

James River Mainstem Investigation

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**Virginia Commonwealth University
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**Completion Report
Job 5 - Fisheries Yield Model
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COMPLETION REPORT
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JAMES RIVER INVESTIGATION

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ABSTRACT

A computer-implemented simulation model was modified to compare various regulation schemes used in recreational fisheries management, and to determine how the efficacy of regulations is influenced by angler non-compliance and voluntary catch-and-release fishing. The model was applied with data on the smallmouth bass fishery of the James River, Virginia. All analyses assumed constant recruitment. Six creel limits (ranging from 0 to 5 per day), six minimum length limits (10, 11, 12, 13, 14, 15 inch), three slot length limits (10-13, 11-14, 12-15 inch), and six maximum length limits (10, 11, 12, 13, 14, 15 inch) were simulated individually and in combination. The 76 regulation scenarios were simulated with estimates of angler non-compliance and voluntary catch-and-release derived for the James River. Simulations (76) were run separately for the upper James River and the lower James River. Model inputs included population parameters, mortality rates, and angler characteristics estimated from the James River Investigation (Jobs I and IV). Model results indicate that proportional stock density (PSD) and catch were improved somewhat with more restrictive regulations, while liberal regulations were most beneficial to harvest and yield. In addition, model results show that voluntary release is presently the dominant variable controlling changes in the James River smallmouth bass fishery; variability in model results among regulations was extremely low. These findings have profound management implications for recreational fisheries management. Although fishing can be improved through regulation changes, the expected outcomes as predicted by the model appear minor. It appears that the voluntary practice of catch and release by a majority of anglers is preventing certain overfishing of desirable size smallmouth bass. Even with the high level of voluntary release, however, the recent declines in citation catches could be explained by the popularly held belief that riverine angling pressure has increased dramatically during the 1980's.

INTRODUCTION

Black bass (*Micropterus* spp.) are popular sport fish in the nation, sought by 42 percent of the nation's anglers (1985 National Survey of Fishing, Hunting, and Associated Wildlife Recreation). Heavy fishing pressure targets black bass in Virginia as well, particularly in the James River where 53 percent of the James River anglers prefer fishing for black bass (Kokel 1991). Consequently, there is a great need for reconsideration of fishing regulations to sustain or enhance fishing quality.

The smallmouth bass, *Micropterus dolomieu*, fishery in the James River, Virginia, is the focus of this study in modelling restrictive regulations and angler behavior. The James River was chosen for several reasons. The James River has long been considered one of the premier smallmouth bass fisheries in the eastern United States (McClane and Gardner 1984). However, in recent years, harvest of citation sized smallmouth bass (five pounds and larger) has declined (Figure 1). One explanation for this reduction is an alleged increase in fishing pressure on rivers in general and on smallmouth bass in particular. An increase in catch-and-release of "trophy" fish could also explain this trend. In order to preserve the status of the James River smallmouth bass fishery, the Virginia Department of Game and Inland Fisheries recently began a program to evaluate the effectiveness of current regulations.

Present regulations for smallmouth bass in the James River have been in place since January 1, 1987. They include an 11-14

inch (280 to 356 mm) protected slot length limit and a daily creel limit of five. Catch and harvest data (Kokel 1991), supported by results of a recent study on the Shenandoah River, Virginia (Smith and Kauffman 1987), indicate that these regulations are not achieving desired objectives (which are to sustain fishing quality by improving growth of small fish), and may not be appropriate for the James River. One explanation for the apparent ineffectiveness of the slot limit is that voluntary catch-and-release of legal sized bass (<280 mm) in the James River is considerable, ranging from 97 to 80 percent (upper James River) and 97 to 87 percent (lower James River) (Kokel 1991). Without adequate harvest of fish below a slot limit, the regulation becomes ineffective in improving growth of younger age classes (Smith and Kauffman 1987). In addition, growth of fish less than 11 inches (280 mm) is good, indicating that growth enhancement via a slot limit may not be effective.

The effect of novel regulations cannot be analyzed without some understanding of the level of angler non-compliance and voluntary release that exists with various regulations. In addition, each smallmouth bass fishery is different (population demographics and angler behavior), and should be treated as such. The present slot length limit and daily creel limit were implemented in 1987 based on field studies from other Virginia streams. New data on smallmouth bass catch, harvest, growth, and angler behavior now available for the James River provide the basis for re-examining the need for and effect of novel regulations.

Also, estimates of non-compliance and voluntary release by anglers on the James River (Kokel 1991) provide for more realistic simulations of the effects of changing regulations. Finally, the profile of recreational users on the James River (Stanovick et al. 1991) provides an objective basis for determining appropriate decision variables on which to base decisions regarding regulations.

The purpose of this study was to present analysis of the effects of alternative regulations for meeting management objectives for the James River smallmouth bass fishery. A number of length limits and creel limits were simulated, including minimums, slots, and maximum length limits. The range of minimum and slot length limits included those regulations commonly employed in fisheries management. The maximum length limits were included because no other study addresses their use in fisheries management.

High voluntary release is potentially important in controlling changes in recreational fisheries (Clark 1983). Given the high levels of voluntary release (Kokel 1991), it seems reasonable to assume that recruitment of young fish would change little with new regulations; however, this assumption of density-independent recruitment remains a fundamental assumption of our analyses. From a management standpoint, improving overall catch and proportional stock density (PSD) would likely be the most important objectives; catching many fish and catching large fish were more important motivations of James River anglers than subsistence (Stanovick et al. 1991). However, in some fisheries, subsistence anglers may be

important. In addition, many catch-and-release anglers may still desire to keep one or two large fish. Harvest and yield, then, need to be included in the overall management plan. Mean length caught and harvested are also measures of quality in a fishery. These two variables were highly correlated with PSD (Wagner 1991) and, therefore, are already considered in this analysis.

METHODS

An age structured, non-linear, population model (Wagner 1991) was modified to look at the role of angler non-compliance and voluntary release in determining the efficacy of special regulations, in particular length and creel limits. In general, population parameters are provided as input to the model. Instantaneous total mortality [Z] was broken down into three component parts, instantaneous rates of fishing [F], hooking [H], and natural [M] mortality. Simulated changes in angler characteristics and regulations impact the rates of fishing and hooking mortality. The model produces output statistics of interest to fisheries managers. A program listing is included in Appendix A to help clarify questions regarding the model's structure.

Model Description

The calculated change in numbers of fish in each cohort for a given year was based on mortality, growth, and number in the cohort at the end of the previous year as shown in equation 4 of Table 1 (based on Walters 1969). The numerical abundance of age-1 fish

recruited each year was determined by the previous years age-0 group (equations 1, 2) and the survival of age-0 as calculated with the density dependent Beverton and Holt stock-recruitment function (equation 3) (Ricker 1975).

The production of age-0 fish was calculated based on egg production and hatching success (equation 1), where egg production by cohort was the product of numbers, proportion of females, maturity rate, and mean fecundity of mature females in the cohort (equation 2). Each simulated year begins at the time of hatching for young-of-the-year fish. At this time each cohort was shifted to the next higher age group. Each cohort was assumed to have the mean length that was entered for that age group. Growth in weight was calculated from the length-weight regression. The mean length for an age group was entered into the regression and the resulting weight was used as the mean weight for the age group.

Annual catch in numbers was calculated from Baranov's catch equation as in equation 21 of Table 1 (Ricker 1975). Yield in weight was calculated from catch, mean biomass, and the instantaneous growth rate for an age group (equations 22, 23, 24).

Data Sources and Derivation of Model Input Parameters

Data specific for the James River was obtained from sampling efforts by Virginia Commonwealth University (fish population statistics) and from creel survey work done at Virginia Polytechnic Institute and State University (angler effort/characteristics and smallmouth bass catch/harvest statistics). To fill any existing gaps, data of a more general nature was obtained from published

literature of smallmouth bass life history. The parameters obtained from published accounts (Clady 1975, Carlander 1977) were those assumed to be relatively constant for the species in similar environments over its entire range, such as age at first spawn, egg content by length, sex ratio, and hatching success (Table 2).

Total mortality for each age group was estimated from age specific survival rates, based on catch per unit effort data (Table 3) from 1987 through 1989. Age specific survival was calculated by the equation:

$$S = \frac{C/f_{t+1}}{C/f_t} \quad (1)$$

where: C/f_{t+1} = catch per unit effort of age t+1 fish, and
 C/f_t = catch per unit effort of age t fish.

Total instantaneous mortality [Z] was determined by taking the negative natural log of survival [S]. A maximum age of 13 was assumed for smallmouth bass because this was the oldest fish caught by sampling on the James River (VCU 1991).

The probability that a fish of age i would die after being caught and released [hm_i] was assumed to be 0.2 for all ages (Clark 1983), and represented an average rate for both bait and artificial lure use. The potential fishing mortality [$F'_{i,j}$] represents an instantaneous catch rate, and was a function of estimated catch, population density, and angling effort (Table 4). Catchability was estimated based on the equation:

$$q_i = \frac{\text{Catch}_i/\text{ha}}{N_i/\text{ha} * f/\text{ha}} \quad (2)$$

where: N_i =age specific density,
f=angling effort in hours, and
Catch=age specific catch.

The catchability coefficient was multiplied by angler effort [q_i*f] to get the instantaneous catch rate.

The adjusted fishing mortality [$F_{i,j}$] was calculated in a similar manner from estimated harvest per hectare (Table 4). This parameter [$F_{i,j}$], although not directly used in the model, was used to calculate age specific natural mortality (Table 5); $F_{i,j}$, along with an adjusted hooking mortality, was subtracted from total mortality (Table 3). The adjusted fishing mortality [$F_{i,j}$] and the catch rate [$F'_{i,j}$] were estimated for three size groups (<280 mm, 280-356 mm, and >356 mm; Table 4) and a curve fit to the estimates to yield age specific rates for model input (Table 5). For the lower James River area the fishing mortality estimate was greater than the total; therefore, we assumed natural mortality (M) was 0.05 for age groups 5 and older.

Parameters of the first year survival function (equation 3) were fit based on age 1 data (Table 6) from the James River (Virginia Commonwealth University 1991), and assuming constant recruitment. I assumed a maximum recruitment of 106,443 age-1 fish in the upper James River that resulted in a density independent value [A] of 0.0000093. The density independent term for the lower James River was 0.0000156 (assumed maximum recruitment of 64,075 age-1 fish). The density dependent term [B] was set equal to zero to simulate constant recruitment.

Population parameters specific to the James River population

(Table 6) were obtained from Virginia Commonwealth University. These included mean and standard deviation of length at age, and coefficients of the length-weight regression. Number at age was estimated from age specific density and sample size data also obtained from Virginia Commonwealth University.

Creel survey information used in this modelling exercise was obtained from a recreational use survey conducted on the James River in 1988 and 1989. A detailed discussion of the sampling procedures can be found in (Stanovick et al. 1991). To prevent over-estimating the zero harvest/day angler group, angler interviews were divided into two categories; those where smallmouth bass were caught and those where smallmouth bass were not caught. For those interviews where smallmouth bass were caught, harvest per angler-day was determined (Tables 7 and 8). Harvest data was in the form of harvest/angler party, therefore, initial estimates needed to be divided by party size to yield harvest/angler. These harvest distributions were transformed into the predicted harvest reductions (Tables 7 and 8) by using the censoring procedure discussed in Wagner (1991). Angling effort, catch rate, and harvest rate for smallmouth bass (Table 9) were calculated for the fraction of anglers who either targeted smallmouth or who had caught smallmouth bass, while fishing for other species. Partitioning angling effort, catch rate, and harvest rate in this manner limited the amount of bias associated with each of the estimates. Statistical analysis of the creel survey data was done with SAS (SAS institute Inc. 1988).

Angler non-compliance [NC] was estimated for current regulations (Kokel 1991) with:

$$NC = \frac{\text{\# of angler trips w/ illegal fish}}{\text{\# of angler trips meeting criteria}} \quad (3)$$

Classification criteria meant that either one fish was caught in the slot (11-14") or more than five fish were harvested per angler-day. Non-compliance was assumed to be constant for all regulations (Table 10); estimates were 0.24 for the upper James River and 0.10 for the lower James River.

Voluntary release was estimated for complying anglers and non-complying anglers. The conditional rate of voluntary release was calculated for two legal size classes; <280 mm and >356 mm (Table 11). For complying anglers these values were 0.97 and 0.67 for the upper James River, and 0.97 and 0.71 for the lower James River. For non-complying anglers these values were lower; 0.80 and 0.0 for the upper James River, and 0.87 and 0.0 for the lower James River. A curve was fit to these estimates to get age specific release rates.

Model Outputs

Model output was generated on a yearly basis, but only the year 50 results were used. This approach was taken, because after 50 years the numbers in each cohort had become constant. The output represents the population immediately after the year's spawn. Outputs by age included numbers, harvest, yield, and catch. Other outputs included mean length and age caught, mean length and age harvested, totals for age specific parameters, proportional

stock density (Anderson 1976), and various other relative stock densities (equations 11-20 in Table 1) (Gablehouse 1984). Mean weight of fish harvested can be estimated by the ratio: yield\harvest. Sample output is provided in Appendix B.

Simulations

Results from two separate data sets (upper and lower James River) were analyzed. With existing conditions of angler non-compliance and voluntary release, combinations of length and creel limits were simulated. Length limit regulations included minimums of 10, 11, 12, 13, 14, and 15 inches; slot length limits of 10-13, 11-14, and 12-15 inches; and maximum of 10, 11, 12, 13, 14, and 15 inches. Creel limits ranged from 0 (catch-and-release) to 5 (existing regulation) fish per angler-day. These regulations were simulated individually and in combination, resulting in a total of 76 simulations.

Four variables (catch, harvest, PSD, and yield) were combined in a utility function to determine the optimal set of regulations. This optimum is a compromise among the four decision variables to determine the best scenario. The four variables were scaled to a range from 0 to 1 based on a range of values obtained from the literature (Table 12); 0 represented the minimum and 1 represented the maximum value. This approach is represented by:

$$U = \sum_{i=1}^n a_i * [(v_i - \min_i) / (\max_i - \min_i)] \quad (4)$$

where: a_i =weighting factor for variable i ,
 v_i =value of variable i from simulations,
 \min_i =minimum value for variable i , and
 \max_i =maximum value for variable i .

For the purpose of this document, all four variables were weighted equally. Realistically, variables would be selected and weighted based on management objectives.

RESULTS

Fishery Parameters

Simulated values of catch, harvest, yield, and PSD for the upper and lower James River are displayed for selected regulation scenarios in Figures 2-11. Appendix C includes all scenarios modelled. The figures include high and low minimum length limits and slot length limits, and one low maximum length limit for clarity. Values for those excluded (minimums and slots) would fall between the extremes for that type of length limit. Catch and PSD would be lower at higher maximums, while harvest and yield would be higher.

The variables depict two general patterns. One pattern reflects catch rates and size in a fishery; the highest value is associated with the most restrictive regulation, catch-and-release. Catch and PSD follow this pattern (Figures 2,5,7,10). Both the catch rate and PSD exhibit maxima under a creel limit of zero, and at higher creel limits have highest values under a 356 mm minimum length limit and lowest values with no length limit. The catch rate in the upper James River was two and a half times that of the lower James River across the regulation scenarios. PSD, however, tended to be higher for the lower James River than for the upper James River.

The two remaining variables, harvest and yield, are measures of quantity output by a fishery. As would be expected, they exhibit patterns quite different from the catch rate and PSD (Figures 3,4,8,9). Both harvest and yield increase with higher creel limits and are minimized by the most restrictive length limits. The highest estimates for harvest and yield occur with no length limit and a creel limit of 5. The lowest estimates appear with the 356 mm minimum length limit and a creel limit of 0. Both harvest and yield tended to be higher for the upper James River as opposed to the lower James River across regulation scenarios. This difference was much greater at lower creel limits (2x) and steadily declined with increasing creel limits (1.5x).

Utility Function

The four variables, catch, harvest, yield, and PSD were combined in a utility function to provide an example of multi-criteria decision making. Results of these calculations for selected regulation scenarios (Figures 6 and 11) suggest that a creel limit of 1 and a 356 mm minimum length limit is the "best" scenario for both the upper and lower James River. However, variability among regulations was minimal. The greatest change in utility occurs between creel limit of 0 and 1. At values of 1 or greater, creel limit changes have less impact than minimum length limits. Thus, a 356 mm minimum length limit gave the highest utility scores at any creel limit. Utility scores were higher for the upper James River; due primarily to higher catch rates, harvest, and yield. Proportional stock density, although

lower for the upper James River, seemed to be less important than catch, harvest, or yield in the overall utility analysis.

Comparative Data

Two additional parameters (i.e. density and biomass) were generated for selected regulation scenarios for comparison to field studies. Selected regulation scenarios included those frequently used in fisheries management (unregulated, 305 mm minimum, 280-356 mm slot, and catch-and-release), the predicted optimum length limit (356 mm minimum) based on the sample utility function, and a 305 mm maximum length limit. Number of smallmouth bass age-1 and older per hectare is given for these 6 scenarios in Table 13. Density in the upper James River ranged from 122 fish/ha with the most liberal regulations (no regulations, the slot limit, and the maximum) to 123 fish/ha with the most restrictive regulations (catch-and-release and both minimums). In the lower James River, density ranged from 41 fish/ha with the most liberal regulations to 42 fish/ha with the most restrictive regulations. Variability in density was minimal due to the assumption of constant recruitment and the high amount of voluntary release that was observed in the fishery. Total biomass of age-1 and older smallmouth bass is also given in Table 13 for these 6 scenarios. In the upper James River, biomass ranged from 7.1 kg/ha with no regulations to 7.6 kg/ha under a 356 mm minimum length limit. For the lower James River, biomass ranged from 3.4 kg/ha with no regulations to 3.6 kg/ha under a 356 mm minimum length limit.

Changes in Exploitation

Catch and RSD-T (relative stock density of trophy size fish) were used to evaluate the present status of the James River fishery, in particular the citation program (presently 5+ lb. smallmouth). Current exploitation rates were reduced by 90%, 75%, 50%, and 25%. This was done for no regulations, current regulations (280-356 mm slot length limit and five fish/day creel limit), and a 305 mm minimum length limit. Catch and RSD-T were lowest for the no regulation scenario and highest for current regulations. Catch was higher for the lower James River, while RSD-T was highest for the upper James River.

With no regulations, catch of citation smallmouth in the upper James increased from six fish (current exploitation) to 1,801 fish at 10% current exploitation; in the lower James catch increased from 0.25 fish to 3,197 fish (Figure 12). For the upper James River, RSD-T increased from 0.000026 to 0.058, and for the lower James River RSD-T increased from 0.0000018 to 0.041 (Figure 13). Under current regulations, catch of trophy fish in the upper James increased from 15 fish to 1,926 fish, while the increase for the lower James River was from 4 fish to 4,246 fish (Figure 14). RSD-T increased from 0.0000487 to 0.053 for the upper James River and from 0.000005 to 0.052 for the lower James River (Figure 15). Catch and RSD-T for the 305 mm minimum length limit were between the two extremes, and are shown in Figures 16 and 17.

DISCUSSION

Utility Function

An example was given above of the use of a utility function to assist decision makers in making management recommendations. It was not intended that this specific formula, which provided uniform weighting of the included variables, be used to generate management recommendations. The goals of the manager of a particular fishery should determine the inclusion and weighting of variables. Two generalities can be drawn from either the utility function of the individual variables. First, the results indicate a narrow range of values for the variables and the utility scores, indicating very little difference among regulation scenarios. This is due in large part to the high degree of voluntary release by James River anglers (Tables 14,15), which tends to diminish differences among regulations (unpublished analysis; A. E. Creamer, M.S. Thesis in prep.). Second, the results of slot limits and maximum length limits are more similar to no length limit than the minimum length limits are. This trend is likely an artifact of the model assumptions. The rationale behind imposing slot length limits assumes that density is limiting growth of individuals below the minimum slot length, while for maximum length limits, the rationale assumes that recruitment is limited. Since the model is based on constant growth and recruitment, it is clear that slot length limits and maximum length limits would have less than the desired effect. This pattern is most evident for the upper James River (Figures 2-6). The lower James exhibits a similar pattern (Figures 7-11), but tends to be much less pronounced; the 254 - 330 mm slot length limit is more similar to the 280 mm minimum length limit.

Comparative Data

Angler harvest statistics from several stream fisheries are given in Table 9. In addition, Table 13 shows density, PSD, and biomass of smallmouth bass age-1 and older for a variety of fisheries.

- The Fishery -

Pressure estimates of 51 (upper sections) and 66 hours (lower sections) per hectare on the James River in Virginia was used to project angler harvest data from the model outputs. These values can be compared to harvest data on other smallmouth bass fisheries (Table 9). The fisheries included received a wide range of pressure levels; from 69 hours per hectare on the Current River in Missouri (Fleener 1973) to 925 on the Maquoketa River in Iowa (Paragamian 1984a). Based on total estimated pressure per hectare (Kokel 1991), the James River fits at the low end of the scale (Table 9).

Model results exhibit a catch rate (total catch/hour) of 1.07 and 0.44 smallmouth bass per hour for the upper and lower James River, respectively. Both estimates fall within the observed range of 0.03 (Big Piney River, Fleener 1974b) to 1.33 (New River, Austen and Orth 1984). These values are somewhat lower than the field estimates of 0.64 (lower James) and 1.31 (upper James) found by Kokel (1991). Catch rates $[F'_{i,j}]$ were estimated based on sizes (<280 mm, 280-356 mm, and >356 mm) reported by anglers. A curve was fit to these three rates, based on subjective judgement as to how it should look. Under-estimating the catch rate for younger

age classes would reduce the overall catch rate, and partially explain the low model predictions.

The model predicts a harvest of 5.1 and 2.4 smallmouth bass per hectare for the upper and lower James River, respectively. These results fall within the observed range of 0 (Courtois Creek, Fleener 1975) to 39.2 (Maquoketa River, Paragamian 1984a). The model predictions are very similar to the field estimates of 4.4 (upper James) and 2.5 (lower James) found by Kokel (1991). Estimated smallmouth bass yield, 1.2 (upper James) and 0.7 (lower James) kilograms per hectare, was within the range of 0 (Courtois Creek, Fleener 1975) to 14.8 (Middle Fork Kentucky River, Turner 1967). The simulation results are lower than the field estimates of 2.5 (upper James) and 1.5 (lower James) kilograms per hectare. Harvest and yield were estimated from size specific densities (<280 mm, 280-356 mm, and 356 mm). For each size category, the younger age groups were under represented, thus creating a situation where the age specific catch rates were under-estimated. This results in lower-than-normal adjusted fishing mortality rates, harvest, and yield calculated by the model.

The James River receives a relatively low amount of angling pressure per hectare, yet ranks among the highest in overall catch per hour, and among the lowest in harvest and yield per hectare. This is indicative of a fishery with a significant amount of catch-and-release fishing occurring. Voluntary release in the James River is extremely high, ranging from 50 percent for legal fish greater than 356 mm to nearly 100 percent for legal fish below 280

mm (Kokel 1991). Such a high catch-and-release rate would overshadow what could be a significant amount of angler non-compliance (10 to 24 percent) under different conditions. Clark (1983) indicated that voluntary release rates greater than 10% would change the interpretation of conventional creel census estimates (based on the number of fish in the creel) of catch and fishing mortality. For this creel survey, estimates of catch and harvest were based on an anglers' responses to questions of how many fish they had caught and how many they had released. The survey therefore introduces an unknown, but suspected bias due to reliance on the accuracy of an anglers' memories.

- The Fish Population -

The proportional stock density (PSD) provides an index of quality in a fishery, based on the length frequency of individual fish in the population. PSD's for stream smallmouth bass fisheries are highly variable. Anderson (1980) proposed a desired PSD range of 40 to 60% for balanced smallmouth bass populations. However, values observed for stream smallmouth bass populations (Table 13) often fall below this range, from 3% on the New River in Virginia (Austen and Orth 1988) to 42% on the Turkey River in Iowa (Paragamian 1984a). Model estimates of PSD for the upper James River (11% to 13%) were slightly lower than those of the lower James River (15% to 16%) (Figures 5,10, Table 13); model estimates were within 1% of the field estimates.

The nine essentially unregulated fisheries (no length limit and creel limit of 5/day or greater) in Table 13 average 20% for a

PSD, with the lowest value being 4% on the New River in West Virginia (Austen and Orth 1988). Therefore, the predicted values of 11% (upper James) and 15% (lower James) under no regulations seem indicative of a fishery with higher than desirable mortality.

The RSD-T is a reflection of potential for trophy catch in the fishery (i.e., the proportion of stock size fish that are of a trophy size). The decline in harvest of citation smallmouth bass (Figure 1) may be indicative of a larger overall decline in larger individuals in the population. This could be the result of an increase in angling effort for this species during the 1980's. Figures 12-17 (based on model simulations) indicate that at present levels, catch and RSD-T of 200+ citation smallmouth (1985/1986 harvest level) cannot be sustained. It is not known, however, how much, if any, of the reduction in citation harvest may be due to a voluntary release of citation smallmouth bass. Estimates of voluntary release for fish larger than 14 inches were based on small sample sizes and could not be stratified further.

Density estimates from other smallmouth bass populations vary greatly depending in part on recruitment variability. Values based on fish approximately age-1 and older (Table 13) ranged from 32 on the Maquoketa River in Iowa (Paragamian 1984b) to 361 on the Galena River in Wisconsin (Forbes 1989), bracketing the model's estimates of 41-42 (lower James) and 122-123 (upper James), which compared well with Virginia Commonwealth University's estimates of 37 and 118 smallmouth bass per hectare under regulations of 280-356 mm slot length limit and 5 fish/day. Model predictions of density per

hectare varied little with changes in regulations. Constant recruitment to age-1, coupled with high voluntary release, would explain this lack of variability.

Smallmouth bass total biomass (Table 13), like density, varies considerably among different smallmouth bass populations. The lowest value reported on an unregulated fishery was 14.1 kilograms per hectare on the Maquoketa River in Iowa (Paragamian 1984a). A maximum value of 42.6 was reported from the Galena River in Wisconsin (Forbes 1989). The model's predictions of 7.1 (upper James) and 3.4 (lower James) for an unregulated fishery fell well below the low end of the observed range. However, predictions for a regulated fishery (280-356 mm slot length limit and 5 fish/day) of 7.2 and 3.4 compare favorably with field estimates of 9.0 and 3.4 kilograms per hectare for the upper and lower James River. One explanation for the low model estimates of biomass is related to the length-weight regression. Growth in weight was determined from the length-weight regression. The mean length for an age group was entered into the regression and the resulting weight was used as the mean weight for the age group. Estimating mean weight with this approach underestimates the true age-specific weights (Nielsen and Schoch 1980).

Harvest Regulations

The purpose of this model was to predict changes in a fishery and the fish population due to a change to more restrictive regulations with given levels of voluntary release and angler non-compliance. This is particularly desirable in the case study,

since relatively few studies have been done to evaluate the interactions between angler behavior and harvest regulations on smallmouth bass fisheries. Most studies of harvest regulations have been confined to largemouth bass fisheries. These results are likely to be inapplicable to smallmouth bass fisheries, due to differences in the two species and their habitats. The model results are compared to a few studies where harvest regulations have been evaluated for smallmouth bass populations.

The most commonly applied regulation in smallmouth bass fisheries is the 305 mm minimum length limit. Model results can be compared to an unregulated situation on the same stream in several field investigations. For simplicity, the upper James River results are used for these comparisons.

Catch rate was predicted to increase from 1.07 (no regulations) to 1.12 (305 mm minimum) smallmouth bass per hour. Paragamian (1984a, 1984b) observed an increase from 0.05 to 0.22 (Table 9); Austen and Orth (1984) and Fleener (1974a, 1974b) also observed higher catch rates associated with 305 mm minimum length limits. Harvest was predicted to decline from 5.4 (no regulations) to 3.8 (305 mm minimum) fish per hectare. Marked declines in harvest (Table 9) were reported by Paragamian (1984a, 1984b) and Fleener (1975a, 1975b). A slight increase in harvest was observed on Courtois Creek (Fajen 1975, 1981), but was likely the result of the intervening years under a catch-and-release regulation. Yield was predicted to decline from 1.3 (no regulations) to 1.1 (305 mm minimum) kilograms per hectare. A slight decline in yield was

reported by Fleener (1974a) for Huzzah Creek in Missouri and Fleener (1975b) for Big Piney River in Missouri. Fajen (1981) also observed slight declines in yield for streams in Missouri.

