239
15

MODELLING TO COMPARE HARVEST REGULATIONS IN RECREATIONAL FISHERIES: CASE STUDY OF SMALLMOUTH BASS FISHERIES

by

Brian K. Wagner

Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Fisheries and Wildlife Sciences

APPROVED:

Donald J. Orth
Donald J. Orth, Chairman

Larry A. Nielsen
Larry A. Nielsen

Louis A. Helfrich
Louis A. Helfrich

February, 1991

Blacksburg, Virginia

MODELLING TO COMPARE HARVEST REGULATIONS IN RECREATIONAL FISHERIES: CASE STUDY OF SMALLMOUTH BASS FISHERIES

by

Brian K. Wagner

Committee Chairman: Donald J. Orth
Fisheries and Wildlife Sciences

(ABSTRACT)

Negative binomial distributions were fitted for ten sets of complete trip creel survey data from the New and Shenandoah Rivers in Virginia and West Virginia. The fits for eight of ten data sets were not significantly different from the observed distributions ($P < 0.05$). The negative binomial provids a good alternative when complete trip data are unavailable or unreliable; however it was still more accurate to use the observed frequency distributions.

An age-structured, non-linear population model employing instantaneous mortality rates was developed to compare the merit of various regulation schemes. Model outputs included parameters commonly measured in recreational fisheries management, including structural indices, catch, harvest, and yield. Eight creel limits (1-8 fish/angler-day) and ten length limits (six minimum limits, three slot limits, and no length limit) were simulated in all possible combinations. A catch-and-release scenario was also simulated, increasing the total number of simulations to 81. As a case study, data were used from the smallmouth bass fishery in a pool of the New River in West Virginia. Principal components analysis revealed that 91% of the total variation in the output variables among the 81 simulations was represented by the first three components. A set of seven variables maximized the differences among simulations: harvest (numbers), size harvested, catch (numbers), size caught, proportional stock density, relative stock density of trophy fish, and yield (weight). Model results for these individual variables revealed that, while harvest and yield were maximized by liberal scenarios, all other variables were improved by the more restrictive regulations. The results also indicate that minimum length limits have a much greater impact than creel limit reductions.

ACKNOWLEDGEMENTS

I am very grateful to my committee chairman, Dr. Donald J. Orth, for his patience, guidance, cooperation, and encouragement toward the completion of this study. The remaining members of my committee, Dr. Louis A. Helfrich and Dr. Larry A. Nielsen, have also exceeded the call of duty with their patience and cooperation and have provided much appreciated advise throughout the course of this study. I am also grateful to my new supervisor, Mr. Steve Filipek, and to the administration and personnel of the Arkansas Game and Fish Commission's Fisheries Division for their interest, encouragement, and administrative support that served to maintain my drive to complete this study. Partial funding for this study was provided by the Virginia Department of Game and Inland Fisheries, which was greatly apppreciated.

A modelling study such as this relies heavily on the availability of data collected by others. I am particularly grateful for the use of data provided by G.E. Lewis, B. E. Pierce, and J. E. Reed, Jr., of the West Virginia Department of Natural Resources, J. Kauffman of the Virginia Department of Game and Inland Fisheries, and Dr. Michael J. Roell of the Missouri Department of Conservation.

TABLE OF CONTENTS

page

TABLE OF CONTENTS (continued)

page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

General Introduction

Many of the world's most valuable commercial and recreational fish stocks have been overexploited. With the increasing number and sophistication of anglers, it is becoming necessary to control harvest in order to maintain the quality of fisheries. As a step in this direction, management agencies are becoming increasingly receptive to novel regulation schemes. The setting of such regulations requires consideration of many facets of the biology of the fish stock in question. Attention must also be given to human impacts on the stock through angling and other activities.

Unlike commercial fisheries, the harvest or effort can't be directly controlled in recreational fisheries. Recreational fisheries can't be closed once a certain harvest is attained, nor can a limit usually be placed on the number of anglers or the amount of time that they fish. The most commonly used controls on harvest in recreational fisheries are season closures, length limits, and creel limits.

