C. Application of Index Methods: Catch and Fishery Independent Abundance Surveys

OVERVIEW

Despite an unmatched time series of synoptic research vessel-based surveys, the ability to apply age-based assessment models to marine finfish stocks in the Northeast USA is limited by the number of years for which age samples are available. Typically this means that such assessments are restricted to time periods beginning in the late 1970's or early 1980's. In many instances, severe overfishing of the resource has already occurred, and the information content of the available series may be problematic for the establishment of biomass reference points. In these situations, it is desirable to apply methods that can incorporate historical catch information, thereby avoiding a myopic perspective on resource conditions. In this report, a number of index-based approaches are developed to more fully utilize the data sets from the surveys and historical landings. The methods are technically simple but are based on linear population models, modern graphical methods, and robust statistical models. The concept of a replacement ratio is introduced here as an analytical tool for examining the historical behavior of a population and any potential influence of removals due to fishing activities.

To test these concepts and to facilitate comparisons, the analyses were applied to both the aged and un-aged stocks. Index-based methods for reference point estimation were considered in light of the specific goal of identifying the limit relative fishing mortality rate (relF) that is associated with stock replacement, in the long term. The replacement ratio method was applied to revise estimates of F proxies for six stocks: Gulf of Maine haddock, Mid-Atlantic yellowtail flounder, pollock, northern and southern windowpane, and ocean pout. In some cases, biomass proxies and MSY values were also updated for these stocks. Catch forecasts are developed for all of the 19 stocks considered as part of the Northeast multispecies groundfish complex. For a limited number of stocks, index-based forecasts are compared to age-based estimates. The proposed methodology was applied to summer flounder and scup as an adjunct to the analyses prepared by the respective subcommittees for these species for SARC 35.

Index-based approaches can be viewed as important tools for the identification and development of parametric models of stock dynamics. Additional simulation work is necessary to support the theoretical basis for the method and the limits of its applicability.

INTRODUCTION

One of the core problems in fisheries science is the estimation of the scaling factor between estimates of relative abundance and true population size. This scaling factor is generally called the catchability coefficient. Assessment models that rely on VPA utilize the record of age-specific catches to approximate the virtual population. The utility of the virtual population as a means of estimating catchability rests on assumptions that the losses due to fishing are both known and large relative to natural mortality.

Age-structured assessments are data intensive and their scope is restricted to years in which both catch and abundance indices can be aged. Such restrictions can greatly reduce the number of the number of years available for analyses. For Northeast USA stocks this often precludes consideration of large-scale reductions in abundance coincident with the presence of distant water fleets in the 1960's and early 1970's.

Reduced-parameter models are often used to analyze non-age structured models. The most common example is the surplus production model (see Prager 1994 for review and modern approaches) but the Collie-Sissenwine model (Collie and Sissenwine 1983), and delay-difference models (Schnute 1985) are also candidates. Even these simple models may fail when the dynamic range of population responses and/or fishing mortality rates is small (Hilborn and Walters 1993). For example, a time series characterized by continuously declining abundance indices contains relatively little information about the productive capacity of that stock. Under these circumstances the maximum population biomass (K) is estimable only if it assumed that the initial population size represents an unfished stock. This assumption is rarely tenable for Northwest Atlantic stocks that have been fished for hundreds of years and monitored since 1960.

The Collie-Sissenwine model replaces a structural model for biomass dynamics with a sequence of recruitment estimates and simple mass balance equation. The increased parameterization may lead to instability in the catchability coefficient and therefore, population estimates. As in delay-difference models, poorly specified growth parameters and sampling variability can greatly influence the ability to estimate abundance. Even the simplest parametric models may be difficult to fit to data characterized by large observation errors.

In this report we explore the general trends in abundance and fishing mortality deducible from a time series of catch (or landings for some species) and survey indices. For all stocks, only the total catch (mt) and autumn and spring research trawl survey indices (kg/tow) are utilized. We explore the relative fishing mortality rate, defined as the ratio of catch to survey index, and relate it to what we call the replacement ratio. The replacement ratio is introduced here as an analytical tool for examining the historical behavior of a population and any potential influence of removals due to fishing activities. To test these concepts and to facilitate comparisons, the analyses were applied to both the aged and un-aged stocks.

REPLACEMENT RATIO THEORY

The replacement ratio draws from the ideas underlying the Sissenwine-Shepherd model, delay-difference models, life-history theory, Collie-Sissenwine model, and statistical smoothing (Simonoff 1996). We begin by defining $\mathbf{I}_{j,s,t}$ as the j-th relative abundance index for species-stock unit s at time t and $\mathbf{C}_{s,t}$ as the catch (or landings) of species-stock unit s at time t. The simple relative fishing mortality rate with respect to index type j, stock s and time t is defined as the ratio of $\mathbf{C}_{s,t}$ to $\mathbf{Ij}_{s,t}$. This ratio can be noisy, owing to imprecision of survey estimates, and the variation can be damped by writing the relative F as a ratio of the catch to some average of the underlying indices. Following the recommendation of the previous reference point panel review team (Applegate et al. 1998), relative F is defined as the ratio of catch in year t to a centered 3-yr average of the survey indices:

$$relF_{j,s,t} = \frac{C_{s,t}}{\left(\frac{I_{j,s,t-1}+I_{j,s,t}+I_{j,s,t+1}}{3}\right)} \qquad (1)$$

Note that under this definition, the estimates of relative F for the first and last years of a time series are based on only 2 years of data.

Noise in the survey indices also affects the ability to relate inter-annual changes in abundance estimates to removal from fishing. The general approach of averaging adjacent years to estimate current stock size underlies statistical smoothing procedures (e.g., LOWESS) as well as formal time series models (e.g., ARIMA methods). One of the difficulties of applying such approaches in the present context, is that the derived parameters, if any, are unrelated to the species' biology or any aspect of the fishery. Moreover, we are interested in a basic questions of whether the current stock is replacing itself and whether the current level of catch is too high or low. Population dynamics models usually come to the rescue and allow approximate answers to these questions. However, if age-structure models cannot be applied, and more importantly, if the recent history of the fishery is uninformative, then most mathematical models will fail. The underlying reasons for model failure may not be immediately obvious from analysis of standard diagnostic measures. Of greater concern is the issue of the model mis-specification, wherein an inappropriate model adequately fits the data but leads to deductions inconsistent with basic biology and the fishery. The proposed replacement ratio is a "data-based" technique relying on fewer assumptions. No technique however, can fully compensate for model mis-specification errors.

If we assume that the survival from eggs to the juvenile stage is largely independent of stock size, then the number of recruits will be proportional to stock size. Locally, (i.e, in the neighborhood of a given stock size) this assumption holds for any stock-recruitment function. Since a population is a weighted sum of recruitment events, the interannual change in total stock size tends to be small relative to the total range of stock sizes (at least in the Northeast USA). Recruitment in any year is likely to be small relative to the biomass of the total population. Thus, the change in total biomass is likely to be small relative to the change in annual recruitment. Although the mathematics are more complicated than this ,the argument is based on the premise that if Var(x/1) = F^2 then Var(Ex/n) F^2 /n. Of course, the magnitude of such changes depends on the variation of recruitment and the magnitude of fishing mortality.