The model predicts a slight increase in PSD from 11% to 13% if a 305 mm minimum length limit was imposed. Generally, field studies (Table 13) have shown PSD to increase (Fajen 1975a, 1975b; Paragamian 1984a, 1984b). Kauffman and Smith (1987) observed a decrease in PSD, which was attributed to an increase in total mortality. Austen and Orth (1988) observed little change in PSD, which they attributed to an increase in mortality and a decline in growth rate. Density was predicted to increase very slightly, from 122 (no regulations) to 123 (305 mm minimum) smallmouth bass per hectare. Paragamian (1984a, 1984b) observed a large decline in density from 232 to 32, which was explained by weak year classes from prior recruitment failures (Table 13). Biomass was predicted to increase slightly from 7.1 (no regulations) to 7.5 (305 mm minimum) kilograms per hectare. Field studies give conflicting results. Fajen (1975a, 1981) reported higher biomass under the 305 mm minimum length limit, while Paragamian (1984a, 1984b) observed a sharp decline in biomass, due to recruitment failure (Table 13).

The model results compare favorably to field study results where a 305 mm minimum length limit was imposed. The contradictory results evident in some studies can be explained by changes in mortality, density dependent growth, and recruitment failures (Paragamian 1984a, 1984b). This provides good support for the theoretical basis of this model. In addition, the slight change in

model predictions when a 305 mm minimum length limit was imposed was the result of high levels of voluntary release by James River anglers; this, even in the face of 23% angler non-compliance (Kokel 1991).

Big Buffalo Creek in Missouri exhibited some of the highest values reported in the literature for PSD, density, and biomass (Reed and Rabeni 1989). This was after a 22 year moratorium on fishing. Model results under a catch-and-release fishery showed a similar pattern (Tables 9, 13). This also suggests that the model predictions of directional change are reasonable.

Assumptions

In any theoretical simulation several assumptions are usually made. Before any firm conclusions are drawn from this study's results, the assumptions must be considered. Assumptions were made about angler behavior, fish behavior, and fish biology.

Anglers influence the effectiveness of harvest regulations through their harvest behavior (ie. voluntary release and non-compliance with regulations). It was assumed that anglers were not size selective under varying regulation scenarios. Voluntary release and angler non-compliance were the focus of this simulation study. However, assumptions were made regarding both behaviors. Voluntary release was regarded as an angling philosophy, and as such, remained constant over the combination of regulations simulated.

Estimates of angler non-compliance on the James River were only available for current regulations (280-356 mm slot length

limit and 5 fish/day). Because of this, a constant non-compliance rate was applied across regulation scenarios. This assumption is unrealistic, because it would seem likely that anglers would alter their non-compliance as regulations become more restrictive. Kokel (1991) discusses a predictive model of angler non-compliance with novel regulations for James River anglers. Angler profiles indicated that anglers were more likely to comply with 356 mm minimum or 280-356 mm slot limit with 5 fish/day than a catch-and-release regulation. Therefore, it seems likely that going from a 356 mm minimum length limit with a daily creel limit of 5 to a catch-and-release fishery would be counteracted by an increase in angler non-compliance.

Changes in fish behavior can impact the effectiveness of harvest regulations. Fishing mortality is dependent on the probability of fish being captured. It was assumed that fish do not change their behavior in such a way as to alter this probability. It was also assumed that this probability was proportional to the number of fish in an age group.

The effectiveness of regulations can also be related to the biology of the fish population. The growth rate is probably the most important population parameter effecting harvest regulations. Changes in growth has often be cited as the primary reason regulations fail to achieve desired outcomes (Paragamian 1984a, 1985b; Austen and Orth 1988). This model assumed that the growth rate remained constant over time and under varying densities and harvest regulations. This would be the case if competition for

food never limited growth; mortality would be the limiting factor. Several studies address this question. A 305 mm minimum length limit appeared to decrease growth (Austen 1984, Fajen 1981, Paragamian 1984a, 1984b), increase growth (Kauffman and Smith 1987), or have no effect (Kauffman 1983). Kauffman and Smith (1987) reported improved growth associated with a 280 to 330 mm slot length limit. These varied responses of growth to certain regulations may reflect size specific changes in population density. However, the narrow range of simulated age-1+ smallmouth bass density in the James River (Table 13) under varying regulation scenarios suggests that the assumption of constant growth was a reasonable one.

Voluntary release was thought of as a harvest philosophy among anglers, and did not change with regulations. The high voluntary release rate for James River anglers appears to be an overriding variable in this fishery. However, this is likely not the case in all smallmouth bass fisheries and, therefore, similar data need to be collected to evaluate regulations in a realistic manner.

One significant assumption was made regarding the first year survival function. The density dependent survival term [B] was set at zero, which meant that recruitment was constant. This partially explains the narrow range observed for catch, harvest, yield, PSD, density, and biomass for both sections of the James River, especially the lower James. Although constant recruitment appeared to be a valid assumption for this modelling study, it seems more realistic that in many fisheries, recruitment would occur at some

point further down the curve (steeper part of the curve), where a slight change in stock density would result in a large change in recruitment. Trends in PSD, catch, harvest, and yield would likely be the same, but with greater variability.

In addition to growth and recruitment, assumptions were made for several other input parameters. These parameters were those generalized from the literature, so it is assumed that they are appropriate for this fishery. No information was available to evaluate the validity of these assumptions.

Maturity rate and hatching success rate would warrant further evaluation, because these two variables are likely to vary considerably in different stream environments (ie. between the northern and southern United States).

Management Recommendations

There are several important management implications regarding angler behavior and the implementation of regulations that fishery managers need to consider when making decisions in recreational fisheries management. First, angler non-compliance was relatively low for James River anglers. This, coupled with the high voluntary catch-and-release rate (nearly 90% on average), most likely means that illegal harvest may not be a major concern for James River managers. Given the relative difficulty of enforcing regulations on widely dispersed stream fisheries, fisheries managers and administrators could probably make better use of limited funds by concentrating on educational programs for the James River.

Second, results of this study indicate that the current

regulations (280-356 mm slot limit and 5 fish/day) are not hurting the James River smallmouth bass fishery. However, these regulations may not be needed; the James River smallmouth bass fishery appears to be a self regulating fishery through the voluntary efforts of most anglers. Results from the 1988/1989 creel survey seem to indicate that harvest and yield of smallmouth bass are of little importance to the anglers. Anglers appear to be more concerned with catch and the size of fish. In addition, Kokel (1991) indicates that being outdoors, being with friends, and catching fish are most important to James River anglers. However, one must be cautious when interpreting the meaning of the high catch-and-release rates. Anglers may be releasing high percentages of fish out of fear of consuming the fish due to pollution problems; 98% of anglers agreed that controlling pollution was an issue (Stanovick et al. 1991). Follow up surveys may help resolve this question.

Third, assuming very little change in voluntary release, the improvement in catch and PSD would be minimal if regulations were to change. Harvest and yield would decline slightly. However, implementing a 356 mm minimum length limit would likely be more beneficial to the fishery, because more of the moderate sized fish would be protected. Additionally, anglers prefer to catch fish between the lengths of 305-405 mm, with the most preferred being 356 mm in length (Kokel 1991). Mean harvest per angler-day is less than one fish, therefore lowered creel limits have less of effect on the mortality than do length limits. The issues of equity and

psychological message associated with daily creel limits may need to be evaluated further. Society places higher values on goods that are limited. A lower creel limit would certainly enhance the value placed on a single harvested smallmouth bass while at the same time allocating a greater share of the large fish to the catch and release anglers.

Fourth, the upper James River smallmouth bass fishery appears to be in better condition than that of the lower James River. Fishing mortality needs to be reduced by 50% for the upper James River and 75% for the lower James River if citation harvest is to be sustained at a level of 200+ fish. A 356-mm minimum length limit with a daily creel limit of 5 or fewer fish/day would likely be beneficial for the upper James River. However, the regulations for the lower James River may need to be more restrictive in order to protect the few large fish in the river.

Fifth, the extent to which released fish succumb to delayed mortality is unknown except for a controlled experiments. We assumed that 20% of released fish died; if this is correct than the rate of hooking related mortality is substantial because of the high rate of catch and release angling on the James River. Management efforts directed at minimizing hooking mortality are probably needed.

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Table 1. Equations used in model.

Survival

$$\text{Eggs} \rightarrow \text{Larvae} \quad L_j = E_j * \text{HATCH} \quad [1]$$

$$E_j = \sum_{i=0}^n N_{i,j} * \text{SEX}_i * \text{MAT}_i * \text{EC}_i \quad [2]$$

$$\text{Larvae} \rightarrow \text{Age 1} \quad N_{1,j+1} = \frac{1}{[a + (b/L_j) + v]} \quad [3]$$

$$\text{Age 1} \rightarrow \text{Age 2, \dots, Age } n-1 \rightarrow \text{Age } n \quad N_{i+1,j+1} = N_{i,j} * e^{-(F_i + M_i + H_i)} \quad [4]$$

Harvest Regulations

$$F_i = (F'_i * (1 - PL_i) * NC) + (F'_i * PL_i * NC) + (F'_i * PL_i * (1 - NC) * (1 - Pr_i)) \quad [5]$$

$$H_i = (F'_i * hm_i * (1 - PL_i) * (1 - NC)) + (F'_i * hm_i * PL_i * Pr_i * (1 - NC)) \quad [6]$$

$$PL_i = RL_i * RC \quad [7]$$

$$PL_i = RL_i + RC - (RL_i * RC) \quad [8]$$

$$RL_i = 1 - [P(z > z^-_{1,i}) - P(z > z^+_{2,i})] \quad [9]$$

$$z^-_i = \frac{[L_1 - L_i \text{ mean}]}{S_i} \quad [10]$$

$$z''_i = \frac{[L_2 - L_i \text{ mean}]}{S_i} \quad [11]$$

Assessing Balance

$$N_k = \sum_{i=0}^n P[z < z_{k,i}] * N_{i,1} \quad [12]$$

$$z_{k,i} = \frac{[L_k - L_i \text{ mean}]}{S_i} \quad [13]$$

$$\text{PSD} = \frac{N_{\text{quality}}}{N_{\text{stock}}} \quad [14]$$

$$\text{RSD}_P = \frac{N_{\text{preferred}}}{N_{\text{stock}}} \quad [15]$$

Table 1. (continued).

$$RSD_M = \frac{N_{\text{memorable}}}{N_{\text{stock}}} \quad [16]$$

$$RSD_T = \frac{N_{\text{trophy}}}{N_{\text{stock}}} \quad [17]$$

$$RSD_{S_Q} = \frac{[N_{\text{stock}} - N_{\text{quality}}]}{N_{\text{stock}}} \quad [18]$$

$$RSD_{Q_P} = \frac{[N_{\text{quality}} - N_{\text{preferred}}]}{N_{\text{stock}}} \quad [19]$$

$$RSD_{P_M} = \frac{[N_{\text{preferred}} - N_{\text{memorable}}]}{N_{\text{stock}}} \quad [20]$$

$$RSD_{M_T} = \frac{[N_{\text{memorable}} - N_{\text{trophy}}]}{N_{\text{stock}}} \quad [21]$$

Catch and Yield

$$C_{i,j} = \frac{N_{i,j} * F_i * [1 - e^{-(F_i + M_i + H_i)}]}{[F_i + M_i + H_i]} \quad [22]$$

$$BIO_{i,j} = N_{i,j} * W * L^y_i \quad [23]$$

$$GTH_i = \frac{W * L^y_{i+1}}{W * L^y_i} \quad [24]$$

$$Y_{i,j} = \frac{BIO_{i,j} * F_i * [1 - e^{-(F_i + M_i + H_i) - GTH_i}]}{[F_i + M_i + H_i] - GTH_i} \quad [25]$$

$$CR_j = \text{SUM} \frac{F'_i * N_{i,j} * [1 - e^{-(F_i + M_i + H_i)}]}{F_i + M_i + H_i} \quad [26]$$

$$\text{Age}_j \text{mean} = \frac{\text{SUM}_{i=0}^n i * C_{i,j}}{\text{SUM}_{i=0}^n C_{i,j}} \quad [27]$$

 Table 1. (continued).

Variables used in equations

$N_{i,j}$	Number in age group i in year j .
L_j	Total number of larvae produced in the j^{th} year.
E_j	Total number of eggs produced in the j^{th} year.
HATCH	Hatching success rate of eggs, expressed as percent of total eggs laid.
a	Density independent term for first year survival.
b	Density dependent term for first year survival.
v	A random normal term to introduce variability in recruitment.
n	The maximim age group.
F'_i	Potential fishing mortality rate for the i^{th} age group, assuming no harvest regulations and no voluntary release.
F_i	Realized fishing mortality rate for the i^{th} age group, accounting for the effect of harvest regulations, angler non-compliance, and voluntary release.
hm_i	Potential hooking mortality rate for the i^{th} age group, assuming no harvest.
H_i	Realized hooking mortality rate for the i^{th} age group, accounting for allowed harvest, angler non-compliance, voluntary release.
M_i	Natural mortality rate for the i^{th} age group.
PL_i	Probability that a fish in age group i is legal. Equation 7 is used if the length and creel limit reductions are independent. Equation 8 is used if the length and creel limit reductions are dependent.
RL_i	Factor for reduction in harvest in the i^{th} age group due to the effect of length limits (expressed as percent reduction).
RC	Overall reduction in harvest due to the effect of a creel limit (expressed as percent reduction).
NC	Overall angler non-compliance rate.
PR_i	Probability of voluntarily releasing a fish in the i^{th} age group.
$P[z > z_{k,i}]$	The probability, based on the standard normal distribution, of z , a random variate, being greater than z_i , the critical value.
$z_{1,i}^-$	The value on the standard normal distribution corresponding to the minimum length (L_1) in the protected length range.

Table 1. (continued).

$z_{2,i}^+$	The value on the standard normal distribution corresponding to the maximum length (L_2) in the protected length range.
$z_{k,i}$	The value on the standard normal distribution corresponding to the minimum length of one of the stock density length groups.
L_1	The minimum length defining the protected range.
L_2	The maximum length defining the protected range.
L_k	The minimum length of one of the stock density length groups, specifically the k^{th} group.
$L_{i\text{mean}}$	The mean length of the i^{th} age class.
S_i	The standard deviation of length for the i^{th} age class.
N_k	The number of fish greater than or equal to the minimum length of the k^{th} stock density length group.
k	Identifies one of the stock density length groups. It can take on the values "Stock", "Quality", "Preferred", "Memorable", or "Trophy".
PSD	Proportional stock density.
RSD_P	The relative stock density of fish preferred size (350mm) and larger.
RSD_M	The relative stock density of fish memorable size (430 mm) and larger.
RSD_T	The relative stock density of fish trophy size (510 mm) and larger.
$RSD_{S Q}$	The relative stock density of fish between stock and quality size.
$RSD_{Q P}$	The relative stock density of fish between quality and preferred size.
$RSD_{P M}$	The relative stock density of fish between preferred and memorable size.
$RSD_{M T}$	The relative stock density of fish between memorable and trophy size.
GTH_i	Instantaneous rate of growth (in weight) for fish in the i^{th} age group.
$BIO_{i,j}$	Mean biomass for fish in the i^{th} age group.
$C_{i,j}$	Number of fish harvested (catch) in the i^{th} age group in year j .

Table 1. (continued).

$Y_{i,j}$	Yield in weight from the i^{th} age group in year j . Units correspond to those used in the length-weight regression from which w and y were obtained.
w	Linear coefficient from length-weight regression.
y	Exponential coefficient from length-weight regression.
$\text{Age}_{j,\text{mean}}$	Mean age harvested in year j .
CR_j	Number of fish caught, but not necessarily harvested, in year j .

Table 2. Reproductive parameter inputs used in equations 1 and 2 of Table 1 (Clady 1975, Carlander 1977).

Age	Maturity	Egg Content
0	0	0
1	0	0
2	0	800
3	0.4	3200
4	0.6	7500
5	1	11000
6	1	17500
7	1	22000
8	1	22500
9	1	22750
10	1	22850
11	1	22900
12	1	22925
13	1	22935
14	1	22940
15	1	22940
16	1	22940
17	1	22940
18	1	22940
19	1	22940
20	1	22940

Hatching Success Rate 0.0994

Sex Ratio (all ages) 0.5

Table 3. Catch per unit effort (#/hour) and age specific survival (and total instantaneous mortality) for smallmouth bass in the James River, Virginia. Derived from VCU (1991).

Year Class	Year			Age	Average Survival S	Mort. Z
	1987 CPUE	1988 CPUE	1989 CPUE			
1986	0.193	0.124	0.083	1-3	0.66	0.43
1985	0.081	0.035	0.012	2-4	0.38	0.98
1984	0.024	0.009	0.003	3-5	0.35	1.04
1983	0.038	0.015	0.007	4-6	0.43	0.85
1982 ^a	0.006	0.007	0.003	6+	0.43	0.84

^a The 1982 year class includes all smallmouth bass age 5 and older in the population. Survival and total mortality based only on 1988 and 1989 catch per unit effort.

TABLE 4. Density/ha, catch/ha harvest/ha, $F_{i,j}$, and $F'_{i,j}$ for age 1+ smallmouth bass in the James River (VPI&SU and VCU 1991). Sample size for both density and catch is represented as the number of prima cord samples and complete trip angler interviews, respectively. Sections included in the upper James River were as follows: 1 - Iron Gate to Snowden Dam and 2 - Monocan Park to Bent Creek. Sections included in the lower James River were as follows: 3 - Norwood to Bremono Bluff, 4 - Columbia to Watkins Landing, and 5 - Boshers Dam to I-95 Bridge (Richmond City).

Section	Size <11"	Size 11-14"	Size >14"	

upper James R.				
density/ha	100.3	4.2	1.1	N=7
catch/ha	55.3	9.4	2.1	N=138
harvest/ha	3.3	0.65	0.46	N=138
$F_{i,j}$	0.04	0.18	0.52	
$F'_{i,j}$	0.65	2.60	2.40	
lower James R.				
density/ha	35.4	1.9	0.38	N=8
catch/ha	26.8	12.6	3.1	N=356
harvest/ha	1.4	0.17	0.95	N=356
$F_{i,j}$	0.04	0.09	2.51	
$F'_{i,j}$	0.76	6.64	8.05	

Table 5. Mortality parameter inputs for smallmouth bass in the James River, Virginia (VPI&SU and VCU 1991). Sections included in the upper James River were as follows: 1 - Iron Gate to Snowden Dam and 2 - Monocan Park to Bent Creek. Sections included in the lower James River were as follows: 3 - Norwood to Bremono Bluff, 4 - Columbia to Watkins Landing, and 5 - Boshers Dam to I-95 Bridge (Richmond City).

Age	Fishing Mort. (F'_i)		Natural Mort. (M_i)		Hooking Mort. (hm_i)
	upper	lower	upper	lower	
1	0.10	0.38	0.42	0.39	0.20
2	1.30	1.10	0.85	0.72	0.20
3	1.80	4.00	0.76	0.28	0.20
4	2.30	6.64	0.32	0.12	0.20
5	2.50	7.50	0.29	0.05	0.20
6	2.60	8.00	0.22	0.05	0.20
7	2.70	8.05	0.14	0.05	0.20
8	2.70	8.10	0.12	0.05	0.20
9	2.70	8.20	0.12	0.05	0.20
10	2.70	8.20	0.12	0.05	0.20
11	2.70	8.20	0.12	0.05	0.20
12	2.70	8.20	0.12	0.05	0.20
13	2.70	8.20	0.12	0.05	0.20
14	4.50	10.0	1.00	1.00	0.20
15	4.50	10.0	1.00	1.00	0.20
16	4.50	10.0	1.00	1.00	0.20
17	4.50	10.0	1.00	1.00	0.20
18	4.50	10.0	1.00	1.00	0.20
19	4.50	10.0	1.00	1.00	0.20
20	4.50	10.0	1.00	1.00	0.20

Table 6. Population parameters for smallmouth bass in the James River, Virginia (VCU 1991) used as model inputs. Sections included in the upper James River were as follows: 1 - Iron Gate to Snowden Dam and 2 - Monocan Park to Bent Creek. Sections included in the lower James River were as follows: 3 - Norwood to Bremono Bluff, 4 - Columbia to Watkins Landing, and 5 - Boshers Dam to I-95 Bridge (Richmond City).

Age	Number*		Mean Total Length (mm)		SD Length	
	upper	lower	upper	lower	upper	lower
0	158,606	483,334	5	5	1	1
1	106,443	64,075	102	113	18	18
2	63,331	28,025	173	197	24	25
3	16,565	10,013	222	263	27	33
4	8,047	6,009	301	312	30	40
5	3,340	2,003	312	331	33	56
6	1,436	401	322	378	45	56
7	617	80	399	478	45	56
8	265	16	427	531	45	56
9	114	8	459	550	45	56
10	49	4	514	555	45	56
11	21	2	545	560	45	56
12	9	1	560	565	45	56
13	4	0	586	570	45	56
14	2	0	595	575	45	56
15	1	0	596	580	45	56
16	0	0	597	585	45	56
17	0	0	598	590	45	56
18	0	0	599	595	45	56
19	0	0	600	597	45	56
20	0	0	600	600	45	56

* Number in study section (upper - 1,694 hectares)
(lower - 2,978 hectares)

Length-Weight Regression parameters used in equations 21 and 22 of Table 1 -

Linear Coefficient	0.0000162
Exponential Coefficient	2.96

Table 7. Harvest per angler-day (percent harvest shown in parenthesis) and predicted harvest reductions due to creel limit reduction (shown as the proportion of harvest remaining), based on data from the upper James River, Virginia (Kokel 1991). Sections are as follows: upper James River; 1 - Iron gate to Snowden Dam and 2 - Monocan Park to Bent Creek.

Section	Harvest per Angler-day						
	0	1	2	3	4	5	
1	183	20	3	3	2	1	
2	47	6	1	1	0	0	
Total	230 (0.861)	26 (0.097)	4 (0.015)	4 (0.015)	2 (0.007)	1 (0.004)	

HARVEST REDUCTIONS

Section	New Creel Limit					
	0	1	2	3	4	5
1	1.000	0.380	0.196	0.076	0.022	0.000
2	1.000	0.187	0.062	0.000	0.000	0.000
Weighted Mean	1.000	0.352	0.176	0.065	0.019	0.000
Proportion remaining	0.000	0.648	0.824	0.935	0.981	1.000

Table 8. Harvest per angler-day (percent harvest shown in parenthesis) and predicted harvest reductions due to creel limit reduction (shown as the proportion of harvest remaining), based on data from the lower James River, Virginia (Kokel 1991). Sections are as follows: lower James River; 3 - Norwood to Bremono Bluff, 4 - Columbia to Watkins landing, and 5 - Boshers's Dam to I-95 Bridge (Richmond City).

Section	Harvest per Angler-day					
	0	1	2	3	4	5
3	150	18	4	3	1	1
4	221	22	2	1	0	0
5	62	2	0	0	0	0
Total	433 (0.889)	42 (0.086)	6 (0.012)	4 (0.008)	1 (0.002)	1 (0.002)

HARVEST REDUCTIONS

Section	New Creel Limit					
	0	1	2	3	4	5
3	1.000	0.333	0.133	0.040	0.013	0.000
4	1.000	0.138	0.034	0.000	0.000	0.000
5	1.000	0.000	0.000	0.000	0.000	0.000
Weighted Mean	1.000	0.241	0.088	0.022	0.007	0.000
Proportion remaining	0.000	0.759	0.912	0.978	0.993	1.000

TABLE 9. Angler harvest statistics for selected smallmouth bass stream fisheries.

Stream, State	Regs.	Pressure hr/ha	Catch #/hr	Harvest #/ha	Yield kg/ha
Field estimates:					
Current R., MO ⁸	--	69	0.09	4.1	2.0
Potomac R., MD ⁴	--	81			4.3
Niangua R., MO ¹⁰	--	94			1.5
L. James R., VA ¹²	C,F	94*	0.64	2.5	1.5
Middle Fork Kentucky R., KY ³	--	121			14.8
U. James R., VA ¹²	C,F	123*	1.31	4.4	2.5
New R., VA ¹³	none	133	0.09	12.0	1.2
Huzzah Cr., MO ⁷	B	148		10.9	4.6
Big Piney R., MO ⁵	none	156	0.06	9.0	3.3
Big Piney R., MO ⁵	B	169	0.03	4.8	2.8
New R., WV ¹⁴	none	185	0.28	29.8	
Shenandoah R., VA ¹¹	B	219	0.53	6.1	
Galena R., WI ¹⁷	C,D	221	0.32	31.1	8.2
Shenandoah R., VA ¹¹	none	227	0.19	24.3	
Courtois Cr., MO ⁷	B	234		24.8	10.8
Courtois Cr., MO ⁶	A	283	0.20	0	0
Plover R., WI ¹⁶	none	318	0.07		5.6
Huzzah Cr., MO ⁹	B	333		14.6	8.6
Courtois Cr., MO ⁶	none	367	0.10	21.1	9.8
Huzzah Cr., MO ⁹	none	413	0.08	34.1	8.7
Maquoketa R., IA ²	B	830	0.22	12.8	8.0
Maquoketa R., IA ¹	none	925	0.05	39.2	7.7
New R., VA ¹⁵	B		1.33		
New R., WV ¹⁵	none		1.05		
St. Lawrence R., NY ¹⁸	--		0.60		
L. Mohawk R., NY ¹⁹	--		1.32	9.6	
Average		261	0.43	15.5	5.6
Simulation results:					
U. James R., VA ²⁰	none	123**	1.07	5.4	1.3
U. James R., VA ²⁰	G,C	123**	1.08	5.2	1.2
U. James R., VA ²⁰	F,C	123**	1.08	5.1	1.2
U. James R., VA ²⁰	B,C	123**	1.12	3.8	1.1
U. James R., VA ²⁰	E,C	123**	1.13	3.6	1.0
U. James R., VA ²⁰	A	123**	1.14	3.6	1.0
L. James R., VA ²⁰	none	94**	0.43	2.8	0.8
L. James R., VA ²⁰	G,C	94**	0.44	2.6	0.8
L. James R., VA ²⁰	F,C	94**	0.44	2.4	0.7
L. James R., VA ²⁰	B,C	94**	0.46	2.1	0.7
L. James R., VA ²⁰	E,C	94**	0.47	1.8	0.6
L. James R., VA ²⁰	A	94**	0.48	1.7	0.6

* Smallmouth bass effort was 51 hours/ha for the upper James River and 66 hours/ha for the lower James River (used to calculate catch/hour).

** Based on Kokel 1991.

(continued on next page)

Table 9 (continued).

References:

1. Paragamian 1984a
2. Paragamian 1984b
3. Turner 1967
4. Sanderson 1959
5. Fleener 1974b
6. Fleener 1975
7. Fajen 1981
8. Fleener 1973
9. Fleener 1974a
10. Funk and Fleener 1966
11. Kauffman 1983
12. Kokel 1991
13. Wollitz 1968
14. Pierce et al. 1981
15. Austen and Orth 1984
16. Paragamian 1973
17. Forbes 1989
18. Green et al. 1986
19. McBride 1983
20. this model

Regulations:

- A. catch and release
- B. 305mm minimum
- C. 5/day creel limit
- D. closed season
- E. 356mm minimum
- F. 280-356mm slot
- G. 305mm maximum
- none

Table 10. Estimated angler non-compliance rates for James River smallmouth bass fisherman. Data derived from an on-site recreational use survey conducted on the James River in 1988 and 1989 (Kokel 1991). Angler non-compliance is represented as 1 minus the compliance rate, and is shown in parenthesis. Sections included on the upper James River were as follows: 1 - Iron Gate to Snowden Dam and 2 - Monocan Park to Bent Creek. Sections included in the lower James River were as follows: 3 - Norwood to Bremono Bluff, 4 - Columbia to Watkins Landing, and 5 - Boshers Dam to I-95 Bridge (Richmond City).

