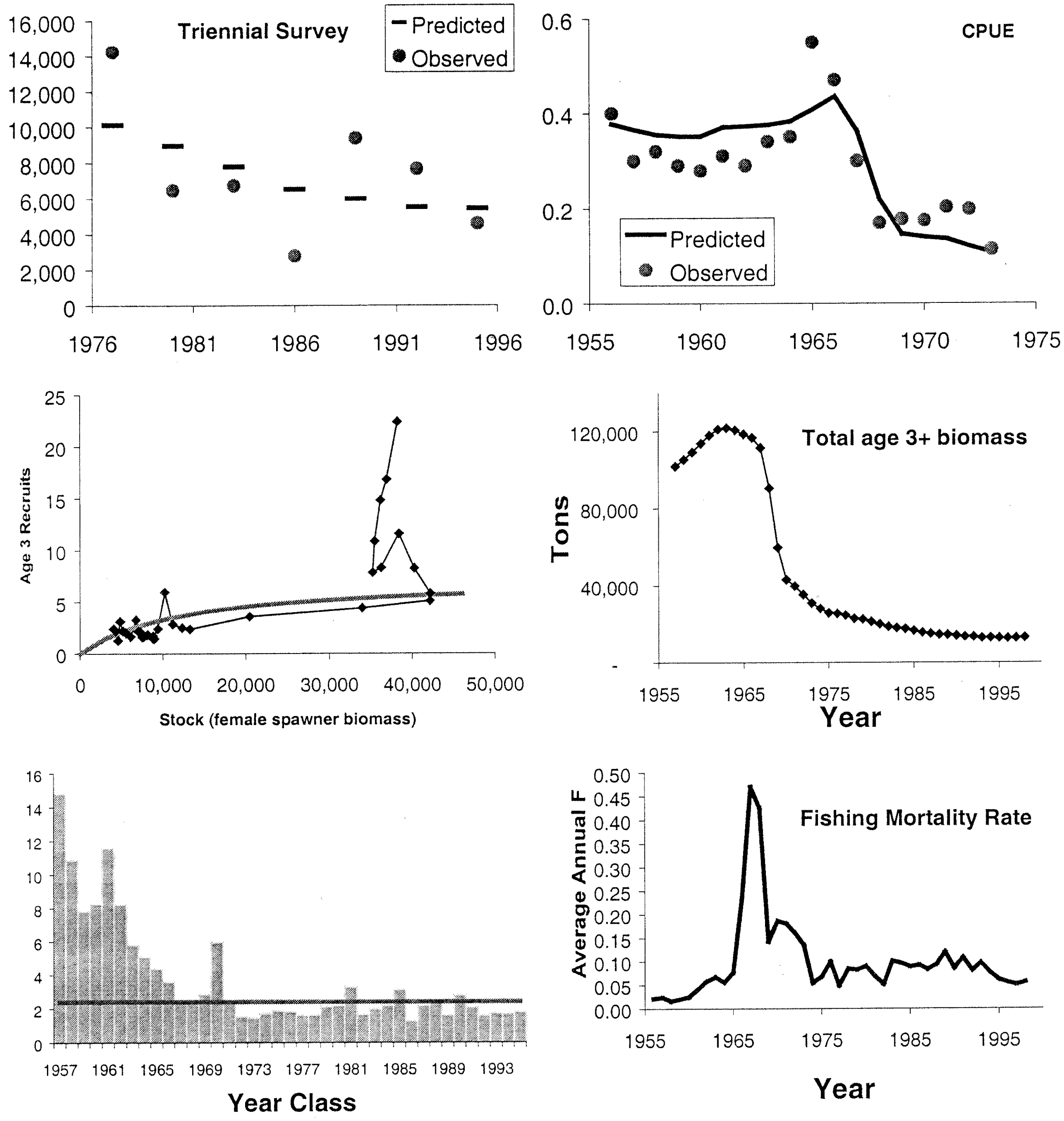

Figure 1. Summary of Model 1 results for Pacific ocean perch.

