Figure 193. Bottom salinity in Chesapeake Bay, 2007.
Figure 195. Bottom salinity in Chesapeake Bay, 2008.
Dissolved Oxygen
Figure 196. Surface dissolved oxygen in Chesapeake Bay, 2002.
Figure 197. Bottom dissolved oxygen in Chesapeake Bay, 2002.
Figure 198. Surface dissolved oxygen in Chesapeake Bay, 2003.
Figure 199. Bottom dissolved oxygen in Chesapeake Bay, 2003.
Figure 200. Surface dissolved oxygen in Chesapeake Bay, 2004.
Figure 201. Bottom dissolved oxygen in Chesapeake Bay, 2004.
Figure 202. Surface dissolved oxygen in Chesapeake Bay, 2005.
Figure 203. Bottom dissolved oxygen in Chesapeake Bay, 2005.
Figure 204. Surface dissolved oxygen in Chesapeake Bay, 2006.
Figure 205. Bottom dissolved oxygen in Chesapeake Bay, 2006.
Figure 206. Surface dissolved oxygen in Chesapeake Bay, 2007.
Figure 207. Bottom dissolved oxygen in Chesapeake Bay, 2007.
Figure 208. Surface dissolved oxygen in Chesapeake Bay, 2008.
Figure 209. Bottom dissolved oxygen in Chesapeake Bay, 2008.
Appendix 1

Blue Crab and Clearnose Skate Abundance
Figure A1. Male blue crab minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay 2002-2008.
Figure A2. Comparison of ChesMMAP catch rates by year, cruise, and region (A) and year, cruise, and depth stratum (B) for male blue crab.
Table A1. Abundance indices (number and biomass) for male blue crab, overall (calculated as geometric and arithmetic means).

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Figure A3. Abundance indices (number and biomass) for male blue crabs based on geometric (A) and arithmetic (B) means.
Figure A4. Abundance (kg per hectare swept) of male blue crab in Chesapeake Bay, 2002.
Figure A5. Abundance (kg per hectare swept) of male blue crab in Chesapeake Bay, 2003.
Figure A6. Abundance (kg per hectare swept) of male blue crab in Chesapeake Bay, 2004.
Figure A7. Abundance (kg per hectare swept) of male blue crab in Chesapeake Bay, 2005.
Figure A8. Abundance (kg per hectare swept) of male blue crab in Chesapeake Bay, 2006.
Figure A9. Abundance (kg per hectare swept) of male blue crab in Chesapeake Bay, 2007.
Figure A10. Abundance (kg per hectare swept) of male blue crab in Chesapeake Bay, 2008.
Figure A11. Mature female blue crab minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay 2002-2008.
Figure A12. Comparison of ChesMMAP catch rates by year, cruise, and region (A) and year, cruise, and depth stratum (B) for mature female blue crab.
Table A2. Abundance indices (number and biomass) for mature female blue crab, overall (calculated as geometric and arithmetic means).

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Figure A13. Abundance indices (number and biomass) for mature female blue crabs based on geometric (A) and arithmetic (B) means.
Figure A14. Abundance (kg per hectare swept) of mature female blue crab in Chesapeake Bay, 2002.
Figure A15. Abundance (kg per hectare swept) of mature female blue crab in Chesapeake Bay, 2003.
Figure A16. Abundance (kg per hectare swept) of mature female blue crab in Chesapeake Bay, 2004.
Figure A17. Abundance (kg per hectare swept) of mature female blue crab in Chesapeake Bay, 2005.
Figure A18. Abundance (kg per hectare swept) of mature female blue crab in Chesapeake Bay, 2006.
Figure A19. Abundance (kg per hectare swept) of mature female blue crab in Chesapeake Bay, 2007.
Figure A20. Abundance (kg per hectare swept) of mature female blue crab in Chesapeake Bay, 2008.
Figure A21. Clearnose skate minimum trawlable abundance estimates in numbers (A) and biomass (B) in Chesapeake Bay 2002-2008.
Figure A22. Comparison of ChesMMAP catch rates by year, cruise, and region (A) and year, cruise, and depth stratum (B) for clearnose skate.
Table A3. Abundance indices (number and biomass) for clearnose skate, overall (calculated as geometric and arithmetic means).

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Figure A23. Overall abundance indices (number and biomass) for clearnose skate based on geometric (A) and arithmetic (B) means.
Figure A24. Abundance (kg per hectare swept) of clearnose skate in Chesapeake Bay, 2002.
Figure A25. Abundance (kg per hectare swept) of clearnose skate in Chesapeake Bay, 2003.
Figure A26. Abundance (kg per hectare swept) of clearnose skate in Chesapeake Bay, 2004.
Figure A27. Abundance (kg per hectare swept) of clearnose skate in Chesapeake Bay, 2005.
Figure A28. Abundance (kg per hectare swept) of clearnose skate in Chesapeake Bay, 2006.
Figure A29. Abundance (kg per hectare swept) of clearnose skate in Chesapeake Bay, 2007.
Figure A30. Abundance (kg per hectare swept) of clearnose skate in Chesapeake Bay, 2008.
Appendix 2

Use of Yield-Per-Recruit and Egg-Per-Recruit Models to Assess Current and Alternate Management Strategies for the Summer Flounder Recreational Fishery in Virginia: An Application of Data Collected by the ChesMMAP Trawl Survey

Introduction

Summer flounder (*Paralichthys dentatus*) are found along the eastern seaboard of North America from Nova Scotia to Florida, and are most abundant between Massachusetts and North Carolina (Ginsberg 1952, Leim and Scott 1966, Gutherz 1967). This species supports valuable commercial and recreational fisheries throughout southern New England and the Mid-Atlantic Bight, which includes Virginia’s waters. With respect to the summer flounder recreational fishery, Virginia has historically ranked third, behind only New Jersey and New York, in terms of annual landings by weight. Approximately 90% of the summer flounder recreational harvest in Virginia is taken from Chesapeake Bay, and within this estuary recreational landings of flounder far exceed the commercial harvest of this species (Pers. comm. from the National Marine Fisheries Service, Fisheries Statistics Division).