Historically, the pendulum of fisheries management philosophy has swung between restriction and liberalization (Redmond 1986). Future trends in harvest regulation will likely include novel approaches to harvest regulation. North Carolina has implemented regulations with variable creel limits based on size. Arkansas is considering using a slot length limit with differing creel limits above and below the slot on trophy largemouth bass lakes (Mike

Armstrong, personal communication). Bennett Springs, a put-and-take trout fishing area in southern Missouri, operates March through October with a daily creel limit of five trout per angler. Since 1980 catch and release fishing for trout has been allowed on weekends during December through February (Hicks et al. 1983). The problem that arises is that with increasingly complex regulation schemes it becomes impossible to infer appropriate regulation schemes from empirical evidence.

The construction of models can help us to understand and predict the response of a complex fishery to alternative regulation schemes. One definition of a model is " a tentative ideational structure used as a testing device" (Morris 1980). This definition fits well the use of models in fisheries. Models provide us a structure, the fishery, represented theoretically, that can be used as a device to test novel management approaches without jeopardizing the fishery. They also allow for screening of natural variability that would make the results more difficult to interpret through field studies. If a simulation model of the fishery can be created that mimics the natural situation acceptably, different sets of regulations can be applied while other factors are held constant. Thus the fishery manager can compare the possible impact of various regulation schemes on the fish population prior to field implementation.

Models have been applied toward several diverse goals in fisheries. They have helped to increase our knowledge about basic biology of unusual species (Hughes 1983), assess the impacts of instream flow variation (Williams 1984), predict recruitment (DeAngelis and Coutant 1979, Gutreuter and Anderson 1985), investigate multi-species interactions (Zuboy and Lackey 1975), analyze trophic relationships (Ploskey and Jenkins 1982), predict the impacts of commercial harvest (Hampton and Majkowski 1986), and simulate recreational exploitation.

The construction of models, in addition to increasing our understanding of population and ecosystem dynamics, can help management agencies to make better decisions. Generally, this has not been done. The limited use of models in fisheries decision making can be attributed to lack of communication between modelers and managers and difficulties in interpreting model results. A notable exception involves the salmon fisheries of British Columbia (Hilborn et al. 1984). This is an instance in which modelling has been applied to formal policy analysis. The model, which incorporates both commercial and recreational harvest, is described by Argue et al. (1983). Hilborn et al. (1984) note that it is important to spend a large portion of model development time making the ultimate user of the model comfortable with the results. This instills confidence in the results and makes it more likely that the model will be used. They found that such a quantitative model was highly beneficial because it provided clarity of assumptions, speed of analysis, a common ground for discussion, a repository for a biologist's knowledge and understanding (making it easier for a new biologist to take over), and easier evaluation of new policies.

A few models have been developed to compare different length limit regulations. Clark et al. (1980) developed such a model for a trout stream fishery and later (Clark 1983) used it to project the potential effects of catch-and-release regulations on the fishery. Taylor (1981) developed an age-structured model addressing length limits and season closures which has been subsequently applied to largemouth bass populations in reservoirs (Zagar and Orth 1986). A further adaptation of Taylor's approach was demonstrated by Rieman and Beamesderfer (1990). These models allow for variable length limit regimes, but do not address the question of creel limit regulations.

In general, most models ignore creel limits, assuming that they have little effect on harvest, but simply serve to redistribute the harvest and make it more equitable. This seems like an unrealistic assumption, since clearly in the extreme (ie. catch-and-release) a creel limit will have a severe impact on harvest. No existing model allows for the consideration of changes in creel limit regulations with the exception of catch-and-release. In addition, most available models measure the success of a management scheme by the total yield from the fishery. While this may be appropriate in a commercial fishery, it is usually not in recreational fisheries. There are other factors that affect the overall quality associated with the recreational fishing experience, such as aesthetics, sporting challenge, and the species and size of fish caught (Lackey 1978). A very important factor in the perceived quality of a fishery is the production of trophy fish. This is discussed in relation to size limits by Jensen (1981) in a model based on the Beverton and Holt (1957) yield equations.

While this study can not hope to create a model capable of predicting the impacts of all the different possible size and season dependant creel limit regulations, it does propose some basic methodologies that may be employed in future studies toward this end. Chapter 1 explores the use of the negative binomial distribution as a theoretical model of angler daily harvest. In Chapter 2 a general model is developed to simulate the effect of combined length and creel limit regulations. The smallmouth bass fishery in a pool of the New River, West Virginia is used a case study. The results of this case study are thoroughly analyzed and compared to field studies.