Using the linearity assumption defined above, we can employ basic life history theory to write abundance at time t as a function of the biomasses in previous time periods. The number of recruits at time t ($\mathbf{R_t}$) is assumed to be proportional to the biomass at time t ($\mathbf{B_t}$). More formally,

$$R_t = S_o \, Egg \, B_t \qquad (2)$$

where **Egg** is the number of eggs produced per unit of biomass, and $\mathbf{S_o}$ is the survival rate between the egg and recruit stages. Survival for recruited age groups at age a and time t ($\mathbf{S_{a,t}}$) is defined as

$$S_{a,t} = e^{-F_{a,t} - M_{a,t}} \qquad (3)$$

where F and M refer to the instantaneous rates of fishing and natural mortality, respectively. We also need to consider the weight at age a and time t ($\mathbf{W_{a,t}}$) and the average longevity (A) of the species
Using these standard concepts we now write the biomass at time t as a linear combination of the **A** previous years. Without loss of generality, we can drop the subscripts on the survival terms and assume that average weight at age is invariant with respect to time. Further, set the product $\mathbf{S_o}$ **Egg** equal to the coefficient **"**.
The biomass at time t can now be written as

$$B_t = R_{t-1}S^1W_1 + R_{t-2}S^2W_2 + R_{t-3}S^3W_3 + .. + R_{t-(A-1)}S^{A-1}W_{A-1} + R_{t-A}S^AW_A \quad (4)$$

Substituting Eq. (2) into Eq. (4) leads to

$$B_t = \alpha B_{t-1}S^1W_1 + \alpha B_{t-2}S^2W_2 + \alpha B_{t-3}S^3W_3 + .. + \alpha B_{t-(A-1)}S^{A-1}W_{A-1} + \alpha B_{t-A}S^AW_A \quad (5)$$

Dividing the left hand side of Eq. (5) by the right hand side specifies the identity

$$1 = \frac{B_t}{\alpha B_{t-1}S^1W_1 + \alpha B_{t-2}S^2W_2 + \alpha B_{t-3}S^3W_3 + .. + \alpha B_{t-(A-1)}S^{A-1}W_{A-1} + \alpha B_{t-A}S^AW_A} \quad (5a)$$

In a steady state, non-growing population, $B_t = B_{t-1} = ... = B_{t-n}$ for all values of n. Therefore all of the biomass terms drop out of Eq. (5a) leading to:

$$1 = \alpha S^1 W_1 + \alpha S^2 W_2 + \alpha S^3 W_3 + .. + \alpha S^{A-1} W_{A-1} + \alpha S^A W_A \quad (5b)$$

If we write N_j = " $S^j W_j$ then Eq. (5b) implies that

$$1 = \sum_{j=1}^{A} \phi_j \qquad (5c)$$

Moreover, since all of the component terms of N_j i.e., " S^j W_j are all positive non-zero values, Eq. (5c) also implies that all N_j terms are less than or equal to one. Finally, Eq. 5 to 5c imply that the biomass at time t must be a moving average of the previous biomasses whose offspring comprise the population at time t. Equations 5-5c further imply that coefficients can be written in terms of basic life history and fishery parameters. In particular, if one writes $F_{a,t}$ as the product of age specific partial recruitment and a fishing mortality rate, say F_{max}, then the N_j terms serve as a explicit empirical test of the assumption that the population trajectory is shaped by an optimal fishing mortality rate. Writing N_j = " $S^j W_j$ = S_o Egg $S^j W_j$ and substituting these terms into Eq. (5c) leads to:

$$S_o = \frac{1}{\sum_{j=1}^{A} Egg\ S^j\ W_j} \qquad (5d)$$

Eq. 5d is similar to the expression derived by Vaughan and Saila (1976) for the solution of the first year survival terms in a Leslie matrix model. The parameter S_o represents the survival rate from the egg to the age at recruitment. It also serves as the primary scaling factor for the Leslie matrix model in which the dominant eigenvalue is defined as one.

Populations are probably never at equilibrium but the relevant question is whether the departures from equilibrium are important. The structural smoothing equation proposed above constitutes an explicit hypothesis of the age-specific weighting factors that would shape a population at equilibrium.

We can now explicitly test the hypothesis that the population is at equilibrium by substituting observed indices of abundance into the equilibrium model (Eq. 5a). If the index of abundance I_t is proportional to abundance B_t we can write $\mathbf{I_t = q\, B_t}$ where **q** is the catchability coefficient. Substituting this relationship into Eq. 5a results in expression that we have called the replacement ratio Q_t

$$\Psi_t = \frac{\frac{I_t}{q}}{\alpha \frac{I_{t-1}}{q} S^1 W_1 + \alpha \frac{I_{t-2}}{q} S^2 W_2 + \alpha \frac{I_{t-3}}{q} S^3 W_3 + .. + \alpha \frac{I_{t-(A-1)}}{q} S^{A-1} W_{A-1} + \alpha \frac{I_{t-A}}{q} S^A W_A} \quad (6)$$

By noting that the q's cancel out, and letting N_j = " $S^j W_j$, Eq. 6 simplifies to

$$\Psi_t = \frac{q\, I_t}{\sum_{j=1}^{A} \phi_j\, q\, I_{t-j}} \qquad (7)$$

Under the null hypothesis that the population is at equilibrium and not growing, Eq. (6) can be used as a measure of population trend. If the coefficients of the moving average are explicitly defined as from externally derived parameters (i.e., S_o, Egg, F_{TARGET}, M, PR_j, W_j) then replacement ratio $\mathbf{Q_t}$ can be used as an explicit test of the equilibrium assumption. Deviations from $\mathbf{Q_t}$ =1 imply either violations of the assumptions embedded in the estimated $\mathbf{N_j}$ weighting terms, measurement variability in the abundance indices I_t, or wide variations in recruitment. Over time, deviations attributable to either measurement error or recruitment are less important than those attributable of variations in the component terms of $\mathbf{N_j}$. The most important of these terms is fishing mortality.

<u>Considerations on the Applicability of the Replacement Ratio</u>

1) Under the assumption that recruitment is proportional to abundance $\mathbf{R_t = S_o\, Egg\, B_t}$, and that $\mathbf{S_o}$ and **Egg** are constants, the population will decline when F increases above its nominal value and increase when F is below its nominal level. Thus $\mathbf{Q_t}$ will be a decreasing function of F and will equal 1 when $F=F_{TARGET}$.

2) If recruitment is assumed to be constant then R_t = R, and the behavior of the replacement ratio will be fundamentally different. Increases in F will induce an initial reduction in $\mathbf{Q_t}$ as the population declines to a new equilibrium level consistent increased value of F. However, as the population approaches this new equilibrium level, the replacement ratio will once again approach unity. Conversely, a reduction in F will induce an increase in population size and a transient increase in $\mathbf{Q_t}$ followed by a gradual return to one as the population approaches its new equilibrium level associated with the decreased value of F. For these cases, the relationship between $\mathbf{Q_t}$ and relF would consist of multiple stable points. The replacement ratio will be one for multiple levels of relF. Values of $\mathbf{Q_t}$ above or below one would be attributable to transient population states as the population moves to its new equilibrium point. It should be noted that the assumption of constant recruitment, irrespective of stock size, invokes the most extreme form of density dependence possible. Constant recruitment implies that the R/SSB ratio approaches infinity at the stock size (SSB) approaches zero. Consistent trends in F, from low to high or vice versa, would tend to maintain the transient behavior in the replacement

ratio for longer periods. Therefore, the relationship between $\mathbf{Q}_t$ and relative F would approximate that observed in paragraph **1)**.