The U.S. Atlantic coast stock of summer flounder was declared overfished in 2000, and the original stock rebuilding deadline of 2010 was extended to 2013 with the 2006 reauthorization of the Magnuson Stevens Fishery Conservation and Management Act (MSFCMA) (Public Law 94-265, NEFSC 2008). This stock is currently managed through total allowable landings (TAL), with 60% of the annual quota allocated to the commercial fishery and 40% to the recreational. Summer flounder TAL has been reduced dramatically in recent years as pressure has mounted to rebuild this stock by the aforementioned deadline. The most recent stock assessment indicated that overfishing of
this stock is not occurring and that the spawning stock biomass (SSB) of summer flounder is currently at 73% of the target level (NEFSC 2008).

Virginia has traditionally used minimum legal harvest sizes and possession limits to control effort and landings in its summer flounder recreational fishery. As TAL, and in turn recreational quotas, has tightened in recent years, minimum legal harvest sizes for flounder taken from Virginia waters by recreational fishermen have typically increased (Figure 1). Because summer flounder have been shown to exhibit sexually dimorphic growth patterns (most fish greater than 17” total length are female) both in Chesapeake Bay and the nearshore ocean waters of Southern New England and the Mid-Atlantic Bight (Figure 2a, b.), questions have been raised as to whether the implementation of relatively large minimum size limits, and therefore the restriction of fishing pressure almost exclusively to the larger, breeding females, is a sound management strategy given stock rebuilding needs. Further, shore-based recreational fishermen have claimed that these increases in minimum harvest sizes violate National Standard 4 of the MSFCMA (i.e., “allocations must be fair and equitable to all fishermen”) since large flounder tend to inhabit deeper waters and therefore are relatively unavailable close to the shore. Based on these concerns, an assessment of current and alternate management strategies for the summer flounder recreational fishery in Virginia is warranted.

Yield-per-recruit (YPR) and egg-per-recruit (EPR) models have been used as measures of harvest and egg production, respectively, in previous investigations designed to assess the effects of various management strategies on fishery yields and stock size (egg production assumed proportional to stock size) (Prager et al. 1987, Barbieri et al. 1997, Olney and Hoenig 1999, Piner and Jones 2004). Specifically, it has been assumed
that management options that result in greater egg production (EPR) at a given level of harvest (YPR) should result in an increase in stock size (while maintaining harvest) and therefore be more compatible with rebuilding, while those that produce a larger YPR at a given level of egg production should provide a greater benefit to the fishery in terms of harvest while maintaining equivalent stock size and rebuilding potential.

In this segment of the report, we use data on summer flounder collected by the ChesMMAP Trawl Survey from 2002 to 2007 along with YPR and EPR models in an effort to:

1) evaluate the compatibility of the current Virginia strategy of increasing minimum legal size limits for the summer flounder recreational fishery with stock rebuilding needs; and

2) assess the rebuilding potential of a combination slot and trophy size limit for this fishery relative to the 2008 minimum legal harvest size.

Harvest trade-offs required to implement the slot/trophy option while maintaining equivalent egg production (stock size and rebuilding potential) are also explored.

Methods

Model Definition and Parameterization

Equilibrium YPR

Definition

An equilibrium YPR model was used to calculate harvest (in terms of weight - kg)-per-recruit at a given instantaneous rate of fishing mortality ($F$) for a summer
flounder population at equilibrium under various management scenarios for the Virginia
recreational fishery (Olney and Hoenig 1999). The model is defined by

\[
YPR_F = \sum_{a=1}^{A} \sum_{s=1}^{S} N_{a,s} \cdot W_{a,s} \cdot \frac{F^* \text{sel}_{a,s}}{M_s + (F^* \text{sel}_{a,s})} \left(1 - e^{-M_s - (F^* \text{sel}_{a,s})} \right),
\]

where \( M_s \) is the instantaneous rate of natural mortality for summer flounder of sex \( s \) (i.e.,

male or female), \( W_{a,s} \) is the average weight (kg) of a summer flounder of age \( a \), sex \( s \),

\( \text{sel}_{a,s} \) is the relative selectivity of the fishing gear (hook and line, in this case) for age \( a \),

sex \( s \), and where

\[
N_{a,s} = N_{(a-1),s} \cdot e^{-M_s - (F^* \text{sel}_{a-1,s})}.
\]

For each management scenario, harvest-per-recruit was calculated over a range of

\( F \). The various management measures were represented by manipulating the \( \text{sel}_{a,s} \) term.

That is, as the legal harvest size for the summer flounder recreational fishery changed, the

size, and therefore age, of the fish exposed to the fishery (selected by the gear) changed.

For the purposes of this study, it was assumed that all fish of legal size were equally

vulnerable to capture by the recreational gear, while those not of legal size were

unavailable for harvest (i.e., had to be released if captured and no mortality due to

capture). This assumption results in a knife-edge selection curve for the gear. Also,

while number of recruits were set as 1000 male \((N_{0,MAL})\) and 1000 female \((N_{0,FEM})\) for this

investigation, any initial number of recruits would have been acceptable as yield was
calculated on a per-recruit basis. The remaining terms were either taken from the primary literature or obtained through data on summer flounder collected by the ChesMMAP Trawl Survey. Because the majority of the summer flounder recreational fishery in Virginia occurs within the ChesMMAP survey area, and approximately 85% of the annual summer flounder catch by the ChesMMAP Trawl Survey is taken from the Virginia portion of the bay, the flounder data collected by this program represent the population available to this fishery. The parameterization of these remaining terms is described below, and it should be noted that these terms were estimated separately for males and females as maximum age and growth rate have been observed to differ between sexes for summer flounder (Smith and Daiber 1977, Bonzek et al. 2007, Bonzek et al. 2008).

