

## Negative Implications of Striped Bass Minimum Size Regulations

C. Phillip Goodyear  
415 Ridgewood Road  
Key Biscayne, FL 33149  
[Phil\\_Goodyear@msn.email.com](mailto:Phil_Goodyear@msn.email.com)

February 4, 1998

*Abstract.* – One component of the management regimen employed to rebuild the Atlantic coastal migratory stock of striped bass was the imposition of large size limits to reduce fishing mortality to zero on the 1982 and subsequent year-classes until 95% of the females had an opportunity to reproduce at least once. Such size limits introduce size selective mortality that favors the survival of slower-growing members of the population, and may select for slower growth in succeeding generations. Size at age data from the Hudson River population were used to examine the effect of alternative size limits on the length distributions of survivors by age using simulation. The results indicate that minimum sizes currently in use can cause profound changes in the size composition of the spawning stock. The mean asymptotic length of unfertilized eggs under equilibrium conditions was estimated as an index of extent to which these changes may influence future growth. With the current best estimates of growth parameters and fecundity at size, this index was reduced by only about 3%. However, because of the size-selective mortality in existing fishery, and uncertainty arising from sampling difficulties, growth is probably poorly characterized by the existing data. Sensitivity analyses revealed that some reasonable combinations of growth and minimum sizes can induce changes in the mean asymptotic length of unfertilized eggs by more than 10%, which would be about 30% in terms of asymptotic mean weight. The extent to which this selective force might be expressed in succeeding generations is uncertain. However, reliance on minimum sizes to constrain catch has the potential to cause profound changes in growth, and probably should not be adopted for long term management of striped bass until this problem is better understood.

### Introduction

The Atlantic coastal migratory stocks of striped bass (*Morone saxatilis*) supported by spawning grounds in the Chesapeake bay declined precipitously during the 1970s as a consequence of excessive fishing mortality (Field 1997). This event spurred research and management intervention beginning in the early 1980s to rebuild the resource. Management authority rested with the Atlantic States Marine Fisheries Commission (ASMFC) through its Interstate Fisheries Management Plan for Striped Bass that was first adopted in 1981. State compliance with the provisions of the plan became mandatory in 1984 with the promulgation of the Atlantic Striped Bass Conservation Act (PL 98 - 613). The plan was amended in 1984 and again in 1985 to provide for increased conservation of the resource. The 1985 Amendment called for state regulations to reduce fishing mortality on the 1982 year-class females, and all subsequent year classes of Chesapeake Bay stocks to zero until 95% of the females of these year classes had an opportunity to reproduce at least once (ASMFC 1985). The Amendment suggested establishment of increasingly large minimum size limits as one approach to achieve this objective. This strategy was adopted for the coastal waters (as opposed to bays), and the minimum sizes were increased on an almost annual basis to 91 cm (36 inches) total length (TL) by 1989. The coastal-

water size limits were lowered in many states with the recovery of the stocks since 1990, and in 1996 they varied from 71 to 86 cm (28 to 34 inches).

The striped bass population of the Hudson River did not experience the same decline in abundance as the Chesapeake stock during the 1970s and 1980s (Field 1997). However, their post-spawning distribution along the Atlantic coast is basically the same area occupied by coastal migrants from the Chesapeake during the summer and fall months (Dorazio et al. 1994; Waldman et al. 1990; 1997). Consequently, the relatively large minimum size limits imposed to conserve and rebuild the Chesapeake stocks of striped bass also applied to the Hudson River population as well.

Minimum sizes can contribute to size selective fishing mortality, and large minimum sizes can significantly enhance the relative survival of slower growing members of a population (Parma and Deriso 1990; Goodyear 1996). To the extent that growth is a heritable trait, this process can select for slow growth in succeeding generations (Parma and Deriso 1990). This problem has been raised as a possible issue with respect to the decline in weight at age in other species (McAllister et al. 1992; Kroan and Kerr 1997, Wohlfarth 1986).

This paper utilizes simulation techniques to evaluate the potential influence of alternative size

limits on the distributions of size at age for the Hudson River striped bass spawning stock and develops a measure of the potential magnitude of the selective force.

### Methods

The model used to examine the potential effects of alternative size limits on the size composition of the striped bass spawning population was an elaboration of the model described by Goodyear (1989). In this model, growth is characterized by dividing the population into an arbitrary number of phenotypic morphs representing portions of the population that differ in growth attributes, and each morph is modeled separately. Given the sexual dimorphism in growth observed in striped bass (Mansueti 1961), each sex was modeled separately. Population characteristics are then evaluated by summing over the morphs and sexes. This approach to characterizing growth is an "assignment-at-birth" Kirkpatrick (1984), in which the growth of each individual follows a distinct pattern that is completely determined at some initial (pre-recruit) stage.

The model uses a seasonal time scale, which is monthly for this analysis. I adopted the value of natural mortality used in the most recent stock assessment of  $M=0.15$  (ASMFC 1997). This level of natural mortality implies a long life span, so the model considered 50 discrete ages. The number of survivors of sex  $S$  and morph  $M$  at age  $A$  and season  $P$  ( $N_{SAMP}$ ) is

$$N_{SAMP} = R_{SAM} \exp(-\mu_{SAMP}),$$

where  $R_{SAM}$  is the initial recruitment of age  $A$  of sex  $S$  represented by morph  $M$ , and  $\mu_{SAMP}$  is the cumulative total mortality suffered by morph  $M$  of sex  $S$  from recruitment to season  $P$  at age  $A$ , or

$$\mu_{SAMP} = \sum_{t=0}^{A-1} \sum_{j=1}^{\Omega} (M_j + F_{lJM}) + \sum_{j=1}^{P-1} (M_j + F_{AJM}),$$

where  $\Omega$  is the number of seasons within a year and is set to 12 for analyses conducted for this report. The seasonal natural mortality ( $M_j$ ) used in the present evaluation was 1/12 the annual assumed rate. The  $F_{lJM}$  is the instantaneous fishing mortality for morph  $M$  during season  $J$  when it was age  $l$ . For the analyses conducted here, the relative susceptibility of striped bass to fishing was assumed constant over age except for the effect of minimum size on retention of captured fish. The instantaneous rate of fishing mortality,  $F$ , for striped bass above the minimum size was varied to examine the effect of the magnitude of fishing on the relative survival of the different morphs to the spawning ages. For ages and seasons when the morph

is below the minimum size, the fishing mortality is reduced to  $dF$  where  $d$  is the fraction of the discarded catch which dies. Note that if a size limit were sufficiently high that some morphs never reach it during their lifetime, and the discard mortality,  $d$ , is less than 100%, then there would be no age where the fishing mortality averaged over all morphs would equal  $F$ . The value of  $d$  was set to 0.07 based on the recreational hooking mortality rate assumed in the most recent stock assessment (ASMFC 1997).