Section	Number of anglers ^a	Compliance with regulations (%)
1	36	77.7
2	12	75.0
Total	48	76.3 (23.7)
3	41	86.6
4	59	84.7
5	11	100.0
Total	111	90.4 (9.6)

^a Anglers who meet classification criteria (caught 1 fish in the slot or caught more than 5 fish).

Table 11. Estimated voluntary release rates for James River smallmouth bass fisherman. Data derived from an on-site recreational use survey conducted on the James River in 1988 and 1989 (Kokel 1991). Voluntary release is shown as the ratio of the number of anglers releasing legal fish who also caught legal fish. Sections included on the upper James River were as follows: 1 - Iron Gate to Snowden Dam and 2 - Monocan Park to Bent Creek. Sections included in the lower James River were as follows: 3 - Norwood to Brems Bluff, 4 - Columbia to Watkins Landing, and 5 - Boshers Dam to I-95 Bridge (Richmond City).

Angler type	upper James		lower James	
	<280 mm	>356 mm	<280 mm	>356 mm

Non-complier				
released ^a	8	0	7	0
caught ^b	10	2	8	3
% releasing fish	80.0	0.0	87.0	0.0
Complier				
released ^a	134	12	239	46
caught ^b	138	18	247	65
% releasing fish	97.0	67.0	97.0	71.0

^a Number of non-complying anglers who release legal fish (anglers who caught more than 1 fish in each size category).

^b Number of complying anglers who release legal fish (anglers who caught more than 1 fish in each size category).

Table 12. The minimum and maximum values for PSD, catch, harvest, and yield used in the utility equation. Values based on a range derived from field studies for smallmouth bass fisheries over their entire range.

Decision variable	Minimum	Maximum
PSD	0.03	0.77 ^a
Catch	0.03	1.33
Harvest	0.0	45.0
Yield	0.0	14.9

^a The maximum value used in the utility analysis was 40%. Simulation results never exceeded 35%, therefore 40% (the lower end of the optimum range) was considered optimum and recieved a scaling factor of 1. Simulation results were scaled accordingly.

Table 13. Smallmouth bass population statistics based on fish age-1 and older from selected streams.

Stream, State	Density (#/ha)	PSD	Biomass (kg/ha)	Regs.
Field estimates:				
Maquoketa R., IA ^{6*}	32	25	4.7	B
L. James R., VA ⁵	37	14	3.4	E,F
Huzzah Cr., MO ¹	58	17	9.0	-
U. James R., VA ⁵	118	11	8.3	E,F
Plover R., WI ³	118		17.5	none
Red Cedar R., WI ³	132		15.1	none
Pats Cr., WI ²	170		19.6	none
Maquoketa R., IA ^{7*}	232	17	14.1	none
New River, WV ⁴	254		16.6	none
Galena R., WI ²	361		42.6	none
Turkey R., IA ⁷		42		none
B. Buffalo Cr., MO ⁸		41		H
New River, VA ⁹		3		B
New River, WV ⁹		4		none
Coffins Gr. Cr., IA ⁷		10		none
Upper Iowa R., IA ⁷		19		none
Volga R., IA ⁷		24		none
Glover Cr., OK ¹⁰		19		none
Courtois Cr., MO ¹¹		20		none
Courtois Cr., MO ¹²		34		B
Shenandoah R., VA ¹³		13		B
Shenandoah R., VA ¹³		28		none
Average	151	20	15.1	
Simulation results:				
U. James R., VA ¹⁴	122	11	7.1	none
U. James R., VA ¹⁴	122	12	7.2	D,F
U. James R., VA ¹⁴	122	12	7.2	E,F
U. James R., VA ¹⁴	123	13	7.2	G
U. James R., VA ¹⁴	123	13	7.5	B,F
U. James R., VA ¹⁴	123	13	7.6	C,F
L. James R., VA ¹⁴	41	15	3.4	none
L. James R., VA ¹⁴	41	15	3.4	D,F
L. James R., VA ¹⁴	41	15	3.4	E,F
L. James R., VA ¹⁴	42	16	3.6	G
L. James R., VA ¹⁴	42	16	3.5	B,F
L. James R., VA ¹⁴	42	16	3.6	C,F

*Estimates based on fish 7.9 inches and larger.

(continued on next page)

Table 13 (continued).

References:

1. Fleener 1974a
2. Forbes 1989
3. Paragamian and Coble 1975
4. Roell 1989
5. VCU 1991
6. Paragamian 1984b
7. Paragamian 1984a
8. Reed and Rabeni 1989
9. Austen and Orth 1988
10. Orth et al. 1983
11. Fajen 1975a
12. Fajen 1975b
13. Kauffman and Smith 1987
14. this model

Regulations:

- A. 203mm minimum
- B. 305mm minimum
- C. 356mm minimum
- D. 305mm maximum
- E. 280-356mm slot
- F. 5/day creel limit
- G. Catch and release
- H. no fishing
- none.

Table 14. Total estimated angling effort, catch, and harvest for black bass in the James River, 1988. Sample size (no. of parties) is shown in parenthesis.

		<u>Effort</u> <u>(hours)</u>	<u>CPUE</u>	<u>(N)</u>	<u>Catch</u> <u>(numbers)</u>	<u>HPUE</u>	<u>(N)</u>	<u>Harvest</u> <u>(numbers)</u>
AREA 1	bank	5,182	0.8449	(11)	4,378	0.0338	(11)	175
	boat	<u>58,708</u>	1.6917	(53)	<u>99,316</u>	0.1335	(53)	<u>7,836</u>
	total	63,890			103,694			8,011
AREA 2	bank	5,410	0.5197	(4)	2,812	0.0000	(4)	0
	boat	<u>26,412</u>	0.6655	(13)	<u>17,577</u>	0.1329	(13)	<u>3,510</u>
	total	31,822			20,389			3,510
AREA 3	bank	4,562	0.5784	(4)	2,639	0.0000	(4)	0
	boat	<u>96,046</u>	0.6280	(40)	<u>60,326</u>	0.0826	(40)	<u>7,933</u>
	total	100,608			62,965			7,933
AREA 4	bank	4,388	0.6219	(6)	2,729	0.0000	(6)	0
	boat	<u>131,677</u>	0.5182	(128)	<u>68,235</u>	0.0160	(128)	<u>2,107</u>
	total	136,065			70,964			2,107
AREA 5	bank	21,918	0.4866	(27)	10,665	0.0066	(27)	145
	boat	<u>13,768</u>	0.6098	(17)	<u>8,396</u>	0.0062	(17)	<u>85</u>
	total	35,686			19,061			230
AREA 6	bank	3,878	0.0000	(0)	0	0.0000	(0)	0
	boat	0	0.0000	(0)	0	0.0000	(0)	0
	total	3,878			0			0
TOTAL		371,949			277,073			21,791
/ha		79.6			59.3			4.7

Table 15. Total estimated angling effort, catch, and harvest for black bass in the James River, 1989. Sample size (no. of parties) is shown in parenthesis.

		<u>Effort</u> <u>(hours)</u>	<u>CPUE</u>	<u>(N)</u>	<u>Catch</u> <u>(numbers)</u>	<u>HPUE</u>	<u>(N)</u>	<u>Harvest</u> <u>(numbers)</u>
AREA 1	bank	7,312	0.5733	(8)	4,192	0.0000	(8)	0
	boat	<u>50,132</u>	1.7564	(31)	<u>88,052</u>	0.0569	(31)	<u>2,853</u>
	total	57,444			92,244			2,853
AREA 2	bank	3,051	0.2710	(5)	827	0.0667	(5)	204
	boat	<u>17,149</u>	0.5379	(12)	<u>9,224</u>	0.0143	(12)	<u>245</u>
	total	20,200			10,051			449
AREA 3	bank	1,975	0.3333	(3)	658	0.0000	(3)	0
	boat	<u>47,276</u>	1.3089	(37)	<u>61,880</u>	0.0698	(37)	<u>3,300</u>
	total	49,251			62,538			3,300
AREA 4	bank	1,850	0.1920	(8)	355	0.0275	(8)	51
	boat	<u>49,996</u>	0.5953	(58)	<u>29,763</u>	0.0283	(58)	<u>1,415</u>
	total	51,846			30,118			1,466
AREA 5	bank	13,181	0.3370	(18)	4,442	0.0000	(18)	0
	boat	<u>6,686</u>	0.4592	(10)	<u>3,070</u>	0.0105	(10)	<u>70</u>
	total	19,867			7,512			70
AREA 6	bank	2,867	0.0000	(1)	0	0.0000	(1)	0
	boat	<u>0</u>	0.0000	(0)	<u>0</u>	0.0000	(0)	<u>0</u>
	total	2,867			0			0
TOTAL		201,475			202,463			8,138
/ha		43.1			43.3			1.7

CITATION HARVEST FOR SMALLMOUTH BASS FROM THE JAMES RIVER

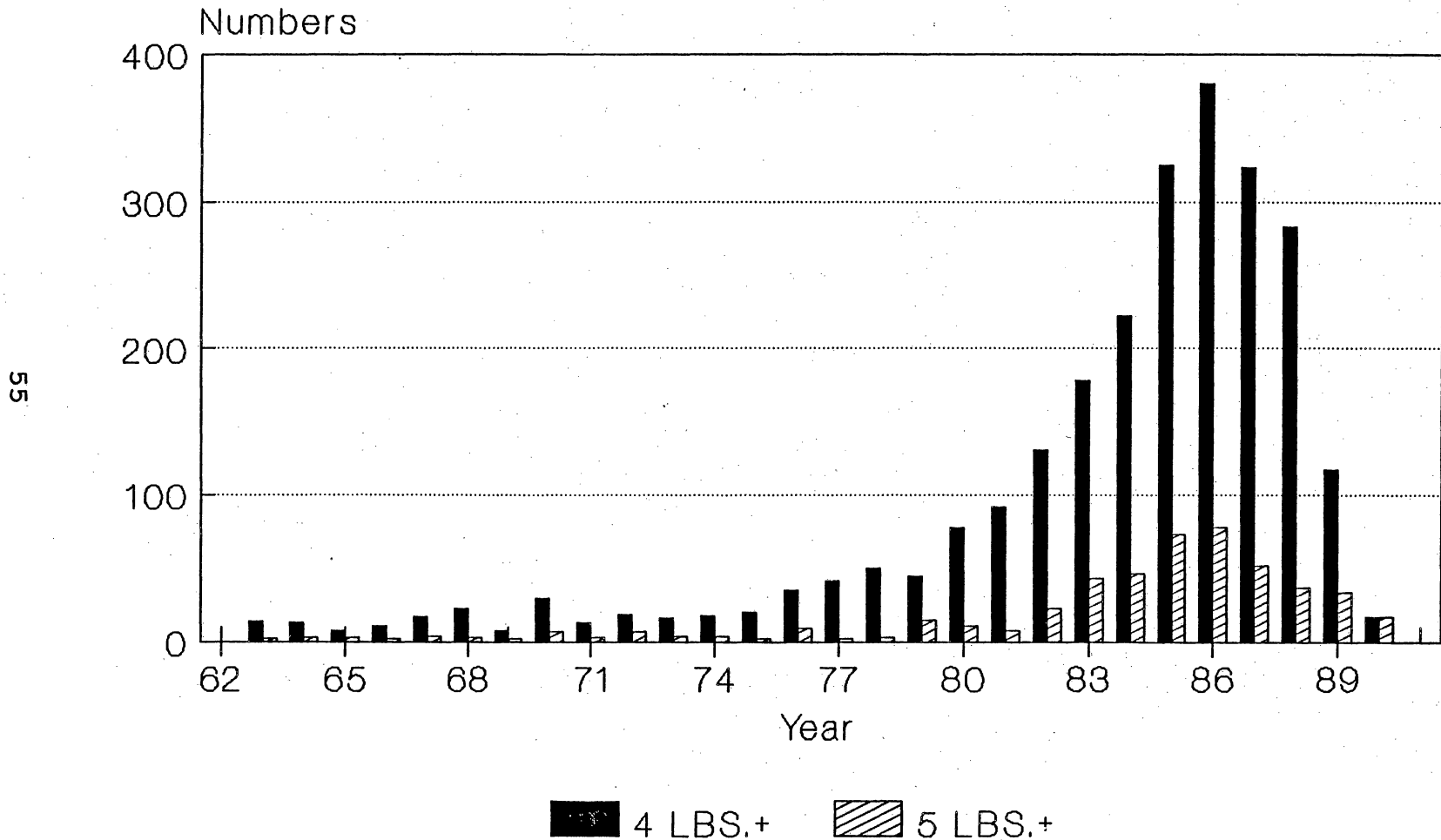


Fig. 1. Change in citation sized smallmouth bass in the James River, Virginia since the inception of the citation program in 1963.

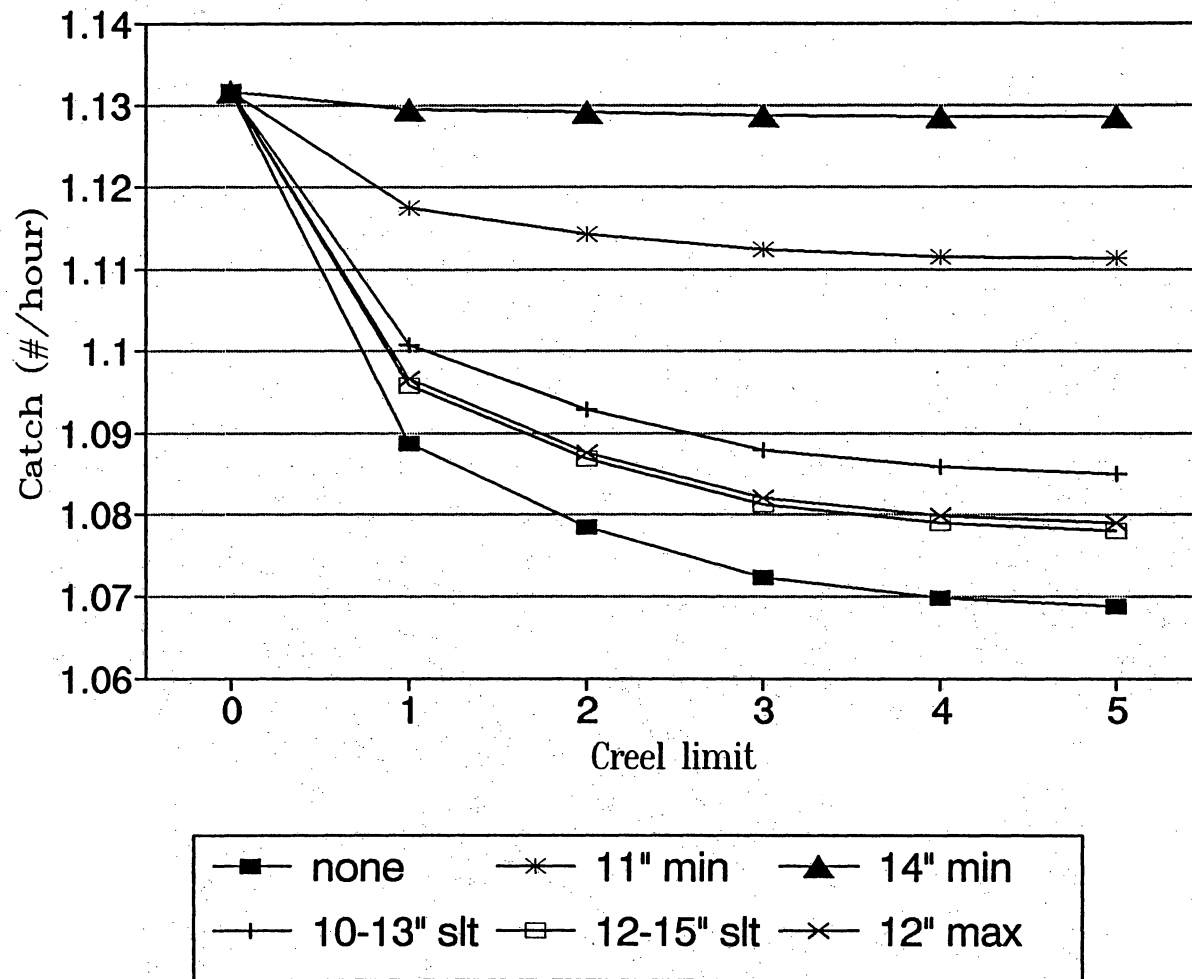


Fig. 2. Number of smallmouth caught per hour under selected combinations of simulated regulations, upper James River, Virginia.

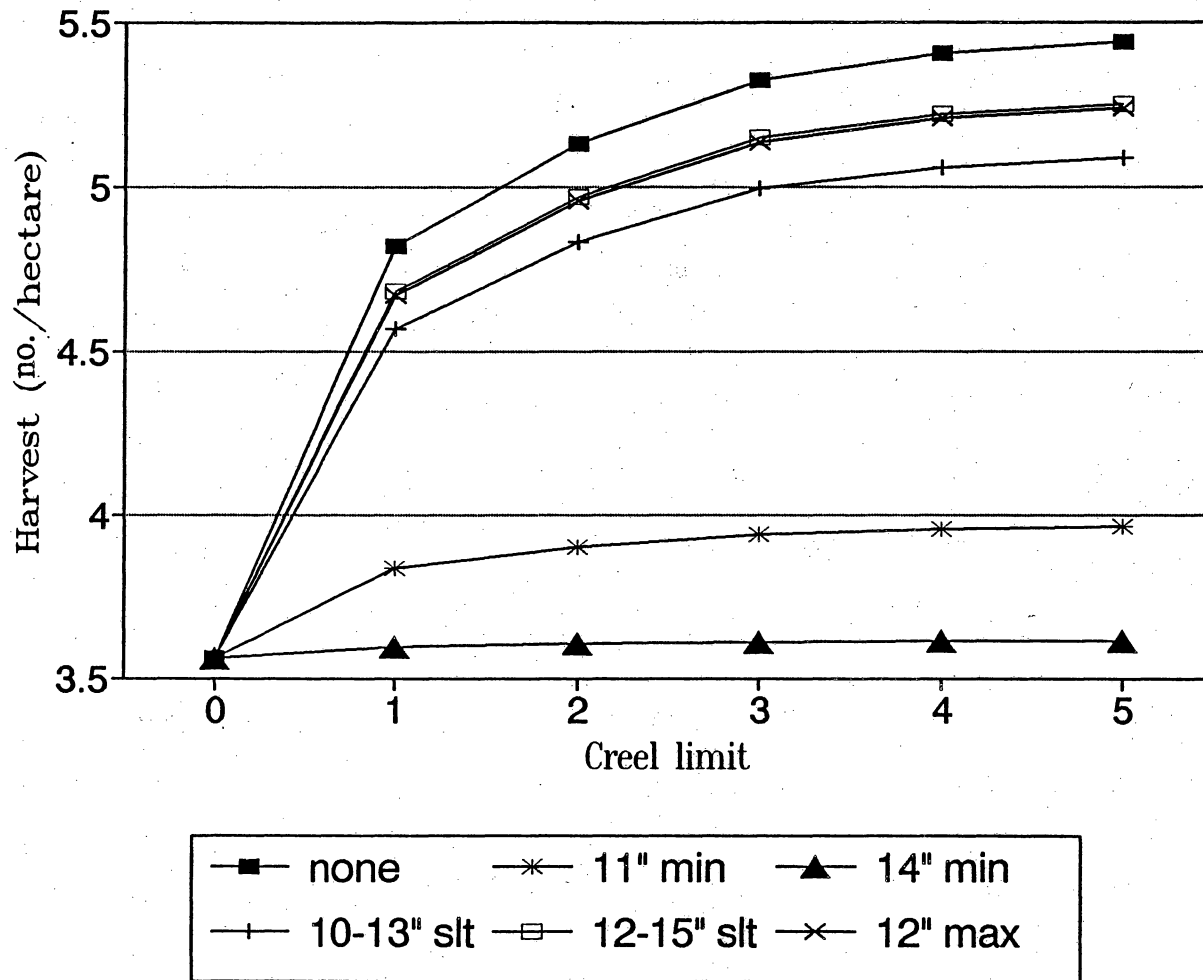


Fig. 3. Number of smallmouth bass harvested per hectare under selected combinations of simulated regulations, upper James River, Virginia.

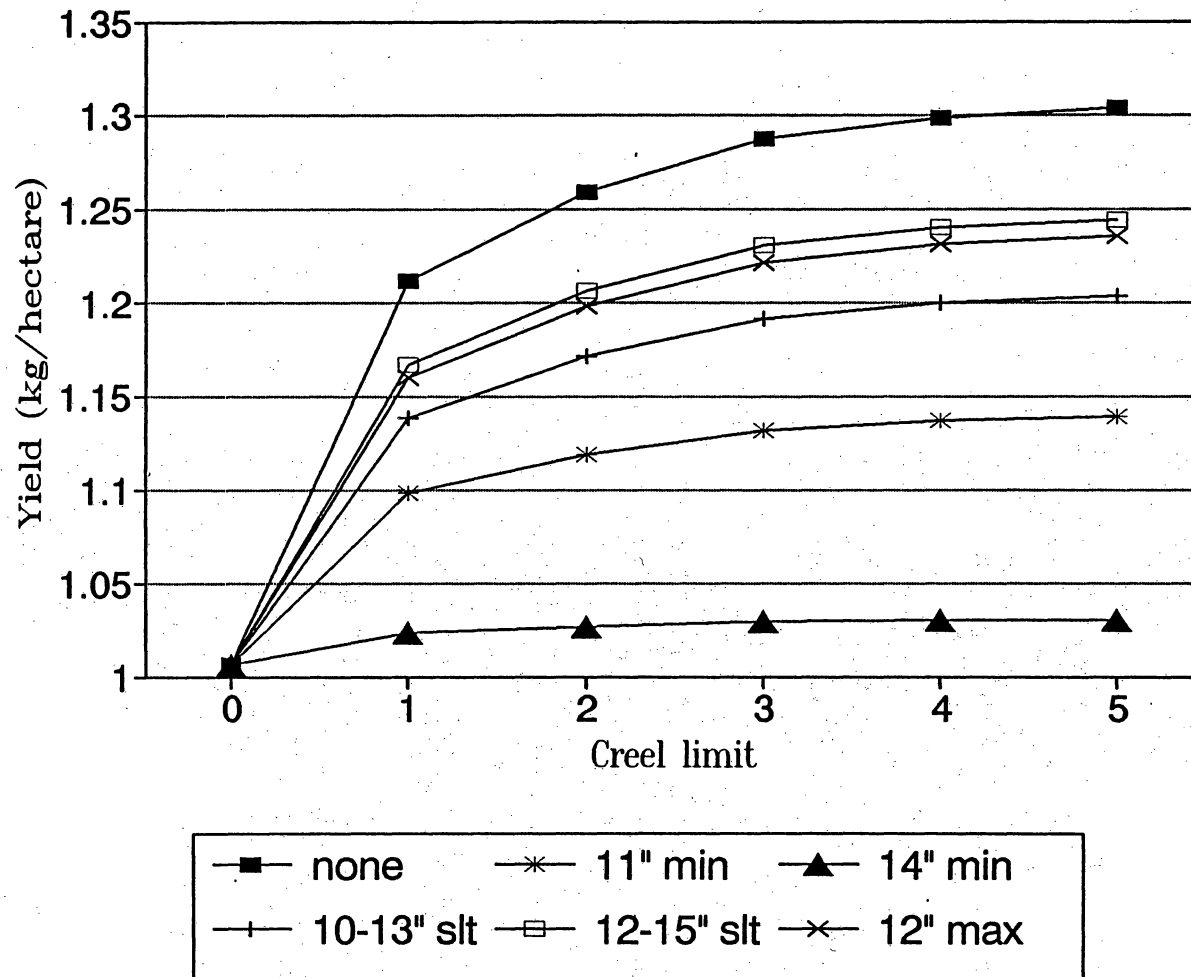


Fig. 4. Yield in kilograms of smallmouth bass under selected combinations of simulated regulations, upper James River, Virginia.

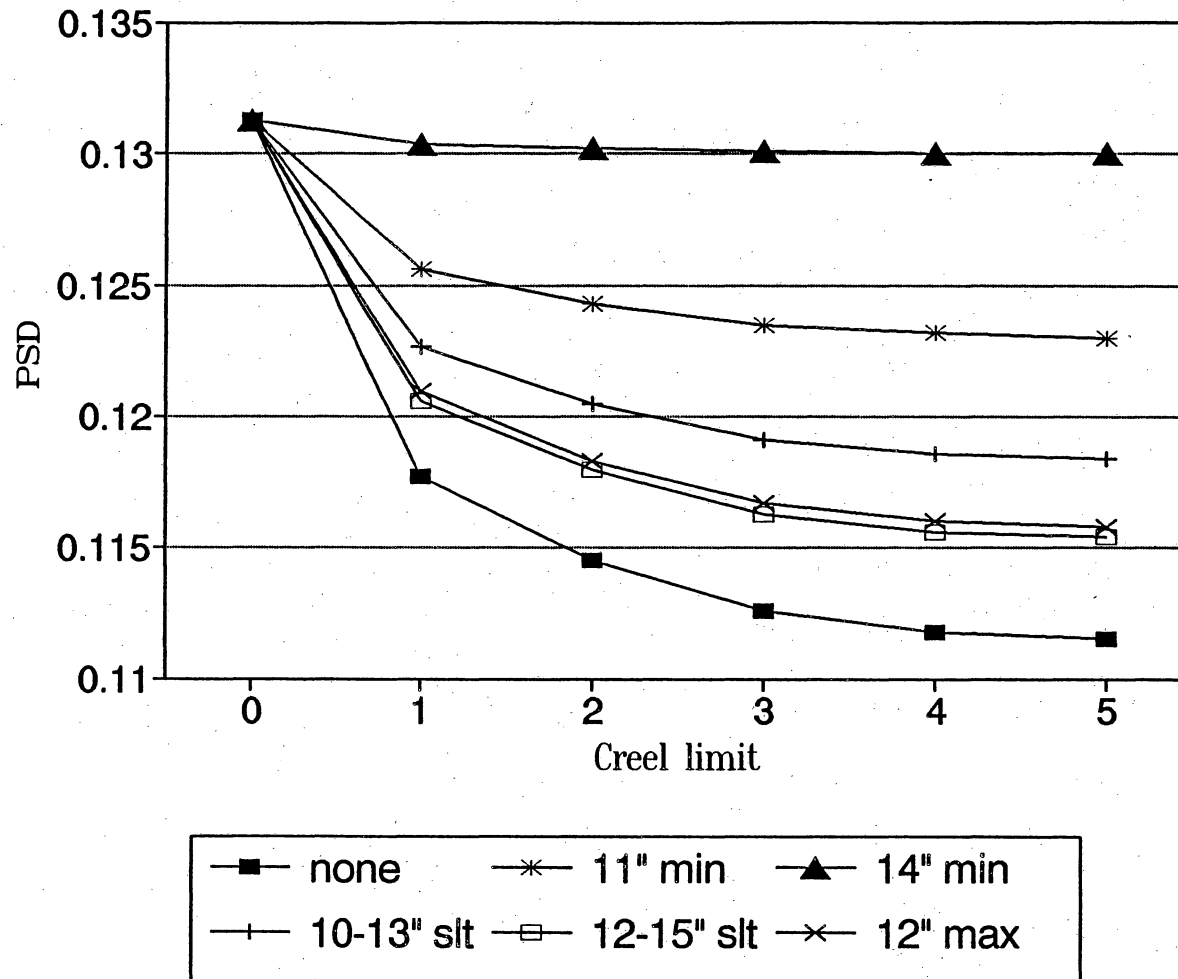


Fig. 5. Proportional stock density of smallmouth bass under selected combinations of simulated regulations, upper James River, Virginia.