**Parameterization**

**Instantaneous rate of natural mortality ($M_s$):** Estimates of $M_s$ were generated by combining sex-specific observations of summer flounder maximum age with Hoenig’s (1983) relationship between maximum age and mortality. The maximum age estimate used for male summer flounder was 10 years, yielding an $M_{MAL}$ of 0.44; females live to 20 years, resulting in an $M_{FEM}$ of 0.22 (Terceiro 2002, Brust 2007, ChesMMAP unpbl. data).

**Weight at age ($W_{a,s}$):** Estimates of summer flounder weight at age by sex ($W_{a,s}$) were obtained by combining sex-specific length at age growth models with sex-specific weight at length relationships for flounder. Specifically, for each age, summer flounder length on August 1 (the annual midpoint and peak of the summer flounder recreational fishery in Virginia) was combined with the weight at length relationships to generate the $W_{a,s}$ term.
for the YPR model used in this study. All individual length, weight, and age data for summer flounder inhabiting the Virginia portion of Chesapeake Bay were collected by the ChesMMAP Trawl Survey from 2002 to 2007. The collection of individual length and weight data from summer flounder is described earlier in this report.

For ageing, the right sagittal otolith was used to determine the age of each flounder sampled for full processing (described earlier in the report) by the ChesMMAP Survey. Sample preparation followed the protocols outlined in Sipe and Chittenden (2001). Specifically, a thin transverse section was cut through the nucleus of an otolith and the resulting section was mounted on a glass slide. Annuli were counted as opaque bands when viewed under a dissecting microscope using transmitted light. Annuli counts, date of capture, and the standard January 1 birthdate, were used to assign fractional ages to each specimen. The choice of birthdate used to assign fractional ages does not affect the results of the investigation. That is, a November 1 birthdate, which represents the approximate peak of the summer flounder spawning season, would have yielded identical results with respect to YPR and EPR.

Length at age

Following the assignment of fractional ages, it was necessary to identifying the model that best described the length at age relationship for summer flounder. This was accomplished by fitting a set of candidate models to these data and applying model selection procedures to identify the most parsimonious explanation of the data (Burnham and Anderson 2002). Since the competing models were not hierarchical, the Akaike Information Criterion (AIC) was used for model selection (Yamaoka et al. 1978). Again, models fitting and selection occurred separately for males and females.
With respect to the candidate models, the von Bertalanffy growth equation was fitted to the summer flounder age/length data:

\[ L_a = L_\infty (1 - e^{-k(a-a_0)}), \]  

(2)

where \( L_\infty \) is the asymptotic length, \( k \) is the instantaneous growth coefficient, and \( a_0 \) is the hypothetical age at which the fish would be zero length.

The second alternative model considered was the Richards (1959) model:

\[ L_a = L_\infty \left(1 - \delta e^{-k(a-a_0)}\right)^{1/\delta}, \]  

(3)

where \( \delta \neq 0 \). This model was chosen primarily because of its flexibility.

The final alternative model tested was the sine wave growth von Bertalanffy length-at-age model (Pitcher and MacDonald 1973):

\[ L_a = L_\infty \exp\left(1 - e^{-(C \sin(2\pi(a-s_1)) + k(a-a_0))} \right), \]  

(4)

where \( C \) is a constant that controls the magnitude of the within-year growth oscillations and \( s_1 \) controls the starting point of the sine. This model allows for smooth changes in growth rate, with growth rate increasing to a maximum in mid-season.

Parameter estimates for each of these models were obtained using nonlinear regression techniques, which require the following general assumptions; 1) the expected
value of \( \varepsilon_i \), the error term associated with the \( i^{th} \) observation, is equal to zero, 2) the \( \varepsilon_i \) are independent, identically distributed normal random variables, and 3) the variance of \( \varepsilon_i \) is constant regardless of the value of the independent variable.

Visual inspection of the \( \varepsilon_i \) showed that approximately 50% were negative for each sex implying that assumption (1) was reasonable. The null hypothesis that the \( \varepsilon_i \) were normally distributed was not rejected for the majority of the age groups for both sexes (Kolomogorov-Smirnov test, \( p > 0.05 \)). The age groups where the test for normality failed were generally those with the smallest number of length observations (i.e., the older ages). Hence, assumption (2) was adopted given the robustness of regression methods to failures of this assumption and the belief that with increased sample sizes of these age groups, the associated length data would follow a normal distribution. Assumption (3) did not hold (homogeneity of variance test, \( p < 0.05 \)) for the males or females, which presented a choice to either assume a multiplicative error structure or adjust for heteroscedasity. We opted to invoke the method of weighted least squares (WSS) for parameter estimation under the assumption of an additive error structure since visual inspection of the residuals for each sex showed only a marginal increase in variance about the von Bertalanffy growth curve. Implicit in the use of WSS is the notion that the variance of \( \varepsilon_i \) is a function of age and that the values of that function are known, at least up to a constant of proportionality. The weighting factor was assumed to be the inverse of the number of length observations at each age value.

According the AIC statistics, the five parameter model developed by Pitcher and MacDonald (1973) provided the best explanation of the length/age relationship for each sex, followed by the von Bertalanffy growth equation. The Richards (1959) model
provided the poorest fit of the three. As a result, the Pitcher and MacDonald (1973) growth model was used to model summer flounder length at age by sex for this study (Figure 3).

Weight at length

With respect to the estimation of summer flounder weight at length by sex, the power function was fitted to the flounder length/weight data:

$$W_i = \alpha L_i^b,$$

(5)

where $\alpha$ determines the steepness of the slope and $b$ scales the height of the curve (Quinn and Deriso 1999).