As a first order approximation of the magnitude of the potential magnitude of size-limit induced changes in the size composition of spawners, I evaluated the ratio of the mean asymptotic length of the unfertilized eggs at a particular size limit to the same measure given no size limit. This would probably be a reasonable approximation of the selective pressure induced by minimum sizes if that attribute is completely heritable. The mean asymptotic length  $\lambda$  of the unfertilized eggs was estimated for the stable age distribution assuming constant recruitment as:

$$\lambda = \left( \sum_{A=1}^{\Delta} \sum_{M=1}^{\Omega} L_{\infty M} E_{AM} N_{AM} \right) / \left( \sum_{A=1}^{\Delta} \sum_{M=1}^{\Omega} E_{AM} N_{AM} \right),$$

where:  $\Delta$  is the number of ages in the unfished population,  $\Omega$  is number of discrete morphs considered,  $L_{\infty M}$  = asymptotic size of female morph  $M$ ,  $E_{AM}$  = mean fecundity of morph  $M$  females at age  $A$ ; and, ( $N_{AM}$ ) number of age  $A$  survivors of female morph  $M$  at the beginning of the spawning season. The fecundity of females at the time of spawning was evaluated from their length using the polynomial equation of Goodyear (1984) derived from fecundity and maturity data presented by Lewis and Bonner (1966) and Mansueti (1961).

Size at age data for Hudson River striped bass were obtained from the New York Department of Environmental Conservation (Cathy Hattala, NYDEC and K. McKown, NYDEC). Additional samples from coastal waters were obtained from National Marine Fisheries Service (Gary Shepherd, NMFS). The latter data were a compilation of samples collected by many investigators using a variety of gears in inshore and coastal waters from North Carolina to Maine that had been used in the most recent stock assessment for this species (ASMFC 1997). The former data were used to describe mean total length age,  $L_t$ , by sex for Hudson River striped bass using the von Bertalanffy growth equation:

$$L_t = L_{\infty} \left( 1 - e^{-k(t-t_0)} \right),$$

where  $L_{\infty}$  is mean asymptotic total length,  $k$  is the

Brody growth coefficient, and  $t_0$  is the hypothetical age at which the fish would have been of zero length if it had always grown in the manner described by the equation (Ricker 1975). These data were also used to characterize the distribution of lengths about the mean and to examine the distributions of size at age available to the coastal fisheries.

Data from the recreational fishery were obtained from the NMFS Marine Recreational Fisheries Statistics Survey (MRFSS). These data included estimates of striped bass catch and release by year, and the size composition of the recreational harvest each year. These data provided information about the proportion of the striped bass recreational catch that was being released.

### Results

The size at age data available from the Hudson River sampling consisted of collections by gillnet, haul seine, and electrofishing. Inspection of these data stratified by gear type revealed the expected selectivity bias in length frequencies at age in samples collected with gill nets. The electrofishing samples were generally upstream from the spawning grounds and were not confined to the spawning season. Consequently, these samples were eliminated from further consideration, and only the haul seine data from the NYDEC spawning stock survey were employed to estimate growth. The length frequencies and sample size for the selected data are given in Figures 1 and 2.

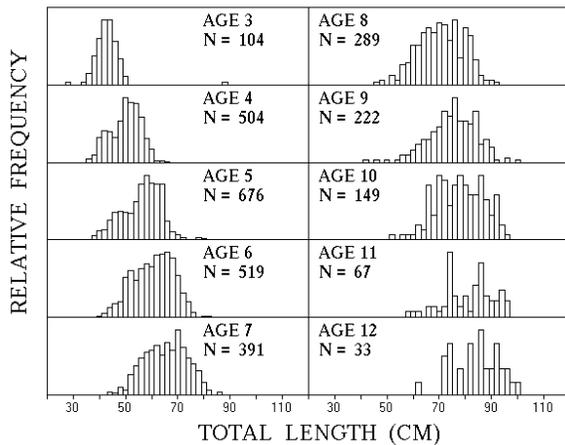


Figure 1. Length frequencies of female Hudson River striped bass from NYDEC spawning stock surveys.

Inspection of the length frequencies of males and females by age confirmed the sexual dimorphism in growth previously reported for striped bass (Mansueti 1961). Consequently, separate growth equations were developed for each sex by fitting von Bertalanffy growth equations to the mean observed lengths and

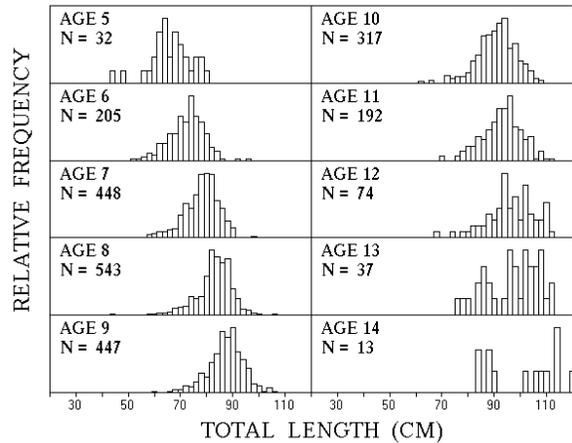


Figure 2. Length frequencies of male Hudson River striped bass from NYDEC spawning stock surveys.

ages of each age class well represented in the samples for each sex (Figures 3 and 4). For both sexes there were few observations of length at age for young fish, undoubtedly do to the difficulty of identifying the sex of immature individuals. Also, there were very few fish older than about 15 years of age in the samples, probably because of lowered abundance resulting from longer exposure to natural and fishing mortality. Consequently, the fitted relationships do not include data from the full range of ages in the stock.