3) The behavior of the replacement ratio in situations where the underlying stock recruitment function invokes varying degrees of compensation (say a Beverton-Holt relation), will be intermediate between behaviors described in paragraphs **1)** and **2)** above. If the stock is near carrying capacity then deviations from an average level of recruitment will be small. For this situation, the behavior of the replacement ratio will be similar to that described in paragraph **2)**. When the population is small relative to the level that produces maximum or near maximum levels of recruitment, the behavior of $\mathbf{Q}_t$ and its relationship to relative F should be similar to that described in paragraph **1)**. The ability to distinguish between the behaviors in $\mathbf{Q}_t$ induced by simultaneous changes in F or constancy in recruitment (as the population increases toward some designated level), will be difficult.

4) Many, if not most, of the stocks in the Northeast are at relatively low levels of abundance and have experienced, until recently, extended periods of increasing fishing mortality. If the populations are controlled by some form of density-dependent stock recruitment function, it is likely that the recruitment is nearly linear in the vicinity of the current stock size. Under these conditions it is expected that the relationship between $\mathbf{Q}_t$ and relF should be similar to that described in paragraph **1)**.

5) For stocks that are approaching carrying capacity or the some value at which recruitment becomes nearly constant (e.g., Georges Bank yellowtail flounder), the utility of the derived value of the relF at replacement is compromised. In this circumstance, a piecewise examination of the data may be instructive.

<u>Appropriate Number of Terms in Moving Average</u>

The survival term $\mathbf{S}^j$ is equivalent to the $\mathbf{l}_x$ term in the Euler-Lotka equation for population growth ($\mathbf{l}_x$ is the probability of surviving to age x). For high levels of fishing mortality the $\mathbf{S}^j$ term is decreasing faster than the average weight $\mathbf{W}_j$ is increasing. Thus the importance of earlier indices rapidly diminishes. All of the $\mathbf{I}_t$ and $\mathbf{N}_j$ terms are positive, and at equilibrium, $\mathbf{I}_t$=$\mathbf{I}_{t+1}$ and $\mathbf{I}_t = G\,\mathbf{N}_j\,\mathbf{I}_{t-j}$ both hold. Therefore, $G\,\mathbf{N}_j = 1$ and all of the $\mathbf{N}_j > 0$. It would be desirable to express each of the $\mathbf{N}_j$ weighting terms as function of the underlying population parameters. As expected, increases in fishing mortality increase the weight to more recent indices, whereas the converse hold for lower fishing mortality rates. As an approximation for this initial analyses, we assumed that all of the $\mathbf{N}_j = \mathbf{N}$ which implies that $\mathbf{N} = 1/\mathbf{A}$.

Given the high rate of fishing mortality observed in Northeast stocks, we further assumed that A=5 was a valid approximation. Note that even moderate levels of fishing mortality imply low $\mathbf{N}_j$ values beyond the fifth term. (e.g., F=0.5, M=0.2 imply $S^5 = 0.03$. For the fifth to be important the ratio of the weights between the youngest and oldest ages would have to be greater than $1/S^5$ which, for this example, would exceed 33. As a first approximation, we defined $\mathbf{N}_j$ =1/5 for all j. Thus Eq. 7 becomes the ratio of the current index to the average of the 5 previous years.

A limited amount of testing was conducted to evaluate the applicability of the 5 term smoothing model. For several stocks it was possible to examine the relationship between spawning stock biomass and recruits derived from long series of data. These stocks included Georges Bank haddock (1931-2000), redfish (1952-2000), Georges Bank yellowtail flounder (1963-2000), Southern New England yellowtail flounder (1963-2000), and Gulf of Maine cod (1963-2000). Cross correlation analyses of the relationship between SSB and recruits suggested statistically significant correlations at lags of 1 to 5 years for SNE yellowtail flounder and GB yellowtail flounder, and lags of 1 to 8 years for GB haddock (see Fig. 3.1 to 3.4). Interestingly, the cross correlations between SSB and recruits for redfish first become significant at about 7 years lag. Correlations with lags between 6 and 10 yr approach the statistically significant threshold, suggesting that the lags underlying the fit of the model can be "recovered" using standard statistical techniques. This bodes well for additional analyses of the replacement ratio and implementation of more formal methods of model identification.

As a elementary test of this principle, linear regression was used to fit a zero intercept model of the form: SSB(t)=aR(t-1) +b R(t-2) + c R(t-3) + d R(t-4) +e R(t-5) to the Georges Bank haddock stock.

Effect	Lag	Coefficient	Lower	< 95%>	Upper
R1	1	0.209809	0.097675		0.321944
R2	2	0.219194	0.101660		0.336728
R3	3	0.376315	0.259659		0.492971
R4	4	0.253541	0.135948		0.371133
R5	5	0.206456	0.094681		0.318231

The unweighted mean of the coefficients is 0.252 and more importantly, there seems to be little variation in the magnitude of the coefficients with this range of lags. Hence the assumption that the $\mathbf{N}_j$ = $\mathbf{N}$ ~ 1/**A** is partially satisfied. Further simulation testing of this property is warranted.

A similar analyses with redfish was also conducted, but the lags of 6 to 10 years were used to account for the pattern observed in the cross correlation plot (i.e., SSB(t)=aR(t-6) +b R(t-7) + c R(t-8) + d R(t-9) +e R(t-10)). Results shown below, suggest that an assumption of equal weighting within the replacement ratio may be a reasonable working hypothesis.

Parameter	Lag	Estimate	A.S.E.	Param/ASE	Lower	< 95%> Upper
R6	6	0.237457	0.069769	3.403497	0.095512	0.379403
R7	7	0.253191	0.071008	3.565651	0.108723	0.397658
R8	8	0.412828	0.100267	4.117281	0.208833	0.616823
R9	9	0.379631	0.099645	3.809814	0.176901	0.582361
R10	10	0.376568	0.098226	3.833696	0.176726	0.576410

RELATION BETWEEN REPLACEMENT RATIO AND RELATIVE F

Application of any smoothing technique reflects a choice between signal and noise (Rago 2001) A greater degree of smoothing eliminates the noise but may fail to detect true changes in the signal. Given the abrupt changes in fishing mortality that have occurred in some Northeast stocks, we chose to utilize the current year in the numerator of the replacement ratio. Use of the current index in the numerator rather than a running average of say k years, increases the sensitivity of the ratio to detect such changes. The penalty for such sensitivity is that the proportions of false positives and false negative responses increase. This penalty was judged acceptable for two reasons. First, it is desirable to detect abrupt changes in resource condition given the magnitude of recent and proposed management regulations. Second, the current formulation of the replacement ratio has a natural relationship to stock-recruitment hypotheses and the ratio can be investigated as a function of variations in underlying parameters, especially survival. Alternative formulations of the replacement ratio, say with a 2-yr average population size in the numerator can be developed, but their basic properties have not been investigated.

When fishing mortality rates exceed the capacity of the stock to replace itself the population is expected to decline over time. The expected behavior of $\mathbf{Q}_t$ under varying fishing mortality and recruitment is complicated, but it will have a stable point = 1 when the fishing mortality rate is in balance with recruitment and growth. Variations in fishing mortality will induce complex patterns, but in general terms, $\mathbf{Q}_t$ will exceed 1 when relative F is too high, and will be below 1 when F is too low. To account for these general properties and to reduce the influence of wide changes in either $\mathbf{Q}_t$ or the relative F, we applied robust regression methods (Goodall 1983) to estimate the relative F corresponding to $\mathbf{Q}_t$ =1. The parameters of the regression model were estimated by

$$\ln(\Psi_t) = a + b \ln(relF_t) \quad (8)$$

minimizing the median absolute deviations. Median Absolute Deviation estimators are known as MAD estimators in the statistical literature (eg. Mosteller and Tukey 1977). Residuals were down weighted using a bisquare distribution in which the sum of the MAD standardized residuals was set to 6. This roughly corresponds to a rejection point of about plus or minus two standard deviations from the mean. (Goodall 1983).