An alternative model considered was the exponential function:

$$W_i = K_1 e^{K_2 L_i},$$

(6)

where $K_1$ scales the y-axis intercept and $K_2$ determines the steepness of the curve.

Again, parameter estimates for all models were obtained using nonlinear regression techniques, which require the same general assumptions as outlined above for the length at age models. Visual inspection of the $\varepsilon_i$ showed that approximately 50% were negative for each sex implying that assumption (1) was reasonable. As with the age/length analysis, instances where the weight at length data were not normally distributed for males or females generally occurred when sample sizes were low. Hence, assumption (2) was adopted under the logic described above. Again, assumption (3) did
not hold for either sex (homogeneity of variance test, \( p < 0.05 \)), however, with no appreciable increase in variance about the power function, WSS assuming an additive error structure was used to derive parameter estimates. Here, the weighting factor was the inverse of the number of weight observations at each length value. Overall, the traditional power model provided the best overall description of the weight at length data for both males and females according to the AIC statistics (Figure 4).

**Equilibrium EPR**

*Definition*

The equilibrium EPR model used to investigate egg production-per-recruit (and therefore relative stock size and rebuilding potential) at a given instantaneous rate of fishing mortality \( (F) \) for a summer flounder population at equilibrium under various management scenarios for the Virginia recreational fishery is defined by

\[
EPR_F = \frac{\sum_{a=1}^{A} N_{a,FEM} \cdot E_{a,FEM} \cdot P_{a,FEM}}{2000},
\]

where \( E_{a,FEM} \) is the fecundity of a female summer flounder at age \( a \), \( P_{a,FEM} \) is the proportion of females mature at age \( a \), and where

\[
N_{a,FEM} = N_{(a-1),FEM} \cdot e^{-M_{FEM} \cdot (F \cdot sel_{a-1,FEM})}.
\]

For each management scenario, EPR was calculated over a range of \( F \). Again, the various management measures were represented by manipulating the \( sel_{a,s} \) term, and the
number of recruits were set as 1000 male \((N_{0,MAL})\) and 1000 female \((N_{0,FEM})\). Although males do not produce eggs and could have been excluded from this calculation, they were included in the initial number as they count as recruits to the population. It should be noted, however, that while the exclusion of male recruits from this model would have affected the absolute values of egg production-per-recruit, the relative EPR across management scenarios would not have changed (i.e., exclusion of males would have lead to a doubling of all EPR values calculated in this investigation, as the denominator in Equation (7) would have been 1000). The remaining terms were either taken from the primary literature or obtained through data on summer flounder collected by the ChesMMAP Trawl Survey, and the parameterization of these terms is described below.

**Parameterization**

Fecundity at age \(E_{a,FEM}\): The fecundity of a female summer flounder at age \(a\) was calculated by combining a fecundity at length model with the female length at age model described earlier. Specifically, fecundity at length was taken from the primary literature (Morse 1981). By combining this relationship with the \(L_{a,FEM}\) term taken from Equation (4) above for female summer flounder, fecundity at age was given by

\[
E_{a,FEM} = 7.7975 \times 10^{-4} \times L_{a,FEM}^{3.402} .
\]  

(8)

It should be noted that the \(L_{a,FEM}\) term was obtained by calculating female length on November 1 for each age using the seasonal growth model, as this date represents the peak of the summer flounder spawning season.
Proportion mature at age \((P_{a,FEM})\): Binary logistic regression was used to determine the proportion of female summer flounder mature at age \(a\) \((P_{a,FEM})\). Each flounder sampled by the ChesMMAP Trawl Survey for full processing (described elsewhere in the report) was assigned a zero if the fish was immature and a one if it was mature. These data were then fitted using the logit function by

\[
\text{Logit}(p) = \beta + \alpha \ast a, \tag{9}
\]

where \(\beta\) is the intercept term and \(\alpha\) is the coefficient of the independent variable (age). This relationship was then used to determine the proportion of female summer flounder mature at age \(a\) (Figure 5).

Transitional YPR

As noted above, the equilibrium YPR model can be used to determine harvest-per-recruit for a population at equilibrium. The U.S. Atlantic coast stock of summer flounder is currently in the rebuilding phase, however, so it is unlikely that this stock is in equilibrium. Further, non-equilibrium situations are likely created whenever any changes to harvest restrictions are implemented, even for a population at equilibrium. The results generated by the equilibrium YPR model should therefore be interpreted as a long-term perspective of what can be expected in terms of harvest-per-recruit under each management scenario (i.e., yield once the population reaches equilibrium under a given harvest strategy). Unfortunately, the equilibrium YPR does not provide insight into the short-term impacts of a particular management measure on yield. Transitional (i.e., non-equilibrium) YPR does provide this information, however.
The transitional YPR model follows the equilibrium YPR model given in Equation (4); model inputs include $sel_{a,s}, M_s$, and $W_{a,s}$ as defined above. Rather than setting the number of recruits at some arbitrary number (e.g., 1000 male and 1000 female recruits), however, and generating the population structure based on an equilibrium assumption (Table 1a.), initial population structure is based on the relative abundances of the various age-classes (i.e., abundance of an age-class is given in relation to the other age-classes) in the population at the time at which a particular management option is implemented. For this investigation, the relative abundances of the age-classes of summer flounder in the Virginia portion of Chesapeake Bay were generated using age-frequency data for summer flounder collected by the ChesMMAP Trawl Survey. This non-equilibrium population structure is then projected into the future under a given $F$ and management scenario (represented by the $sel_{a,s}$ term) until an equilibrium population structure is attained (Table 1b. - number of years to equilibrium is equivalent to the number of age-classes in the population). A YPR is generated for each year in the projection, providing information on short-term harvest, while the YPR of the final year in the projection (when the population has reached equilibrium) is equivalent to the YPR that would be generated from Equation (4) using the same $F$.