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Table 2. Decision table showing outcomes of alternative harvest rate applications (rows) by different 1998 stock size hypotheses (columns). The labels low, mod, and high represent the lower, middle, and upper third quantile of the 1998 stock size. For these columns, the values shown represent the expected outcome within that quantile.

1998 Stock Size			
Low	Mod	High	Expected Value
3,970	5,384	7,275	5,543

Policy	1999 Harvest (tons)
F=0	0
Fmsy	794
F40	695
F35	834
F30	1,007

	2009 Stock Size			
Policy	Low	Mod	High	Expected Value
F=0	10,160	12,966	16,295	13,140
Fmsy	6,097	8,940	12,299	9,112
F40	6,500	9,338	12,694	9,511
F35	5,942	8,786	12,146	8,958
F30	5,307	8,158	11,523	8,329

	Ratio 2009 / 1998 Stock Size			
Policy	Low	Mod	High	Expected Value
F=0	256%	241%	224%	237%
Fmsy	154%	166%	169%	164%
F40	164%	173%	174%	172%
F35	150%	163%	167%	162%
F30	134%	152%	158%	150%

	Ratio 2009 / Bmsy			
Policy	Low	Mod	High	Expected Value
F=0	105%	142%	186%	143%
Fmsy	63%	98%	140%	99%
F40	67%	102%	145%	104%
F35	62%	96%	138%	98%
F30	55%	89%	131%	91%

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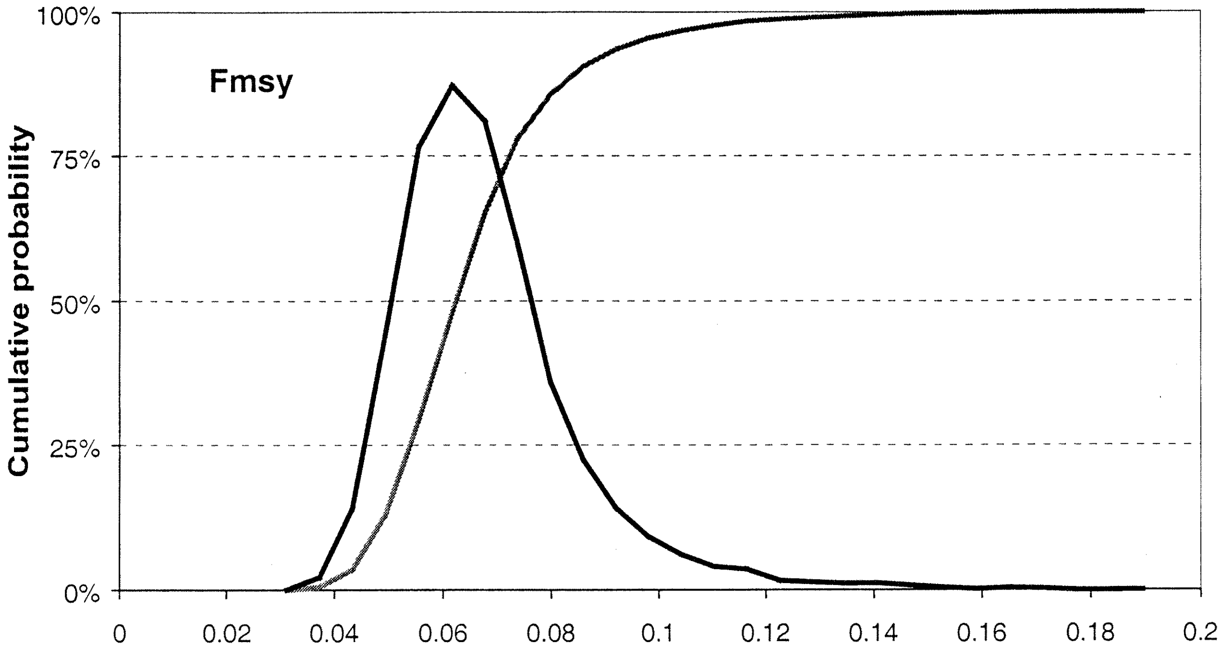

Figure 4. Estimated probability distribution for Model 1 F_{msy} level based on the MCMC integration for POP.