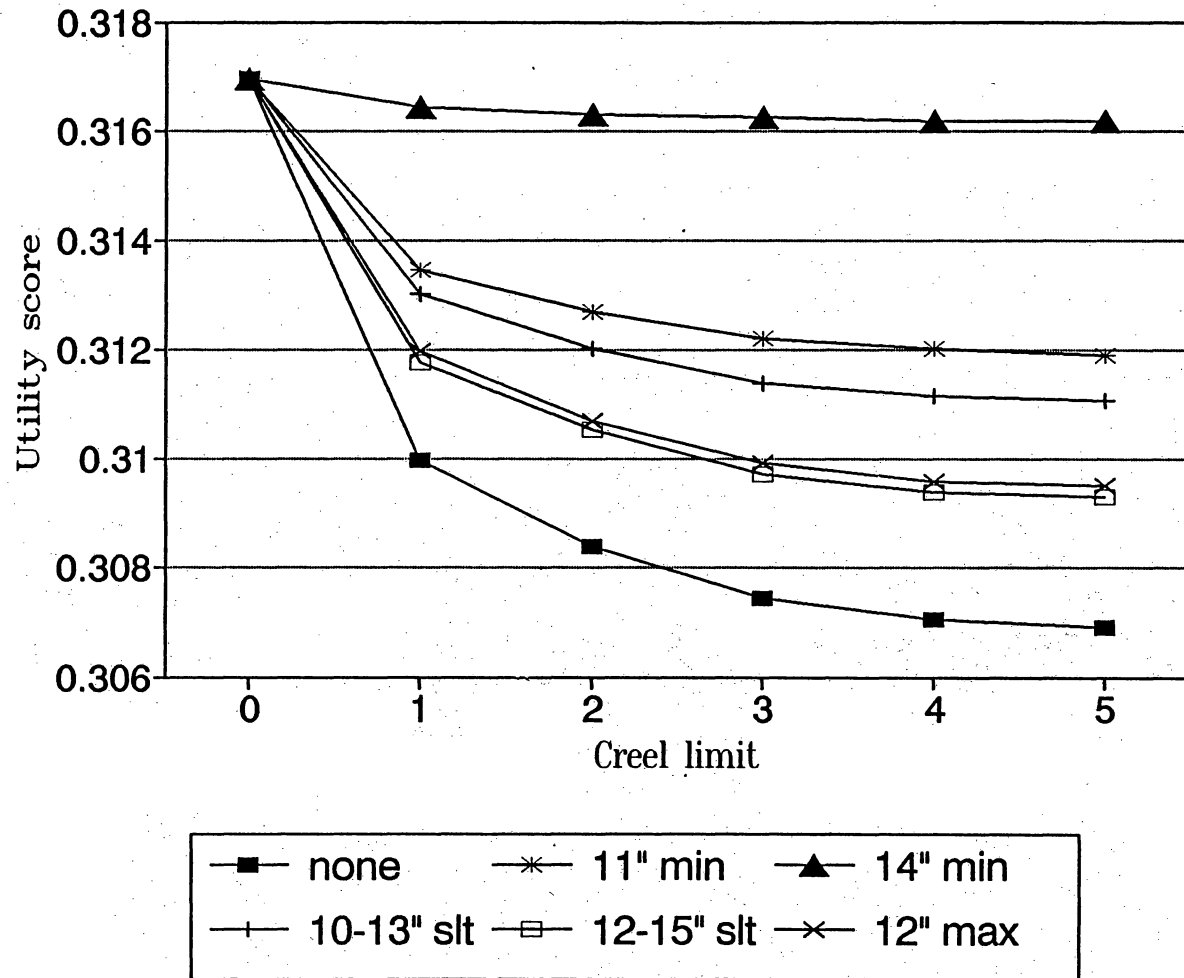


Fig. 6. Utility scores under selected combinations of simulated regulations, upper James River, Virginia.

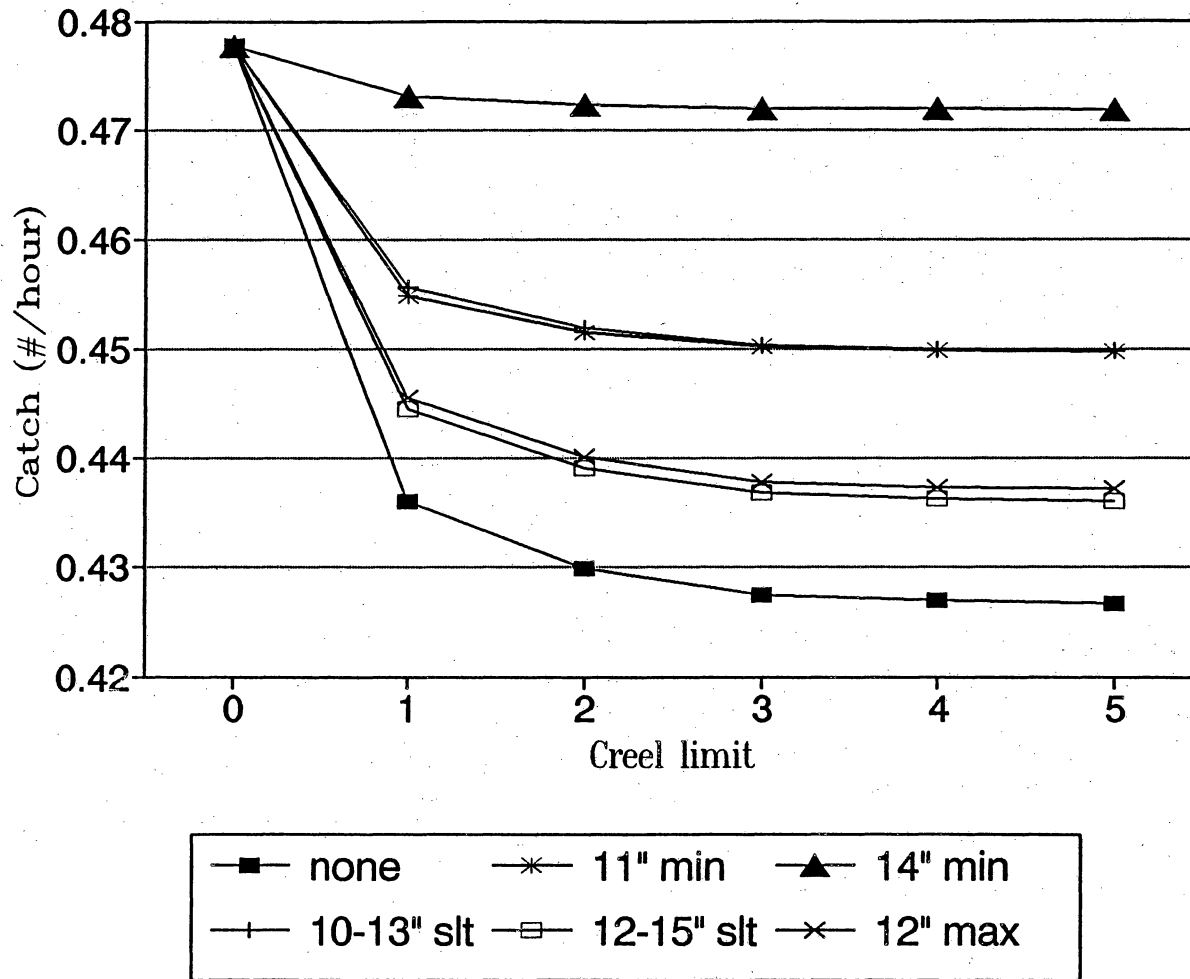


Fig. 7. Number of smallmouth caught per hour under selected combinations of simulated regulations, lower James River, Virginia.

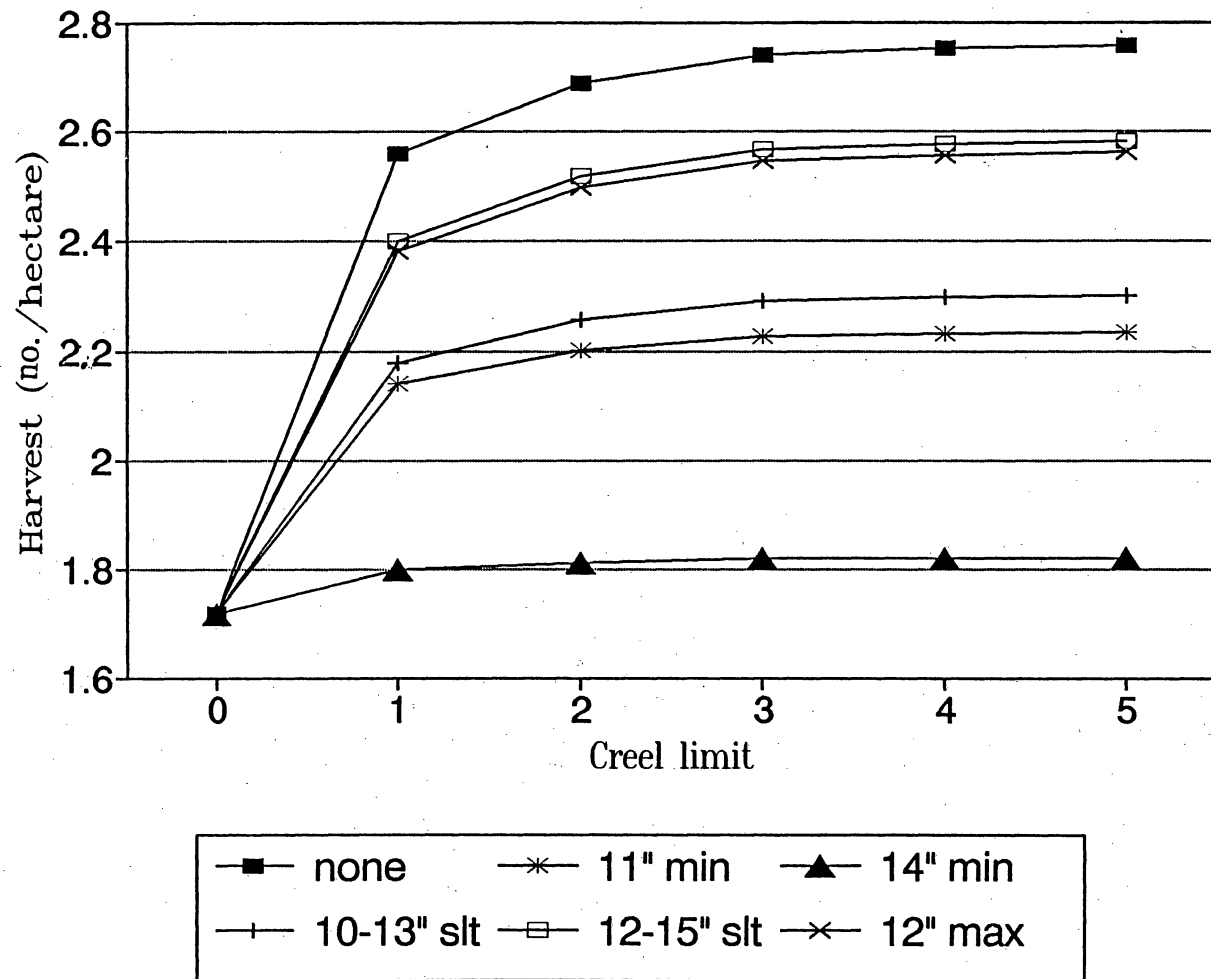


Fig. 8. Number of smallmouth bass harvested per hectare under selected combinations of simulated regulations, lower James River, Virginia.

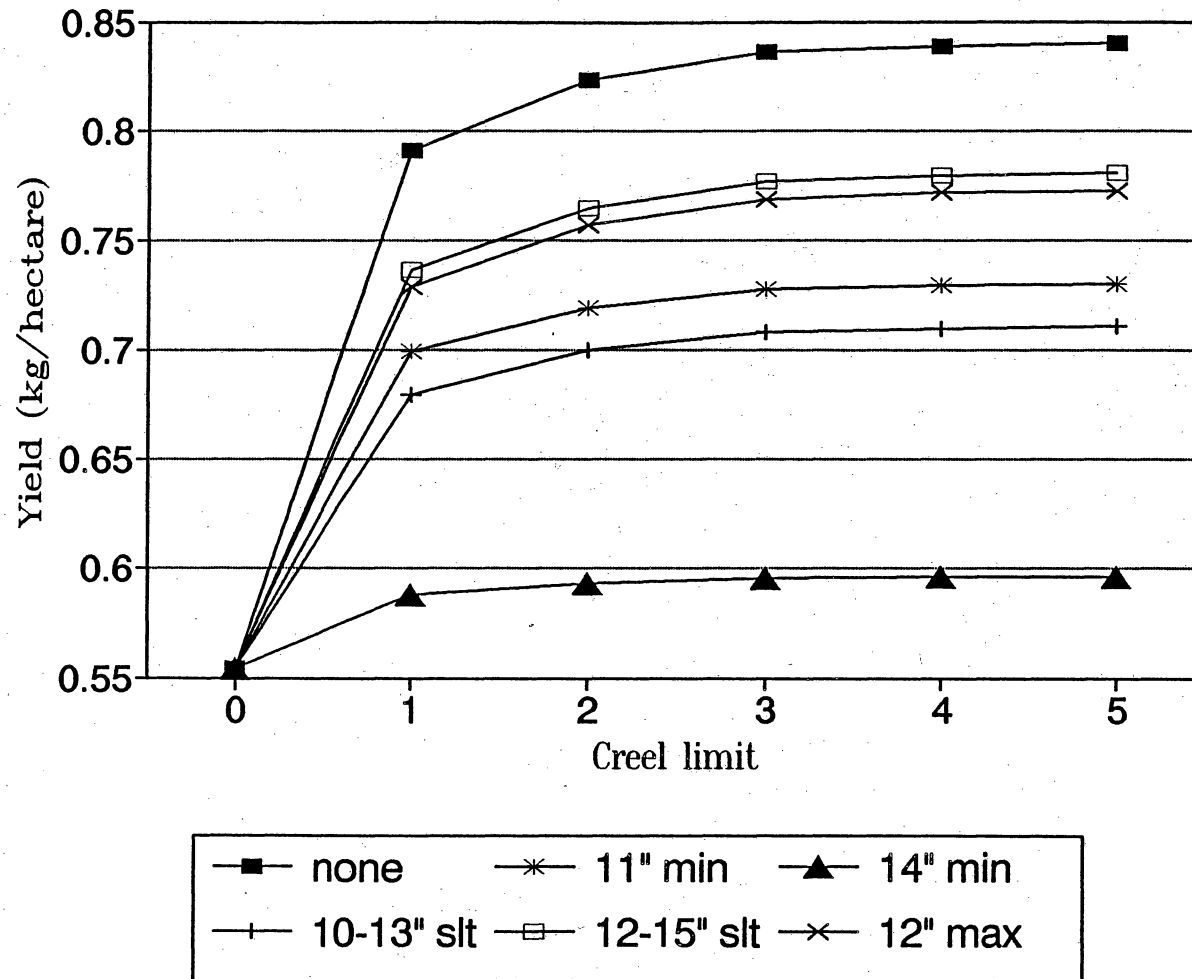


Fig. 9. Yield in kilograms of smallmouth bass under selected combinations of simulated regulations, lower James River, Virginia.

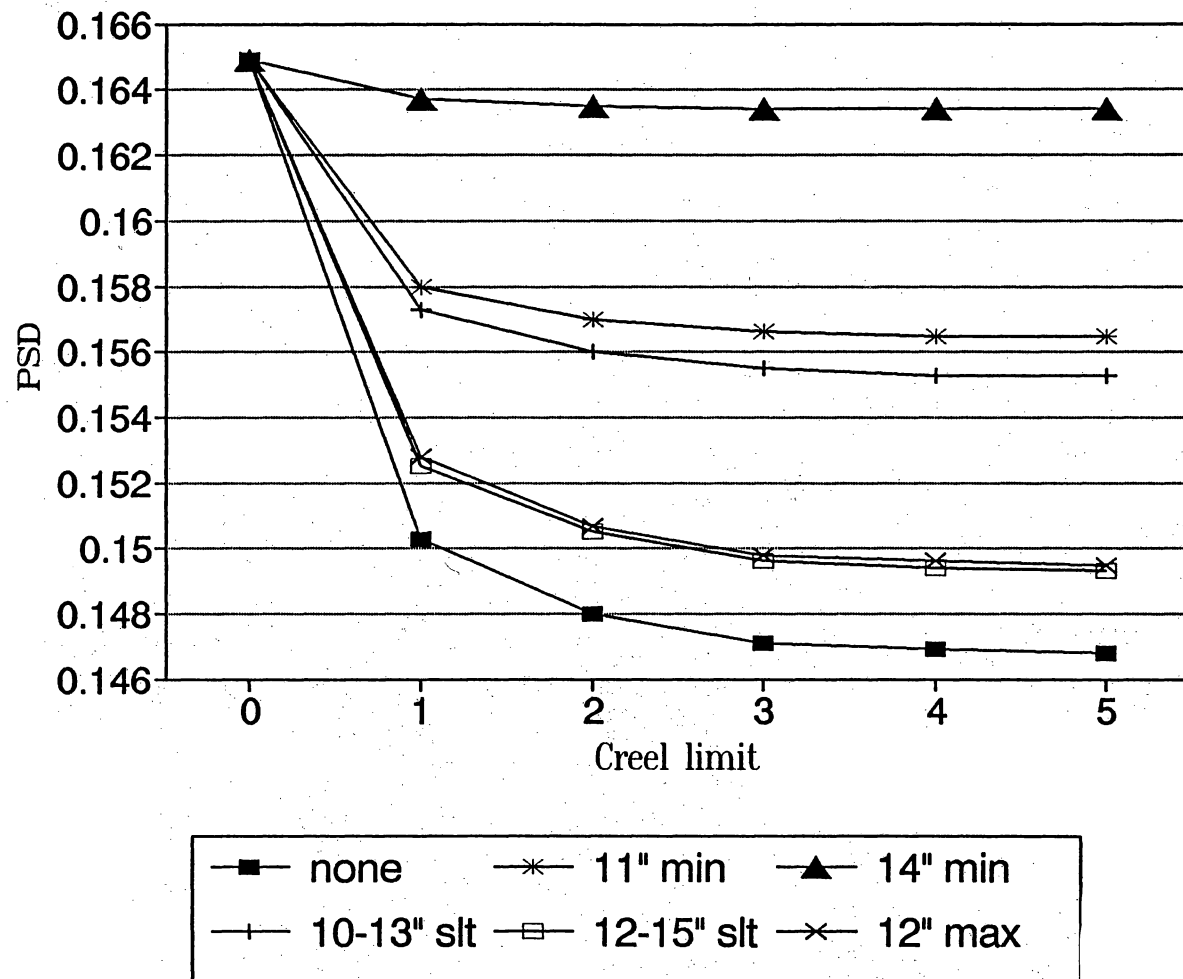


Fig. 10. Proportional stock density of smallmouth bass under selected combinations of simulated regulations, lower James River, Virginia.

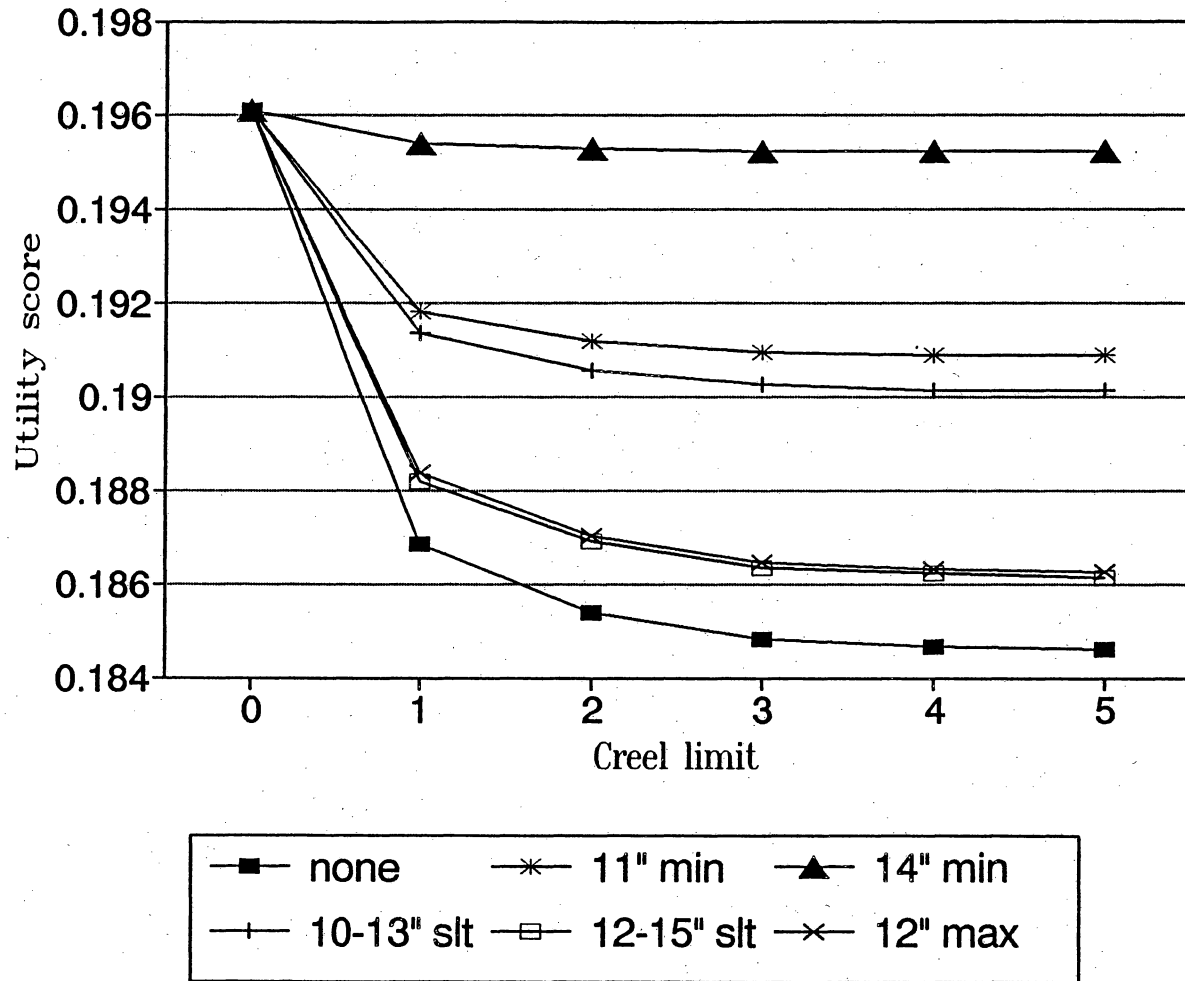


Fig. 11. Utility scores under selected combinations of simulated regulations, lower James River, Virginia.

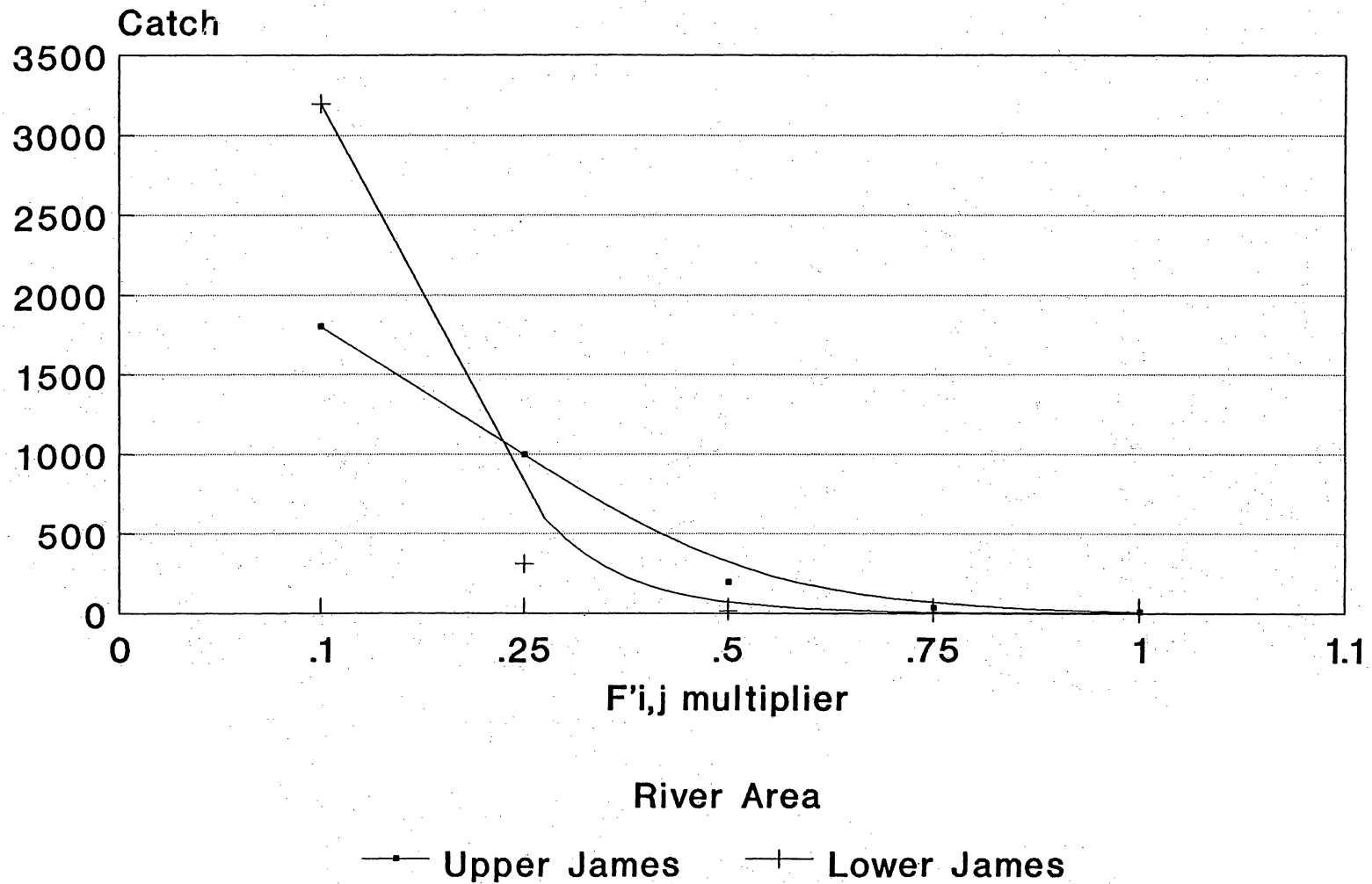


Fig. 12. Change in catch associated with a change in the $F'_{i,j}$ multiplier under no regulations, upper and lower James River, Virginia.