**Transitional EPR**

While the equilibrium EPR provides information regarding egg production (and it is assumed, relative stock size) on more of a long-term scale, it fails to convey short-term information for non-equilibrium populations. A transitional (non-equilibrium) EPR model, however, does produce this information. The transitional EPR follows Equation (7), as $E_{a,FEM}$ and $P_{a,FEM}$ are included in this non-equilibrium model. Again, rather than
starting with an arbitrary number of recruits and generating a population structure based on an equilibrium assumption (Table 1a.), the initial population structure is constructed using the relative abundances of the various age-classes in the population at the time at which a particular management option is implemented (Table 1b). Age-frequency data for summer flounder collected by the ChesMMAP Trawl Survey were used to represent initial population structures for the non-equilibrium EPR. Similar to the approach taken with the transitional YPR model, the non-equilibrium population structure is then projected into the future under a given $F$ and management scenario (represented by the $s_{el_{a,s}}$ term) until an equilibrium population structure is attained. An EPR is generated for each year in the projection, providing information as to how egg production (and therefore stock size) would be impacted in the short-term, while the EPR of the final year in the projection (when the population has reached equilibrium) is equal to the EPR that would be generated from Equation (7) using the same $F$.

Assessment of Current Management Strategies

Equilibrium YPR and EPR models were used to assess the compatibility of Virginia’s current management strategy for its recreational summer flounder fishery, increasing minimum legal harvest size, with coastwide stock rebuilding needs. Specifically, summer flounder equilibrium YPR and EPR were calculated for a range of $F$ (i.e., 0.0, 0.1, 0.2, 0.28, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, and 1.5 yr$^{-1}$) for each of the minimum legal harvest sizes implemented since 2005 (i.e., 16.5” in 2005 & 2006, 18.5” in 2007, and 19” in 2008). We chose to evaluate the compatibility of the Commonwealth’s current management strategy with rebuilding goals beginning with
the 2005 fishing season, since quotas have consistently tightened (and, in turn, minimum sizes have steadily increased) since this time as pressure has mounted to rebuild by the 2013 deadline. This approach supported an evaluation of relative egg production (and therefore relative stock size) under each of the minimum legal harvest sizes at various levels of harvest (YPR), of relative harvest levels across these management scenarios at equivalent levels of egg production, and of relative egg production and harvest for each minimum size regulation at particular levels of \( F \) (which is assumed to be proportional to effort).

The short-term effects each of these management measures were evaluated by projecting a non-equilibrium population structure to equilibrium and calculating YPR and EPR for each year from the time at which a particular management option was implemented to that at which the population reached equilibrium. Because each projection is made for a particular \( F \) (rather than over a range of \( F \) as seen with the equilibrium models), \( F=0.28 \) yr\(^{-1} \) was chosen as this was identified as the instantaneous fishing mortality rate for this stock during the time period covered in this investigation (NEFSC 2008). A 16.5” minimum harvest size limit along with \( F=0.28 \) yr\(^{-1} \) was implemented for a 2005 non-equilibrium population structure, which was generated using age-frequency data on summer flounder collected by the ChesMMAP Trawl Survey from 2002 to 2005, and this projection was allowed to run to equilibrium. The projection provided a measure of relative harvest and egg production (YPR and EPR) by year as the population moved toward equilibrium under a 16.5” minimum size. Because the minimum size was increased to 18.5” in 2007, the 2007 population structure from the 16.5” projection was taken as the initial population for an 18.5” minimum size, \( F=0.28 \)
yr^{-1} scenario and projected forward to equilibrium. This allowed for a comparison of YPR and EPR by year for the 18.5” minimum size relative to the 16.5” minimum. Finally, the 2008 population structure from the 18.5” projection was taken as the starting point for a 19” minimum size, $F=0.28$ yr^{-1} projection, since the minimum legal size was increased to 19” at that time. This projection was also allowed to run to equilibrium, facilitating comparisons of relative egg production and harvest by year with the two smaller minimum legal size limits.

Assessment of Alternate Management Strategies

As noted above, concerns have been raised regarding the strategy of increasing minimum legal harvest size for the summer flounder recreational fishery in Virginia in response to tightening quotas and stock rebuilding needs both because targeting larger flounder for harvest places almost all of the fishing pressure on the most fecund breeding females, and because these larger fish are relatively unavailable to shore-based anglers. As an alternative to the minimum legal size management strategy, we investigated summer flounder yield and egg production under a slot and trophy fish management scenario.

Specifically, we compared equilibrium YPR and EPR over the range of $F$ defined above for a 19” minimum size limit (the 2008 regulation) with that for a 15”-18” slot limit, 22”+ trophy fish combination. The slot was chosen as it gives female summer flounder the opportunity to spawn at least once before entering the fishery and includes a portion of the male population, which is effectively absent from the fishery under the current minimum size regulations. The 22+ trophy fish was added because it was felt that
most anglers would be reluctant to forgo the opportunity to harvest a very large summer flounder, if captured. Transitional YPR and EPR models were also constructed for each of these management scenarios, using an initial non-equilibrium population structure for 2008 generated from summer flounder age-frequency data collected by the ChesMMAP Trawl Survey from 2005-2007. This approach enabled the comparison of relative egg production and harvest by year as the summer flounder population moved toward equilibrium under each of these management options.

Finally, because the weight of fish harvested is often less important to recreational anglers than is the opportunity to harvest a number of fish, YPR was calculated in terms of numbers (rather than weight) for each of these management options. This was accomplished by eliminating the $W_{as}$ term from Equation (4), and facilitated the comparison of harvest with respect to number at equivalent levels of egg production (stock size and rebuilding potential).