Additional age-length data from the consolidated stock-assessment NMFS data file were available to characterize size at age but did not provide information on sex. Since the sexual dimorphism in size at age

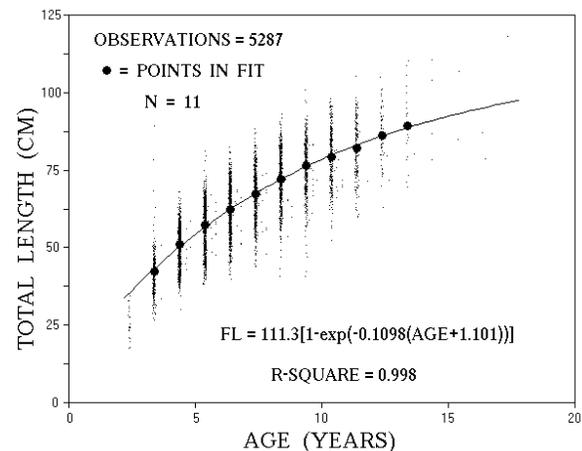


Figure 3. Scattergram of male Hudson River striped bass from NYDEC spawning stock surveys and fitted von Bertalanffy growth equation.

increases with age, the lengths at age for the youngest fish in these samples might reasonably represent the size of young striped bass of both sexes at early ages.

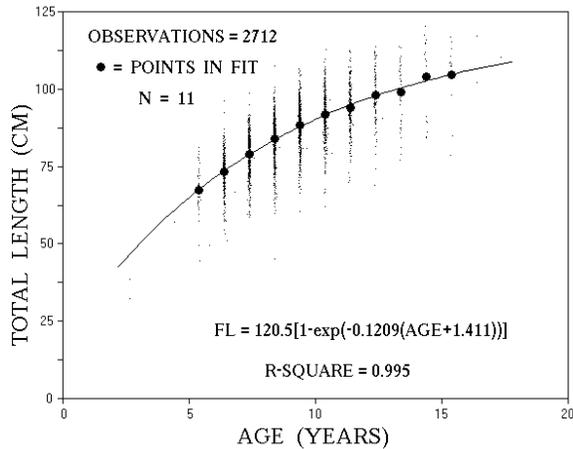


Figure 4. Scattergram of female Hudson River striped bass from NYDEC spawning stock surveys and fitted von Bertalanffy growth equation.

Samples that had been collected with gear other than gillnets from New York northward were extracted from the available data file and stratified by age. Since the emigration of striped bass from the Chesapeake Bay generally doesn't occur in significant numbers before the spring of their second calendar year of life (Merriman 1941; Dorazio et al.1994), most individuals in their first or second calendar year of life in this area should be from the Hudson River.

The data were inspected to identify clusters of measurements where there were sufficient numbers of observations of lengths at age within time intervals sufficiently short, that growth within the interval was not an important consideration. The resulting best set of length frequency information is presented in Figure 5 for ages 1 to 12. The mean size at age for each sex was interpolated from age 0 to the youngest ages

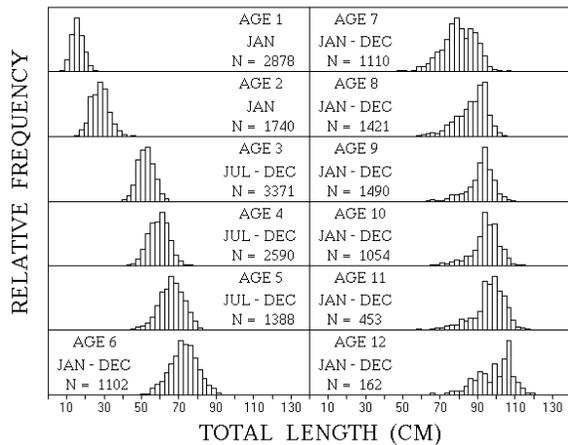


Figure 5. Length frequencies of selected samples of striped bass from coastal waters by age.

included in the von Bertalanffy fit by drawing a smooth curve through the observed mean size during January at age 1 and the predicted length at the age of the youngest age-class included in the fit (Figures 3 and 4). Otherwise, mean size at age used in this analysis was the predicted value from the appropriate von Bertalanffy equation (Table 1), and within-year growth was assumed constant.

Table 1. Mean total lengths at age for male and female striped bass used in this study

Age	Male	Female	Age	Male	Female
1	16.2	16.2	16	94.2	105.8
2	28.1	32.5	17	96.0	107.4
3	38.3	45.6	18	97.6	108.9
4	46.2	56.7	19	99.0	110.2
5	54.3	64.9	20	100.3	111.4
6	60.2	71.3	21	101.4	112.4
7	65.5	76.9	22	102.4	113.3
8	70.3	81.8	23	103.4	114.2
9	74.5	86.2	24	104.2	114.9
10	78.4	90.1	25	104.9	115.5
11	81.8	93.6	30	107.6	117.8
12	84.8	96.6	35	109.1	119.0
13	87.6	99.4	40	110.0	119.6
14	90.1	101.8	45	110.6	120.0
15	92.3	103.9	50	110.8	120.2

Inspection of the length frequencies in Figures 1 and 2 does not provide firm guidance on the shape of the underlying distribution of size at age, especially since size selective fishing may have altered the distributions in the older age classes. These data were further stratified to month (May and June) and age and the distributions tested for normality using Chi Square. For the male samples, 6 of the resulting 17 strata with 25 or more observations failed the test of normality. However, there was an apparent effect of month and age as none of the 7 June-age samples failed the test of normality, and the 6 of 10 May-age samples which failed the test of normality were the youngest ages with sufficient sample sizes to conduct the test. It is possible that this result is an artifact of the effect of sample size on the power of the test. However, it also may be an outcome of non-randomness associated with relative maturation of individuals by size within age, since mature individuals would be more likely identified to sex and be present in the sampling areas.

The same type of examination of the female length frequency data revealed that 4 of the 12 age-month strata failed the test of normality. Consequently it is not evident that a normal distribution is completely appropriate for describing the variation of length at age for the unfinished condition of striped bass. The propensity for samples to fail the test for normality might be the result of the underlying true distribution of size at age not being normal. Or, it might be the result of sampling, spatial distributions of striped bass by length, size selective mortality, or some

other vagary. However, data from the youngest age group of males in Figure 1, and the January samples of age 1 for sexes combined do not show a strong skew that suggests the normal distribution is inappropriate for this analysis. Consequently, the pre-fishing distribution of size at age was assumed normal for the purpose of this study.