CHAPTER 1

The Negative Binomial Distribution to Characterize Angler Harvest in Smallmouth Bass Fisheries

Introduction

The smallmouth bass has become an increasingly popular sport fish due to its reputation as a strong fighter and increased interest in stream fishing. The number of streams available is limited, and many are being adversely impacted by human activity, which results in limited availability and a potential for overexploitation.

In order to prevent overexploitation and realize all the benefits from these fisheries, it is often necessary to control harvest with regulations such as length limits, season closures, gear restrictions, catch-and-release, or creel limits.

Creel limits can be used to reallocate harvest more equitably and generate an overall reduction in harvest. Catch-and-release regulations have become more popular, especially in wild trout fisheries (Barnhart and Roelofs 1977). Similar results could be achieved through restrictive creel limits that would still allow limited harvest. Advantages of creel limits include possible angler preference over other forms of regulation and ease of enforcement (Chipman and Helfrich 1988). However, creel limits have proved unacceptable to anglers in some fisheries (e.g. Renyard and Hilborn 1986).

To predict the result of reducing the creel limit on a fishery, it is necessary to estimate the distribution of harvest per angler. Creel surveys are a common means of collecting harvest information in recreational fisheries (e.g. Funk and Fleener 1974, Austen and Orth 1984, Paragamian 1984a). The frequency distribution of the number of fish harvested per angler-day can be estimated from complete trip creel survey data. This frequency distribution can be used to predict the effect of a change in the creel limit by censoring the distribution of number of fish harvested per angler-day (Figure 1). Censoring is achieved by transferring all anglers that, if unregulated, would have harvested beyond the limit into the group that harvested exactly the limit. The censoring approach was evaluated in detailed simulations by Porch (1988), who found it to consistently underestimate catch. However, the bias was less than 15% in all cases except when the variance was unrealistically large compared to the mean. This approach assumes that there is no illegal harvest, the limit does not act as a goal that competitive anglers strive to achieve, and angling effort and effectiveness is unaffected by the change. None of these assumptions can be addressed quantitatively at this time.

Highly successful fishing trips are a rare event. Rare events often follow a Poisson distribution, but this distribution assumes a uniform probability of success. This is likely not the case since there is great variation in the skill level of anglers. The negative binomial distribution (Figure 2) is a generalized form of the Poisson (Williamson and Bretherton 1963, Pielou 1977). The negative binomial allows the mean to take on values less than the variance, whereas the Poisson assumes that the mean is equal to the variance of the distribution. Elliott (1977) referred to the negative binomial as the most useful model for phenomena that exhibit contagious distributions. The negative binomial distribution has been used frequently in fisheries, including for the evaluation of creel limits as detailed by Porch (1988).

The use of a generalized form of harvest distribution would allow for a great reduction in the number of parameter estimates needed, and for approximation of distributions in fisheries where harvest data were unavailable. Through this study we hoped to evaluate the utility of the negative binomial distribution as a generalized distribution for daily angler harvest. Additionally, a theoretical approach was used to predict the reduction in harvest and proportion of anglers affected by creel limit reductions.

Methods

Data sets from complete trip creel surveys on the New and Shenandoah Rivers in Virginia and West Virginia were obtained from the Virginia Department of Game and Inland Fisheries and the West Virginia Department of Natural Resources (Table 1, Appendix A). Survey methods were described in Pierce et al. (1981), Lewis (1985), and Kauffman and Smith (1987). All stream sections were governed by an eight-fish-per-day creel limit, which was felt to have no significant impact on total harvest. Fishing was otherwise unregulated, with the exception of harvest in sections B and C of the Shenandoah River, Virginia (Kauffman and Smith 1987), which was restricted by a 280 to 330 mm slot length limit. Frequency distributions of harvest were calculated for each of the 10 data sets obtained. Harvest means were compared between the two river systems using Welch's approximate t-test for comparing means with unequal variances.