Results and Discussion

Assessment of Current Management Strategies

Equilibrium EPR/YPR curves over a range of $F$ are given for each of the minimum legal harvest sizes implemented for the summer flounder recreational fishery in Virginia since 2005 (Figure 6). These curves indicate that at equilibrium, for any given level of harvest (YPR), a larger minimum legal harvest size will result in a greater egg production (EPR) and in theory, stock size. Therefore, increasing minimum legal size to achieve a particular level of harvest for this recreational summer flounder fishery appears to have the potential to result in larger stock size. From a long-term perspective then,
Virginia’s strategy of increasing minimum legal harvest size in response to stock rebuilding needs has been compatible with those needs. While it was noted above that summer flounder exhibit sexually dimorphic growth patterns, females typically grow faster and larger than males, and that increasing minimum legal harvest size tends to place most (if not all) of the recreational fishing pressure directly on the most fecund breeding females, it appears that the loss of egg production through the harvest of large females is more than compensated by the reduction of fishing pressure on the smaller, but more numerous, mature females. It is likely that this compensation is possible due to the early maturation and high fecundity of the summer flounder (Figure 7).

A key assumption for the notion that increased egg production will result in a long-term increase in stock size is that egg viability must be equivalent across all sizes of spawning summer flounder. Deviations from this assumption (e.g., if eggs spawned by larger females are of higher quality and therefore more viable than those spawned by younger, smaller fish), have the potential to invalidate our conclusions regarding the relationship between minimum legal harvest size and stock size (from egg production) at a given level of harvest. Also, it was assumed that only flounder of legal size experienced fishing mortality (release mortality for sub-legal fish was minimal), which has been the subject of some debate. Data on the relationship between minimum legal harvest size and release mortality would be necessary to assess the validity of this assumption and quantify the effects of release mortality on YPR and EPR. Unfortunately, this information is presently unavailable.

These equilibrium YPR/EPR curves also indicate that, for the three minimum legal harvest sizes implemented for this summer flounder recreational fishery since 2005,
it is possible to achieve varying levels of yield (YPR) while maintaining a particular potential stock size (EPR). Specifically, for any given level of summer flounder EPR, a greater harvest can be gained by using a larger minimum legal size, which again is likely related to the early maturation and high fecundity of this species. The current regulatory process for the summer flounder recreational fishery along the U.S. Atlantic Coast requires that each state either adopt coastwide or develop individual equivalent management measures designed to ensure that state-specific harvest quotas are not exceeded. These YPR/EPR analyses show however, that if provided with a target $F$ and minimum legal harvest size based on some desired level of egg production, states could use such analyses to generate alternate management options that would be equivalent with respect to egg production (and therefore stock size and rebuilding potential), but may provide the state with a greater yield than would otherwise be allowed under the current management structure. This type of strategy was employed by Rhode Island in the 1980s to develop management options for the striped bass fishery (Prager et al. 1987).

Finally, the equilibrium YPR/EPR curves show that, among the minimum legal harvest sizes implemented from 2005 to 2008, egg production increases with minimum size through all levels of effort. In particular, assuming effort is proportional to $F$, egg production increases with increasing minimum legal size not only at lower levels of effort, but this trend holds at high levels of effort as well, indicating that the largest minimum legal size should afford the most protection to stock size and egg production should effort increase dramatically for some reason. Again, it appears that Virginia’s strategy of increasing minimum legal harvest size in the face of rebuilding needs has been consistent with these needs.
Transitional YPR and EPR models were constructed for the 16.5”, 18.5”, and 19” minimum legal harvest sizes beginning with the non-equilibrium population structures from 2005, 2007, and 2008, respectively (corresponding to the years in which each of these minimum sizes were implemented) and with $F=0.28$ yr$^{-1}$ (Figure 8). Each of these management scenarios were projected to 2021 to facilitate comparisons among the measures, as this was the earliest year in which all three projections would reach equilibrium. The transitional YPR/EPR models indicate that the shift to an 18.5” minimum size in 2007 from the 16.5” minimum resulted in a reduction in yield in 2007 relative to the harvest had the smaller minimum size been retained for that year. The egg production under each of these regulations was approximately equal in 2007. For each of the subsequent years to 2021, the yield from the 18.5” minimum size at $F=0.28$ yr$^{-1}$ was less than that under the 16.5” minimum, but the egg production, and therefore stock size and rebuilding potential, was greater. Similarly, when shifting from the 18.5” minimum legal size to the 19” minimum in 2008, yield was smaller each year with the larger minimum size relative to the 2007 regulation, egg production was equivalent to the 18.5” measure for the first year of the 19” regulation, and egg production under the larger minimum harvest size was greater for each of the following years.

One of the main concerns with using the equilibrium YPR and EPR models is that they only provide information regarding yield and egg production at equilibrium (long-term), and do not supply any indication as to whether a particular change in management regulations could produce a short-term population collapse. Based on the results presented for the transitional YPR/EPR, it does not appear that Virginia’s strategy of increasing legal minimum harvest size for the summer flounder recreational fishery posed
any such risk to the stock. Also, it should be noted that, while the projections for each of these management scenarios used $F=0.28$ yr$^{-1}$, it would be possible to construct a similar analysis where the desired $F$ varied by management strategy. Such an analysis could prove useful when trying to determine the short-term impacts of a management option that has been shown to generate equivalent egg production (potential stock size) but larger yield and $F$ through equilibrium YPR/EPR modeling efforts.

**Assessment of Alternate Management Strategies**

A 15”-18” slot, 22”+ trophy management option for the summer flounder recreational fishery in Virginia was compared to the 2008, 19” minimum legal harvest size using equilibrium YPR and EPR models (Figure 9). For all levels of yield, the 19” minimum size limit was associated with a greater egg production, and therefore potential stock size. These results indicate that the current strategy of using a relatively large minimum harvest size is more compatible with rebuilding goals at a particular level of harvest than the slot/trophy combination modeled in this investigation. All combinations of the 15”-18” slot limit, as well as two alternates (i.e., 15”-17” and 16”-18”), and trophy sizes ranging from 21”+ to 24”+ yielded similar results. Also, for a given level of egg production (EPR), the 19” minimum legal size resulted in a greater yield than any of the slot/trophy options tested. Finally, egg production was greater under the 2008, 19” minimum size limit for all levels of $F$, indicating that this large minimum size is a safer option from a stock rebuilding standpoint even if effort was to increase dramatically. Overall, it appears that the Virginia strategy of implementing relatively large minimum
harvest sizes for its summer flounder recreational fishery is more compatible with stock rebuilding needs than are the slot/trophy options tested here.