The relative F at which $\mathbf{Q}_t$ = 1 was estimated from Eq. 8. as

$$relF_{threshold} = e^{-a/b} \quad (9)$$

where the estimates of **a** and **b** from Eq. 8 were substituted into Eq. 9. This derived quantity may be appropriately labeled as a threshold since values in excess of it are expected to lead to declining populations. Alternatively, populations are expect to increase when $\mathbf{relF_t} < \mathbf{relF_{threshold}}$. Employing the general standard that managers should attempt to rebuild fish stocks within 10 years, we estimated the relative fishing mortality rate at which the expected value of $\mathbf{Q_t}$ = 1.1 as a measure of $\mathbf{relF_{target}}$. Applying a little algebra to the Eq. 8 leads to the following estimator of $\mathbf{relF_{target}}$:

$$relF_{target} = e^{\frac{0.09531 - a}{b}} \qquad (10)$$

The asymptotic standard errors of $\mathbf{relF_{threshold}}$ and $\mathbf{relF_{target}}$ were derived from the Hessian matrix of the regression model.

RANDOMIZATION TESTS

The usual tests of statistical significance do not apply for the model described in Eq. 8. The relation between $\mathbf{Q_t}$ and $\mathbf{relF_t}$ is of the general form of Y/X vs X where X and Y are random variables. The expected correlation between Y/X and X is less than zero and is the basis for the oft stated criticism of spurious correlation. To test for spurious correlation we developed a sampling distribution of the correlation statistic using a randomization test. The randomization test is based on the null hypothesis that the catch and survey time series represent a random ordering of observations with no underlying association. The randomization test was developed as follows:

1. Create a random time series of length **T** of $\mathbf{C_{r,t}}$ from the set $\{\mathbf{C_t}\}$ and $\mathbf{I_{r,t}}$ from the set $\{\mathbf{I_t}\}$ by sampling with replacement.

2. Compute a random time series of relative F ($\mathbf{relF_{r,t}}$) and replacement ratios ($\mathbf{Q_{r,t}}$)
3. Compute the r-th correlation coefficient, say $\mathbf{D_r}$ between ln($\mathbf{relF_{r,t}}$) and ln($\mathbf{Q_{r,t}}$).
4. Repeat steps 1 to 3 1000 times.
5. Compare the observed correlation coefficient $\mathbf{r_{obs}}$ with the sorted set of $\mathbf{D_r}$
6. The approximate significance level of the observed correlation coefficient $\mathbf{r_{obs}}$ is the fraction of values of $\mathbf{D_r}$ less than $\mathbf{r_{obs}}$

It should be emphasized that relF is not necessarily an adequate proxy for Fmsy, since this parameter only estimates the average mortality rate at which the stock was capable of replacing itself. Thus, while relF defined as average replacement fishing mortality is a necessary condition for an F_{msy} proxy, it is not sufficient, since the stock could theoretically be brought to the stable point under an infinite array of biomass states.

Even with an estimate of relF derived from the above procedure, externally-derived estimates of B_{msy} or MSY are necessary in order to develop consistent estimates of all the management reference points: MSY, Bmsy and Fmsy or their proxies. For index-based assessments these terms are related by

$$MSY/I_{Bmsy} = relF$$

where I_{Bmsy} is the survey index associated with Bmsy. Knowledge of any two of these terms allows for estimation of the third. For some index stocks (e.g. Gulf of Maine haddock) an external estimate of MSY was considered, based on average catches over a stable period. For others, the I_{Bmsy} proxy was considered more reliable.

GRAPHICAL ANALYSES

The six panel plot developed for the "index" species attempts to show the interrelationships among survey estimates of abundance, landings, functions of landings and relative abundance, and time. The two functions of landings and relative abundance considered are the replacement ratio (Eq. 6, section 3.0) and relative F (Eq. 9, section 4.0). The concept of using multiple panels to relate multiple variables over time has been advocated for use in fisheries science (e.g . Clark 1976, Hilborn and Walters 1992) and other fields (e.g. Cleveland 1993). The 6-panel plots attempt to show the logical connections among variables and to estimate underlying biological rates. The example for GOM Haddock (Fig. 6.1) will be discussed in detail here.

The first aspect to note about the plots are the shared axes in the top four plots (A. B., C, D) and F. Panels B , D and F show the time series for the replacement ratio, the fall survey index, and the relative F, respectively. The horizontal line in A and B is the replacement ratio =1 line. The relationship between the replacement ratio and relative F in panel A is the key to understanding the influence of fishing mortality on stock size. Panel A is a phase plane that describes the relationship between two variables ordered by time. The degree of association between these variables is characterized by a Gaussian bivariate ellipsoid with a nominal probability level of p=0.6827 equivalent to $\pm$ 1 SD about the mean of the x and y variables. The primary and secondary axes of the ellipse are the first and second principal components, respectively. When the degree of association between relative F and replacement ratio decreases, the ellipse becomes more circle-like. The implication is that either the survey is too imprecise to detect changes induced by historical levels of fishing removals, or that the levels of fishing effort have been too low to effect changes in relative abundance. These alternatives can often be distinguished by consideration of the sampling gear and its interaction with the behavior of the species. Similarly incompleteness of the catch record, particularly for species in which the magnitude of discard mortality has varied widely, is another critical factor in the interpretation of the confidence ellipse.

The assumption that the relative F and replacement ratio have a joint bivariate normal distribution in the log –log scale may not hold for all (or any) species. In particular, the replacement ratio model is designed to be sensitive to contemporary changes, so that by definition it will be highly variable. Large changes that are subsequently validated by future observations imply true changes in population status. When the converse is true, it is proper to conclude that the change was an artifact of sampling variation. The degree to which high residuals influence the pattern is tested using the robust regression method of Tukey (Mosteller and Tukey 1977) that downweights large residuals using a bisquare distribution (see Goodall 1983 for details). Thus the regression line in panel A will not be aligned with the primary axis of the ellipse when high residuals distort the confidence ellipse. The expected value of correlation between the replacement rate and relative F is negative. The empirically derived estimate of the sampling distribution for the correlation coefficient , via the randomization test, provides a way of judging the significance of the robust regression line.

The predicted value of relative F at which the replacement ratio is 1 is defined by Eq. 8 and denoted by the vertical line in Panel A and B. The precision of that point depends largely upon where it lies within the confidence ellipse. If the confidence ellipse is nearly centered about the intersection point, then the precision of the relative F threshold will be high. This also indicates that over time, a wide range of F and replacement ratios greater than one have been observed. In contrast, when the intersection point lies in the upper right portion of ellipse, the precision will be low. This is, of course, is a common property of linear regression in which the prediction interval for Y increases with the square of the distance between the independent variable X and its mean. Thus a high degree of correlation between relative F and the replacement ratio does not necessarily ensure high precision in the threshold if relatively few observations have replacement ratios greater than one. Panel A demonstrates, in a slightly different way, the implications of the "one-way trip" described in Hilborn and Walters (1992)

Panel C depicts the phase plane for relative biomass (i.e., . The index) and the relative F. At equilibrium, the population should move up and down a linear isocline. The degree of departure from linearity reflects both sampling variation as well as true variations induced by recruitment pulses and its transient influence on total biomass. Thus the trace of points can give useful insights into parametric model selection of population dynamics under exploitation .