The probability density function for the negative binomial is (Williamson and Bretherton 1963):

$$P(x) = \left|1+\frac{u}{k}\right|^{-k} \frac{(k+x-1)!}{x!(k-1)!} \left|\frac{u}{u+k}\right|^{x} \qquad (1)$$

where:

x represents a given number of fish harvested per angler-day,
P(x) is the probability of x daily harvest,
u is the mean daily harvest per angler, and
k is a parameter inversely related to the degree ofdispersion.

This equation can not be evaluated for non-integer values of k, which are likely to occur. This problem can be overcome using the following properties of Gamma functions (Walpole and Myers 1989):

$$\text{Gamma}(n) = (n-1)! \text{ for any integer, } n, \text{ and} \qquad (2)$$

$$\text{Gamma}(x) = (x-1)\text{Gamma}(x-1). \qquad (3)$$

Equation 1 can be modified by reversing the property given in equation 2, since factorials are only defined for integers, giving the new equation:

$$P(x) = \left|1+\frac{u}{k}\right|^{-k} \frac{\text{Gamma}(k+x)}{x!\text{Gamma}(k)} \left|\frac{u}{u+k}\right|^{x} \qquad (4)$$

The property in equation 3 can then be applied, giving:

$$P(x) = \left|1+\frac{u}{k}\right|^{-k} \frac{(k+x-1)\text{Gamma}(k+x-1)}{x!\text{Gamma}(k)} \left|\frac{u}{u+k}\right|^{x} \qquad (5)$$

This property can be applied repeatedly until the term '(k)Gamma(k)' is attained:

$$P(x) = \left|1+\frac{u}{k}\right|^{-k} \frac{(k+x-1)\ldots(k)\text{Gamma}(k)}{x!\text{Gamma}(k)} \left|\frac{u}{u+k}\right|^{x} \qquad (6)$$

And the Gamma(k) terms cancel giving:

$$P(x) = \left|1+\frac{u}{k}\right|^{-k} \frac{(k+x-1)\ldots(k)}{x!} \left|\frac{u}{u+k}\right|^{x} \qquad (7)$$

Since (k+x-1) could become negative when x=0, this equation was evaluated for values of x from 1 to 8. the results were then summed and subtracted from 1 to give a frequency for the 0 group.

In order to fit a negative binomial distribution to the data, u, the arithmetic mean of the data, and k were estimated iteratively (Elliott 1977). A listing of the computer program used is provided as Appendix B and sample input and output as Appendix C.

Because a limit of eight-fish-per-day limit was in effect for all fisheries surveyed, there were no reliable data for greater harvests. Therefore, because observations were missing from the high end of the distribution, the arithmetic mean was an underestimate of the mean of the complete distribution. To correct for this underestimation, the estimated mean was increased by an increment of 0.01 and the distribution refit until an improved fit to the observed distribution was achieved based on the chi-square goodness of fit test (Snedecor and Cochran 1967).

The hypothesized negative binomial distribution was used to calculate the expected frequency of anglers harvesting the various numbers of fish per day. When the expected value in any group was less than five, adjoining groups were combined until expected values were greater than five in all groups to meet chi-square testing requirements.

Results

Angler success was quite variable among the ten data sets analyzed (Table 2). Mean harvest ranged from 0.2 to 2.5 fish per angler-day. Harvest rates were not significantly different between the two rivers (Welch's Test, $P > 0.05$).

Empirical frequency distributions were similar in form. The zero-fish-per-day group (i.e. unsuccessful anglers) was the most frequent group (Table 1). After the peak, the distribution declined rapidly until frequencies became quite low and the decline became progressively slower, similar to the negative binomial distribution (Figure 2).

Estimates of the dispersion parameter, k, were also quite variable (Table 2), ranging from 0.06 to 0.35. These values were low considering this parameter can theoretically take on any value less than the mean. This indicates a high degree of dispersion in all cases. As with harvest, there was no significant difference between estimates of k for the two rivers (Welch's Test, $P > 0.05$). There was a strong relationship between the estimated k and the harvest ($k = 0.0762 + 0.1113u$, $r = 0.93$, $P < 0.005$) (Figure 3).

In eight of the ten cases, there was no significant difference ($P < 0.05$) between the estimated and empirical distributions (Appendix D). The two that were significantly different were among the three data sets exhibiting the highest mean harvests. In both cases the observed distribution had a much lower frequency in group-0 than the negative binomial predicted.