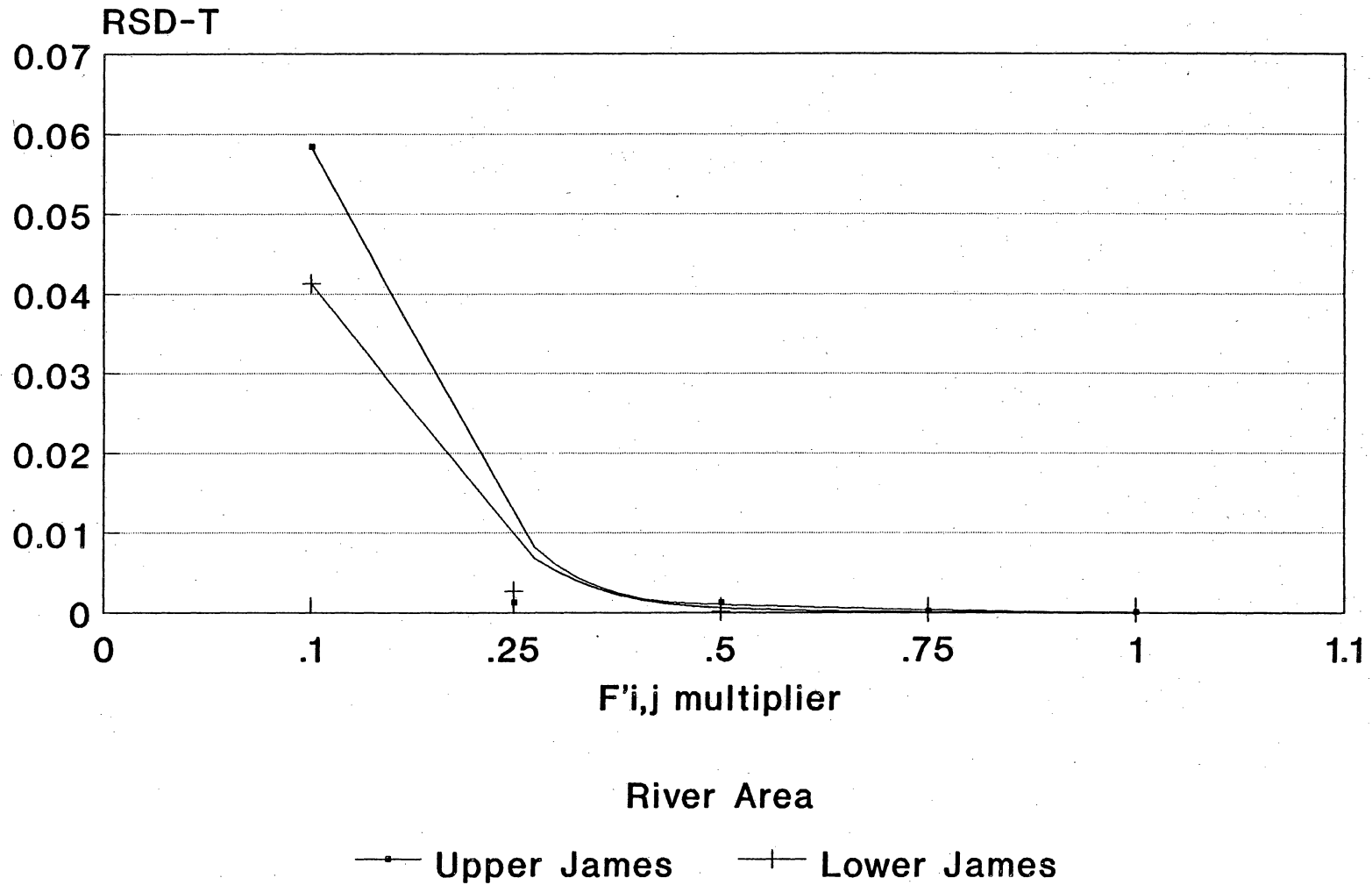


Fig. 13. Change in RSD-T associated with a change in the $F'_{i,j}$ multiplier under no regulations, upper and lower James River, Virginia.

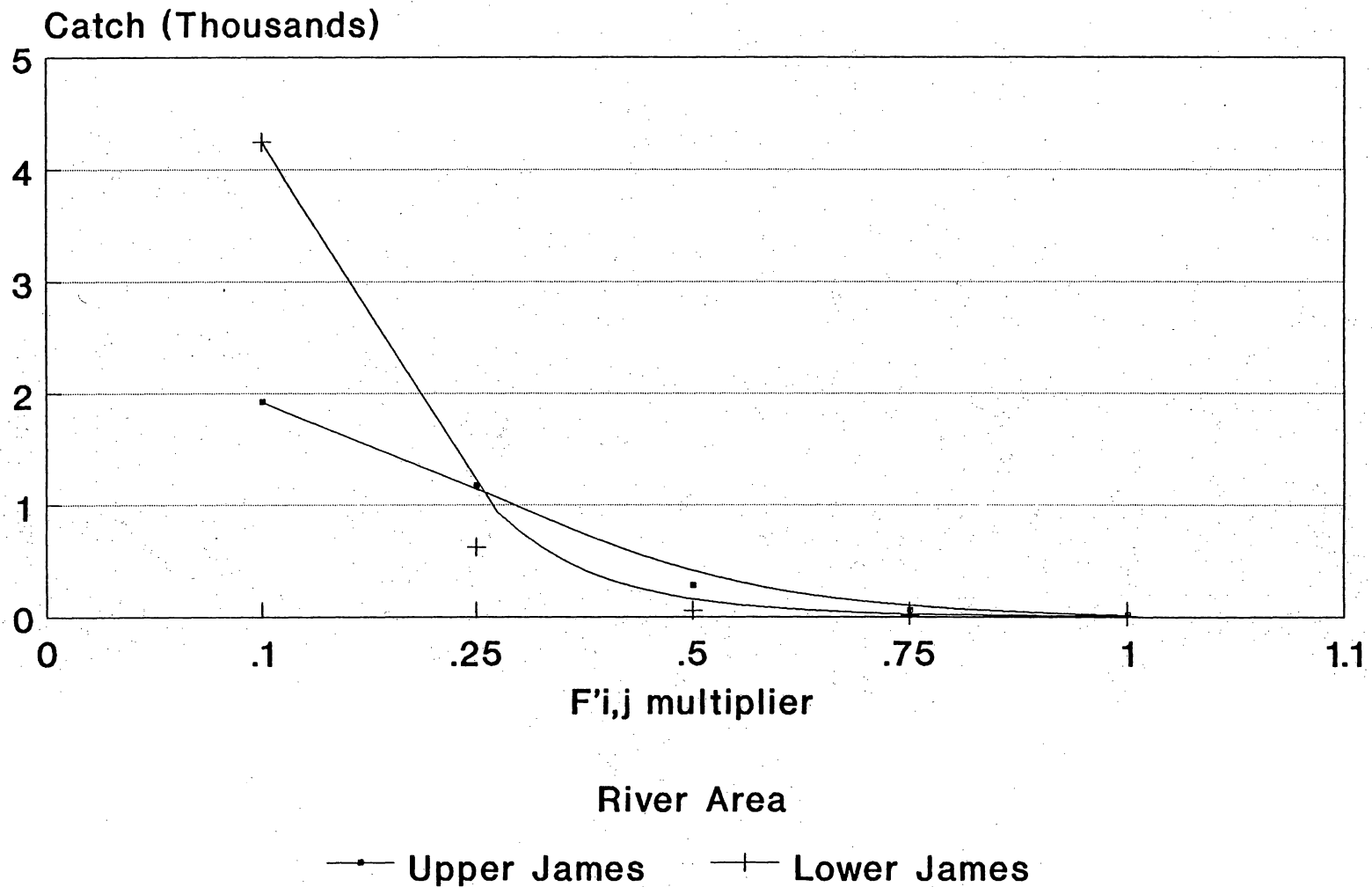


Fig. 14. Change in trophy catch associated with a change in the $F'_{i,j}$ multiplier under current regulations (280-356 mm slot length limit), upper and lower James River, Virginia.

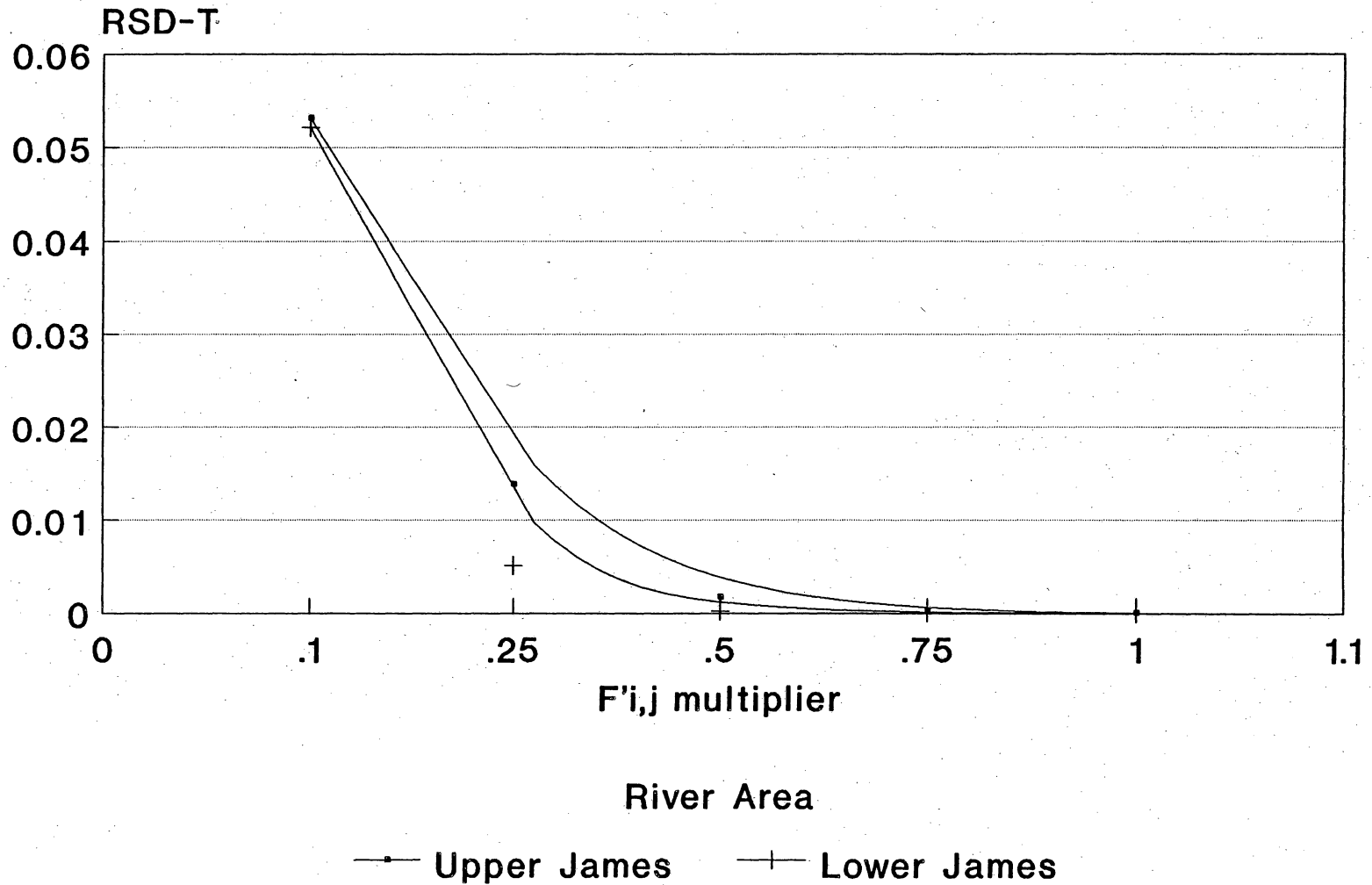


Fig. 15. Change in RSD-T associated with a change in the $F'_{i,j}$ multiplier under current regulations (280-356 mm slot length limit), upper and lower James River, Virginia.

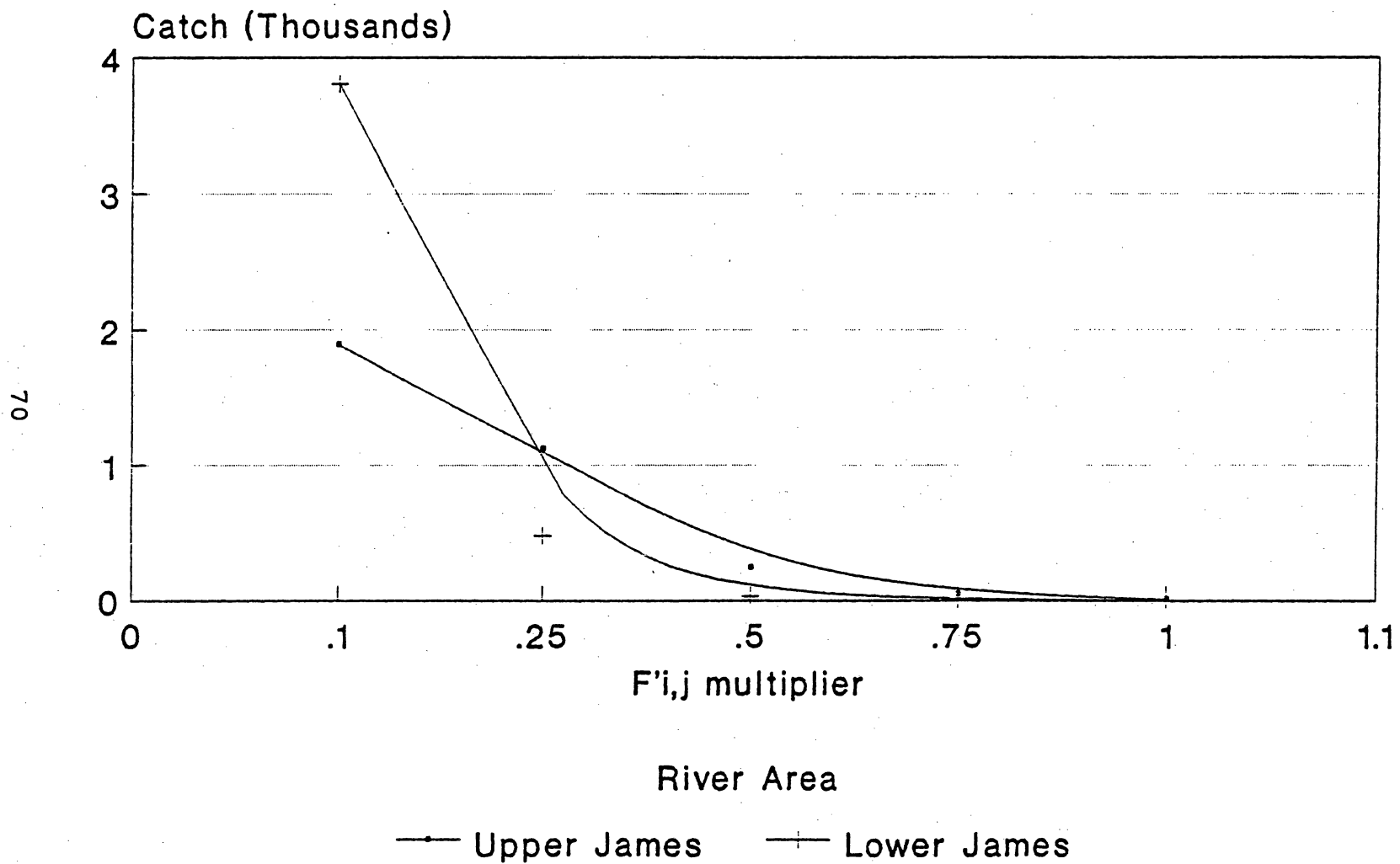


Fig. 16. Change in trophy catch associated with a change in the $F'_{i,j}$ multiplier under a 305-mm minimum length limit, upper and lower James River, Virginia.

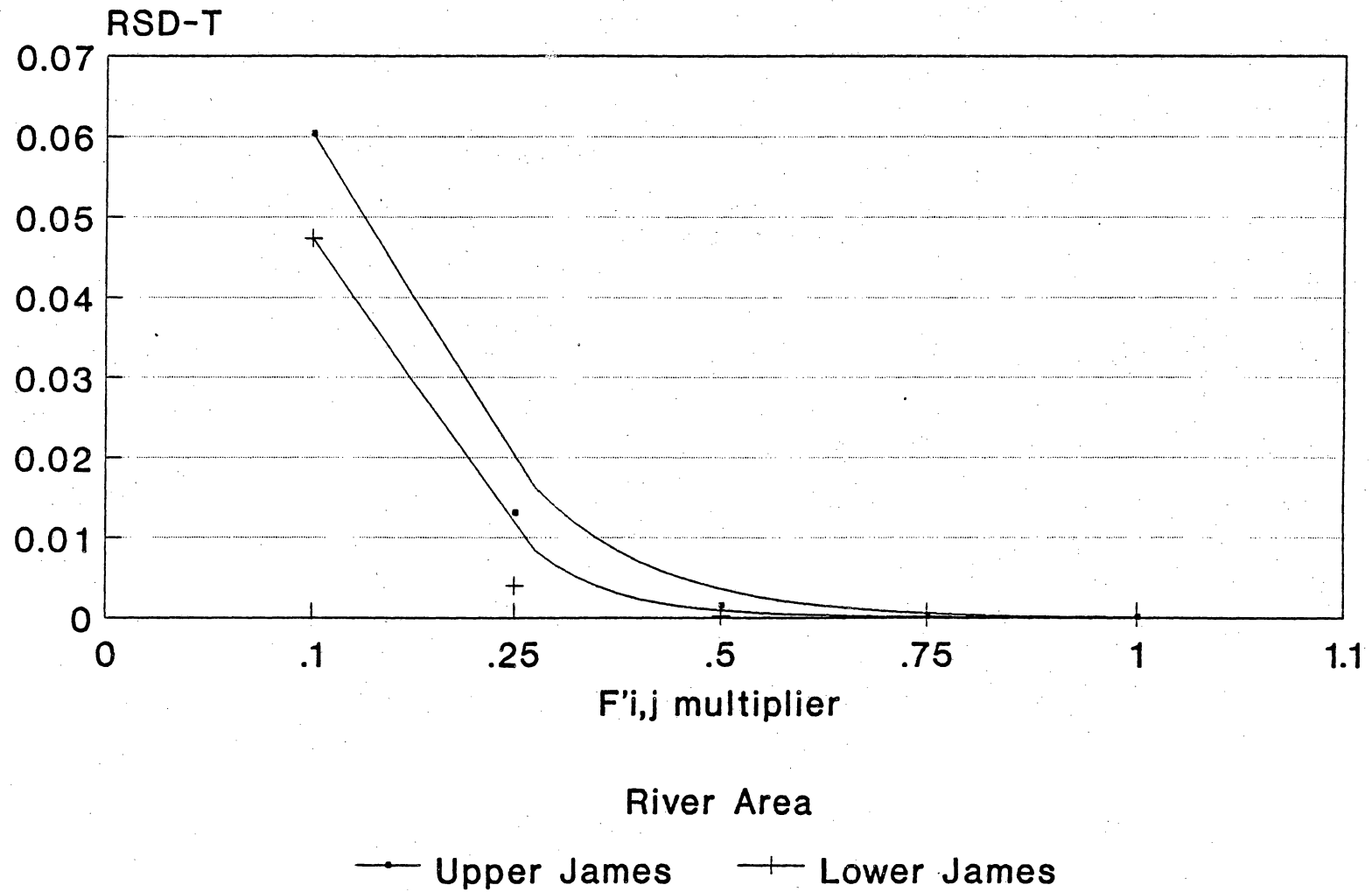


Fig. 17. Change in RSD-T associated with a change in the $F'_{i,j}$ multiplier under a 305-mm minimum length limit, upper and lower James River, Virginia.

APPENDIX A - PROGRAM LISTING

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PROGRAM MODEL(INPUT,OUTPUT,INFILE,LIST);
```

{A population model for simulating the effects of creel limits, length limits, and combinations of the two; angler non-compliance; and voluntary catch-and-release fishing. This program employs a differential equation approach, and partitions mortality into that due to natural causes, harvest, and the hooking mortality of released fish. The program allows for a maximum of 21 age groups, numbered from zero to 20. Density-dependent survival is allowed for the age 0 group only and is based on the Beverton - Holt stock/recruit function. All input parameters are stored in the file (INPUT) so that the same base data can be readily used for multiple simulations. The parameters in this file can be modified using any text processing program that can produce ASC-II text files. The results of the simulation are stored in the file (LISTING) and this file can be edited and imported into most spreadsheet programs for further analysis. This program was initially developed in PERSONAL PASCAL on an ATARI 1040-ST. It was then transferred and further modified in TURBO PASCAL on an IBM-PC AT. While we have tried to follow standard pascal procedures as much as possible, it is likely that some changes will be necessary before it will compile properly under implementations of pascal other than Borland's TURBO PASCAL under MS-DOS systems.}

```
CONST
```

```
INPFILE='INPUT';           {FILENAME OF INPUT DATA FILE}  
LISTFILE='LISTING';       {FILENAME OF RESULTS FILE}
```

```
TYPE
```

```
DISTRIBUTION= ARRAY[0..20] OF REAL;  
ARRAYDIST= ARRAY[0..20] OF ARRAY[0..1] OF REAL;  
ARRAY5= ARRAY[1..5] OF REAL;  
NORMDIST= ARRAY[0..72] OF REAL;
```

```
VAR
```

```
TITLE: STRING[80]; {TITLE OF REPORT}  
ANSWER: CHAR; {A Y/N RESPONSE TO A QUESTION}  
INFILE: TEXT; {INPUT FILE IDENTIFIER}  
LIST: TEXT; {RESULTS FILE IDENTIFIER}  
YEARS: INTEGER; {NUMBER OF YEARS TO RUN SIMULATION}  
I:INTEGER; {AGE GROUP-0 TO 20}  
J:INTEGER; {0= PREVIOUS YEAR, 1= CURRENT YEAR}  
N:ARRAYDIST; {# IN AGE GROUP I AT END OF YEAR J}  
F:DISTRIBUTION; {INSTANEOUS RATE OF FISHING MORTALITY FOR  
AGE GROUP I, REFLECTED AS A CATCH RATE}  
M:DISTRIBUTION; {INSTANEOUS RATE OF NATURAL MORTALITY FOR  
AGE GROUP I}  
H:DISTRIBUTION; {INSTANEOUS RATE OF HOOKING MORTALITY FOR  
AGE GROUP I}
```

```

NC:REAL; {RATE AT WHICH ANGLERS WILL NON-COMPLY WITH
REGULATIONS}
PR:DISTRIBUTION; {PROBABILITY OF RELEASING A FISH IN AGE
GROUP I BY COMPLYING ANGLERS}
NR:DISTRIBUTION; {PROBABILITY OF RELEASING A FISH IN AGE
GROUP I BY NON-COMPLYING ANGLERS}
PL:DISTRIBUTION; {PROBABILITY THAT A FISH OF AGE I IS
LEGAL}
SEX:DISTRIBUTION; {PROPORTION OF FEMALES IN AGE GROUP I}
MAT:DISTRIBUTION; {PROPORTION OF FEMALES THAT ARE MATURE
IN AGE GROUP I}
EC:DISTRIBUTION; {MEAN EGG CONTENT OF FEMALES IN AGE
GROUP I}
HATCH:REAL; {HATCHING RATE OF EGGS}
COEFA,
COEFB:REAL; {COEFFICIENTS FOR DENSITY-DEPENDENT FIRST
YEAR SURVIVAL}
X:INTEGER; {COUNTER FOR MAIN LOOP}
LGTHAGE:DISTRIBUTION; {LENGTH AT AGE DATA}
SDAGE:DISTRIBUTION; {STANDARD DEVIATION OF LENGTH AT AGE}
LENGTH:ARRAY5; {CUT-OFF FOR EACH LENGTH GROUP}
COELW:REAL; {COEFICIENT FROM L-W REGRESSION}
EXPLW:REAL; {EXPONENT FROM L-W REGRESSION}
CV:REAL; {COEF. OF VAR. IN YEAR CLASS STRENGTH}
NORMAL:NORMDIST; {RIGHT TAIL AREAS FOR INDEXED NORMAL
DISTRIBUTION}
TOTALN:REAL; {TOTAL POPULATION SIZE DURING GIVEN YEAR}
FPRIME:DISTRIBUTION; {ORIGINAL RATE OF FISHING MORTALITY
(F IS THE REALIZED RATE, WHICH IS MODIFIED
BY REGULATIONS)}
CR:REAL; {TEMP. VARIABLE USED IN CALCULATING CATCH}
TOTALC:REAL; {TOTAL CATCH}
TOTALCI:REAL; {TOTAL OF CATCH TIMES AGE (TO GET MEAN)}
L1,L2:REAL; {LENGTHS AT AGES BRACKETING MEAN}
LM:REAL; {INTERPOLATED MEAN LENGTH}

```

```

{*****}

```

```

PROCEDURE NORMSET(
  VAR NORMAL:NORMDIST {RIGHT TAIL AREAS FOR INDEXED NORMAL
DISTRIBUTION}
);

```

```

{THIS PROCEDURE FILLS AN ARRAY CALLED NORMAL WHICH CONTAINS
RIGHT TAIL AREAS FOR A STANDARD NORMAL CURVE. THE INDEX IS
ACHIEVED BY MULTIPLYING THE Z-SCORE BY 10, TRUNCATING IT, AND
ADDING 36 (ALL RESULTING VALUES LESS THAN 0 ARE SET TO ZERO,
ALL GREATER THAN 72 ARE SET TO 72)}

```

```

BEGIN{NORMSET}
  NORMAL[0]:=1;

```

NORMAL[1]:=0.9998; {CORRESPONDS TO A Z-SCORE OF -3.5}
 NORMAL[2]:=0.9997;
 NORMAL[3]:=0.9995;
 NORMAL[4]:=0.9993;
 NORMAL[5]:=0.999;
 NORMAL[6]:=0.9987; {CORRESPONDS TO A Z-SCORE OF -3.0}
 NORMAL[7]:=0.9981;
 NORMAL[8]:=0.9974;
 NORMAL[9]:=0.9965;
 NORMAL[10]:=0.9953;
 NORMAL[11]:=0.9938; {CORRESPONDS TO A Z-SCORE OF -2.5}
 NORMAL[12]:=0.9918;
 NORMAL[13]:=0.9893;
 NORMAL[14]:=0.9861;
 NORMAL[15]:=0.9821;
 NORMAL[16]:=0.9772; {CORRESPONDS TO A Z-SCORE OF -2.0}
 NORMAL[17]:=0.9713;
 NORMAL[18]:=0.9641;
 NORMAL[19]:=0.9554;
 NORMAL[20]:=0.9452;
 NORMAL[21]:=0.9332; {CORRESPONDS TO A Z-SCORE OF -1.5}
 NORMAL[22]:=0.9192;
 NORMAL[23]:=0.9032;
 NORMAL[24]:=0.8849;
 NORMAL[25]:=0.8643;
 NORMAL[26]:=0.8413; {CORRESPONDS TO A Z-SCORE OF -1.0}
 NORMAL[27]:=0.8159;
 NORMAL[28]:=0.7881;
 NORMAL[29]:=0.758;
 NORMAL[30]:=0.7257;
 NORMAL[31]:=0.6915; {CORRESPONDS TO A Z-SCORE OF -0.5}
 NORMAL[32]:=0.6554;
 NORMAL[33]:=0.6179;
 NORMAL[34]:=0.5793;
 NORMAL[35]:=0.5398;
 NORMAL[36]:=0.5; {CORRESPONDS TO A Z-SCORE OF 0}
 NORMAL[37]:=0.4602;
 NORMAL[38]:=0.4207;
 NORMAL[39]:=0.3821;
 NORMAL[40]:=0.3446;
 NORMAL[41]:=0.3085; {CORRESPONDS TO A Z-SCORE OF 0.5}
 NORMAL[42]:=0.2743;
 NORMAL[43]:=0.242;
 NORMAL[44]:=0.2119;
 NORMAL[45]:=0.1841;
 NORMAL[46]:=0.1587; {CORRESPONDS TO A Z-SCORE OF 1.0}
 NORMAL[47]:=0.1357;
 NORMAL[48]:=0.1151;
 NORMAL[49]:=0.0968;
 NORMAL[50]:=0.0808;
 NORMAL[51]:=0.0668; {CORRESPONDS TO A Z-SCORE OF 1.5}

```

NORMAL[52]:=0.0548;
NORMAL[53]:=0.0446;
NORMAL[54]:=0.0359;
NORMAL[55]:=0.0287;
NORMAL[56]:=0.0228; {CORRESPONDS TO A Z-SCORE OF 2.0}
NORMAL[57]:=0.0179;
NORMAL[58]:=0.0139;
NORMAL[59]:=0.0107;
NORMAL[60]:=0.0082;
NORMAL[61]:=0.0062; {CORRESPONDS TO A Z-SCORE OF 2.5}
NORMAL[62]:=0.0047;
NORMAL[63]:=0.0035;
NORMAL[64]:=0.0026;
NORMAL[65]:=0.0019;
NORMAL[66]:=0.0013; {CORRESPONDS TO A Z-SCORE OF 3.0}
NORMAL[67]:=0.001;
NORMAL[68]:=0.0007;
NORMAL[69]:=0.0005;
NORMAL[70]:=0.0003;
NORMAL[71]:=0.0002; {CORRESPONDS TO A Z-SCORE OF 3.5}
NORMAL[72]:=0;
END; {NORMSET}

```