Given the selection of a normal distribution to characterize the distribution about the mean size at age, the Coefficient of Variation (CV) is useful for specifying the cumulative frequency distribution of lengths at age. Consequently, I estimated the CV for each age used to fit the von Bertalanffy equation by sex (Figure 6). The average CV was 0.12 for males and 0.085 for females. For each sex I regressed the CV on age to determine if it changed with age. CV declined slightly with age for the males but the trend was not significant. For females the CV initially declined with age but increased with the older fish such that the slope of the relation was positive. However, as with the males the regression was not significant. Consequently I assumed that the CV was constant with age and that it was equal to the mean of the observed values (0.12 for males and 0.085 for females).

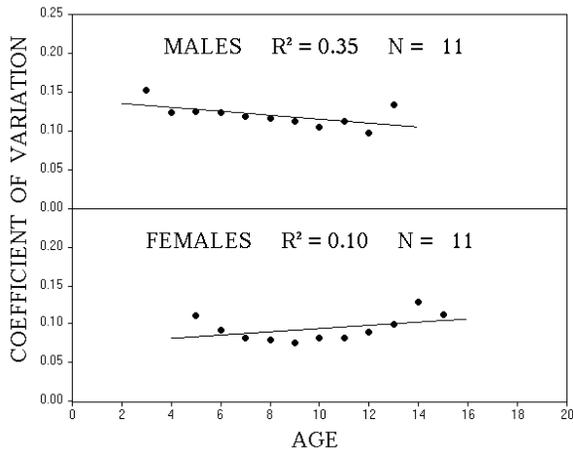


Figure 6. Coefficient of Variation (CV) of size at age for male and female striped bass and associated regressions.

The length distribution for each sex in the model population was divided into 101 equal length intervals with a cumulative range of  $\pm 3$  standard deviations from the mean. Initial recruitment to each morph was based on the proportion of the cumulative normal distribution within the length range represented by morph. All analyses were performed for the stable age distribution and assumed recruitment and all other factors were constant.

Calculations of the relative change in size distributions of survivors at age were made using these estimates of the growth parameters and a level of

fishing mortality equal to the most recent estimate for fully recruited striped bass in the coastal fishery of  $F=0.31$  (ASMFC 1997). Analyses considered no minimum size and minimum sizes of 40.6, 55.9, 71.1, 83.8, and 91.4-cm total length (TL). The distributions of survivors at age by morph at age were plotted for each sex (Figures 7 and 8). At the 40.6 cm minimum size limit there was an almost imperceptible shift of the distribution to the left with increasing age for both sexes. At the 55.9 cm minimum size, the effect was more discernible and was slightly more pronounced for females. At minimum sizes of 71.1 cm and larger, the effect of the size limit on the relative survival of faster versus slower growing morphs was very pronounced for males (Figure 7). A similar trend is seen for females but beginning at a slightly higher minimum size (Figure 8).

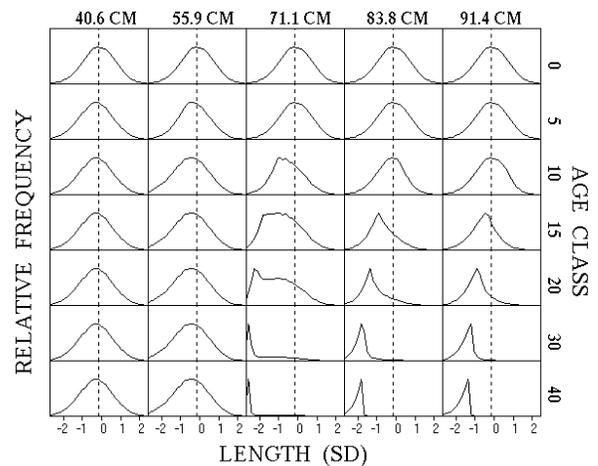


Figure 7. Change in survivorship by growth morph and age for male striped bass at several different size limits.

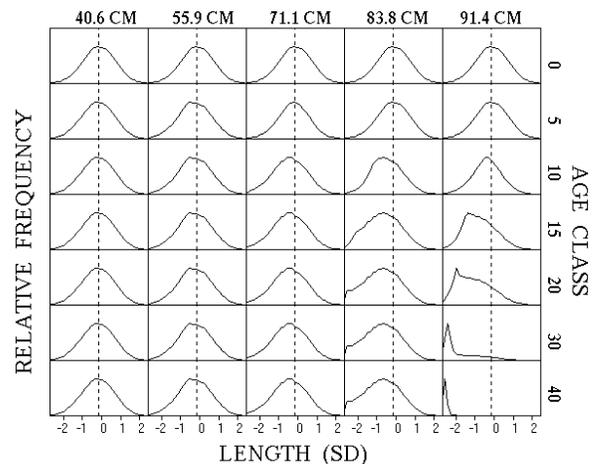


Figure 8 Change in survivorship by growth morph and age for female striped bass at several different size limits.

The length frequency distributions for males, females, and sexes combined that arise from the analyses with minimum sizes set to 71.1 cm and 91.4 cm are presented in Figures 9-14. In each of these figures, the smooth curve is the result of the analysis with fishing mortality but no size limit imposed and all other conditions are the same. For the smaller of these two size limits, the effects on the distribution of male survivors is more dramatic than that of the females through age 12 (Figures 9 and 10). With the larger size limit, the effect is more pronounced for females (Figures 12 and 13).

The length frequency distributions for sexes combined are noticeably skewed with a left-hand tail even for the analyses that assume no minimum size (Figures 11 and 14). Among other considerations, this finding suggests that the observation of right-handed truncation of length frequency distributions from unsexed samples (as in many of the length frequencies in Figure 5) is not necessarily evidence for reduced survival of faster growing individuals. It may rather only reflect the mixing of the two distributions arising from the sexual dimorphism of growth.

However, the additional effect of the size-selective mortality imposed by the minimum size causes the distributions to become even more skewed. In the case of the 71.1 cm size limit, the distribution of lengths is shifted to the left and appears increasingly truncated on the left with age (Figure 11). In contrast, with the larger 91.4 cm size limit the combined length frequencies appear truncated on the other side and become progressively more so with age (Figure 14).

The decline in the mean asymptotic length of unfertilized eggs for the minimum sizes evaluated here for the current best estimate of fishing mortality in the stock ( $F=0.31$ ) increased from less than 1% to about 3% as the minimum size increased from 40.6 cm to 91.4 cm.