The simple data of catch and survey are generally not sufficient to estimate simultaneously both the threshold F and biomass targets. This property characterizes the common property of indeterminancy of r and K in standard surplus production models. For the GOM haddock example, the relative biomass target is defined external to the model (Panel C and D).

To facilitate the detection of temporal patterns, Lowess smoothing is applied in panels B, D, and F. A relatively low tension =0.3 (i.e., 30% of the span of data are used for the estimate of each smoothed Y value) is used to allow for more sensitive flexing of the smoothed line. As noted earlier, the heightened sensitivity is desirable for this particular application in fisheries management. In a sense, the Lowess smoothing counterbalances the sensitivity built into the definitions of replacement ratio and relative F, by damping the rates of change and allowing for detection of general trends.

The final point to note is that the 6 panel plot may allow one to develop a reasonable picture of the population dynamics in relation to exploitation. With the exception of a brief period in the late 70's the replacement rate for GOM haddock was below one and continued its downward trend until 1990 (Panel A). This was accompanied by a continuously decreasing population size (Panel D). The reduction in landings from nearly 8000 mt in 1984 to less than 500 mt by 1989 (Panel E) greatly reduced the relative F (Panel F) below the threshold level and subsequently led to the replacement ratio exceeding one. The inter-relationships among Panels B, D, and F resemble the kinetics of simple chemical reactions and conceptually one should look for counteracting trends among indices and the influence of the trends in catch and relative survey abundance.

Graphical analyses of all 19 Northeast stocks for the fall and spring surveys may be found in the Final Report on Re-Evaluation of Biological Reference Points for New England Groundfish (NEFSC 2002).

PROJECTIONS FROM INDEX-BASED METHODS

Simple Forecasts for Index Stocks

The estimates of $\mathbf{relF}_{\mathbf{threshold}}$ and $\mathbf{relF}_{\mathbf{target}}$ from Eq. 9 and 10 respectively, can be used to project the expected catches during any forecast period. Under the theory, multiplication of the current abundance index I_t by $\mathbf{relF}_{\mathbf{threshold}}$ leads to an estimate of Ct. If the estimate of $\mathbf{relF}_{\mathbf{threshold}}$ is unbiased then the population is expected to remain constant. This leads to the rather uninteresting forecast of constant catches over any time horizon. Conversely, when the population is fished at $\mathbf{relF}_{\mathbf{target}}$, the population is expected to grow by an average of 10% per year and the catches will grow at a similar rate. For short time periods and low initial population sizes, this approximation is likely to hold. Results of this approach, summarized in Table 2, suggest a reasonable degree of coherence with rebuilding schedules and catch projections derived from more complicated age-structured models. Thus, the catch projection estimates for the species without more complicated models may be used for planning and management purposes.

Estimates of relative F at replacement, generated for all stocks and surveys, are summarized in Table 1. In addition the estimates of the relative F necessary for a 10% growth rate of the population are provided in Table 1. The 10% criterion for population growth should not be construed as a fixed value or scientific recommendation. Rather, it provides a rough measure of the population's capacity for growth that is consistent with the available data. The precision of this estimate as well as the relative F at replacement is provided along with the results of the randomization tests to test for spurious correlations. In general, low precision of the estimates of relF at replacement are associated with uninformative times series. These times series also suggest a weak relationship between the replacement ratio and relative F. In most instances the analyses for the NMFS spring trawl survey mirror the results for the longer time series of autumn (fall) indices. Table 1 also provides a comparison between the current 3yr average of relative F and the predicted relative F s at replacement and at 10% growth rate. The ratio of the current relative F to these nominal target levels provides an alternative measure of the relative magnitude of fishing mortality.

The index based method can also be used to generate simple projections of landings over the period 2002-2009. Catch estimates are obtained by multiplying the current population value (in kg/tow) by the target relative F (000 mt/(kg/tow)) in Eq. 10. Thus:

$$\hat{C}_t = relF_{target}\, I_t$$

By definition, application of **$relF_{target}$** to the population results in 10% rate of increase per year. Of course this assumption is appropriate for a limited number of years. A 10% rate of population increase implies a doubling of the population in roughly 8 years. In more formal notation, we can project the population status as:

$$\hat{I}_{t+1} = 1.1 * I_t(F = relF_{target})$$

Recursive application of the above two equations allows for projection of the population status (in units of kg/tow) and catch (in thousands of mt; Table 2). Comparisons of recent average catches with the average during the rebuilding period suggest that landings would have to be reduced for most species. Note however, that these catch projections are not defined in terms of a target index biomass at the end of 2009.

Due to the developmental nature of these analyses, they should not necessarily be considered reliable for the purposes of management. Initial comparisons however, between these projections and those generated by the age-structured models, suggest reasonable coherence.

Complex Forecasts for Index Stocks

Forecasts for index-based stocks rely on the basic concepts that the 1) the survey indices are proportional to stock biomass, 2) fishing mortality is proportional to the ratio of total catch to survey index, 3) population growth rate can be expressed as a linear function of stock size, and 4) the relationship between the replacement ratio (Eq. 7) and relative F can be summarized with a linear regression in the log-log scale. The index-based can provide useful advice on the current magnitude of fishing mortality and the approximate magnitude of reduction in F necessary to initiate rebuilding for depleted stocks.

Extension of the index approaches to estimate catches consistent with rebuilding plan requires consideration of several additional factors. These include the magnitude of the desired increase in population size, the time frame over which the target population size is to be attained, and catches that may have been removed from the population since the estimate of relative density was obtained. (In this specific example, the population in must be advanced to the start of 2002 based on the removals in 2001.) As noted earlier, the index methodology is not sufficient to uniquely specify the target level of relative biomass. Instead this information is obtained from examination of the trajectories of one or more survey indices, and external information about the historical fisheries. These data are often sufficient to allow scientists to define a proper target biomass. In most instances the defined target biomass coincides with a period of moderate to high abundance, stable catches and replacement ratios at or above 1.0. Let $\mathbf{I_{TARGET}(T)}$ represent the desired relative population size at year **T**, the end year of the rebuilding period. The current condition of the resource at the start of the rebuilding period is defined as $\mathbf{I_{CURRENT}(t)}$. In order to grow from $\mathbf{I_{CURRENT}(t)}$ to $\mathbf{I_{TARGET}(T)}$ over the period **t** to **T** the population must grow at a constant average rate of at least $Q_{rebuild}$ which is defined as:

$$\Psi_{rebuild} = \frac{\log_e\left(\frac{I_{TARGET}(T)}{I_{CURRENT}(t)}\right)}{T - t}$$

The next step is to estimate the relative F necessary to induce a population growth rate equal to $Q_{rebuild}$. The robust linear regression model (Eq. 8 Working Group Report) can be used to estimate the relative F sufficient for rebuilding ($relF_{rebuild}$). This can be defined by rearranging Eq. 8 (Working Group Report) to solve for $relF_{rebuild}$ as follows:

$$relF_{rebuild} = \frac{\Psi_{rebuild} - a}{b}$$

The projected catches consistent with the rebuilding strategy can now be estimated by multiplying the relative F by the current index of abundance, i.e.,

$$C_{rebuild}(t) = relF_{rebuild}\, I(t)$$

The last step in the projection process is to project the population to the next year. This is accomplished by multiplying the current population by the $Q_{rebuild.}$

$$\hat{I}(t+1) = \Psi_{rebuild}\, I(t)$$

The preceding two equations are simply applied recursively until year T, the end of the rebuilding period.