Using the empirical distribution, decreasing the creel limit from 8 to 3 fish resulted in an average harvest reduction of 22% (SD = 4.26); the average reduction was 16% (SD = 3.04) using the negative binomial. Decreasing from 8 to 1 yielded an average reduction of 60% (SD = 4.63) and 46% (SD = 5.91) using the empirical data and the negative binomial, respectively. In all but one case, use of the estimated negative binomial distribution yielded a lower reduction than the empirical frequency distribution (Table 3), resulting the bias being greatest for the larger reductions in creel limit.

Discussion

Success rates were highly variable within each study stream, but similar to the wide range of those found in smallmouth bass fisheries (e.g. Fajen 1981, Austen and Orth 1984, Serns 1984).

The empirical data presented showed a strong similarity to the negative binomial distribution, fitting the observed distribution well in eight of the ten cases. Estimates of the dispersion parameter, k, were confined to a narrow range, and were strongly correlated with the mean harvest. This would allow for rough estimation of a negative binomial distribution if an estimate of mean harvest was available. Such an approach would be useful when complete-trip creel survey data were unavailable.

The two cases where there was a significant difference between the empirical data and the negative binomial distribution were among the three with the highest mean daily harvest. In these cases it is likely that the best fitting negative binomial distribution might extend well beyond eight with noticable frequencies. Since the predicted frequency in the zero group was calculated by subtracting the total of the other frequencies from one, failure to deduct for significant frequencies beyond eight could lead lead to an inflated prediction for the zero group. All of the data sets used presented harvest based on parties rather than individual anglers, and individual data points in some cases had to be partitioned from total party harvest. This may well result in empirical distributions where the zero group frequencies are artificially depressed and the lower (but non-zero) harvest groups exhibit increased frequencies. It is clear that the failure of the negative binomial to fit well in two cases could be explained as a combination of these two factors that would lead to divergence of the zero frequency group.

The mean of the distribution can easily be seen to represent the success rate in a fishery - the mean harvest per angler-day. The meaning of the dispersion parameter, k, is less evident. When k is low, dispersion is high and success varies more widely on an individual basis. Thus, k may be related to the homogeneity of the angling population or other condition affecting angling success. When k is high, the population is more uniform, being composed of anglers with similar levels of success. Correspondingly, when k is low there is much variation within the angling population. Another possibility is that k is related to dispersion of the fish population. When k is high, fish populations are likely to be randomly dispersed and success is more homogenous, while at low values of k, the fish are more clustered and success rates more variable.

The homogeneity of the angling population can be used as a basis for speculation to explain the apparent relationship between k and the mean. It is likely that there is always a component of anglers of low specialization present in these unrestricted fisheries. These would be mostly unselective anglers seeking to catch fish to eat. The occurrence of more highly specialized anglers, who fish primarily for sport and enjoyment, would decrease both the mean harvest and the homogeneity of the angling population.

The distributions of daily angler harvest were used to predict the effect of reducing the creel limit. Due to low numbers of anglers harvesting large numbers of fish, the reduction in creel limit would need to be severe to have a significant impact on harvest and thus on fishing mortality. However, the reduction would impact a relatively small portion of the anglers in a fishery. In the empirical example illustrated in Figure 1, reduction of the creel limit from 8 to 1 fish per angler-day would reduce harvest by nearly 60%, yet the regulation would affect only 10% of the angler-days in the fishery. Therefore, creel limits may be a restriction that can have a positive effect on fishing success and yet have a minimal impact on the angling population.

Obviously, there are additional biological, sociological, economic, and political concerns to address before creel limits are changed. Is the prey base available to support acceptable growth if the density of fish is increased? Would some form of natural mortality compensate for the reduced fishing mortality? Would hooking and handling mortality of released fish render the reduction less effective? Would the new limit be acceptable to the angling public? Would better results be achieved by using another regulatory approach in combination with the creel limit or alone? Adding an 'artificials-only' regulation might help to reduce the problem with hooking mortality. What impact would the increased density of smallmouth bass, if achieved, have on other fisheries present in the stream?