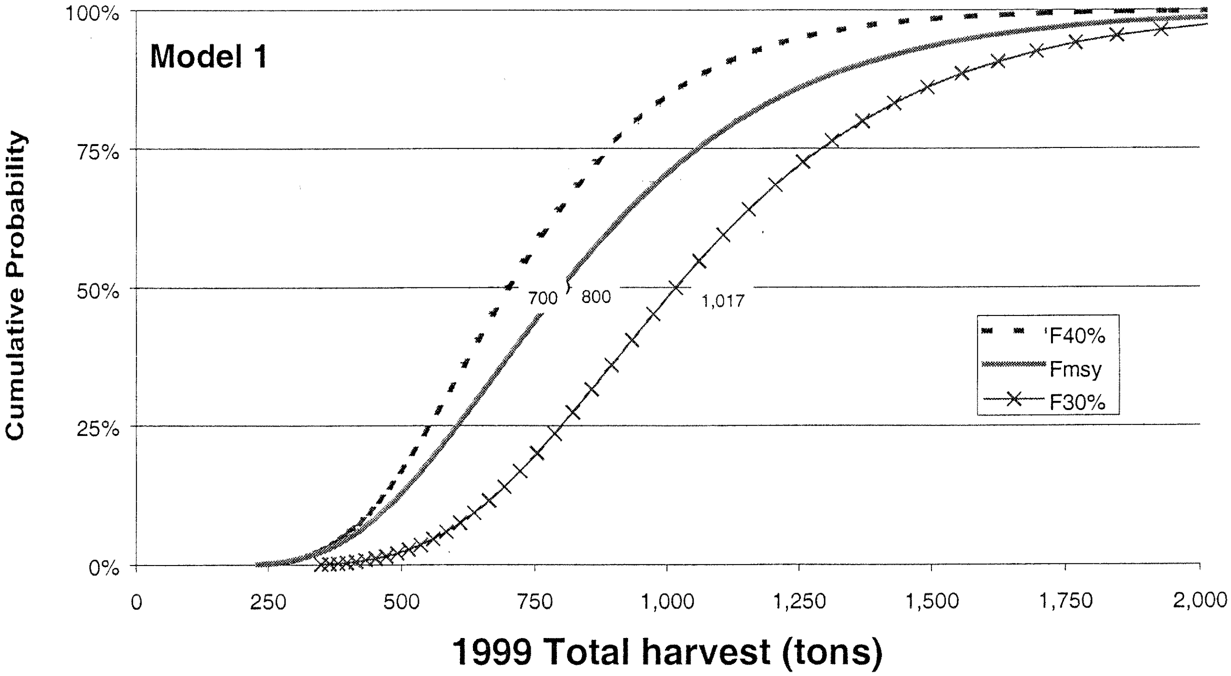

Figure 5. Cumulative probability distribution of 1999 POP yield under different harvest rates, Model 1.