Transitional YPR/EPR projections were developed for the 15”-18” slot, 22”+ trophy management option as well as for the 19” minimum legal size to compare the short-term effects of each of these measures on harvest and egg production. Both projections used 2008 as the initial year for implementation of these options and ran to 2021, the year in which equilibrium would be reached for each of these management scenarios in the models. Yield was greater under the slot/trophy combination from 2008 to 2011, while harvest was larger with the 19” minimum from 2012 to 2021 (Figure 10). Egg production was greater under the 19” minimum legal size relative to the slot/trophy option for all years. Overall, it appears that the large minimum size was more compatible with rebuilding needs relative to the slot/trophy in the short-term as well, but that neither option would result in a short-term stock collapse. While both management scenarios were modeled using transitional YPR and EPR under the same $F$, it would be possible to conduct a similar analysis with $F$ differing between options (i.e., to investigate the short-term effects of various management options identified by equilibrium models as having equivalent egg production but varying YPR and $F$) if so desired.

As noted earlier, measuring yield in terms of weight when evaluating management options for a recreational fishery may not be entirely appropriate, as often recreational fishermen are more interested in the number, rather than the biomass, of fish that they are permitted to harvest. This consideration prompted an evaluation of the harvest trade-offs necessary to maintain equivalent egg production if a shift from a 19” minimum legal harvest to a 15”-18” slot, 22”+ trophy combination was desired.
Assuming that the current $F$ with the 19” minimum harvest size is 0.28 (NEFSC 2008), YPR in terms of weight under this regulation was determined to be 0.190 kg recruit$^{-1}$, based on the models used in this investigation (Figure 11). Equivalent egg production (and therefore stock size and rebuilding potential) was maintained under the aforementioned slot/trophy combination when yield was 0.171 kg recruit$^{-1}$, meaning that a 10% reduction in harvest with respect to weight would be necessary relative to the 19” minimum. When yield was calculated in terms of number (by eliminating the $W_{a,s}$ term in Equation 4), however, the YPR under the 19” minimum size at $F=0.28$ yr$^{-1}$ was 0.113 fish recruit$^{-1}$. At an equivalent level of egg production, yield under the 15”-18” slot, 22”+ trophy combination was 0.155 fish recruit$^{-1}$, representing a 37% increase in the number of summer flounder that could be harvested. This relatively large increase in permissible harvest with respect to number without loss of egg production is likely possible because summer flounder fecundity, while large at the population level at smaller fish sizes (Figure 7), is much greater at the individual level at larger sizes (i.e., it takes the removal of several, smaller mature females to equal the egg loss incurred by the removal of a single, larger one). Furthermore, the slot/trophy combination includes males in the exploitable segment of the population, which are typically not found at larger sizes and do not contribute to the loss of egg production upon harvest.

Finally, it is important to note that while implementing the aforementioned slot/trophy scenario should allow for an increase in the total number of summer flounder harvested by the recreational fishery, individual fishermen may or may not realize an increase in the number of flounder that they are permitted to land. If, by implementing the slot/trophy combination, effort were to increase dramatically (e.g., due to the
inclusion of more shore-based anglers in the fishery), the number of fish that any givenangler may harvest per day or per season may not increase, and perhaps could decline,relative to the current management strategy. Evaluating potential changes in effort in thesummer flounder recreational fishery in Virginia due to changes in managementregulations was beyond the scope of this investigation, but the quantification of thisrelationship would be necessary before setting possession limits for a slot/trophycombination, if such a management option was considered desirable.

References


Table 1a. A generalized population structure based on an assumption of equilibrium and used in equilibrium yield-per-recruit and egg-per-recruit modeling. The $N$ column gives number at age, and the $R$ term represents hypothetical recruitment.

<table>
<thead>
<tr>
<th>Age</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>R</td>
</tr>
<tr>
<td>1</td>
<td>Re^{-Z}</td>
</tr>
<tr>
<td>2</td>
<td>Re^{-2Z}</td>
</tr>
<tr>
<td>12</td>
<td>Re^{-12Z}</td>
</tr>
</tbody>
</table>

Table 1b. A generalized population structure based on an assumption of non-equilibrium and used in transitional yield-per-recruit and egg-per-recruit modeling. The $I_a$ term represents an index of abundance at age $a$.

<table>
<thead>
<tr>
<th>Age</th>
<th>Yr 1</th>
<th>Yr 2</th>
<th>Yr 3</th>
<th>→</th>
<th>Yr 12</th>
</tr>
</thead>
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<td>$I_0$</td>
<td>$I_0$</td>
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<td>→</td>
<td>$I_0$</td>
</tr>
<tr>
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<td>$I_1$</td>
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<td>$I_0e^{-Z}$</td>
<td>→</td>
<td>$I_0e^{-Z}$</td>
</tr>
<tr>
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<td>$I_0e^{-2Z}$</td>
</tr>
<tr>
<td>12</td>
<td>$I_{12}$</td>
<td>$I_{11}e^{-Z}$</td>
<td>$I_{10}e^{-2Z}$</td>
<td>→</td>
<td>$I_0e^{-12Z}$</td>
</tr>
</tbody>
</table>
Figure 1. Coastwide quota (millions of pounds) for the U.S. Atlantic Coast summer flounder recreational fishery, along with minimum legal harvest size of summer flounder for the recreational fishery in Virginia, given by year (2003 – 2008).
Figure 2a. Length-frequency, by sex, of summer flounder collected by the ChesMMAP Trawl Survey from 2002 to 2007. Males are given in blue while females are given in red.