Creel limit reductions carry the benefits of being simple, easy to understand, and convenient. The use of the negative binomial distribution appears useful in assessments of the potential impact of creel limit reductions on harvest and anglers. When compare to empirical data to which it was fit, the negative binomial distribution slightly underestimates harvest reduction due to creel limit reduction. The level of this bias is greatest when considering larger reductions in creel limit.

TABLES: CHAPTER 1

Table 1: Frequency distributions of smallmouth bass harvest per angler-day from creel surveys on the New and Shenandoah Rivers in Virginia and West Virginia. Site numbers designate the following sites- 1 Upper, New R., WV, 1980; 2 Bluestone Dam to Hinton, New R., WV, 1980; 3 Hinton to Sandstone Falls, New R., WV, 1980; 4 Shenandoah R., WV, 1985; 5 Section A, Shenandoah R., VA, 1984; 6 Section A, Shenandoah R., VA, 1985; 7 Section B, Shenandoah R., VA, 1984; 8 Section B, Shenandoah R., VA, 1985; 9 Section C, Shenandoah R., VA, 1984; and 10 Section C, Shenandoah R., VA, 1985.

Harvest per Angler-day	Site Number									
	1	2	3	4	5	6	7	8	9	10
0	0.791	0.828	0.662	0.454	0.904	0.847	0.384	0.750	0.746	0.833
1	0.083	0.084	0.123	0.288	0.044	0.080	0.150	0.090	0.098	0.073
2	0.067	0.034	0.095	0.102	0.017	0.025	0.177	0.061	0.035	0.021
3	0.017	0.015	0.050	0.070	0.010	0.016	0.082	0.040	0.035	0.026
4	0.021	0.011	0.028	0.040	0.007	0.013	0.085	0.028	0.028	0.013
5	0.004	0.011	0.017	0.021	0.007	0.016	0.031	0.009	0.031	0.017
6	0	0.009	0.014	0.005	0	0.003	0.041	0.009	0.010	0.013
7	0.013	0.004	0.007	0.009	0.003	0	0.031	0.009	0.003	0.004
8	0.004	0.004	0.005	0.012	0.007	0	0.020	0.002	0.014	0

Table 2: Mean daily harvest per angler of smallmouth bass and estimated dispersion coefficients (k) of the negative binomial distribution.

Section, River, State, and Year	Mean harvest /angler-day	est. k
Upper, New R., WV, 1980	0.55	0.15
Bluestone Dam to Hinton, New R., WV, 1980	0.44	0.12
Hinton to Sandstone Falls, New R., WV, 1980	1.00	0.23
Shenandoah R., WV, 1985	0.99	0.18
Section A, Shenandoah R., VA, 1984	0.23	0.06
Section A, Shenandoah R., VA, 1985	0.29	0.14
Section B, Shenandoah R., VA, 1984	2.52	0.35
Section B, Shenandoah R., VA, 1985	0.72	0.17
Section C, Shenandoah R., VA, 1984	0.94	0.14
Section C, Shenandoah R., VA, 1985	0.45	0.11
Means-	0.81	0.17

Table 3: Predicted percent harvest reductions based on the empirical frequency distributions (EFD) and the fitted negative binomial distributions (NBD) for reductions in creel limit from 8 to 3, and from 8 to 1 fish per angler-day.

	8 to 3		8 to 1	
Section, River, State, and Year	EFD	NBD	EFD	NBD
Upper, New R., WV, 1980	20.3	17.6	57.6	51.6
Bluestone Dam to Hinton, New R., WV, 1980	23.6	16.7	58.1	49.4
Hinton to Sandstone Falls, New R., WV, 1980	18.8	19.9	59.3	54.1
Shenandoah R., WV, 1985	16.8	13.5	52.7	35.1
Section A, Shenandoah R., VA, 1984	27.4	13.8	61.6	42.0
Section A, Shenandoah R., VA, 1985	16.5	10.5	53.4	39.6
Section B, Shenandoah R., VA, 1984	26.5	19.3	67.0	45.8
Section B, Shenandoah R., VA, 1985	19.7	18.4	60.6	51.0
Section C, Shenandoah R., VA, 1984	27.8	19.1	65.6	48.5
Section C, Shenandoah R., VA, 1985	23.5	16.2	61.8	46.3