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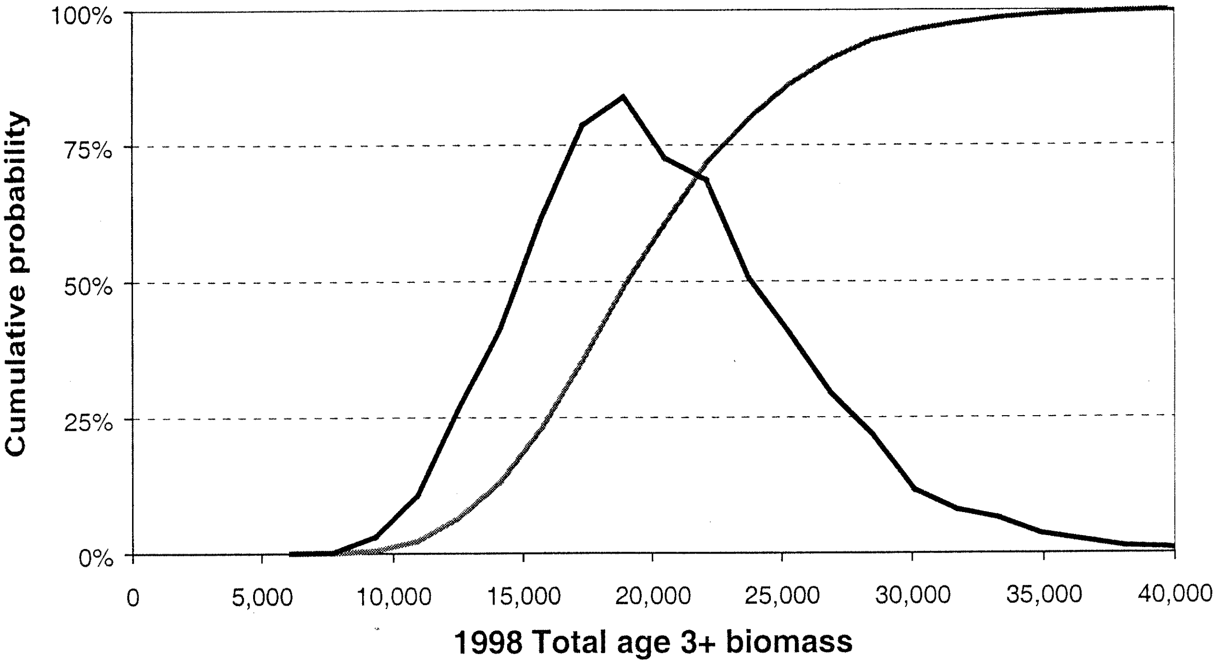

Figure 2. Estimated 1998 POP stock size probability distribution for Model 1. MCMC integration was used to obtain this marginal distribution (Gilks *et al.* 1996).

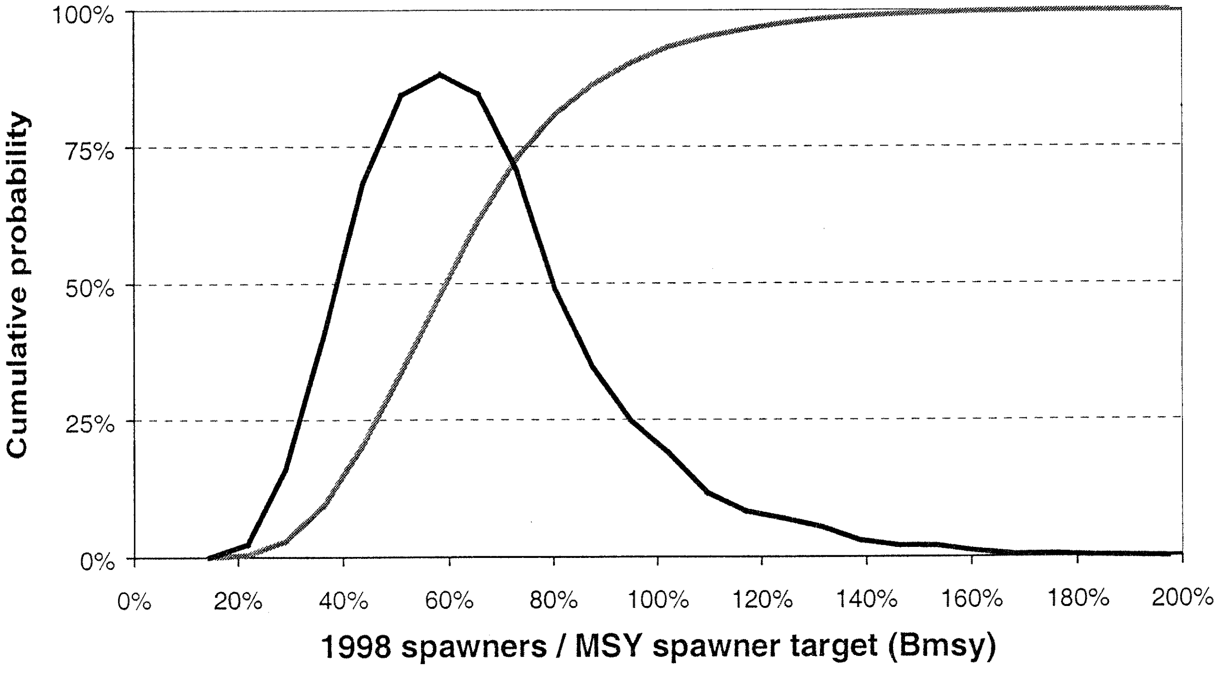

Figure 3. Estimated probability distribution for Model 1 current POP spawning biomass over the MSY target spawning biomass level. MCMC integration was used to obtain this marginal distribution (Gilks *et al.* 1996).