```
{*****}
```

```

PROCEDURE READDATA(
  VAR INFILE: TEXT; {INPUT DATA FILE IDENTIFIER}
  VAR N:ARRAYDIST; {# IN AGE GROUP I AT END OF YEAR J}
  VAR F:DISTRIBUTION; {INSTANEOUS RATE OF FISHING MORTALITY
    FOR AGE GROUP I, REFLECTED AS THE
    CATCH RATE}
  VAR M:DISTRIBUTION; {INSTANEOUS RATE OF NATURAL MORTALITY
    FOR AGE GROUP I}
  VAR H:DISTRIBUTION; {INSTANEOUS RATE OF HOOKING MORTALITY
    FOR AGE GROUP I}
  VAR PR:DISTRIBUTION; {PROBABILITY OF RELEASE FOR FISH IN
    AGE GROUP I BY COMPLYING ANGLERS}
  VAR NR:DISTRIBUTION; {PROBABILITY OF RELEASING A FISH IN
    AGE GROUP I FOR NON-COMPLYING
    ANGLERS}
  VAR SEX:DISTRIBUTION; {PROPORTION OF FEMALES IN AGE
    GROUP I}
  VAR MAT:DISTRIBUTION; {PROPORTION OF FEMALES THAT ARE
    MATURE IN AGE GROUP I}
  VAR EC:DISTRIBUTION; {MEAN EGG CONTENT OF FEMALES IN AGE
    GROUP I}
  VAR HATCH:REAL; {HATCHING RATE OF EGGS}
  VAR COEFA:REAL;
  VAR COEFB:REAL; {COEFFICIENTS FOR DENSITY-DEPENDENT
    FIRST YEAR SURVIVAL}
  VAR LGTHAGE:DISTRIBUTION; {LENGTH AT AGE DATA}

```

```

VAR SDAGE:DISTRIBUTION; {STANDARD DEVIATION OF LENGTH
                        AT AGE}
VAR LENGTH:ARRAY5; {CUT-OFF FOR EACH LENGTH GROUP}
VAR COELW:REAL; {COEFFICIENT FROM L-W REGRESSION}
VAR EXPLW:REAL; {EXPONENT FROM L-W REGRESSION}
VAR CV:REAL {COEF. OF VAR. IN YEAR CLASS STRENGTH}
);

```

{THIS PROCEDURE READS IN DATA FROM AN EXISTING ASC-II DATA FILE. IT ASSUMES THAT THE DATA IS IN THE APPROPRIATE FORMAT AND ORDER TO RESEMBLE A DATA FILE PRODUCED BY THIS PROGRAM. THIS PROCEDURE IS PROVIDED TO ALLOW THE USE OF PREVIOUSLY CREATED DATA FILES WHICH MAY BE MODIFIED USING ANY TEXT PROCESSING PROGRAM WHICH PRODUCES ASC-II FORMAT OUTPUT FILES. THE DATA MUST BE CONTAINED IN A FILE CALLED 'INPUT' (NOTE THAT THERE IS NO FILE TYPE)}

```

VAR
  I:INTEGER; {AGE GROUP-0 TO 20}
  DUMMY: REAL;

```

```

BEGIN {READDATA}
  RESET(INFILE);
  READ(INFILE,HATCH);
  READ(INFILE,COEFA);
  READ(INFILE,COEFB);
  FOR I:=0 TO 20 DO
  BEGIN{FOR}
    READ(INFILE,SEX[I]);
  END;{FOR}
  FOR I:=0 TO 20 DO
  BEGIN{FOR}
    READ(INFILE,MAT[I]);
  END;{FOR}
  FOR I:=0 TO 20 DO
  BEGIN{FOR}
    READ(INFILE,EC[I]);
  END;{FOR}
  FOR I:=0 TO 20 DO
  BEGIN{FOR}
    READ(INFILE,F[I]);
  END;{FOR}
  FOR I:=0 TO 20 DO
  BEGIN{FOR}
    READ(INFILE,M[I]);
  END;{FOR}
  FOR I:=0 TO 20 DO
  BEGIN{FOR}
    READ(INFILE,H[I]);
  END;{FOR}
  FOR I:=0 TO 20 DO

```

```

BEGIN{FOR}
    READ(INFILE,PR[I]);
END;{FOR}
FOR I:=0 TO 20 DO
BEGIN{FOR}
    READ(INFILE,NR[I]);
END;{FOR}
FOR I:=0 TO 20 DO
BEGIN{FOR}
    READ(INFILE,LGTHAGE[I]);
END;{FOR}
FOR I:=0 TO 20 DO
BEGIN{FOR}
    READ(INFILE,SDAGE[I]);
END;{FOR}
READ(INFILE,LENGTH[1]);
READ(INFILE,LENGTH[2]);
READ(INFILE,LENGTH[3]);
READ(INFILE,LENGTH[4]);
READ(INFILE,LENGTH[5]);
READ(INFILE,COELW);
READ(INFILE,EXPLW);
FOR I:=0 TO 20 DO
BEGIN{FOR}
    READ(INFILE,N[I,0]);
END;{FOR}
READ(INFILE,CV);
END; {READDATA}

```

{*****}

```

PROCEDURE ENTERDATA(
    VAR INFILE: TEXT; {INPUT DATA FILE IDENTIFIER}
    VAR N:ARRAYDIST; {# IN AGE GROUP I AT END OF YEAR J}
    VAR F:DISTRIBUTION; {INSTANEOUS RATE OF FISHING MORTALITY
        FOR AGE GROUP I, REFLECTED AS THE
        CATCH RATE}
    VAR M:DISTRIBUTION; {INSTANEOUS RATE OF NATURAL MORTALITY
        FOR AGE GROUP I}
    VAR H:DISTRIBUTION; {INSTANEOUS RATE OF HOOKING MORTALITY
        FOR AGE GROUP I}
    VAR PR:DISTRIBUTION; {PROBABILITY OF RELEASING A FISH IN
        AGE GROUP I BY COMPLYING ANGLES}
    VAR NR:DISTRIBUTION; {PROBABILITY OF RELEASING A FISH IN
        AGE GROUP I BY NON-COMPLYING ANGLERS}
    VAR SEX:DISTRIBUTION; {PROPORTION OF FEMALES IN AGE
        GROUP I}
    VAR MAT:DISTRIBUTION; {PROPORTION OF FEMALES THAT ARE
        MATURE IN AGE GROUP I}
    VAR EC:DISTRIBUTION; {MEAN EGG CONTENT OF FEMALES IN AGE
        GROUP I}

```

```

VAR HATCH:REAL; {HATCHING RATE OF EGGS}
VAR COEFA:REAL;
VAR COEFB:REAL; {COEFFICIENTS FOR DENSITY-DEPENDENT
                FIRST YEAR SURVIVAL}
VAR LGTHAGE:DISTRIBUTION; {LENGTH AT AGE DATA}
VAR SDAGE:DISTRIBUTION; {STANDARD DEVIATION OF LENGTH
                        AT AGE}
VAR LENGTH:ARRAY5; {CUT-OFF FOR EACH LENGTH GROUP}
VAR COELW:REAL; {COEFFICIENT FROM L-W REGRESSION}
VAR EXPLW:REAL; {EXPONENT FROM L-W REGRESSION}
VAR CV:REAL {COEF. OF VAR. IN YEAR CLASS STRENGTH}
);

```

{THIS PROCEDURE READS IN DATA FROM THE KEYBOARD AND CREATES AN ASC-II DATA FILE CALLED 'INPUT' (NOTE THAT THERE IS NO FILE TYPE). THIS DATA FILE MAY LATER BE MODIFIED USING ANY TEXT PROCESSING PROGRAM WHICH PRODUCES ASC-II FORMAT OUTPUT FILES.}

```

VAR
    I:INTEGER; {AGE GROUP-0 TO 20}

BEGIN {ENTERDATA}
    REWRITE(INFILE);
    WRITELN('ENTER RATE OF HATCHING SUCCESS-');
    READLN(HATCH);
    WRITELN(INFILE,HATCH);
    WRITELN('ENTER A COEF. OF DENSITY-DEP. 1ST-YR.
SURVIVAL-');
    READLN(COEFA);
    WRITELN(INFILE,COEFA);
    WRITELN('ENTER B COEF. OF DENSITY-DEP. 1ST-YR.
SURVIVAL-');
    READLN(COEFB);
    WRITELN(INFILE,COEFB);
    WRITELN(INFILE);
    FOR I:=0 TO 20 DO
        BEGIN{FOR}
            WRITELN('ENTER PROPORTION OF FEMALES IN AGE GROUP
                    ',I);
            READLN(SEX[I]);
            WRITELN(INFILE,SEX[I]);
        END;{FOR}
    WRITELN(INFILE);
    FOR I:=0 TO 20 DO
        BEGIN{FOR}
            WRITELN('ENTER PROP. OF FEM. MATURE IN AGE GROUP
                    ',I);
            READLN(MAT[I]);
            WRITELN(INFILE,MAT[I]);
        END;{FOR}

```

```

WRITELN(INFILE);
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN('ENTER MEAN EGG CONTENT OF FEMALES AGE ',I);
    READLN(EC[I]);
    WRITELN(INFILE,EC[I]);
END;{FOR}
WRITELN(INFILE);
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN('ENTER INST. RATE OF FISHING MORT. FOR AGE
            ',I);
    WRITELN('ANSWER SHOULD REFLECT THE INSTANTANEOUS
            CATCH RATE');
    READLN(F[I]);
    WRITELN(INFILE,F[I]);
END;{FOR}
WRITELN(INFILE);
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN('ENTER INST. RATE OF NATURAL MORT. FOR AGE
            ',I);
    READLN(M[I]);
    WRITELN(INFILE,M[I]);
END;{FOR}
WRITELN(INFILE);
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN('ENTER INST. RATE OF HOOKING MORT. FOR AGE
            ',I);
    READLN(H[I]);
    WRITELN(INFILE,H[I]);
END;{FOR}
WRITELN(INFILE);
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN('WHAT IS THE PROBABILITY THAT A COMPLYING');
    WRITELN('ANGLER WILL RELEASE A FISH IN AGE GROUP
            ',I);
    READLN(PR[I]);
    WRITELN (INFILE,PR[I]);
END;{FOR}
WRITELN(INFILE);
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN('WHAT IS THE PROBABILITY THAT A
            NON-COMPLYING ANGLER');
    WRITELN('WILL RELEASE A FISH IN AGE GROUP ',I);
    READLN(NR[I]);
    WRITELN (INFILE,NR[I]);
END;{FOR}

```

```

WRITELN(INFILE);
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN('ENTER MEAN LENGTH AT AGE ',I);
    READLN(LGTHAGE[I]);
    WRITELN(INFILE, LGTHAGE[I]);
END;{FOR}
WRITELN(INFILE);
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN('ENTER STANDARD DEVIATION OF LENGTH AT AGE
            ',I);
    READLN(SDAGE[I]);
    WRITELN(INFILE, SDAGE[I]);
END;{FOR}
WRITELN(INFILE);
WRITELN('ENTER STOCK SIZE');
READLN(LENGTH[1]);
WRITELN(INFILE, LENGTH[1]);
WRITELN('ENTER QUALITY SIZE');
READLN(LENGTH[2]);
WRITELN(INFILE, LENGTH[2]);
WRITELN('ENTER PREFERRED SIZE');
READLN(LENGTH[3]);
WRITELN(INFILE, LENGTH[3]);
WRITELN('ENTER MEMORABLE SIZE');
READLN(LENGTH[4]);
WRITELN(INFILE, LENGTH[4]);
WRITELN('ENTER TROPHY SIZE');
READLN(LENGTH[5]);
WRITELN(INFILE, LENGTH[5]);
WRITELN(INFILE);
WRITELN('ENTER COEFFICIENT FOR L-W REGRESSION');
READLN(COELW);
WRITELN(INFILE, COELW);
WRITELN('ENTER EXPONENT FOR L-W REGRESSION');
READLN(EXPLW);
WRITELN(INFILE, EXPLW);
WRITELN(INFILE);
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN('ENTER INITIAL # IN AGE GROUP ',I);
    READLN(N[I,0]);
    WRITELN(INFILE, N[I,0]);
END;{FOR}
WRITELN(INFILE);
WRITELN('ENTER C.V. FOR YEAR CLASS STRENGTH');
READLN(CV);
WRITELN(INFILE, CV);
WRITELN(INFILE);
END; {ENTERDATA}

```

{*****}

```
PROCEDURE PRNTDATA(  
  VAR LIST:TEXT; {RESULTS FILE IDENTIFIER*}  
  VAR N:ARRAYDIST; {# IN AGE GROUP I AT END OF YEAR J}  
  VAR F:DISTRIBUTION; {INSTANEOUS RATE OF FISHING MORTALITY  
    FOR AGE GROUP I, REFLECTED AS THE  
    CATCH RATE}  
  VAR M:DISTRIBUTION; {INSTANEOUS RATE OF NATURAL MORTALITY  
    FOR AGE GROUP I}  
  VAR H:DISTRIBUTION; {INSTANEOUS RATE OF HOOKING MORTALITY  
    FOR AGE GROUP I}  
  VAR PR:DISTRIBUTION; {PROBABILITY OF RELEASING A FISH IN  
    AGE GROUP I BY COMPLYING ANGLERS}  
  VAR NR:DISTRIBUTION; {PROBABILITY OF RELEASING A FISH IN  
    AGE GROUP I BY NON-COMPLYING ANGLERS}  
  VAR SEX:DISTRIBUTION; {PROPORTION OF FEMALES IN AGE  
    GROUP I}  
  VAR MAT:DISTRIBUTION; {PROPORTION OF FEMALES THAT ARE  
    MATURE IN AGE GROUP I}  
  VAR EC:DISTRIBUTION; {MEAN EGG CONTENT OF FEMALES IN AGE  
    GROUP I}  
  VAR HATCH:REAL; {HATCHING RATE OF EGGS}  
  VAR COEFA:REAL;  
  VAR COEFB:REAL; {COEFFICIENTS FOR DENSITY-DEPENDENT FIRST  
    YEAR SURVIVAL}  
  VAR LGTHAGE:DISTRIBUTION; {LENGTH AT AGE DATA}  
  VAR SDAGE:DISTRIBUTION; {STANDARD DEVIATION OF LENGTH  
    AT AGE}  
  VAR LENGTH:ARRAY5; {CUT-OFF FOR EACH LENGTH GROUP}  
  VAR COELW:REAL; {COEFFICIENT FROM L-W REGRESSION}  
  VAR EXPLW:REAL; {EXPONENT FROM L-W REGRESSION}  
  VAR CV:REAL {COEF. OF VAR. IN YEAR CLASS STRENGTH}  
);
```

{THIS PROCEDURE LABELS AND OUTPUTS ALL INITIAL DATA (IE. THAT
ATTAINED IN THE READDATA OR ENTERDATA PROCEDURES). THIS DATA
IS THEN INCLUDED AT THE BEGINNING OF THE FILE 'LISTING',
WHICH WILL CONTAIN ALL OF THE OUTPUT FROM THE PROGRAM}

```
VAR  
  I:INTEGER; {AGE GROUP-0 TO 20}  
  J:INTEGER; {YEAR- 0 TO 50}  
  DUMMY: REAL;
```

```
BEGIN {PRNTDATA}  
  WRITELN(LIST);  
  WRITELN(LIST, 'HATCHING SUCCESS RATE=', HATCH);  
  WRITELN(LIST);  
  WRITELN(LIST, 'COEFFICIENTS FOR DENSITY-DEP. 1ST YR.  
    SURVIVAL');
```

```

WRITELN(LIST, 'COEFA=', COEFA, ' COEFB=', COEFB);
WRITELN(LIST);
WRITELN(LIST, 'AGE SPECIFIC SEX RATIOS');
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN(LIST, 'AGE=', I, ' SEX RATIO=', SEX[I]);
END;{FOR}
WRITELN(LIST);
WRITELN(LIST, 'AGE SPECIFIC MATURITY RATES');
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN(LIST, 'AGE=', I, ' MATURITY=', MAT[I]);
END;{FOR}
WRITELN(LIST);
WRITELN(LIST, 'EGG CONTENT OF FEMALES BY AGE');
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN(LIST, 'AGE=', I, ' EGG CONTENT=', EC[I]);
END;{FOR}
WRITELN(LIST);
WRITELN(LIST, 'FISHING MORTALITY RATES BY AGE');
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN(LIST, 'AGE=', I, ' F=', F[I]);
END;{FOR}
WRITELN(LIST);
WRITELN(LIST, 'NATURAL MORTALITY BY AGE');
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN(LIST, 'AGE=', I, ' M=', M[I]);
END;{FOR}
WRITELN(LIST);
WRITELN(LIST, 'HOOKING MORTALITY BY AGE');
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN(LIST, 'AGE=', I, ' H=', H[I]);
END;{FOR}
WRITELN(LIST);
WRITELN(LIST, 'RELEASE PROBABILITY BY AGE CLASS,
    COMPLYING ANGLERS');
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN(LIST, 'AGE=', I, ' PROB=', PR[I]);
END;{FOR}
WRITELN(LIST);
WRITELN(LIST, 'RELEASE PROBABILITY BY AGE CLASS,
    NON-COMPLYING ANGLERS');
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN(LIST, 'AGE=', I, ' PROB=', NR[I]);
END;{FOR}

```

```

WRITELN(LIST);
WRITELN(LIST,'INITIAL NUMBERS BY AGE CLASS');
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN(LIST,N[I,0]);
END;{FOR}
WRITELN(LIST);
WRITELN(LIST,'MEAN LENGTH AT AGE');
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN(LIST,LGTHAGE[I]);
END;{FOR}
WRITELN(LIST);
WRITELN(LIST,'STANDARD DEVIATION OF LENGTH AT AGE');
FOR I:=0 TO 20 DO
BEGIN{FOR}
    WRITELN(LIST,SDAGE[I]);
END;{FOR}
WRITELN(LIST);
WRITELN(LIST,'PSD CUTOFF POINTS');
WRITELN(LIST,'    STOCK SIZE=    ',LENGTH[1]);
WRITELN(LIST,'    QUALITY SIZE=    ',LENGTH[2]);
WRITELN(LIST,'    PREFERRED SIZE=    ',LENGTH[3]);
WRITELN(LIST,'    MEMORABLE SIZE=    ',LENGTH[4]);
WRITELN(LIST,'    TROPHY SIZE=    ',LENGTH[5]);
WRITELN(LIST);
WRITELN(LIST,'COEFFICIENTS FROM L-W REGRESSION');
WRITELN(LIST,'COELW= ',COELW,' EXPLW= ',EXPLW);
WRITELN(LIST);
WRITELN(LIST,'C.V. OF YEAR CLASS STRENGTH = ',CV);
WRITELN(LIST);
END; {PRNTDATA}

```

{*****}

```

PROCEDURE REGS(
    VAR LIST:TEXT; {OUTPUT FILE}
    VAR F:DISTRIBUTION; {INSTANEOUS RATE OF FISHING MORTALITY
        FOR AGE GROUP I, REFLECTED AS THE
        CATCH RATE}
    VAR FPRIME:DISTRIBUTION; {CATCH RATE OR REALIZED FISHING
        MORTALITY RATE FOR AGE GROUP I}
    VAR H:DISTRIBUTION; {INSTANEOUS RATE OF HOOKING MORTALITY
        FOR AGE GROUP I}
    VAR NC:REAL; {RATE AT WHICH ANGLERS WOULD NON-COMPLY WITH
        REGULATIONS}
    VAR PR:DISTRIBUTION; {PROBABILITY OF RELEASING A FISH IN
        AGE GROUP I BY COMPLYING ANGLERS}
    VAR NR:DISTRIBUTION; {PROBABILITY OF RELEASING A FISH IN
        AGE GROUP I BY NON-COMPLYING ANGLERS}
    VAR PL:DISTRIBUTION; {PROBABILITY THAT A FISH OF AGE I IS

```

```

                                LEGAL}
NORMAL:NORMDIST {RIGHT TAIL AREAS FOR STD. NORMAL}
);

{THIS PROCEDURE PROVIDES FOR IMPOSING EITHER LENGTH OR CREEL
LIMIT REGULATIONS ON THE FISHERY, AND PERFORMS THE NECESSARY
MODIFICATIONS TO THE RATES OF FISHING AND HOOKING MORTALITY.
ANGLER NON-COMPLIANCE AND VOLUNTARY CATCH-AND-RELEASE FISHING
ARE FACTORED IN AS WELL.}

VAR
    REDUCTION:REAL; {REDUCTION IN HARVEST DUE TO CREEL LIMIT}
    REDUCE:DISTRIBUTION; {REDUCTIONS DUE TO LENGTH LIMIT}
    ANSWER:CHAR;
    I:INTEGER;

{-----}

PROCEDURE CREELLIMIT(
    VAR LIST:TEXT; {OUTPUT FILE}
    VAR REDUCTION:REAL {REDUCTION IN HARVEST DUE TO CREEL
                        LIMIT}
);

{THIS PROCEDURE CALCULATES THE PORTION OF PREVIOUS HARVEST
MAINTAINED UNDER A CREEL LIMIT BASED ON A NEGATIVE BINOMIAL
DISTRIBUTION WITH USER-DEFINED PARAMETERS MEAN AND K, OR
ALLOWS DIRECT INPUT OF ESTIMATED PORTION MAINTAINED.
REDCUTION IN HARVEST IS ASSUMED TO BE CONSTANT ACROSS ALL AGE
GROUPS.}

VAR I,J: INTEGER; {LOOP INDEXES}
    LIMIT:INTEGER; {CREEL LIMIT}
    ALPHA,TOP,BOTTOM,LEFT,RIGHT,TOPTERM,BOTTOMTERM,SUM: REAL;
        {USED IN CALCULATING THE NEGATIVE
        BINOMIAL DIST'N PROBABILITIES.}
    MEAN,KHAT:REAL; {PARAMETERS OF THE NEGATIVE BINOMIAL}
    NEWDISTF:DISTRIBUTION; {N. B. DIST'N PROBABILITIES}
    ANSWER: CHAR; {RESPONSE TO Y/N QUESTIONS}

BEGIN {CREELLIMIT}
    WRITELN('WHAT DO YOU WISH THE NEW CREEL LIMIT TO BE?');
    WRITELN('PLEASE SPECIFY AS MAX. NUMBER OF
            FISH/ANGLER/DAY');
    WRITELN('NOTE THAT THE ANSWER MUST BE A POSITIVE
            INTEGER');
    REPEAT
        READLN(LIMIT);
    UNTIL NOT (LIMIT < 0);
    WRITELN(LIST);
    WRITELN(LIST, 'CREEL LIMIT = ',LIMIT);

```

```

WRITELN('DO YOU WISH TO USE A NEGATIVE BINOMIAL
        DIST.?Y/N');
WRITELN('OTHERWISE YOU MUST ESTIMATE THE REDUCTION.');
```

READLN(ANSWER);

```

IF (ANSWER = 'Y') OR (ANSWER = 'y') THEN
BEGIN{THEN}
  WRITELN('ENTER THE MEAN HARVEST/ANGLER/DAY -');
  READLN(MEAN);
  WRITELN('AND THE ESTIMATED K PARAMETER -');
  READLN(KHAT);
  WRITELN(LIST, 'BASED ON A NEGATIVE BINOMIAL WITH');
  WRITELN(LIST, '      MEAN=', MEAN, ' AND K=', KHAT);
  LEFT:=EXP(-KHAT*LN(1+(MEAN/KHAT)));
  SUM:=0;
  FOR I:=1 TO 20 DO
  BEGIN {FOR}
    ALPHA:=KHAT+I-1;
    TOP:=1;
    TOPTERM:=ALPHA;
    REPEAT
      TOP:=TOP*TOPTERM;
      TOPTERM:=TOPTERM-1;
    UNTIL TOPTERM < (ALPHA-I+1);
    BOTTOM:=1;
    BOTTOMTERM:=1;
    REPEAT
      BOTTOM:=BOTTOM*BOTTOMTERM;
      BOTTOMTERM:=BOTTOMTERM+1;
    UNTIL BOTTOMTERM > I;
    RIGHT:=1;
    FOR J:=1 TO I DO
      RIGHT:=RIGHT*(MEAN/(MEAN+KHAT));
    NEWDISTF[I]:=LEFT*(TOP/BOTTOM)*RIGHT;
    SUM:=SUM+NEWDISTF[I];
  END; {FOR}
  NEWDISTF[0]:=1-SUM;
  REDUCTION:=0;
  FOR I:=0 TO LIMIT DO
  BEGIN{FOR}
    {CALCULATE THE PORTION OF THE OLD AVERAGE CATCH
     PER ANGLER PER DAY CONTRIBUTED BY ANGLERS
     CATCHING LESS THAN THE LIMIT.}
    REDUCTION:=REDUCTION+(NEWDISTF[I]*I);
  END; {FOR}
  FOR I:= LIMIT+1 TO 20 DO
  BEGIN{FOR}
    {CALCULATE THE PORTION CONTRIBUTED TO THE NEW
     AVERAGE BY ANGLERS THAT ARE CONSTRAINED BY THE
     LIMIT.}
    REDUCTION:=REDUCTION+(NEWDISTF[I]*(LIMIT));
  END; {FOR}

```

```

      {DIVIDE BY MEAN TO PUT ON A SCALE OF ZERO TO ONE.
      NOTE THAT IF LIMIT IS SET TO ZERO IN THE ABOVE
      EQUATION, AND IT IS SUMMED OVER THE ENTIRE RANGE,
      THAT THE RESULT WILL BE EQUAL TO THE MEAN.}
      {THE RESULT IS THE PROBABILITY THAT ANY GIVEN FISH
      WILL NOT BE PROTECTED BY THE LIMIT.}
      REDUCTION:=REDUCTION/MEAN;
      WRITE(LIST,'THE ESTIMATED NEW HARVEST IS ');
      WRITELN(LIST,REDUCTION,' TIMES THE PREVIOUS
      HARVEST. ');
      WRITELN(LIST);
    END {THEN}
  ELSE
  BEGIN{ELSE}
    WRITE('PLEASE ENTER YOUR ESTIMATE OF THE
    REDUCTION');
    WRITELN(' IN HARVEST -');
    WRITELN('( NEW HARVEST WILL BE ? TIMES OLD
    HARVEST) ');
    READLN(REDUCTION);
    WRITE(LIST,'YOU ESTIMATED REDUCTION IN HARVEST
    OF ');
    WRITELN(LIST,REDUCTION,' TIMES THE PREVIOUS
    HARVEST. ');
    WRITELN(LIST);
  END; {ELSE}
END; {CREELLIMIT}

```

{-----}

```

PROCEDURE LENGTHLIMIT(
  VAR LIST:TEXT; {OUTPUT FILE}
  VAR REDUCE:DISTRIBUTION;{REDUCTIONS IN HARVEST DUE TO
  LENGTH LIMIT}
  NORMAL:NORMDIST {RIGHT TAIL AREAS FOR STD. NORMAL}
);

```

{THIS PROCEDURE CALCULATES THE PORTION OF PREVIOUS HARVEST MAINTAINED UNDER A LENGTH LIMIT BY AGE GROUP. THE ASSUMPTION THAT LENGTHS OF INDIVIDUALS ARE NORMALLY DISTRIBUTED WITH THE USER-SUPPLIED MEAN AND STANDARD DEVIATION. THE LAYOUT HAS THE APPEARANCE OF BEING WRITTEN FOR SLOT LENGTH LIMITS. A MINIMUM LENGTH LIMIT CAN BE SIMULATED BY SETTING MAX TO THE DESIRED LENGTH LIMIT AND MIN TO ZERO. A MAXIMUM LENGTH LIMIT CAN BE SIMULATED BY DOING THE OPPOSITE.}

```

VAR
  MIN:REAL; {MIN LENGTH OF PROTECTED RANGE}
  MAX:REAL; {MAX LENGTH OF PROTECTED RANGE}
  ZMIN:REAL; {Z-SCORE OF MIN LENGTH OF PROTECTED RANGE}
  ZMAX:REAL; {Z-SCORE OF MAX LENGTH OF PROTECTED RANGE}

```