A complication that arises for projection of catches in 2002 and 2003 is that neither the catches nor survey values in 2001 were available when the index-based reference points were derived. The values in Tables 1 and 2 represent estimates for year 2000 relative biomasses and relative fishing mortality rates.

Thus it was necessary to advance the population to the start of 2002 before applying Eq. 1 to 4. The following approach was used:

1. Project the population in 2000 to 2001 by computing the predicted replacement ratio (i.e., growth rate) associated with the average relative F in 2000.

$$\Psi(2000) = \exp^{a + b \log_e(relF_{2000})}$$

2. The average predicted population size in 2001 is obtained as:

$$\hat{I}(2001) = \frac{\Psi_{2000}\, I(2000) + I(2000) + I(1999)}{3}$$

3. The relative F for 2001 as the ratio of catch divided by the predicted population size. To retain consistency with the methods used in Table 2, the point estimate of relative F in 2001 is estimated as the ratio of catch over average relative biomass of the three year period as follows:

$$relF(2001) = \frac{C(2001)}{\left(\frac{\hat{I}(2001) + I(2000) + I(1999)}{3}\right)}$$

4. Substitute the result of Eq. 7 into Eq. 5 to obtain the replacement rate associated with the removals in 2001.

$$\Psi(2001) = \exp^{a + b \log_e(relF_{2001})}$$

5. Project the population in 2002 is similar to the step 2 except that the estimates are substituted for the replacement rate in 2001 and relative biomass in 2001.

$$\hat{I}(2002) = \frac{\Psi_{2001}\, \hat{I}(2001) + \hat{I}(2001) + I(2000)}{3}$$

6. Equations can now be applied recursively using $\mathbf{relF_{rebuild}}$ to estimate the catches in 2002 and 2003 consistent with the long term goal of restoring the population to I_{TARGET} in year T =2009.

An additional complication arise if the predicted relative population size in 2002 exceed the target index measure. This arises for GOM haddock because the recent low relative Fs lead to the prediction of high replacement ratios. For this stock, the relative F was capped at the replacement level of F. Therefore the catches and population sizes are predicted to remain constant over the rebuilding period. Results of these forecast methods are summarized for index-based and age-based stocks in Tables 3 and 4, respectively.

Comparisons with Age-Based Projections

Application of the above forecast procedures are compared to age-based assessments for Georges Bank cod, haddock, and yellowtail stocks (Fig. 7.1, 7.2, 7.3, respectively), Gulf of Maine cod (Fig. 7.4), Cape Cod yellowtail flounder (Fig. 7.5), American plaice (Fig. 7.6), witch flounder (Fig. 7.7), and Acadian redfish (Fig. 7.8). Comparisons of index-based catches were also done for the Southern New England stock of winter flounder (Fig. 7.9). Results of comparisons are mixed. Projections for Georges Bank cod and haddock are similar for both methods and the survey methods lie within the 80% confidence interval for the age-based projection. American plaice and redfish also show a high degrees of overlap. Comparisons for the other stocks, however, reveal moderate to severe deviations. The correlations between the catch projections are very high but the scaling issues need additional work.

Stock	Correlation between age and index-based catch projections
GOM cod	0.974
GB cod	0.998
GB haddock	0.973
GB yellowtail flounder	0.628
CC yellowtail flounder	0.178
Amer Plaice	0.061
SNE winter	0.924
Redfish	0.65

Lack of correspondence between the two approaches appears to be greatest for stocks which are either rebuilding rapidly (e.g., GB yellowtail) or stock requiring major rebuilding. I anticipate that a more thorough examination of the prediction error in the regression model for replacement ratio and relative F will allow for more rigorous comparisons. It should also be noted that the validity of replacement ratio concept diminishes for stocks whose fishing mortality rate greatly departs from the replacement F.

APPLICATION OF THE ENVELOPE PLOT

The "Envelope Plot" is a tool introduced at SARC 33 (NEFSC 2001) to develop bounds on the likely magnitude of population estimates. The basic concept is to combine a long series of catch data with a shorter time series of catch and survey data as a way of inferring historical population sizes. As a simple example, division of an observed catch series C_t by a constant value of exploitation rate U gives an estimate of the biomass at time t (B_t). As F approaches a large value, U approaches 1.0 and biomass B approaches the observed C. Conversely, if it is assumed that the observed catches are the result of a very low level of exploitation, then the population size will be very high. Thus

$$\hat{B}_{t,\,low} = \frac{C_t}{U_{high}}$$

$$\hat{B}_{t,\,high} = \frac{C_t}{U_{low}}$$

One can extend this simple notion by considering the observed time series of relative F as measure of the historical exploitation pattern. The inverse of this quantity, i.e, I_t/C_t, can be used as a multiplier of historical catch to obtain an estimate of the possible values of survey estimates. Thus one can impute a historical time series of relative abundance indices based on the an observed set of I_t/C_t value. More precisely consider a catch series C_t where t=1, 2,..., T. Suppose that a survey I_t beginning in year m has been conducted such that we also have a series of indices I_t, t=m, m+1, ...,T. The set of ratios {I_t/C_t , t=m,..., T} can now be used as a way of estimating possible values of I_t for the period t=1, 2,..., m-1. Define $p_{"}(I_t/C_t)$ as the "%-ile of I_t/C_t. If it is reasonable to assume that the observed range of I_t/C_t is representative of possible values of I_t/C_t during the unobserved period (i.e., t=1, ..., m-1). If we let $p_{"}(I_t/C_t)$ and $p_{\$}(I_t/C_t)$ represent lower and upper percentiles, respectively, for the observed ratios then the estimates of relative abundance for the period t=1, 2,..., m-1 can be approximated as:

$$\hat{I}_{t,\alpha} = C_t \, p_\alpha\left(\left\{\frac{I_\tau}{C_\tau}\right\}\right) \; for \; \forall\tau \in \{m, m+1, \ldots, T\}, \; \forall t \in \{1, 2, \ldots, m-1\}$$

$$\hat{I}_{t,\beta} = C_t \, p_\beta\left(\left\{\frac{I_\tau}{C_\tau}\right\}\right) \; for \; \forall\tau \in \{m, m+1, \ldots, T\}, \; \forall t \in \{1, 2, \ldots, m-1\}$$

A similar equation can be constructed for the median of I_t/C_t and the imputed time series can be concatenated with the observed series.

At first glance one might wonder about the value of estimating the likely range of relative abundance estimates from surveys that were never conducted. Simple plots of the concatenated time series for Georges Bank haddock (Fig. 8.1), cod (Fig. 8.2), yellowtail flounder (Fig. 8.3), and redfish (Fig.8.4) confirm commonly held notions that the historical population sizes of haddock and redfish were much higher than values observed in the last 40 years. Importantly, plots for both haddock and redfish suggest that conditions similar to long-term median values existed at the start of the fall survey time series (early 1960's). In contrast Fig. 8.2 for cod suggests that average densities between 1963 and 1980 were generally higher that the median imputed estimates for the period 1890 to 1960. If the landings for this early period are representative and complete, then the average relative abundance estimates between 1963-80 are similar to the 90%-ile of the imputed abundance index. This conclusion however is highly speculative and other information about the nature of the fishery and landings during this period must be considered. For example, if the fishery was prosecuted only on inshore stocks and most of the offshore population was unaffected by fishing, then the contemporary estimates of I_t/C_t may be of little use for interpreting historical patterns.