Appendix Solving for F_{msy} in an integrated model context

Recruitment in year i is given by

$$R_i = \frac{S_{i-3}e^{\varepsilon_i}}{\alpha + \beta S_{i-3}}$$

where

R_i is recruitment at age 3 in year i,

S_i is the biomass of female spawners in year i,

ε_i is the "recruitment anomaly" for year i,

α, β are stock-recruitment function parameters.

Since ϕ (see below) is the expected female spawning biomass produced by a single recruit, then at equilibrium we have

$R_{eq} = \dfrac{R_{eq}\phi}{\alpha + \beta R_{eq}\phi}$. Solving for R_{eq} gives $R_{eq} = \dfrac{(\phi - \alpha)}{\beta\phi}$ with

$$\phi = 0.5\sum_{j=3}^{25+} W_j N_j s_j f_j$$

$$N_j = 1 \qquad j = 3$$

$$N_j = N_{j-1}s_{j-1} \qquad 3 \le j \le 25$$

Note that the survival rate, s_j, and proportion mature, f_j, are age specific. Equilibrium yield (Y) is computed for a given exploitation rate (F), giving $Y = F \cdot \overline{B}$ where $\overline{B}$ is the average equilibrium exploitable biomass. Solving for the MSY simply involves determining the exploitation rate where yield is maximized. Analytical methods are commonly used to find this value by taking the first derivative with respect to F, setting the result equal to zero, and solving for F. Unfortunately, such analytical methods are not readily available for common forms of stock-recruitment functions used in fisheries with non-trivial age-specific selectivities. Here we implement a numerical method which solves for MSY and can be applied to a broad family of models. The method implements the Newton-Raphson technique for finding the root of an equation (here, the first derivative of yield). The steps are outlined as:

1) pick a trial F and evaluate the equilibrium yield, $f(F)$;
2) compute the first and second derivatives of yield wrt F;
3) update original trial F from 1) by subtracting the ratio $\dfrac{f'(F)}{f''(F)}$
4) repeat steps 1) – 3) a fixed number of times so that the final adjustment in step 3) is very small. Note, convergence is usually implemented through the use of some sort of tolerance level. However, in our case we wish maintain differentiability, therefore we use a fixed number of iterations.

In practice, finite difference approximations for the derivatives given above appear to work satisfactorily which further improves one's ability to implement this type of algorithm. That is, let $f'(F) = \dfrac{f(F+d) - f(F-d)}{2d}$ and $f''(F) = \dfrac{f(F+d) - 2f(F) + f(F-d)}{d^2}$ where d is some small value, say $1\text{x}10^{-7}$.