These estimates, of course, are conditioned on the accuracy of the growth parameters used in the analyses. To study the problem more thoroughly, I evaluated the percent reduction in mean asymptotic length of unfertilized eggs as a function of fishing mortality, CV of size at age, the value of  $k$  in the von Bertalanffy equation and minimum size. Since the parameters,  $L_\infty$  and  $k$  of the von Bertalanffy equation cannot vary independently and pass through a common age and length (except at the intercept), the value of  $L_\infty$  for each value of  $k$  was adjusted so that the resulting equation passed through the observed mean length at age 10. As a consequence, the minimum sizes were set as a percentage of  $L_\infty$ . Analyses were performed with no minimum size and for minimum sizes of 10 to 100 percent of  $L_\infty$  in 10 percent intervals; values of  $k$  ranged from 0.05 to 0.25 in increments of 0.05; and the instantaneous fishing

mortality rate was varied from 0.1 to 1.0 in increments of 0.1.

The percentage reduction in the mean asymptotic length of unfertilized eggs increased with increasing fishing mortality rates, and with increasing minimum sizes to some intermediate minimum size and then declined as the minimum size approached  $L_\infty$ . The results for constant CV of 0.15 and von Bertalanffy  $k$  of 0.15 show the maximum percentage reduction in mean asymptotic length of unfertilized eggs increased from about 2% to nearly 12% as fishing mortality increased from 0.1 to 1.0 (Figure 15). Also, the minimum size at which the bias was maximized decreased with increasing fishing mortality from about 90% of  $L_\infty$  at  $F = 0.1$  to 70% of  $L_\infty$  at  $F = 1.0$  (Figure 15).

A similar analysis holding fishing mortality constant at  $F = 0.5$  and the von Bertalanffy  $k$  constant at 0.15 while varying the CV of size at age from 0.05

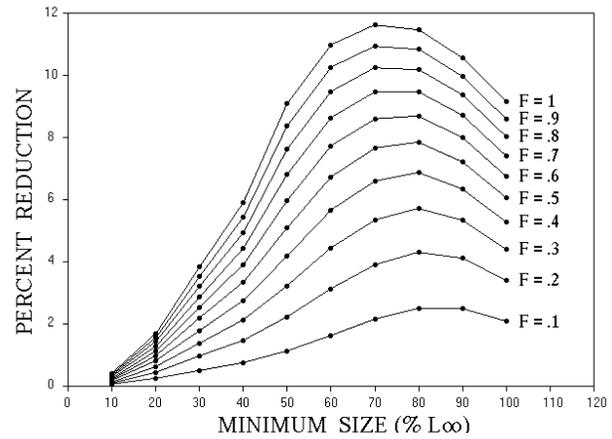


Figure 15. Percent reduction in mean asymptotic length of unfertilized eggs as a function of minimum size and fishing mortality.

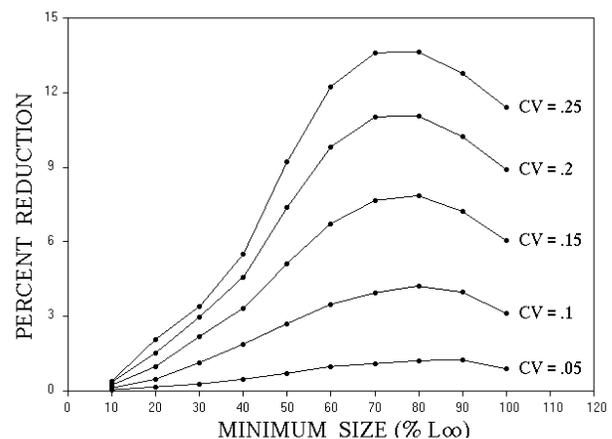


Figure 16. Percent reduction in mean asymptotic length of unfertilized eggs as a function of minimum size and CV of length at age.

to 0.25 over minimum sizes from 10 to 100% of  $L_\infty$  is presented in Figure 16. The percentage reduction in mean asymptotic length of eggs increased with increasing CV for all minimum sizes considered. As with increasing fishing mortality, the effect of increasing the size limit for each CV examined was an initial increase in the bias followed by a decline at the largest size limits considered. The maximum bias observed was about 14% at a minimum size of 80% of  $L_\infty$  for CV=0.25. The minimum size at which the bias was maximized decreased with increasing CV from about 90% of  $L_\infty$  at CV = 0.05 to 70% of  $L_\infty$  at CV = 0.25 (Figure 16).

Analyses that varied the von Bertalanffy  $k$  and minimum size while holding the CV constant at 0.15 and fishing mortality constant at  $F = 0.5$  are presented in Figure 17. These results also show that the percentage reduction in the mean asymptotic length of unfertilized eggs initially increases with increasing minimum size, but then declines after some intermediate minimum size is reached. In contrast to the other parameters, the absolute magnitude of the maximum bias was only marginally changed by the value of the von Bertalanffy  $k$  over the range evaluated. However, the size limit at which the bias was maximized increased with increasing  $k$  from about 40% of  $L_\infty$  for  $k$  equal 0.05 to 90% of  $L_\infty$  for  $k$  equal to 0.25 (Figure 17).

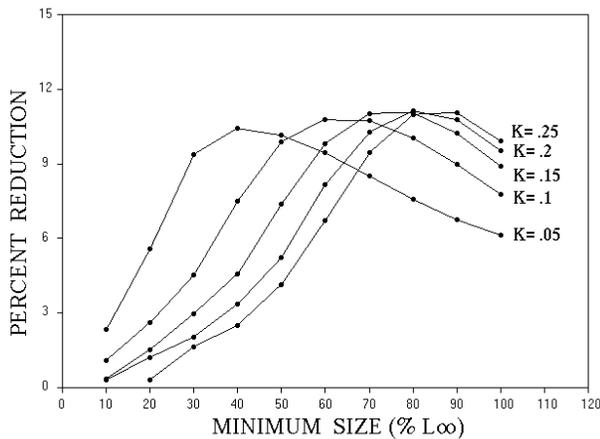


Figure 17. Percent reduction in mean asymptotic length of unfertilized eggs as a function of minimum size and the value of the von Bertalanffy parameter  $k$ .