A similar set of arguments could be made for Georges Bank yellowtail flounder (Fig. 8.3). Envelope plot results suggest that the abundance levels in the 1960's were higher than imputed relative indices during the 1940-1960 period. The history of the geographical expansion of this fishery however, needs to be considered. Nonetheless, the envelope plot provides a diagnostic tool for evaluating the historical population and may provide confirmatory information for estimates of target biological reference points that are higher than recently observed values. The following text table compares the age-based and index-based estimates of the ratio of current biomass to biomass levels under Bmsy levels.

Comparison of B(t)/ Bmsy estimates based on age- and index based methods.				
Species	GB haddock	GB cod	GB Yellowtail	Redfish (/1)
Survey Average 1998-2000 (kg/tow)	14.76	2.40	6.05	5.51
Age-based estimated ratio of B(t) to B_msy (/2)	0.26	0.13	0.72	0.5
90%-ile of composite median index (kg/tow)	48.88	12.63	7.41	10.55
Index based ratio 1998-00 average index to 90%ile of median composite index	0.30	0.19	0.82	0.52
Difference between age and index based estimates of B(t)/Bmsy	- 0.04	-0.06	-0.10	-0.02
(/1) The 75%-ile of the median was used for redfish				
(/2) obtained from Fig. 4.2.3 of Panel Report				

APPLICATION OF METHODOLOGY TO SUMMER FLOUNDER AND SCUP

The fourth Term of Reference for the Methods Working Group is to "Investigate the applicability of these methods to summer flounder and scup assessments for SAW 35". These issues are addressed below.

Data

The raw data for summer flounder and scup are summarized in Tables 9.1 and 9.2 respectively. For both species, total catch estimates are available for only part of the available time series. The relative contributions of recreational landings and discards to the total catch have varied considerably over time. The Southern Demersal Working Group on summer flounder did not prepare total catch estimates for years prior to 1982. Therefore, for the purpose of testing the applying the index methodology to summer flounder, commercial landings were used as proxy for total catch. A simple linear regression of total catch versus commercial landings for the period 1982-2001 explained 80% of the variation in total catch ($P<0.001$), suggesting that the relative exploitation rate derived from commercial landings would characterize the fishery. Since 1991 however, the relative contributions of commercial and recreational landings, and discards to the total catch have changed in response to management measures designed to increase spawning stock abundance.

Estimates of total catch for scup are hampered by incomplete information on landings and discard. The scup Working Group used a variety of extrapolation methods to estimate total catch from landings and discard data. Incomplete landings records, removals by distant water fleets, limited discard sampling, and extrapolated recreational landings estimates were all noted as sources of uncertainty by the scup Working Group. Despite these limitations, restricting the index analyses to only one catch component, say commercial landings, was considered inappropriate. Therefore the index-based estimates of relative F and replacement ratios were based on the best estimates of total catch.

Replacement Ratio Estimates

Graphical analyses of summer flounder (Fig. 9.2 , 9.3) reveal similar patterns with respect to the spring and fall trawl surveys. Both surveys show a strong upward trend in abundance since 1990, consistent with the imposition of quota regulations in same period. Relative F estimates exhibit the opposite trend and reached the lowest levels on record in 2001. The replacement ratio has increased above 1.0 in the spring survey (Fig. 9.2) about 1993 and about 1996 in the fall survey (Fig. 9.3). Estimates of the relationship between the replacement ratio and relative F suggest a consistent pattern for both surveys. As shown below, randomization tests of both regressions were statistically significant. Low levels of relative F in recent years are strongly associated with replacement ratios above 1.0. The results provide strong evidence that the reduced fishing mortality rates of the past decade have been instrumental in the recovery

Summer Flounder				
Fall Survey			**Spring Survey**	
Randomization Test Summary			***Randomization Test Summary***	
Observed Correlation	**-0.622**		Observed Correlation	**-0.619**
Sampling Distribution Stats			***Sampling Distribution Stats***	
median	-0.308		median	-0.317
min	-0.664		min	-0.744
max	0.239		max	0.273
95%ile	-0.015		95%ile	-0.020
5%ile	-0.535		5%ile	-0.554
Approximate Significance			***Approximate Significance***	
Level of test statistic			***Level of test statistic***	
P(Corr<Obs Correlation)			***P(Corr<Obs Correlation)***	
0.00704			**0.01829**	

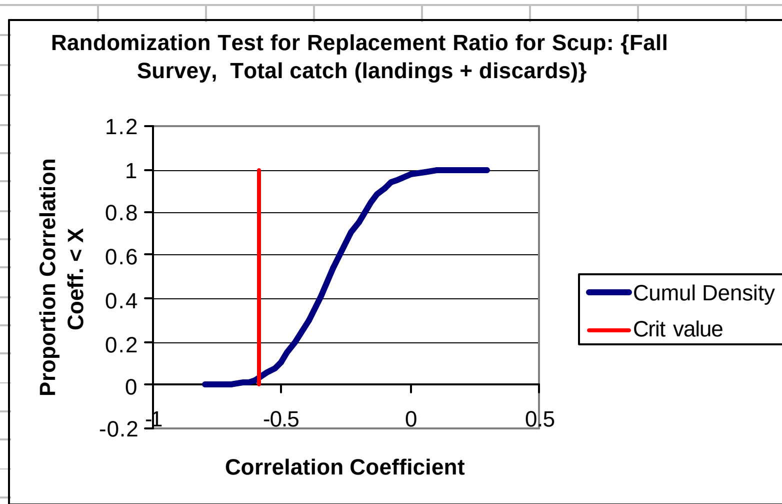
of summer flounder.

Results for scup were less conclusive(Fig. 9.3-4). Analyses of the fall survey (Fig. 9.3) suggest that the recent increase in fallu survey biomass is strongly associated with the decline in relative F. The replacement ratio first increased above 1.0 about 1996 and the regression between replacement ratio and relative F is statistically significant (below).

Randomization Test Summary	
Observed Correlation	-0.590

Sampling Distribution Stats	
median	-0.314
min	-0.723
max	0.296
95%ile	-0.031
5%ile	-0.567

Approximate Significance Level of test statistic P(Corr<Obs Correlation)
0.03599



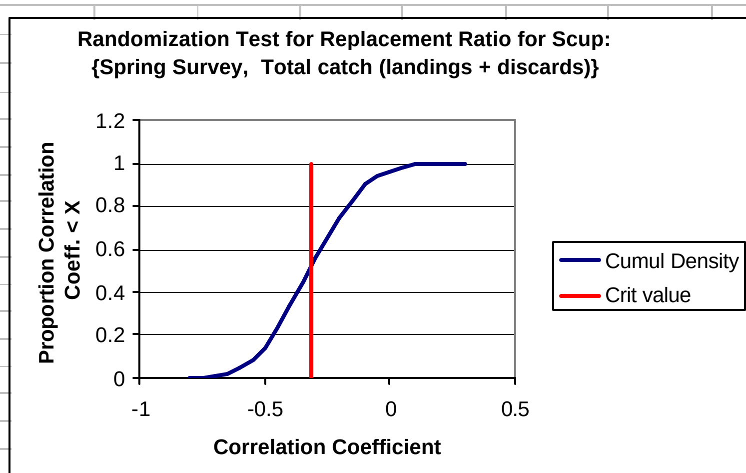
In contrast the randomization test for scup suggests the relative F at replacement is imprecisely estimated and not statistically significant (below). Spring survey abundance has generally declined since the late 1960s and has, only in recent years, shown any sign of reversal.