```
IZMIN:INTEGER; {INDEX OF MIN LENGTH OF PROTECTED RANGE}
IZMAX:INTEGER; {INDEX OF MAX LENGTH OF PROTECTED RANGE}
```

```
BEGIN{LENGTHLIMIT}
  WRITELN('ENTER MINIMUM LENGTH FOR PROTECTED RANGE:');
  READLN(MIN);
  WRITELN('ENTER MAXIMUM LENGTH FOR PROTECTED RANGE:');
  READLN(MAX);
  WRITELN(LIST);
  WRITE(LIST,'FISH MAY NOT BETWEEN THE LENGTHS OF ');
  WRITELN(LIST,MIN,' AND ',MAX,'.');
  WRITELN(LIST,'THE LENGTH LIMIT MODIFICATION FACTORS FOR
    F ARE:');
  FOR I:=0 TO 20 DO
    BEGIN{FOR}
      {STANDARDIZE VALUES}
      ZMIN:=(MIN-LGTHAGE[I])/SDAGE[I];
      ZMAX:=(MAX-LGTHAGE[I])/SDAGE[I];
      {TRANSLATE TO INDICES FOR NORMAL ARRAY
        ( I = [ROUND(Z*10)] + 36 )}
      ZMIN:=ZMIN*10;
      ZMAX:=ZMAX*10;
      IZMIN:=ROUND(ZMIN);
      IZMAX:=ROUND(ZMAX);
      IZMIN:=IZMIN+36;
      {KEEP INDEX WITHIN RANGE}
      IF IZMIN < 0 THEN IZMIN:=0;
      IF IZMIN > 72 THEN IZMIN:=72;
      IZMAX:=IZMAX+36;
      IF IZMAX < 0 THEN IZMAX:=0;
      IF IZMAX > 72 THEN IZMAX:=72;
      {THE PROPORTION OF HARVEST STILL TAKEN IS
        REPRESENTED AS 1 - THE PROBABILITY OF BEING IN THE
        PROTECTED RANGE (ZMIN TO ZMAX)}
      REDUCE[I]:=1-(NORMAL[IZMIN]-NORMAL[IZMAX]);
      WRITELN(LIST,REDUCE[I]);
    END; {FOR}
  WRITELN(LIST);
END; {LENGTHLIMIT}
```

{-----}

```
PROCEDURE NONCOMPLIANCE(
  VAR LIST:TEXT; {OUTPUT FILE}
  VAR NC:REAL {RATE AT WHICH ANGLERS WOULD NON-COMPLY WITH
    REGULATIONS});
```

{THIS PROCEDURE CALCULATES ANGLER NON-COMPLIANCE TO BE USED IN
MODIFYING FISH MORTALITY. THIS VALUE IS BASED ON THE RATIO
OF NUMBER OF ANGLER TRIPS WITH ILLEGAL FISH TO TOTAL NUMBER
OF ANGLER TRIPS MEETING HARVEST CRITERIA. HARVEST CRITERIA

MEANS EITHER A FISH WAS CAUGHT WITHIN A PROTECTED LENGTH RANGE OR MORE FISH WERE CAUGHT ABOVE A SPECIFIED CREEL LIMIT. }

VAR

IL:INTEGER; {NUMBER OF ANGLER TRIPS WITH ILLEGAL FISH}
CF:INTEGER; {NUMBER OF ANGLER TRIPS MEETING HARVEST
CRITERIA}

BEGIN {NONCOMPLIANCE}

WRITELN('ENTER THE NUMBER OF ANGLER TRIPS WITH ILLEGAL
FISH - ');

READLN(IL);

WRITELN('ENTER THE NUMBER OF ANGLER TRIPS MEETING HARVEST
CRITERIA - ');

READLN(CF);

NC:=IL/CF;

WRITELN(LIST,'THE ANGLER NON-COMPLIANCE FACTOR FOR F IS
,NC);

END; {NONCOMPLIANCE}

{-----}

BEGIN{REGS}

{BY SETTING ALL MODIFYING PARAMETERS INITIALLY TO ONE, IT
IS ENSURED THAT IF NO REGULATIONS ARE IMPOSED, THERE
WILL BE NO EFFECT ON THE RATE OF FISHING MORTALITY.}

REDUCTION:=1;

FOR I:=0 TO 20 DO

REDUCE[I]:=1;

FOR I:=0 TO 20 DO

FPRIME[I]:=F[I];

{THE INITIAL VALUE OF THE MODIFYING PARAMETER
NON-COMPLIANCE IS SET EQUAL TO ZERO. THIS INSURES THAT
IF ZERO NON-COMPLIANCE EXISTS, THERE WILL BE NO EFFECT
ON FISHING MORTALITY.}

NC:=0;

{ASK USER WHETHER OR NOT TO IMPOSE EACH TYPE OF
REGULATION, AND ON RESPONSES OF YES BRANCH TO THE
PROCEDURE FOR CALCULATING THE MODIFIER(S) FOR THAT TYPE
OF REGULATION.}

WRITELN('DO YOU WISH TO USE REGULATIONS? (Y/N)');

READLN(ANSWER);

IF (ANSWER = 'Y') OR (ANSWER = 'y') THEN

BEGIN{THEN}

WRITELN('DO YOU WISH TO IMPOSE A DAILY CREEL LIMIT?
(Y/N)');

READLN(ANSWER);

IF (ANSWER = 'Y') OR (ANSWER = 'y')

THEN CREELLIMIT(LIST,REDUCTION);

WRITELN('DO YOU WISH TO IMPOSE A LENGTH LIMIT?');

```

        (Y/N)');
READLN(ANSWER);
IF (ANSWER = 'Y') OR (ANSWER = 'y')
    THEN LENGTHLIMIT(LIST,REDUCE,NORMAL);
WRITELN('DO YOU WISH TO ADJUST ANGLER
        NON-COMPLIANCE? (Y/N)');
READLN(ANSWER);
IF (ANSWER = 'Y') OR (ANSWER = 'y')
    THEN NONCOMPLIANCE(LIST,NC);
{APPLY MODIFICATIONS TO FISHING MORTALITY VECTOR}
WRITELN(LIST,'THE MODIFIED FISHING MORTALITY RATES
        ARE:');
FOR I:=0 TO 20 DO
BEGIN{FOR}
    PL[I]:=REDUCE[I]*REDUCTION;
END; {FOR}
FOR I:=0 TO 20 DO
BEGIN{FOR}
    IF I=1 THEN
    BEGIN{THEN}
        F[I]:= (F[I]*PL[I]*(1-PR[I]));
        WRITELN(LIST,F[I]);
    END {THEN}
    ELSE
    BEGIN{ELSE}
        F[I]:= (F[I]*PL[I]*(1-NR[I])*NC) +
                (F[I]*(1-PL[I))*(1-NR[I])*NC) +
                (F[I]*PL[I]*(1-NC)*(1-PR[I]));
        WRITELN(LIST,F[I]);
    END; {ELSE}
END; {FOR}
{APPLY MODIFICATIONS TO HOOKING MORTALITY VECTOR}
{THE ONLY FISH THAT ACTUALLY EXPERIENCE HOOKING
MORTALITY ARE THOSE THAT ARE PROTECTED BY
REGULATIONS. THIS IS DUE TO THE ASSUMPTION THAT
THERE IS NO VOLUNTARY CATCH AND RELEASE AND NO
ILLEGAL HARVEST. MODIFICATIONS FOR VIOLATION OF
THESE ASSUMPTIONS ARE MADE AT THIS POINT SIMILAR TO
THOSE FOR LENGTH LIMITS AND CREEL LIMITS. THUS,
THE INITIAL VALUES FOR HOOKING MORTALITY ARE
SUPPOSED TO REPRESENT THE INSTANTANEOUS RATES AT
THE MAXIMUM, AND ARE MODIFIED TO REFLECT THE
REDUCED HARVEST DUE TO ILLEGAL HARVEST AND
VOLUNTARY CATCH-AND-RELEASE FISHING.}
WRITELN(LIST,'THE MODIFIED HOOKING MORTALITY RATES
        ARE:');
FOR I:=0 TO 20 DO
BEGIN{FOR}
    H[I]:= (FPRIME[I]*H[I]*(1-PL[I))*(1-NC)) +
            (FPRIME[I]*H[I]*(1-PL[I])*NR[I]*NC) +
            (FPRIME[I]*H[I]*PL[I]*PR[I]*(1-NC)) +

```

```

                (FPRIME[I]*H[I]*PL[I]*NR[I]*NC);
        WRITELN(LIST,H[I]);
    END; {FOR}
END {THEN}
ELSE
BEGIN{ELSE}
    WRITELN(LIST,'THE MODIFIED FISHING MORTALITY RATES
                ARE:');
    FOR I:=0 TO 20 DO
    BEGIN{FOR}
        F[I]:=F[I]*(1-PR[I]);
        WRITELN(LIST,F[I]);
    END; {FOR}
    WRITELN(LIST,'THE MODIFIED HOOKING MORTALITY RATES
                ARE:');
    FOR I:=0 TO 20 DO
    BEGIN{FOR}
        H[I]:=H[I]*PR[I];
        WRITELN(LIST,H[I]);
    END; {FOR}
END; {ELSE}
END; {REGS}

```

{*****}

```

FUNCTION LARVAE(
    N:ARRAYDIST; {# IN AGE GROUP I AT END OF YEAR J}
    SEX:DISTRIBUTION; {PROPORTION OF FEMALES IN AGE GROUP I}
    MAT:DISTRIBUTION; {PROPORTION OF FEMALES THAT ARE MATURE
                        IN AGE GROUP I}
    EC:DISTRIBUTION; {MEAN EGG CONTENT OF FEMALES IN AGE
                        GROUP I}
    HATCH:REAL {HATCHING RATE OF EGGS}):REAL;

```

{THIS FUNCTION RETURNS PRODUCTION OF LARVAL FISH (N[0,1])
 BASED ON THE NUMBER OF EGGS PRODUCED BY THE POPULATION AND
 THE HATCHING SUCCESS RATE EXPERIENCED}

```

VAR
    I:INTEGER; {AGE GROUP-0 TO 20}
    EGGS:REAL; {TOTAL EGG PRODUCTION}

```

```

BEGIN{LARVAE}
    EGGS:=0;
    {CALCULATE TOTAL EGG PRODUCTION BASED ON NUMBER IN EACH
    AGE GROUP, PROPORTION MATURE FEMALES, AND MEAN EGG
    CONTENT}
    FOR I:=0 TO 20 DO
    BEGIN {FOR}
        EGGS:=EGGS+(N[I,0]*SEX[I]*MAT[I]*EC[I]);
    END; {FOR}

```

```

    {CALCULATE LARVAE PRODUCTION BASED ON TOTAL EGG
    PRODUCTION AND
    HATCHING SUCCESS RATE}
    LARVAE:=EGGS*HATCH;
END{LARVAE};

{*****}

FUNCTION FIRSTYEAR(
    NO:REAL; {# IN AGE GROUP AT START OF YEAR}
    COEFA:REAL; {A COEFFICIENT OF DENSITY DEPENDENT SURVIVAL}
    COEFB:REAL; {B " " " " " " " " " " }
    CV:REAL {COEF. OF VAR. IN YEAR CLASS STRENGTH}
) : REAL;

{THIS FUNCTION RETURNS THE NUMBER OF LAST YEAR'S AGE 0 FISH
THAT SURVIVES TO AGE ONE (N[1,1]). IT ALLOWS FOR DENSITY
DEPENDENT CONTROL OF THIS AGE GROUP.}

VAR
    I:INTEGER; {LOOP COUNTER}
    SUM,RX,V:REAL; {USED IN GENERATING RANDOM NORMAL VARIATE}

BEGIN{FIRSTYEAR}
    {GENERATE V, A RANDOM NORMAL WITH MEAN 0 AND SPECIFIED
    STANDARD DEVIATION, (A*CV)}
    SUM:=0;
    FOR I:=1 TO 12 DO
    BEGIN{FOR}
        RX:=RANDOM;
        SUM:=SUM+RX;
    END; {END}
    V:=(SUM-6)*CV;
    {APPLY RANDOM VARIABILITY}
    FIRSTYEAR:=1/(COEFA+(COEFB/NO)+V);
END{FIRSTYEAR};

{*****}

FUNCTION MORTALITY(
    NO:REAL; {# IN AGE GROUP AT START OF YEAR}
    F:REAL; {INSTANEOUS RATE OF FISHING MORTALITY}
    M:REAL; {INSTANEOUS RATE OF NATURAL MORTALITY}
    H:REAL {INSTANEOUS RATE OF HOOKING MORTALITY}) : REAL;

{THIS FUNCTION RETURNS THE NUMBER OF LAST YEAR'S AGE I FISH
THAT SURVIVE TO AGE I+1. IT PARTITIONS MORTALITY INTO
INSTANEOUS RATES DUE TO HOOKING, FISHING (HARVEST), AND
NATURAL CAUSES.}

BEGIN{MORTALITY}

```

```

MORTALITY:=NO*EXP(-(F+M+H));
END(MORTALITY);

```

```

{*****}

```

```

PROCEDURE BALANCE(
  VAR LIST:TEXT; {OUTPUT FILE}
  VAR N:ARRAYDIST; {# IN AGE GROUP I}
  LGTHAGE:DISTRIBUTION; {LENGTH AT AGE DATA}
  SDAGE:DISTRIBUTION; {STANDARD DEVIATION OF LENGTH AT AGE}
  LENGTH:ARRAY5; {CUT-OFF FOR EACH LENGTH GROUP}
  NORMAL:NORMDIST {RIGHT TAIL AREAS FOR STD. NORMAL});

```

```

{THIS PROCEDURE CALCULATES PROPORTIONAL STOCK DENSITY AND A
VARIETY OF RELATIVE STOCK DENSITIES TO BE USED TO ASSESS THE
GENERAL SIZE CHARACTERISTICS OF THE POPULATION. THESE VALUES
ARE OUTPUT TO THE FILE 'LISTING'. THE VALUES ARE CALCULATED
BASED ON THE NORMAL LENGTH FREQUENCIES WITHIN EACH AGE GROUP
BEING SUMMED OVER ALL AGE GROUPS.}

```

```

VAR
  STOCK:ARRAY [1..5] OF REAL; {# IN EACH GROUP}
  GSTOCK:ARRAY [1..5] OF REAL; {# EACH SIZE OR GREATER}
  I:INTEGER; {AGE GROUP-0 TO 20}
  K:INTEGER;
  J:INTEGER; {YEAR- 0 TO 50}
  PROB: REAL; {PROBABILITY OF AGE I FISH BEING GREATER THAN
              LENGTH[K]}
  Z:REAL; {Z-SCORE OF LENGTH IN QUESTION}
  INDEX:INTEGER; {INDEX OF LENGTH IN QUESTION}

```

```

BEGIN {BALANCE}
  FOR K:=1 TO 5 DO
    BEGIN{FOR}
      GSTOCK[K]:=0;
      FOR I:=0 TO 20 DO
        BEGIN{FOR}
          {STANDARDIZE VALUE}
          Z:=(LENGTH[K]-LGTHAGE[I])/SDAGE[I];
          {CONVERT TO INDEX}
          Z:=Z*10;
          IF Z>32767 THEN Z:=32766;
          IF Z<-32767 THEN Z:=-32766;
          INDEX:=ROUND(Z);
          INDEX:=INDEX+36;
          {KEEP INDEX WITHIN PRESCRIBED RANGE}
          IF INDEX < 0 THEN INDEX:=0;
          IF INDEX > 72 THEN INDEX:=72;
          GSTOCK[K]:=GSTOCK[K]+N[I,0]*NORMAL[INDEX];
        END; {FOR}
      END; {FOR}
    END; {FOR}

```

```

FOR K:=1 TO 4 DO
BEGIN{FOR}
    STOCK[K]:=GSTOCK[K]-GSTOCK[K+1];
END; {FOR}
STOCK[5]:=GSTOCK[5];
WRITELN(LIST);
IF GSTOCK[1] = 0 THEN
BEGIN{THEN}
    WRITELN(LIST,'NO FISH GREATER THAN STOCK SIZE!');
    WRITELN(LIST,'          ...PSD AND RSD VALUES
                UNDEFINED!');
END {THEN}
ELSE
BEGIN{ELSE}
    WRITELN(LIST,'PSD AND RSD VALUES');
    WRITELN(LIST,'PSD=',(GSTOCK[1]-STOCK[1])/GSTOCK[1]);
    WRITELN(LIST,'RSD-P=',
              (GSTOCK[1]-STOCK[1]-STOCK[2])/GSTOCK[1]);
    WRITELN(LIST,'RSD-M=',
              (STOCK[4]+STOCK[5])/GSTOCK[1]);
    WRITELN(LIST,'RSD-T=', (STOCK[5])/GSTOCK[1]);
    WRITELN(LIST,'RSD-SQ=', (STOCK[1])/GSTOCK[1]);
    WRITELN(LIST,'RSD-QP=', (STOCK[2])/GSTOCK[1]);
    WRITELN(LIST,'RSD-PM=', (STOCK[3])/GSTOCK[1]);
    WRITELN(LIST,'RSD-MT=', (STOCK[4])/GSTOCK[1]);
END; {ELSE}
END;{BALANCE}

```

{*****}

```

PROCEDURE BARANOV(
    VAR LIST:TEXT; {OUTPUT FILE}
    VAR F:DISTRIBUTION;
    VAR M:DISTRIBUTION;
    VAR H:DISTRIBUTION;
    VAR N:ARRAYDIST;
    VAR LGTHAGE:DISTRIBUTION;
    VAR COELW:REAL;
    VAR EXPLW:REAL);

```

{THIS PROCEDURE CALCULATES CATCH (IN NUMBERS) AND YIELD (IN WHATEVER UNITS WERE ASSOCIATED WITH THE SUPPLIED LENGTH-WEIGHT REGRESSION COEFFICIENTS. RESULTS ARE OUTPUT AS A VECTOR BY AGE (0 TO 20) TO THE FILE 'LISTING'.}

```

VAR I:INTEGER; {A LOOP COUNTER VARIABLE}
MORT:REAL; {TOTAL MORTALITY FOR AN AGE GROUP (Z)}
C:REAL; {HARVEST FOR AN AGE GROUP}
CTERM:DISTRIBUTION; {A TERM THAT REPRESENTS MEAN WEIGHT
                    FOR AN AGE GROUP}
GTH:REAL; {GROWTH RATE FOR AN AGE GROUP}

```

```

BIO:REAL; {MEAN BIOMASS FOR AN AGE GROUP}
AGEY,AGEC:REAL; {AGE SPECIFIC YIELD AND HARVEST,
                  RESPECTIVELY}
TOTY,TOTC:REAL; {TOTAL YIELD AND TOTAL HARVEST,
                  RESPECTIVELY}
TOTCI:REAL; {TOTAL OF HARVEST TIMES AGE (TO GET MEAN)}
L1,L2:REAL; {LENGTHS AT AGES BRACKETING MEAN}
LM:REAL; {INTERPOLATED MEAN LENGTH}

```

```

BEGIN{BARANOV}
  WRITELN(LIST);
  WRITELN(LIST,' CATCH(HARVEST) VECTOR=');
  TOTC:=0;
  TOTCI:=0;
  FOR I:=0 TO 19 DO
    BEGIN{FOR}
      MORT:=F[I]+M[I]+H[I];
      AGEY:=(N[I,0]*F[I]*(1-EXP(-MORT)))/MORT;
      TOTC:=TOTC+AGEY;
      TOTCI:=TOTCI+AGEY*I;
      WRITELN(LIST,AGEY);
    END;{FOR}
  WRITELN(LIST);
  WRITELN(LIST,' TOTAL HARVEST= ',TOTC);
  WRITELN(LIST);
  IF TOTC>0 THEN
    BEGIN{THEN}
      WRITELN(LIST,'MEAN AGE HARVESTED = ',TOTCI/TOTC);
      L1:=LGTHAGE[TRUNC(TOTCI/TOTC)];
      L2:=LGTHAGE[TRUNC(TOTCI/TOTC)+1];
      LM:=L1+((L2-L1)*((TOTCI/TOTC)-TRUNC(TOTCI/TOTC)));
      WRITELN(LIST,'MEAN LENGTH HARVESTED = ',LM);
    END;{THEN}
  WRITELN(LIST);
  WRITELN(LIST,' YIELD VECTOR=');
  TOTY:=0;
  FOR I:=0 TO 20 DO
    BEGIN{FOR}
      CTERM[I]:=EXP(LN(COELW)+(LN(LGTHAGE[I])*EXPLW));
    END;{FOR}
  FOR I:=0 TO 19 DO
    BEGIN{FOR}
      MORT:=F[I]+M[I]+H[I];
      BIO:=N[I,0]*CTERM[I];
      GTH:=LN(CTERM[I+1]/CTERM[I]);
      AGEY:=(BIO*F[I]*(1-EXP(-(MORT-GTH)))/(MORT-GTH);
      TOTY:=TOTY+AGEY;
      WRITELN(LIST,AGEY);
    END;{FOR}
  WRITELN(LIST);
  WRITELN(LIST,' TOTAL YIELD= ',TOTY);

```

```

WRITELN(LIST);
END; {BARANOV}

{*****}

BEGIN {MAIN PROGRAM}
  NORMSET(NORMAL);
  ASSIGN(INFILE, INPFILE);
  WRITELN('TWO FILES WILL BE CREATED: ');
  WRITELN('THE FILE (INPUT) WILL CONTAIN THE INPUT
    VALUES. ');
  WRITELN('DO YOU NEED TO CREATE THIS FILE?(Y/N) ');
  READLN(ANSWER);
  IF (ANSWER = 'N') OR (ANSWER = 'n')
    THEN READDATA(INFILE, N, F, M, H, PR, NR, SEX, MAT, EC, HATCH,
      COEFA, COEFB, LGTHAGE, SDAGE, LENGTH, COELW, EXPLW, CV)
    ELSE ENTERDATA(INFILE, N, F, M, H, PR, NR, SEX, MAT, EC,
      HATCH, COEFA, COEFB, LGTHAGE, SDAGE, LENGTH, COELW,
      EXPLW, CV);
  CLOSE(INFILE);
  ASSIGN(LIST, LISTFILE);
  REWRITE(LIST);
  WRITELN('THE FILE (LISTING) WILL CONTAIN THE FINAL
    REPORT');
  WRITELN('ENTER A TITLE FOR REPORT');
  READLN(TITLE);
  WRITELN(LIST, TITLE);
  WRITELN(LIST);
  WRITELN(LIST, 'INITIAL DATA');
  WRITELN(LIST);
  PRNTDATA(LIST, N, F, M, H, PR, NR, SEX, MAT, EC, HATCH, COEFA, COEFB,
    LGTHAGE, SDAGE, LENGTH, COELW, EXPLW, CV);
  BALANCE(LIST, N, LGTHAGE, SDAGE, LENGTH, NORMAL);
  BARANOV(LIST, F, M, H, N, LGTHAGE, COELW, EXPLW);
  FOR I:=0 TO 20 DO
  BEGIN {FOR}
    FPRIME[I]:=F[I];
  END; {FOR}
  REGS(LIST, F, FPRIME, H, NC, PR, NR, PL, NORMAL);
  WRITELN('ENTER NUMBER OF YEARS TO SIMULATE');
  READLN(YEARS);
  WRITELN(LIST);
  WRITELN(LIST, 'DOING A ', YEARS, ' YEAR SIMULATION');
  FOR X:=1 TO YEARS DO
  BEGIN {FOR}
    WRITELN('RUNNING SIMULATION FOR YEAR - ', X);
    WRITELN(LIST);
    WRITE(LIST, '*****');
    WRITELN(LIST, '*****'),
    WRITELN(LIST);
    WRITELN(LIST, 'YEAR = ', X);
  END; {FOR}

```