The likelihood that the fishery is actually causing such selection is related to the fraction of the catch that is being released because of the size limits. Observations of the sizes of striped bass encountered during the intercept portion of MRFSS from 1981 to 1996 from New York northward were sorted into three groups. The first group consisted of observations that had been made in locations and seasons where the

minimum size at been less than 71 cm, the second included observations where the minimum size was 71 cm, and the last included observations where the minimum size was at least 91 cm. The length frequencies of these observations of the recreational landings for these three groupings show a rather dramatic effect of the regulations on the size composition of the recreational harvest (Figure 18).

In addition to harvest, MRFSS also estimates the numbers of striped bass that are discarded by anglers each year. This data indicates that for this same area the discard rate increased from about 50% to almost 98% in 1989 as a result of the increased size limits (Figure 19). A discard rate of 50% means that 1 out of every 2 fish caught is released. At 98% 49 of every 50 fish caught are released. While many of the releases may be due to factors other than the minimum size, it seems clear that the minimum sizes that have been

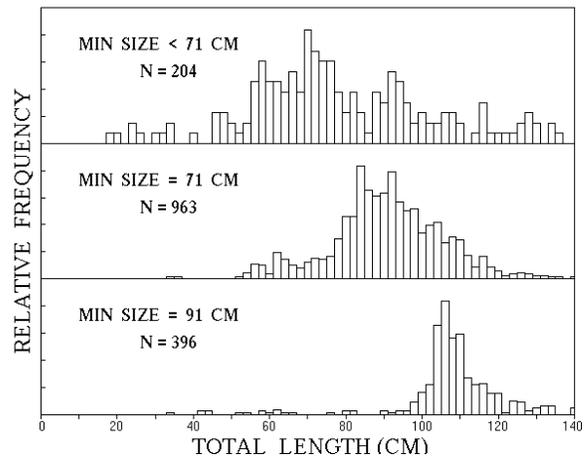


Figure 18. Length frequencies of striped bass sampled from the recreational harvest from New York through Maine for three size limit regimes

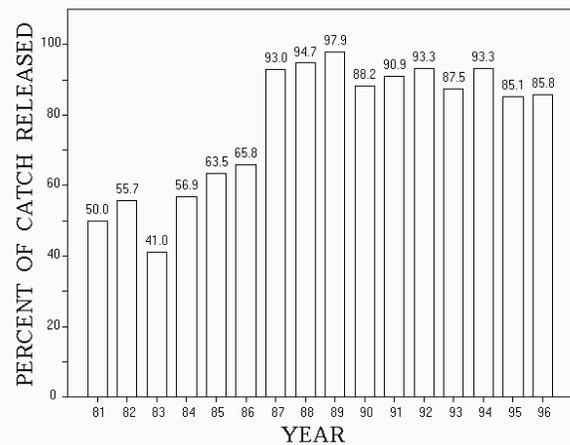


Figure 19. Percent of the recreational catch of striped bass from New York through Maine that were released during the years 1981-1995.

employed in striped bass management have imposed size selective mortality that would enhance survival of slower-growing individuals over their faster growing siblings.

### Discussion

The potential effects of size limits in the range of 40.6 cm TL (16 inches) to 91.4 cm TL (36 inches) on survivor length frequencies at age are depicted in Figures 7 and 8. At the 40.6-cm size limit, all of the morphs grew to sizes larger than the minimum size fairly early in their life. Consequently, the duration of differential fishing mortality across morphs within a cohort was relatively short, and the size bias in survivorship is not large. At the larger minimum sizes for both sexes, recruitment of a year class to the fishery occurs over an extended period, and the slower growing members of the cohort suffer much less exposure to the full impact of fishing mortality than the faster growing members. In the case of males the bias begins to diminish with size limits above 71.1 cm. This is simply the result of the higher size limit increasing the proportion of the length distribution protected from the fishery. Further increases in the size limit would continue to fill in the distribution until the size limit exceeded the size of any fish in the population. At this point the size bias would disappear, but so would all harvest. Intermediate size limits tend to maximize the selection for slow growth among survivors.

The unit developed here as an index of the magnitude of the potential selective force, the percent change in the mean length of unfertilized eggs ( $\lambda$ ), has both positive and negative attributes. On the positive side, it accounts for the entire reproductive history of individuals who may have contributed significantly to reproduction before being exposed to the increased risk of harvest as they grow into legal sizes. On the other hand, it assumes that the asymptotic size is completely controlled by heritable processes. Also, the contribution of males is neglected completely by this measure as it is currently defined.

Males were only excluded from the analysis because I was unable to find data to characterize the reproductive importance of males by size or age. The analyses could be significantly enhanced with such data. As a consequence,  $\lambda$  serves only as a first-order approximation of the importance of the potential selection that might result from the size-selective mortality associated with minimum sizes.

With the current best estimates of the growth parameters, fecundity at size and fishing mortality,  $\lambda$  was reduced by only about 3% at the minimum size of 91.4 cm TL (36 inches) which was widely adopted as a management tool in 1989. This same measure was about 2% for a minimum size of 71.1 cm. TL (28

inches) which was widely adopted for management in 1995. These results would appear to suggest the possibility that the potential selective force is of minimal concern. However, since weight is typically a cubed function of length, the level of change in mean asymptotic weight could be on the order of 4-10% if these results accurately characterize the processes involved. In part, the accuracy of these estimates depends upon the adequacy of the striped-bass growth model.

The potential effects of size limits above 55.9 cm TL (22 inches) on survivor length frequencies is clearly illustrated by the results shown in Figures 7 - 14. Actual size limits for striped bass in the coastal waters of New Jersey northward have been 61 cm TL (24 inches) or greater since 1985. It seems unlikely that size at age data collected from a population subjected to such size limits would reflect the average growth of individuals in the population that would exist in the absence of fishing. Consequently, analyses of such data could never be expected to accurately recover the growth parameters of the original population (Goodyear 1995; Garmendia 1998).