Figure 2b. Length-frequency, by sex, of summer flounder collected by the NEAMAP Trawl Survey (nearshore coastal ocean, Martha’s Vineyard, MA to Cape Hatteras, NC) in 2007. Males are given in blue while females are given in red.
Figure 3. Length at age, by sex, of summer flounder collected by the ChesMMAP Trawl Survey from 2002 to 2007. Males are represented in blue while females are given in red, and seasonal growth models are given for each in corresponding colors.

**Female:** \[ L_a = 631.4 \times (1 - e^{-(0.07\times \sin(2\pi \times (a - 0.62)) + 0.29(a + 1.01))}) \]

**Male:** \[ L_a = 417.3 \times (1 - e^{-(0.15\times \sin(2\pi \times (a - 1.12)) + 0.61(a + 0.56))}) \]
Figure 4. Weight at length, by sex, for summer flounder collected by the ChesMMAP Trawl Survey from 2002 to 2007. Males are given in blue while females are represented in red, and weight at length models are provided for each in corresponding colors.

**Female:** \( W_a = 1.517 \times 10^{-9} \times L_a^{3.3138} \)

**Male:** \( W_a = 3.209 \times 10^{-9} \times L_a^{3.1927} \)
Figure 5. Probability of encountering a mature female summer flounder by age (equivalent to percentage of mature female summer flounder by age). Individual observations of female summer flounder maturity at age are given by black dots (0 = immature, 1 = mature); data are from summer flounder collected by the ChesMMAP Trawl Survey from 2002 to 2007. The model of summer flounder maturity at age is given by the red line and is provided by the corresponding equation.

Logit(p) = 4.16 – 3.23*(age)
Figure 6. Equilibrium egg-per-recruit (EPR) versus yield-per-recruit (YPR by weight – kg) for summer flounder under the current minimum harvest size management strategy implemented by Virginia for its recreational fishery. The purple line represents EPR/YPR over a range of instantaneous rates of fishing mortality ($F$) under a 16.5” minimum size limit (regulation in 2005 & 2006), the green line an 18.5” minimum size limit (2007 regulation), and the black line a 19” size limit (2008 regulation). Points represent particular $F$ on the summer flounder available for harvest. Beginning at the upper left portion of each curve, fishing mortalities are $F = 0.0, 0.1, 0.2, 0.28, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, and 1.5$ yr$^{-1}$. Note that EPR increases with increasing minimum size over all levels of $F$. 

More eggs at YPR with larger min. size

More yield at EPR with larger min. size

$F=0.1$

$F=0.5$

16.5” (2005 & 2006)

18.5” (2007)

19” (2008)
Figure 7. Population-level relative egg production by length (total length) for summer flounder in the absence of fishing. These values were generated by combining average fecundity at age with the relative number of female summer flounder at each age, assuming 1000 recruits and an equilibrium population structure where $M = 0.22 \text{ yr}^{-1}$ and $F = 0 \text{ yr}^{-1}$. Average fecundity at age was produced by combining length at age and fecundity at length.
Figure 8. Transitional (non-equilibrium) egg-per-recruit (EPR) versus yield-per-recruit (YPR by weight – kg) for summer flounder under the current minimum harvest size management strategy implemented by Virginia for its recreational fishery. The purple line gives EPR/YPR by year to equilibrium under a 16.5” minimum size limit (regulation in 2005 & 2006), the green line for an 18.5” minimum size (2007 regulation), and the black line for a 19” size limit (2008 regulation). Initial population structure for the 16.5” projection was taken from summer flounder age-frequency data collected by the ChesMMAP Trawl Survey between 2002-2005, while the initial structure for the 18.5” projection was taken as the 2007 population from the 16.5” projection. The 2008 population structure from the 18.5” projection was used as the starting point for a 19” minimum size.
Figure 9. Equilibrium egg-per-recruit (EPR) versus yield-per-recruit (YPR by weight – kg) for summer flounder under the 2008 minimum harvest size regulation (19") implemented by Virginia for its recreational fishery, and a slot/trophy management option. The orange line represents EPR/YPR over a range of instantaneous rates of fishing mortality (F) under a 15”-18” slot, 22”+ trophy combination, and the black line the 19” minimum size limit. Points represent particular F on the summer flounder available for harvest. Beginning at the upper left portion of each curve, fishing mortalities are $F = 0.0, 0.1, 0.2, 0.28, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4,$ and 1.5 yr$^{-1}$. Note that EPR is greater with the 19” minimum size over all levels of F.
Figure 10. Transitional (non-equilibrium) egg-per-recruit (EPR) versus yield-per-recruit (YPR by weight – kg) for summer flounder under the 2008 minimum harvest size regulation (19”) implemented by Virginia for its recreational fishery, and a slot/trophy management option. The orange line gives EPR/YPR by year to equilibrium under a 15”-18”, 22”+ slot/trophy combination, and the black line for a 19” size limit. Initial population structure for each of these projections was taken from summer flounder age-frequency data collected by the ChesMMAP Trawl Survey from 2005-2007.
Figure 11. Equilibrium egg-per-recruit (EPR) versus yield-per-recruit (YPR by weight – kg) for summer flounder under the 2008 minimum harvest size regulation (19”) implemented by Virginia for its recreational fishery, and a slot/trophy management option. The orange line represents EPR/YPR under a 15”-18” slot, 22”+ trophy combination, and the black line the 19” minimum size limit. The horizontal black dotted line represents harvest trade-offs, both in terms of biomass (YPR) and number (NPR – number-per-recruit) of summer flounder harvested, between these management options under the assumption of a current $F = 0.28$ yr$^{-1}$ for the 19” minimum size limit.