Relative F has declined in 2000 and 2001 but the contrast with previous years is sharp (Fig. 9.4). The relative information content of the two surveys is further depicted in Fig. 9.5. The imprecision of the spring survey-based estimates of replacement F lead to wide asymptotic parametric confidence intervals but much smaller intervals for the fall surveys. These results suggest that possible re-examination of the reliance on the spring survey rather than the fall survey as a signal of stock abundance trends may be warranted.

Randomization Test Summary	
Observed Correlation	-0.315

Sampling Distribution Stats	
median	-0.324
min	-0.771
max	0.298
95%ile	-0.025
5%ile	-0.587

Approximate Significance Level of test statistic P(Corr<Obs Correlation)
0.512



Projections of relative biomass and landings

As described in Section 7.0 the index methodology can be extended to provide projections of catch (or landings) and relative stock. The validity of these projections is primarily governed by the difference in magnitude of the current relative F and the relative F at replacement. As with any linear regression, projections that rely independent variables that are far from their means are less reliable that estimates close to the mean. For the index methodology, transient effects during stock rebuilding may result in overly optimistic projections of stock recovery and/or landings.

The projection scenarios for summer flounder and scup (Table 7) were based on a continuation of contemporary rates of relative exploitation. Relative F levels for both summer flounder and scup are sufficiently low such that continuing increases are expected in the short term. Projections for summer flounder suggest a near 3-fold increase in relative biomass and landings through 2005. Projected landings for scup are similarly optimistic irrespective of whether the analyses include or exclude discard estimates from the total catch estimates.

The dynamics of both species are likely to be dominated by strong year classes and the projections may not be realistic in the longer term. However, both scenarios suggest that the populations and landings should continue to increase in the short run, predictions that are consistent with more detailed projections derived from analytical models.

SARC COMMENTS - INDEX METHODS

The SARC reviewed a working document on the development of empirical methods for stock assessments based on analysis of total catch and trends in abundance indices. The work discussed is in progress and, while it was developed with feedback from the SAW methods group, it had not been subject to extensive peer review prior to the SARC.

TERMS OF REFERENCE

1. Describe the underlying theoretical basis for the index-based assessment and projection methodologies
2. Identify critical limitations for application of such methodologies.
3. Compare reference point estimates and projections with results from VPA and other modeling approaches.
4. Investigate the applicability of these methods to summer flounder and scup assessments for SAW 35.

<u>Potential of the methods</u>

The SARC concluded that the method has considerable potential as a monitoring tool that to evaluate stock trajectories and provide valuable information in interim years between analytical assessments. Similarly, the technique has utility in presenting an integrated picture of stock dynamics for resources where only catch statistics and survey trends are available. The visual techniques were considered very useful as a summary of stock status trends.

The SARC also discussed the value of the method in terms of its usefulness for providing objective estimates of proxies for management reference points. While the method does not provide, *a priori*, a proxy for Fmsy, it has potential for estimating a relative F for stock replacement, especially in cases where density-dependence is not apparent and other conditions of the method (discussed below) are met. In such cases, the method may be preferable to subjective methods currently used to provide reference points. Under conditions of low stock density, the level of recruitment is likely to be proportional to stock abundance and thus increase the applicability of the method.

The SARC further provided technical comments on aspects of the derivation of the method, and conditions under which it might be inappropriate to apply this method. Most of these limitations also apply to the application of alternative methods.

<u>Theoretical bases for the methods</u>

A number of issues were raised at the SARC regarding the theoretical basis for the index-based assessment and projection methods:

- The use of the moving average in the denominator of the replacement ratio statistic could be generalized to a broader family of smoothing equations, thereby retaining the empirical nature and extending the flexibility of the method; the link to survival and recruitment is an unnecessary constraint and may limit the development of better predictors of stock status based on available indices. On the other hand, development of a theoretical basis for the method could allow interpretation of underlying assumptions leading to stock replacement.

- The ratio of current biomass to the weighted sum of previous biomasses, as specified in the current derivation (equation 6) equals one, irrespective of the trend in the population. However, the SARC concluded that the statistic proposed, defined as the ratio between the last index of abundance and the moving average of the previous five indices, can be used as an empirical measure of biomass trend because of variation in population processes (survival and recruitment).

- The basis for estimating the relative rate of fishing mortality at which the stock would replace itself from the empirical regression between the index of trend and the relative fishing mortality was questioned on the following grounds: if density-dependence was operating, there would be infinite levels of replacement F; results of the regression approach would reflect a composite of alternative stable points and transient effects. It is possible that clustering of data points in various quadrants can be taken as indications of multiple stable equilibria.

Conditions for application of the methods

- The method requires the use of reliable catch statistics so it would not be applicable to stocks for which catch records are inadequate, or substantial portions of the catch are poorly estimated (e.g. discards, recreational catch etc).

- The method assumes that the survey indices adequately represent the fishable biomass. Concern was raised by the SARC that this assumption could be problematic as the surveys often catches younger fish than the fishery. The problem may be more severe when there have been major changes in the exploitation pattern.

- The method will not adequately estimate relF at replacement when stock trends are mainly driven by environmental effects. Strong year classes or, worse, persistent changes in productivity such as connected to regime shifts would lead to spurious results.

- The method would be unsuitable for developing fisheries, or situations when fishing mortality is increasing from a low value. It may be unsuitable for other types of fisheries depending on their exploitation history, but that needs to be investigated.

- Similar to the limitations of using biomass-weighted F as an overfishing definition (SAW 33) relF and $relF_{rep}$ will be sensitive to transition effects due to variations in recruitment, PR, average weights, age structure and other factors.

- The validity of the envelope plots used to reconstruct historical stock trajectories clearly depends on the historical exploitation being in the range of observed relFs. In instances where the catch series represents a developing fishery, then the envelope would be insufficient to estimate stock size.

<u>Comparison of projections with results from VPA and other modeling approaches</u>

- Projections are based on linear rates of increase and as such they should not be used to project population trends beyond a few years.

- Projections are sensitive to transient effects even in the absence of density dependence. For example, initial stock increases obtained in response to reductions in F may be fast initially but the increase would slow down as the age structure broadens.

- The selection of the relative F needed to achieve a given rate of increase in the projections would be sensitive to transient conditions. For example, a stock that is rebuilding fast in response to a recent large reduction in F may transiently show a replacement index higher than required; in this case the procedure would produce an increase in relative F when in fact such an increase would not be guaranteed. When required relative F differs markedly from the current, catch projections will be off scale compared to projections made using conventional age-structured models (e.g. in GB yellowtail).

- Further evaluation of the degree to which the method produces results that are comparable with those produced by VPA are required, noting that the new method has the potential to be applied when data limit the applicability of other methods

<u>Applicability to summer flounder and scup assessments for SAW 35</u>

Due to inadequate catch records, the SARC concluded that the method was not applicable to the scup assessment.

The method could have potential for summer flounder as an interim technique between analytical assessments to evaluate new catch and survey data relative to management targets, especially in combination with medium-term projections from assessments.

RESEARCH RECOMMENDATIONS

- Evaluate the performance of the proposed index methods using age-structured simulations representing different histories of exploitation, fishery selectivity, assumptions of density dependence, stock trajectories, and time lags.

- Compare reference points resulting from the method with traditional BRPs

ACKNOWLEDGEMENTS

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