This observation implies that the von Bertalanffy parameter estimates derived from the Hudson River striped bass spawning stock sampling data are likely biased with respect to the growth of average recruits to the population. In particular, the mean asymptotic maximum length,  $L_{\infty}$ , is most likely biased downward for both sexes. Similarly, the size selective mortality imposed by a size limit would likely cause an upward bias in the growth coefficient,  $k$ , of the von Bertalanffy equation (Garmendia 1998). And if faster, growing fish mature earlier than their slower growing siblings, then  $k$  might also be inflated because the slower-growing (and immature) fish would be relatively less abundant in the samples from the spawning stock upon which the growth model was based. These same factors would tend to bias the estimates of the coefficient of variation of length at age downward, because parts of the (unfished) distributions would be underrepresented in the samples. In addition to these considerations, the paucity of observations of older fish in the stock makes the estimates of  $L_{\infty}$  uncertain at best.

The results of the sensitivity analyses of the percent reduction in the mean asymptotic length of unfertilized eggs,  $\lambda$ , indicate certain combinations of parameters could lead to changes of about 20 %, which implies potential reductions in asymptotic weights of about 50%. However, the parameter combinations that produced the highest  $\lambda$  values were at fishing mortality rates of  $F = 1.0$ , and a CV of size at age of 0.25. This value for the CV is unlikely to be valid for striped bass; however, the upper limit of the potential magnitude of  $F$  is less certain.

Recall that  $F$  in this analysis applies to fully recruited growth morphs that are above the minimum size. Where size limits are sufficiently high that some morphs never attain the minimum size during their lifespan, there will be no age in the population where the fishing mortality for the age will be as high as the fishing mortality rate on those individuals that exceed the minimum size. As a consequence, the fishing mortality rates estimated by age for stock assessment purposes tend to be less than the fishing mortality rate on the fully recruited individuals of each age. The actual potential magnitude of the fishing mortality on fully recruited individuals in the stock has not been estimated, but could be considerably higher than the current best estimate of  $F=0.31$  from the most recent assessment (ASMFC 1997).

The results of the sensitivity analysis for parameter ranges that may be reasonably considered, given knowledge about the uncertainty in growth and mortality rates, suggest values of  $\lambda$  in excess of 10% are well within the realm of possibility. This would imply potential reductions in asymptotic weights of up to about 30%. I believe that inclusion of males in the analysis (i.e. estimating  $\lambda$  as a percent reduction in the mean asymptotic length of *fertilized* eggs) would reduce these values because of the earlier age at maturity for males. However, since all of the growth parameters are different for the two sexes, the actual outcome of including the males in the calculation is not clear.

I was unable to locate recent fecundity data for the Hudson River or any other stock of striped bass. The fecundity at size equation used in this analysis was developed for an earlier study (Goodyear 1984). It was based on data on fecundity by size collected from the Roanoke River from 1958 to 1963 (Lewis and Bonner 1966), and maturity at age data collected from size selective fishing gears in Maryland in the late 1950s (Mansueti 1961). Since the Maryland samples were taken near spawning areas, the proportion of mature fish in his samples was likely upwardly biased. If so, then the maturity schedule drawn from Mansueti's work probably overestimates the percent mature for young females. If so, then the estimates of  $\lambda$  herein are biased downward.

The level of mortality associated with fish caught and released because of the minimum size is an important factor for the type of analyses considered herein. Higher mortality rates of fish discarded because of minimum sizes tend to reduce the selection for slow growth among survivors. The present analyses assume a discard mortality of 7% based on the value used for the recreational fishery in the most recent stock assessment (ASMFC 1997). The discard mortalities estimated for the commercial gears ranged from 5% to 47% depending on gear type. However, the ratio of

commercial to recreational discards averaged only 0.15 for the last five years in the assessment (1992-1996). Also, the predominant harvesting method in the area of greatest abundance of Hudson River striped bass (New Jersey northward) is hook and line. Consequently, while the overall discard mortality for the Hudson River stock is uncertain, it is probably not much different than that for the recreational component of the fishery.

The importance of the selection for slow growth among survivors in the spawning stock depends upon the degree to which growth is heritable. Interspecific differences in asymptotic sizes suggest that some aspect of growth must be heritable. Although realized growth depends on available resources, there is strong evidence that growth is a heritable trait. Most of the direct evidence is from studies of domesticated stocks. Kinghorn (1983) and Gjedrem (1983) compiled the results of genetic studies of heritabilities of body-weights for many stocks involving 5 fish species. Mean heritability varied by species from 0.04 to 0.49. Gjedrem (1975) predicted a gain in mean weight of 3.5 to 7 percent per year for selective breeding of rainbow trout *Onchorhynchus mykiss* based on heritabilities of 0.1 to 0.2. This compared favorably with experimental findings of a 30.1 percent net genetic gain in mean weight of rainbow trout in 8 years of selective breeding (Kincaid et al., 1977). Other studies have shown also that size and age at maturation are heritable (Mckenzie et al. 1983; Gall et al. 1988; Tipping 1991; Resnick 1997; Svensson 1997).

Several studies of fished wild stocks have noted changes in growth with exploitation that may have had a genetic basis (Ricker 1981; Wohlfarth et al. 1975; Wohlfarth 1986; Nelson and Soule 1987; Nuhfer and Alexander 1994; Krohn and Kerr 1997). These observations provide only circumstantial evidence because each case is confounded by possible alternative explanations. However, it is unlikely that even rather considerable changes in growth in important exploited populations could be unambiguously attributed to an underlying genetic cause using retrospective analyses of observed downward trends in growth. Such data will probably require well designed and executed large-scale fishing experiments as proposed by McAllister et al. (1992) for pink salmon. Even then, it could be argued that the conclusions derived might be only applicable to the particular species or even the stock that was the subject of the experiment.

The large size limits that were established as a protective measure to increase survival of the 1982 year class of striped bass from the Chesapeake Bay were put in place to constrain the striped bass harvest, and not to optimize yield per recruit or some other aspect of the fishery. In the short term, these measures

performed well and increased survival and spawning stock biomass that led to stock recovery. However, adoption of large size limits to constrain total harvest levels may induce important selection for slow growth in both the Hudson River population and those of the more southern spawning grounds as well. The problem is not yet well understood, and the appropriate information to judge the significance of the potential for long-term impairment of the productivity of the stock will be difficult and possibly impossible to obtain.

The results of the current study argue against using minimum sizes as a principal mode of constraining total catches, at least until the problem is better understood. So long as such size limits remain a management measure of choice, research should continue on this topic. Important areas for future research include determination of the actual distributions of sizes at age across ages for both sexes in the absence of size-selective fishing mortality; a better characterization of the relationship between fecundity and size and age; the relative value of sperm with size and age of the males to the fertilization of ova; and further investigations into the heritability of growth in striped bass and other species.