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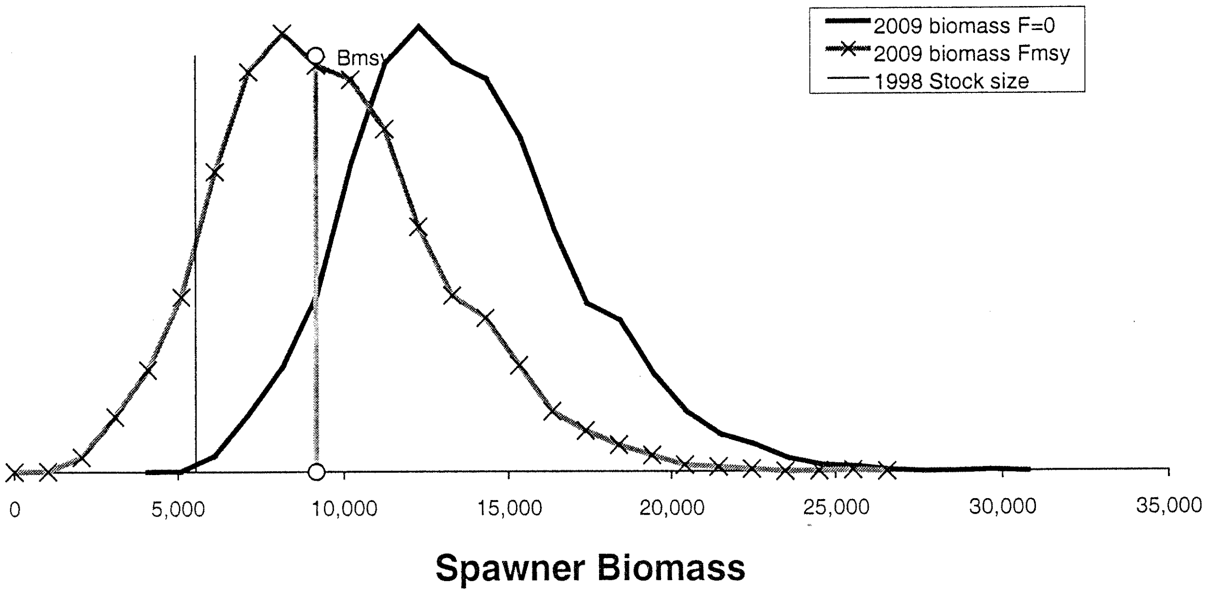

Figure 6. Probability distributions of projected POP female spawning biomass in the year 2009 under F_{msy} harvest compared to F=0 harvests. Vertical lines are reference points.

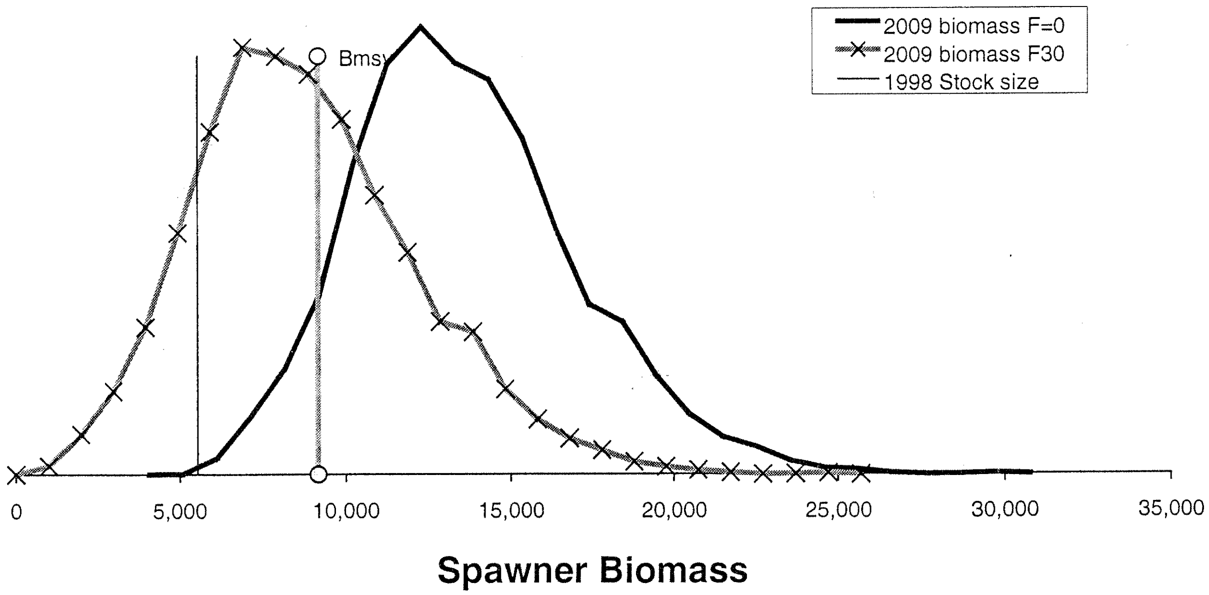

Figure 7. Probability distributions of projected POP female spawning biomass in the year 2009 under $F_{30\%}$ harvest compared to F=0 harvests. Vertical lines are reference points.