```

WRITELN(LIST);
WRITE(' ');
N[0,1]:=LARVAE(N,SEX,MAT,EC,HATCH);
WRITE(' ');
N[1,1]:=FIRSTYEAR(N[0,0],COEFA,COEFB,CV);
FOR I:=1 TO 19 DO
BEGIN{FOR}
    WRITE(' ');
    N[I+1,1]:=MORTALITY(N[I,0],F[I],M[I],H[I]);
END{FOR};
WRITELN;
WRITELN;
{WRITE TO FILE 'LIST' AS A VECTOR BY AGE (0 - 20).}
WRITELN(LIST,'NUMBERS BY AGE GROUP');
TOTALN:=0;
FOR I:=0 TO 20 DO
BEGIN{FOR}
    IF (N[I,1] < 0.5) THEN N[I,1]:=0;
    WRITELN(LIST,N[I,1]);
    N[I,0]:=N[I,1];
    N[I,1]:=0;
    TOTALN:=TOTALN+N[I,0];
END{FOR};
WRITELN(LIST);
WRITELN(LIST,'TOTAL = ',TOTALN);
BALANCE(LIST,N,LGTHAGE,SDAGE,LENGTH,NORMAL);
BARANOV(LIST,F,M,H,N,LGTHAGE,COELW,EXPLW);
WRITELN(LIST);
WRITELN(LIST,'CATCH VECTOR (NOT NECESSARILY
    HARVESTED)');
TOTALC:=0;
TOTALCI:=0;
FOR I:=0 TO 20 DO
BEGIN{FOR}
    CR:=(FPRIME[I]*N[I,0]*(1-EXP(-(F[I]+M[I]+
        H[I])))/(F[I]+M[I]+H[I]));
    WRITELN(LIST,CR);
    TOTALC:=TOTALC+CR;
    TOTALCI:=TOTALCI+CR*I;
END {FOR};
WRITELN(LIST);
WRITELN(LIST,'TOTAL CATCH = ',TOTALC);
WRITELN(LIST,'MEAN AGE CAUGHT = ',TOTALCI/TOTALC);
L1:=LGTHAGE[TRUNC(TOTALCI/TOTALC)];
L2:=LGTHAGE[TRUNC(TOTALCI/TOTALC)+1];
LM:=L1+((L2-L1)*((TOTALCI/TOTALC)-
    TRUNC(TOTALCI/TOTALC)));
WRITELN(LIST,'MEAN LENGTH CAUGHT = ',LM);
END {FOR};
CLOSE(LIST);
END. {MAIN PROGRAM}

```

APPENDIX B - SAMPLE MODEL OUTPUT (UPPER JAMES)

SAMPLE TITLE

INITIAL DATA

HATCHING SUCCESS RATE= 9.9400000000E-02

COEFFICIENTS FOR DENSITY-DEP. 1ST YR. SURVIVAL
COEFA= 9.3000000000E-06 COEFB= 0.0000000000E+00

AGE SPECIFIC SEX RATIOS

AGE=0 SEX RATIO= 5.0000000000E-01
AGE=1 SEX RATIO= 5.0000000000E-01
AGE=2 SEX RATIO= 5.0000000000E-01
AGE=3 SEX RATIO= 5.0000000000E-01
AGE=4 SEX RATIO= 5.0000000000E-01
AGE=5 SEX RATIO= 5.0000000000E-01
AGE=6 SEX RATIO= 5.0000000000E-01
AGE=7 SEX RATIO= 5.0000000000E-01
AGE=8 SEX RATIO= 5.0000000000E-01
AGE=9 SEX RATIO= 5.0000000000E-01
AGE=10 SEX RATIO= 5.0000000000E-01
AGE=11 SEX RATIO= 5.0000000000E-01
AGE=12 SEX RATIO= 5.0000000000E-01
AGE=13 SEX RATIO= 5.0000000000E-01
AGE=14 SEX RATIO= 5.0000000000E-01
AGE=15 SEX RATIO= 5.0000000000E-01
AGE=16 SEX RATIO= 5.0000000000E-01
AGE=17 SEX RATIO= 5.0000000000E-01
AGE=18 SEX RATIO= 5.0000000000E-01
AGE=19 SEX RATIO= 5.0000000000E-01
AGE=20 SEX RATIO= 5.0000000000E-01

AGE SPECIFIC MATURITY RATES

AGE=0 MATURITY= 0.0000000000E+00
AGE=1 MATURITY= 0.0000000000E+00
AGE=2 MATURITY= 0.0000000000E+00
AGE=3 MATURITY= 4.0000000000E-01
AGE=4 MATURITY= 6.0000000000E-01
AGE=5 MATURITY= 1.0000000000E+00
AGE=6 MATURITY= 1.0000000000E+00
AGE=7 MATURITY= 1.0000000000E+00
AGE=8 MATURITY= 1.0000000000E+00
AGE=9 MATURITY= 1.0000000000E+00
AGE=10 MATURITY= 1.0000000000E+00
AGE=11 MATURITY= 1.0000000000E+00
AGE=12 MATURITY= 1.0000000000E+00
AGE=13 MATURITY= 1.0000000000E+00
AGE=14 MATURITY= 1.0000000000E+00
AGE=15 MATURITY= 1.0000000000E+00
AGE=16 MATURITY= 1.0000000000E+00
AGE=17 MATURITY= 1.0000000000E+00
AGE=18 MATURITY= 1.0000000000E+00

AGE=19 MATURITY= 1.0000000000E+00
AGE=20 MATURITY= 1.0000000000E+00

EGG CONTENT OF FEMALES BY AGE

AGE=0 EGG CONTENT= 0.0000000000E+00
AGE=1 EGG CONTENT= 0.0000000000E+00
AGE=2 EGG CONTENT= 8.0000000000E+02
AGE=3 EGG CONTENT= 3.2000000000E+03
AGE=4 EGG CONTENT= 7.5000000000E+03
AGE=5 EGG CONTENT= 1.1000000000E+04
AGE=6 EGG CONTENT= 1.7500000000E+04
AGE=7 EGG CONTENT= 2.2000000000E+04
AGE=8 EGG CONTENT= 2.2500000000E+04
AGE=9 EGG CONTENT= 2.2750000000E+04
AGE=10 EGG CONTENT= 2.2850000000E+04
AGE=11 EGG CONTENT= 2.2900000000E+04
AGE=12 EGG CONTENT= 2.2925000000E+04
AGE=13 EGG CONTENT= 2.2935000000E+04
AGE=14 EGG CONTENT= 2.2940000000E+04
AGE=15 EGG CONTENT= 2.2940000000E+04
AGE=16 EGG CONTENT= 2.2940000000E+04
AGE=17 EGG CONTENT= 2.2940000000E+04
AGE=18 EGG CONTENT= 2.2940000000E+04
AGE=19 EGG CONTENT= 2.2940000000E+04
AGE=20 EGG CONTENT= 2.2940000000E+04

FISHING MORTALITY RATES BY AGE

AGE=0 F= 0.0000000000E+00
AGE=1 F= 1.0000000000E-01
AGE=2 F= 1.3000000000E+00
AGE=3 F= 1.8000000000E+00
AGE=4 F= 2.3000000000E+00
AGE=5 F= 2.5000000000E+00
AGE=6 F= 2.6000000000E+00
AGE=7 F= 2.7000000000E+00
AGE=8 F= 2.7000000000E+00
AGE=9 F= 2.7000000000E+00
AGE=10 F= 2.7000000000E+00
AGE=11 F= 2.7000000000E+00
AGE=12 F= 2.7000000000E+00
AGE=13 F= 2.7000000000E+00
AGE=14 F= 4.5000000000E+00
AGE=15 F= 4.5000000000E+00
AGE=16 F= 4.5000000000E+00
AGE=17 F= 4.5000000000E+00
AGE=18 F= 4.5000000000E+00
AGE=19 F= 4.5000000000E+00
AGE=20 F= 4.5000000000E+00

NATURAL MORTALITY BY AGE

AGE=0 M= 1.2039720000E+00
AGE=1 M= 4.2000000000E-01

AGE=2 M= 8.5000000000E-01
 AGE=3 M= 7.6000000000E-01
 AGE=4 M= 3.2000000000E-01
 AGE=5 M= 2.9000000000E-01
 AGE=6 M= 2.2000000000E-01
 AGE=7 M= 1.4000000000E-01
 AGE=8 M= 1.0000000000E-01
 AGE=9 M= 1.0000000000E-01
 AGE=10 M= 1.0000000000E-01
 AGE=11 M= 1.0000000000E-01
 AGE=12 M= 1.0000000000E-01
 AGE=13 M= 1.0000000000E-01
 AGE=14 M= 1.0000000000E+01
 AGE=15 M= 1.0000000000E+01
 AGE=16 M= 1.0000000000E+01
 AGE=17 M= 1.0000000000E+01
 AGE=18 M= 1.0000000000E+01
 AGE=19 M= 1.0000000000E+01
 AGE=20 M= 1.0000000000E+01

HOOKING MORTALITY BY AGE

AGE=0 H= 0.0000000000E+00
 AGE=1 H= 2.0000000000E-01
 AGE=2 H= 2.0000000000E-01
 AGE=3 H= 2.0000000000E-01
 AGE=4 H= 2.0000000000E-01
 AGE=5 H= 2.0000000000E-01
 AGE=6 H= 2.0000000000E-01
 AGE=7 H= 2.0000000000E-01
 AGE=8 H= 2.0000000000E-01
 AGE=9 H= 2.0000000000E-01
 AGE=10 H= 2.0000000000E-01
 AGE=11 H= 2.0000000000E-01
 AGE=12 H= 2.0000000000E-01
 AGE=13 H= 2.0000000000E-01
 AGE=14 H= 2.0000000000E-01
 AGE=15 H= 2.0000000000E-01
 AGE=16 H= 2.0000000000E-01
 AGE=17 H= 2.0000000000E-01
 AGE=18 H= 2.0000000000E-01
 AGE=19 H= 2.0000000000E-01
 AGE=20 H= 2.0000000000E-01

RELEASE PROBABILITY BY AGE CLASS, COMPLYING ANGLERS

AGE=0 PROB= 1.0000000000E+00
 AGE=1 PROB= 1.0000000000E+00
 AGE=2 PROB= 9.6000000000E-01
 AGE=3 PROB= 9.2000000000E-01
 AGE=4 PROB= 8.6000000000E-01
 AGE=5 PROB= 8.1000000000E-01
 AGE=6 PROB= 7.8000000000E-01
 AGE=7 PROB= 7.5000000000E-01

AGE=8 PROB= 7.3000000000E-01
AGE=9 PROB= 7.1000000000E-01
AGE=10 PROB= 7.0000000000E-01
AGE=11 PROB= 7.0000000000E-01
AGE=12 PROB= 7.0000000000E-01
AGE=13 PROB= 7.0000000000E-01
AGE=14 PROB= 7.0000000000E-01
AGE=15 PROB= 7.0000000000E-01
AGE=16 PROB= 7.0000000000E-01
AGE=17 PROB= 7.0000000000E-01
AGE=18 PROB= 7.0000000000E-01
AGE=19 PROB= 7.0000000000E-01
AGE=20 PROB= 7.0000000000E-01

RELEASE PROBABILITY BY AGE CLASS, NON-COMPLYING ANGLERS

AGE=0 PROB= 1.0000000000E+00
AGE=1 PROB= 1.0000000000E+00
AGE=2 PROB= 9.5000000000E-01
AGE=3 PROB= 4.5000000000E-01
AGE=4 PROB= 2.0000000000E-01
AGE=5 PROB= 1.0000000000E-01
AGE=6 PROB= 5.0000000000E-02
AGE=7 PROB= 0.0000000000E+00
AGE=8 PROB= 0.0000000000E+00
AGE=9 PROB= 0.0000000000E+00
AGE=10 PROB= 0.0000000000E+00
AGE=11 PROB= 0.0000000000E+00
AGE=12 PROB= 0.0000000000E+00
AGE=13 PROB= 0.0000000000E+00
AGE=14 PROB= 0.0000000000E+00
AGE=15 PROB= 0.0000000000E+00
AGE=16 PROB= 0.0000000000E+00
AGE=17 PROB= 0.0000000000E+00
AGE=18 PROB= 0.0000000000E+00
AGE=19 PROB= 0.0000000000E+00
AGE=20 PROB= 0.0000000000E+00

INITIAL NUMBERS BY AGE CLASS

1.5860600000E+05
1.0644300000E+05
6.3331000000E+04
1.6565000000E+04
8.0475000000E+03
3.3400000000E+03
1.4360000000E+03
6.1700000000E+02
2.6500000000E+02
1.1400000000E+02
4.9000000000E+01
2.1000000000E+01
9.0000000000E+00
4.0000000000E+00

4.5000000000E+01

PSD CUTOFF POINTS

STOCK SIZE= 1.8000000000E+02
QUALITY SIZE= 2.8000000000E+02
PREFERRED SIZE= 3.5000000000E+02
MEMORABLE SIZE= 4.3000000000E+02
TROPHY SIZE= 5.1000000000E+02

COEFFICIENTS FROM L-W REGRESSION

COELW= 1.6200000000E-05 EXPLW= 2.9600000000E+00

C.V. OF YEAR CLASS STRENGTH = 0.0000000000E+00

PSD AND RSD VALUES

PSD= 2.1311048663E-01
RSD-P= 4.0903038045E-02
RSD-M= 7.9901142452E-03
RSD-T= 1.5411256931E-03
RSD-SQ= 7.8688951337E-01
RSD-QP= 1.7220744858E-01
RSD-PM= 3.2912923801E-02
RSD-MT= 6.4489885521E-03

CATCH(HARVEST) VECTOR=

0.0000000000E+00
7.5877263359E+03
3.1692990751E+04
1.0119503385E+04
6.1723364202E+03
2.6522073255E+03
1.1759588646E+03
5.2178021631E+02
2.2662578419E+02
9.7491846785E+01
4.1904390285E+01
1.7959024408E+01
7.6967247462E+00
3.4207665539E+00
1.7103832769E+00
8.5519163847E-01
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00

TOTAL HARVEST= 6.0320167410E+04

MEAN AGE HARVESTED = 2.5442808195E+00

MEAN LENGTH HARVESTED = 1.9966976015E+02

YIELD VECTOR=

0.0000000000E+00
2.3885358002E+05
2.7907644547E+06
1.9335425797E+06
2.2392520490E+06
1.0649849388E+06
6.1010308027E+05
4.3931956654E+05
2.2816601138E+05
1.3174100051E+05
7.5464955543E+04
3.7446905768E+04
1.7663191288E+04
8.7527537184E+03
4.5267388242E+03
2.2746424246E+03
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00

TOTAL YIELD= 9.8228564484E+06

CREEL LIMIT = 5

YOU ESTIMATED REDUCTION IN HARVEST OF 1.0000000000E+00 TIMES
THE PREVIOUS HARVEST.

FISH MAY NOT BETWEEN THE LENGTHS OF 2.8000000000E+02
AND 3.5600000000E+02.

THE LENGTH LIMIT MODIFICATION FACTORS FOR F ARE:

1.0000000000E+00
1.0000000000E+00
1.0000000000E+00
9.8210000000E-01
2.7790000000E-01
2.5550000000E-01
3.9600000000E-01
8.4600000000E-01
9.2020000000E-01
9.8930000000E-01
9.9980000000E-01
1.0000000000E+00
1.0000000000E+00
1.0000000000E+00
1.0000000000E+00
1.0000000000E+00
1.0000000000E+00
1.0000000000E+00
1.0000000000E+00

1.0000000000E+00
1.0000000000E+00
1.0000000000E+00

THE ANGLER NON-COMPLIANCE FACTOR FOR F IS 2.3404255319E-01

THE MODIFIED FISHING MORTALITY RATES ARE:

0.0000000000E+00
0.0000000000E+00
5.5042553193E-02
3.4002566809E-01
4.9917908085E-01
6.1955425532E-01
7.5158365957E-01
1.0693148936E+00
1.1457389106E+00
1.2252423064E+00
1.2522163404E+00
1.2523404255E+00
1.2523404255E+00
1.2523404255E+00
1.2523404255E+00
1.2523404255E+00
2.0872340426E+00
2.0872340426E+00
2.0872340426E+00
2.0872340426E+00
2.0872340426E+00

THE MODIFIED HOOKING MORTALITY RATES ARE:

0.0000000000E+00
2.0000000000E-02
2.4899148936E-01
2.9199486638E-01
3.6016418383E-01
3.7608914893E-01
3.6968326808E-01
3.2613702127E-01
3.1085221787E-01
2.9495153872E-01
2.8955673191E-01
2.8953191489E-01
2.8953191489E-01
2.8953191489E-01
2.8953191489E-01
2.8953191489E-01
4.8255319149E-01
4.8255319149E-01
4.8255319149E-01
4.8255319149E-01
4.8255319149E-01

DOING A 1 YEAR SIMULATION

YEAR = 1

NUMBERS BY AGE GROUP

7.1262039344E+06
1.0752688172E+05
6.8553168769E+04
1.9972191842E+04
4.1176042491E+03
2.4744501742E+03
9.2341862668E+02
3.7553430377E+02
1.3287609919E+02
5.5876209402E+01
2.2556078886E+01
9.4881839126E+00
4.0659608938E+00
1.7425546688E+00
7.7446874167E-01
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00

TOTAL = 7.3303745636E+06

PSD AND RSD VALUES

PSD= 1.3000345089E-01
RSD-P= 2.4560565639E-02
RSD-M= 4.2809079583E-03
RSD-T= 7.2429517701E-04
RSD-SQ= 8.6999654910E-01
RSD-QP= 1.0544288525E-01
RSD-PM= 2.0279657682E-02
RSD-MT= 3.5566127812E-03

CATCH(HARVEST) VECTOR=

0.0000000000E+00
0.0000000000E+00
2.2385586384E+03
3.6658850872E+03
1.2069594790E+03
8.6276493953E+02
3.8212278000E+02
2.0520614878E+02
7.7181915050E+01
3.3894710694E+01

1.3872692340E+01
5.8358936773E+00
2.5008490235E+00
1.0717924386E+00
4.7635219495E-01
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00

TOTAL HARVEST= 8.6963312783E+03

MEAN AGE HARVESTED = 3.3947254100E+00

MEAN LENGTH HARVESTED = 2.5318330739E+02

YIELD VECTOR=

0.0000000000E+00
0.0000000000E+00
2.1070812149E+05
7.6632295473E+05
4.4319369121E+05
3.5018638582E+05
2.1365006362E+05
1.7515684679E+05
7.9817516539E+04
4.7243258306E+04
2.5373762197E+04
1.2255660228E+04
5.8083500327E+03
2.7533670346E+03
1.2612763820E+03
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00

TOTAL YIELD= 2.3337312544E+06

CATCH VECTOR (NOT NECESSARILY HARVESTED)

0.0000000000E+00
8.6990121925E+03
5.2870480404E+04
1.9406161876E+04
5.5611441027E+03
3.4813938090E+03
1.3219010490E+03
5.1814166717E+02
1.8188364618E+02
7.4691935135E+01

2.9911979350E+01
1.2581972607E+01
5.3917387203E+00
2.3107451658E+00
1.0269978515E+00
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00
0.0000000000E+00

TOTAL CATCH = 9.2166034114E+04
MEAN AGE CAUGHT = 2.4579807607E+00
MEAN LENGTH CAUGHT = 1.9544105728E+02

APPENDIX C - MODEL RESULTS

Catch (number) for the upper James River:

Length Limit	Creel Limit					
	0	1	2	3	4	5
None	98,087	94,377	93,489	92,949	92,730	92,640
Minimums:						
254 mm	98,087	96,551	96,200	95,989	95,904	95,870
280 mm	98,087	96,871	96,590	96,421	96,353	96,325
305 mm	98,087	97,258	97,061	96,942	96,894	96,874
330 mm	98,087	97,668	97,567	97,506	97,481	97,471
356 mm	98,087	97,908	97,865	97,839	97,829	97,824
381 mm	98,087	98,002	97,982	97,970	97,966	97,964
Slots:						
254 mm- 330 mm	98,087	95,408	94,724	94,300	94,127	94,055
280 mm- 356 mm	98,087	95,292	94,577	94,136	93,954	93,880
305 mm- 381 mm	98,087	94,987	94,206	93,725	93,529	93,448
Maximums:						
254 mm	98,087	95,791	95,187	94,811	94,656	94,593
280 mm	98,087	95,445	94,759	94,333	94,158	94,086
305 mm	98,087	95,050	94,278	93,801	93,606	93,526
330 mm	98,087	94,681	93,836	93,319	93,108	93,022
356 mm	98,087	94,491	93,614	93,079	92,862	92,773
381 mm	98,087	94,423	93,536	92,997	92,778	92,688

Harvest (number) for the upper James River:

Length Limit	Creel Limit					
	0	1	2	3	4	5
None	6,031	8,163	8,694	9,020	9,154	9,209
Minimums:						
254 mm	6,031	6,643	6,687	6,873	6,908	6,922
280 mm	6,031	6,497	6,607	6,673	6,700	6,711
305 mm	6,031	6,342	6,418	6,463	6,482	6,489
330 mm	6,031	6,183	6,220	6,243	6,252	6,256
356 mm	6,031	6,093	6,107	6,116	6,120	6,122
381 mm	6,031	6,058	6,064	6,068	6,070	6,070
Slots:						
254 mm- 330 mm	6,031	7,737	8,181	8,458	8,571	8,618
280 mm- 356 mm	6,031	7,804	8,266	8,553	8,671	8,719
305 mm- 381 mm	6,031	7,928	8,417	8,720	8,844	8,895
Maximums:						
254 mm	6,031	7,598	8,012	8,271	8,377	8,421
280 mm	6,031	7,752	8,203	8,484	8,600	8,647
305 mm	6,031	7,908	8,394	8,695	8,819	8,870
356 mm	6,031	8,123	8,650	8,974	9,107	9,161
381 mm	6,031	8,148	8,679	9,005	9,138	9,193

Yield (kg) for the upper James River (1,694 ha):

Length Limit	Creel Limit					
	0	1	2	3	4	5
None	1,704	2,054	2,134	2,181	2,201	2,208
Minimums:						
254 mm	1,704	1,897	1,940	1,966	1,977	1,981
280 mm	1,704	1,861	1,896	1,918	1,926	1,930
305 mm	1,704	1,833	1,838	1,854	1,860	1,862
330 mm	1,704	1,762	1,776	1,784	1,787	1,788
356 mm	1,704	1,734	1,740	1,743	1,745	1,746
381 mm	1,704	1,721	1,724	1,727	1,727	1,728
Slots:						
254 mm- 330 mm	1,704	1,929	1,985	2,019	2,033	2,039
280 mm- 356 mm	1,704	1,941	1,999	2,035	2,050	2,056
305 mm- 381 mm	1,704	1,978	2,044	2,085	2,101	2,108
Maximums:						
254 mm	1,704	1,877	1,921	1,949	1,960	1,965
280 mm	1,704	1,916	1,970	2,004	2,018	2,023
305 mm	1,704	1,965	2,030	2,070	2,086	2,093
330 mm	1,704	2,012	2,086	2,131	2,150	2,157
356 mm	1,704	2,036	2,114	2,162	2,181	2,189
381 mm	1,704	2,045	2,125	2,173	2,192	2,200

Proportional Stock Density for the upper James River:

Length Limit	Creel Limit					
	0	1	2	3	4	5
None	0.1313	0.1177	0.1145	0.1126	0.1118	0.1115
Minimums:						
254 mm	0.1313	0.1241	0.1224	0.1214	0.1210	0.1209
280 mm	0.1313	0.1256	0.1243	0.1235	0.1232	0.1230
305 mm	0.1313	0.1274	0.1265	0.1259	0.1257	0.1256
330 mm	0.1313	0.1293	0.1288	0.1285	0.1284	0.1284
356 mm	0.1313	0.1304	0.1302	0.1301	0.1300	0.1300
381 mm	0.1313	0.1308	0.1307	0.1307	0.1307	0.1307
Slots:						
254 mm- 330 mm	0.1313	0.1227	0.1205	0.1191	0.1186	0.1184
280 mm- 356 mm	0.1313	0.1221	0.1198	0.1183	0.1177	0.1175
305 mm- 381 mm	0.1313	0.1206	0.1180	0.1163	0.1156	0.1154
Maximums:						
254 mm	0.1313	0.1245	0.1227	0.1216	0.1212	0.1210
280 mm	0.1313	0.1228	0.1207	0.1193	0.1187	0.1185
305 mm	0.1313	0.1210	0.1183	0.1167	0.1160	0.1158
330 mm	0.1313	0.1192	0.1162	0.1144	0.1136	0.1133
356 mm	0.1313	0.1183	0.1151	0.1132	0.1125	0.1121
381 mm	0.1313	0.1179	0.1148	0.1128	0.1121	0.1117

Utility Scores for the upper James River:

Length Limit	Creel Limit					
	0	1	2	3	4	5
None	0.32	0.31	0.31	0.31	0.31	0.31
Minimums:						
254 mm	0.32	0.31	0.31	0.31	0.31	0.31
280 mm	0.32	0.31	0.31	0.31	0.31	0.31
305 mm	0.32	0.31	0.31	0.31	0.31	0.31
330 mm	0.32	0.32	0.32	0.32	0.32	0.32
356 mm	0.32	0.32	0.32	0.32	0.32	0.32
381 mm	0.32	0.32	0.32	0.32	0.32	0.32
Slots:						
254 mm- 330 mm	0.32	0.31	0.31	0.31	0.31	0.31
280 mm- 356 mm	0.32	0.31	0.31	0.31	0.31	0.31
305 mm- 381 mm	0.32	0.31	0.31	0.31	0.31	0.31
Maximums:						
254 mm	0.32	0.31	0.31	0.31	0.31	0.31
280 mm	0.32	0.31	0.31	0.31	0.31	0.31
305 mm	0.32	0.31	0.31	0.31	0.31	0.31
330 mm	0.32	0.31	0.31	0.31	0.31	0.31
356 mm	0.32	0.31	0.31	0.31	0.31	0.31
381 mm	0.32	0.31	0.31	0.31	0.31	0.31

Catch (number) for the lower James River:

Length Limit	Creel Limit					
	0	1	2	3	4	5
None	93,962	85,751	84,556	84,070	83,962	83,912
Minimums:						
254 mm	93,962	87,926	87,052	86,696	86,617	86,580
280 mm	93,962	89,476	88,820	88,553	88,494	88,466
305 mm	93,962	90,957	90,508	90,324	90,283	90,264
330 mm	93,962	92,222	91,945	91,830	91,805	91,793
356 mm	93,962	93,044	92,891	92,827	92,813	92,806
381 mm	93,962	93,552	93,480	93,450	93,444	93,441
Slots:						
254 mm- 330 mm	93,962	89,624	88,892	88,587	88,519	88,487
280 mm- 356 mm	93,962	88,577	87,662	87,280	87,195	87,155
305 mm- 381 mm	93,962	87,434	86,356	85,910	85,810	85,763
Maximums:						
254 mm	93,962	91,101	90,555	90,322	90,270	90,245
280 mm	93,962	89,206	88,348	87,987	87,905	87,868
305 mm	93,962	87,640	86,570	86,126	86,026	85,980
330 mm	93,962	86,590	85,425	84,947	84,840	84,791
356 mm	93,962	86,091	84,900	84,413	84,305	84,255
381 mm	93,962	85,865	84,669	84,182	84,074	84,023

Harvest (number) for the lower James River:

Length Limit	Creel Limit					
	0	1	2	3	4	5
None	5,113	7,623	8,003	8,159	8,194	8,210
Minimums:						
254 mm	5,113	6,839	7,096	7,200	7,224	7,234
280 mm	5,113	6,369	6,556	6,633	6,650	6,658
305 mm	5,113	5,934	6,058	6,109	6,120	6,126
330 mm	5,113	5,581	5,656	5,687	5,694	5,697
356 mm	5,113	5,357	5,397	5,414	5,418	5,420
381 mm	5,113	5,221	5,240	5,248	5,250	5,251
Slots:						
254 mm- 330 mm	5,113	6,483	6,721	6,820	6,843	6,853
280 mm- 356 mm	5,113	6,813	7,109	7,233	7,261	7,274
305 mm- 381 mm	5,113	7,154	7,500	7,644	7,676	7,691
Maximums:						
254 mm	5,113	6,085	6,272	6,352	6,370	6,378
280 mm	5,113	6,646	6,926	7,045	7,071	7,084
305 mm	5,113	7,100	7,443	7,587	7,619	7,634
330 mm	5,113	7,394	7,765	7,918	7,952	7,968
356 mm	5,113	7,531	7,910	8,066	8,101	8,117
381 mm	5,113	7,592	7,973	8,129	8,164	8,180

Yield (kg) for the lower James River (2,978 ha):

Length Limit	Creel Limit					
	0	1	2	3	4	5
None	1,650	2,357	2,451	2,490	2,498	2,502
Minimums:						
254 mm	1,650	2,206	2,282	2,312	2,319	2,322
280 mm	1,650	2,083	2,143	2,167	2,172	2,175
305 mm	1,650	1,956	2,000	2,018	2,021	2,023
330 mm	1,650	1,834	1,863	1,874	1,877	1,878
356 mm	1,650	1,752	1,768	1,774	1,776	1,777
381 mm	1,650	1,699	1,706	1,710	1,710	1,711
Slots:						
254 mm- 330 mm	1,650	2,025	2,085	2,110	2,116	2,118
280 mm- 356 mm	1,650	2,100	2,172	2,202	2,209	2,212
305 mm- 381 mm	1,650	2,194	2,279	2,314	2,322	2,326
Maximums:						
254 mm	1,650	1,870	1,911	1,929	1,933	1,935
280 mm	1,650	2,032	2,099	2,127	2,133	2,136
305 mm	1,650	2,171	2,256	2,291	2,299	2,302
330 mm	1,650	2,272	2,365	2,402	2,411	2,415
356 mm	1,650	2,321	2,416	2,455	2,463	2,467
381 mm	1,650	2,345	2,440	2,478	2,487	2,490

Proportional Stock Density for the lower James River:

Length Limit	Creel Limit					
	0	1	2	3	4	5
None	0.1649	0.1503	0.1480	0.1471	0.1469	0.1468
Minimums:						
254 mm	0.1649	0.1548	0.1533	0.1527	0.1526	0.1525
280 mm	0.1649	0.1580	0.1570	0.1566	0.1565	0.1565
305 mm	0.1649	0.1607	0.1601	0.1599	0.1598	0.1598
330 mm	0.1649	0.1625	0.1622	0.1621	0.1620	0.1620
356 mm	0.1649	0.1637	0.1635	0.1634	0.1634	0.1634
381 mm	0.1649	0.1643	0.1642	0.1642	0.1642	0.1642
Slots:						
254 mm- 330 mm	0.1649	0.1573	0.1560	0.1555	0.1553	0.1553
280 mm- 356 mm	0.1649	0.1548	0.1530	0.1523	0.1521	0.1521
305 mm- 381 mm	0.1649	0.1525	0.1505	0.1496	0.1494	0.1493
Maximums:						
254 mm	0.1649	0.1593	0.1582	0.1577	0.1576	0.1576
280 mm	0.1649	0.1556	0.1539	0.1532	0.1530	0.1529
305 mm	0.1649	0.1528	0.1507	0.1498	0.1496	0.1495
330 mm	0.1649	0.1513	0.1490	0.1481	0.1479	0.1478
356 mm	0.1649	0.1506	0.1484	0.1475	0.1473	0.1472
381 mm	0.1649	0.1504	0.1481	0.1472	0.1470	0.1469

Utility Scores for the lower James River:

Length Limit	Creel Limit					
	0	1	2	3	4	5
None	0.20	0.19	0.19	0.18	0.18	0.18
Minimums:						
254 mm	0.20	0.19	0.19	0.19	0.19	0.19
280 mm	0.20	0.19	0.19	0.19	0.19	0.19
305 mm	0.20	0.19	0.19	0.19	0.19	0.19
330 mm	0.20	0.19	0.19	0.19	0.19	0.19
356 mm	0.20	0.20	0.20	0.20	0.20	0.20
381 mm	0.20	0.20	0.20	0.20	0.20	0.20
Slots:						
254 mm- 330 mm	0.20	0.19	0.19	0.19	0.19	0.19
280 mm- 356 mm	0.20	0.19	0.19	0.19	0.19	0.19
305 mm- 381 mm	0.20	0.19	0.19	0.19	0.19	0.19
Maximums:						
254 mm	0.20	0.19	0.19	0.19	0.19	0.19
280 mm	0.20	0.19	0.19	0.19	0.19	0.19
305 mm	0.20	0.19	0.19	0.19	0.19	0.19
330 mm	0.20	0.19	0.19	0.19	0.19	0.19
356 mm	0.20	0.19	0.19	0.19	0.18	0.18
381 mm	0.20	0.19	0.19	0.18	0.18	0.18