### References

- ASMFC (Atlantic States Marine Fisheries Commission). 1997. Stock assessment of Atlantic striped bass. 26th stock assessment workshop stock assessment review committee. ASMFC, Washington, D.C.
- ASMFC (Atlantic States Marine Fisheries Commission). 1985. Interstate fisheries management plan for the striped bass of the Atlantic coast from Maine to North Carolina: Amendment 3. ASMFC, Washington, D.C.
- Dorazio, R. M., K. A. Hattala, C. M. McCollough, and J. E. Skjelveland. 1994. Transactions of the American Fisheries Society 123:950-963.
- Field, J. D. 1997. Atlantic striped bass management: where did we go right? Fisheries 22 (7):6-8.
- Gall, G. A. E., J. Baltodano and N. Huang. 1988. Heritability of age at spawning for rainbow trout. Aquaculture 68:93-102.
- Goodyear, C. P. 1984. Analysis of potential yield per recruit for striped bass produced in Chesapeake Bay. North American Journal of Fisheries Management 4:488-496.
- Goodyear, C. P. 1989. LSIM-a length-based fish population simulation model. NOAA (National Oceanic and Atmospheric Administration) Technical Memorandum NMFS (National Marine Fisheries Service), SEFC (Southeast Fisheries Center) 219, Miami.
- Goodyear, C. P. 1995. Mean size at age: an evaluation of sampling strategies using simulated red grouper data. Transactions of the American Fisheries Society 124:746-755.
- Goodyear, C. P. 1996. Minimum sizes for red grouper: consequences of considering variable size at age. North American Journal of Fisheries Management 16:505-511.
- Gjedrem, T. 1975. Possibilities for genetic gain in salmonids. Aquaculture 6:23-29.
- Gjedrem, T. 1983. Genetic variation in quantitative traits and selective breeding in fish and shellfish. Aquaculture 33:51-72.
- Kincaid, H. L., W. R. Bridges, and B. von Limbach. 1977. Three generations of selection for growth rate in fall-spawning rainbow trout. Transactions of the American Fisheries Society 106:621-628.
- Kinghorn, B. P. 1983. A review of quantitative genetics in fish breeding. Aquaculture 31:283-304.
- Kirkpatrick, M. 1984. Demographic models based on size, not age, for organisms with indeterminate growth. Ecology 65: 1874-1884.
- Krohn, M. M., and S. R. Kerr. 1997. Declining weight-at-age in northern cod and the potential importance of the early years and size-selective fishing mortality. NAFO Sci. Cont. Studies 29:43-50.
- Lewis, R. M. and R. R. Bonner, Jr. 1966. Fecundity of the striped bass, *Morone saxatilis* (Walbaum). Transactions of the American Fisheries Society 95:328-331.
- Mansueti, R. J. 1961. Age, growth, and movements of the striped bass, *Morone saxatilis*, taken in size selective fishing gear in Maryland. Chesapeake Science 2:9-36.
- Martinez-Garmendia, J. 1997. Effects of length-at-age data on both an management benchmark F0.1 estimates in the face of size-selective mortality. Fisheries Research 32:233-247.
- Merriman, D. 1941. Studies on the striped bass (*Morone saxatilis*) of the Atlantic coast. U.S. Fish and Wildlife Service, Fishery Bulletin 50:1-77.
- McAllister, M. K., R.M. Peterman, and D. M. Gillis. 1992. Statistical evaluation of a large-scale fishing experiment designed to test for a genetic effect of size-selective fishing on British Columbia pink salmon (*Oncorhynchus gorbuscha*). Canadian Journal of Fisheries and Allied Aquatic Sciences 49:1294-1304.
- McKenzie, W. D., D. Crews, K. D. Kallman, D. Policansky and J. Sohn. 1983. Age, weight and the genetics of sexual maturation in the platyfish, *Xiphophorus maculatus*. Copeia 183:770-774.
- Nelson, K., and M. Soule. 1987. Genetical conservation of exploited fishes. Pages 345-368 in N. Ryman and F. Utter, editors. Population genetics and fishery management. Washington Sea Grant, University of Washington Press, Seattle.
- Nuhfer, A. J., and G. R. Alexander. 1994. Growth, survival and vulnerability to angling of three wild brook trout strains exposed to different levels of angler exploitation. North American Journal of Fisheries Management 14:423-434.

- Parma, A. M., and R. B. Deriso. 1990. Dynamics of age and size composition in a population subject to size-selective mortality: effects of phenotypic variability in growth. *Canadian Journal of Fisheries and Aquatic Science* 47:274-289.
- Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board of Canada* 19: 382 pp.
- Ricker, W. E. 1981. Changes in the average size and average age of Pacific salmon. *Canadian Journal of Fisheries and Aquatic Science* 38:1636-1656.
- Tipping, J. M. 1991. Heritability of age at maturity in steelhead. *North American Journal of Fisheries Management*. 11:105-108.
- Waldman, J.R., D.J. Dunning, Q. E. Ross, and M. T. Mattson. 1990 Range dynamics of Hudson River striped bass along the Atlantic coast. *Transactions of the American Fisheries Society* 119:902-919.
- Wohlfarth, G. 1986. Decline in natural fisheries - a genetic analysis and suggestion for recovery. *Canadian Journal of Fisheries and Aquatic Science* 43:1298-1306.
- Wohlfarth, G., R. Moav, and G. Hulata. 1975. Genetic differences the Chinese and European races of the common carp. 2. Multicharacter variation-a response to the diverse methods of fish cultivation in Europe and China. *Heredity* 34:341-350.

### **Acknowledgments**

I thank Kathy Hattala, NYDEC, who provided data on the size and age composition of the Hudson River striped bass spawning stock, and Kim McKown, NYDEC, who provided additional age-length data from the Hudson River and western Long Island Sound. I also thank Patty Phares of the U.S. National Marine Fisheries Service for providing the MRFSS striped bass statistics, and Gary Shepherd of the U.S. National Marine Fisheries Service for a compilation of size at age data for Atlantic coastal striped bass. The research contained in this report has been financed through a research grant from the Hudson River Foundation for Science and Environmental Research, Inc. The views expressed herein do not necessarily reflect the belief or opinions of the Foundation, which assumes no responsibility for liability for the contents or use of the information herein.