FIGURES: CHAPTER 1

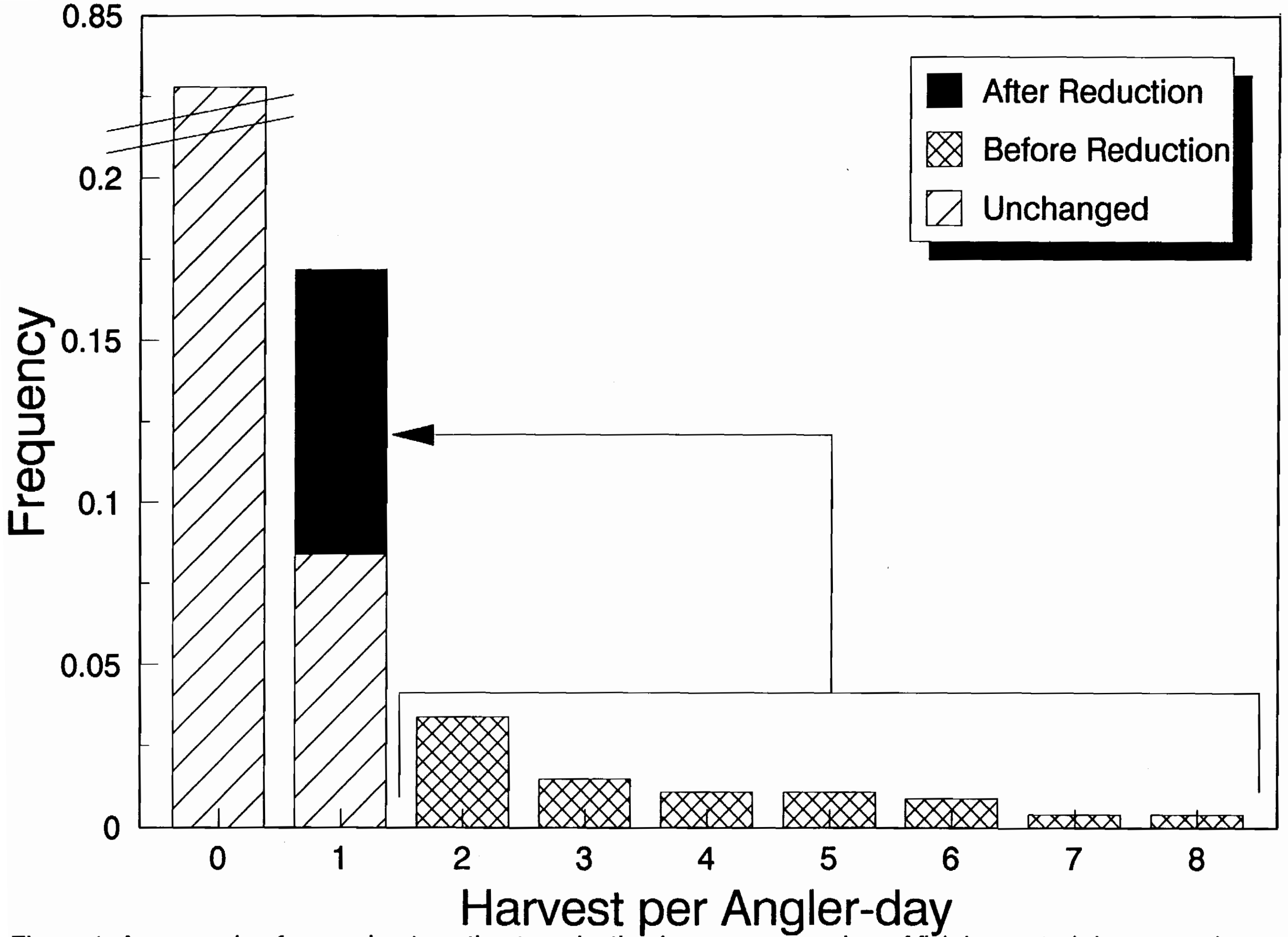


Figure 1: An example of censoring to estimate reduction in mean number of fish harvested due to creel limit reduction. Frequency distribution based on New R., Bluestone Dam to Hinton, WV.

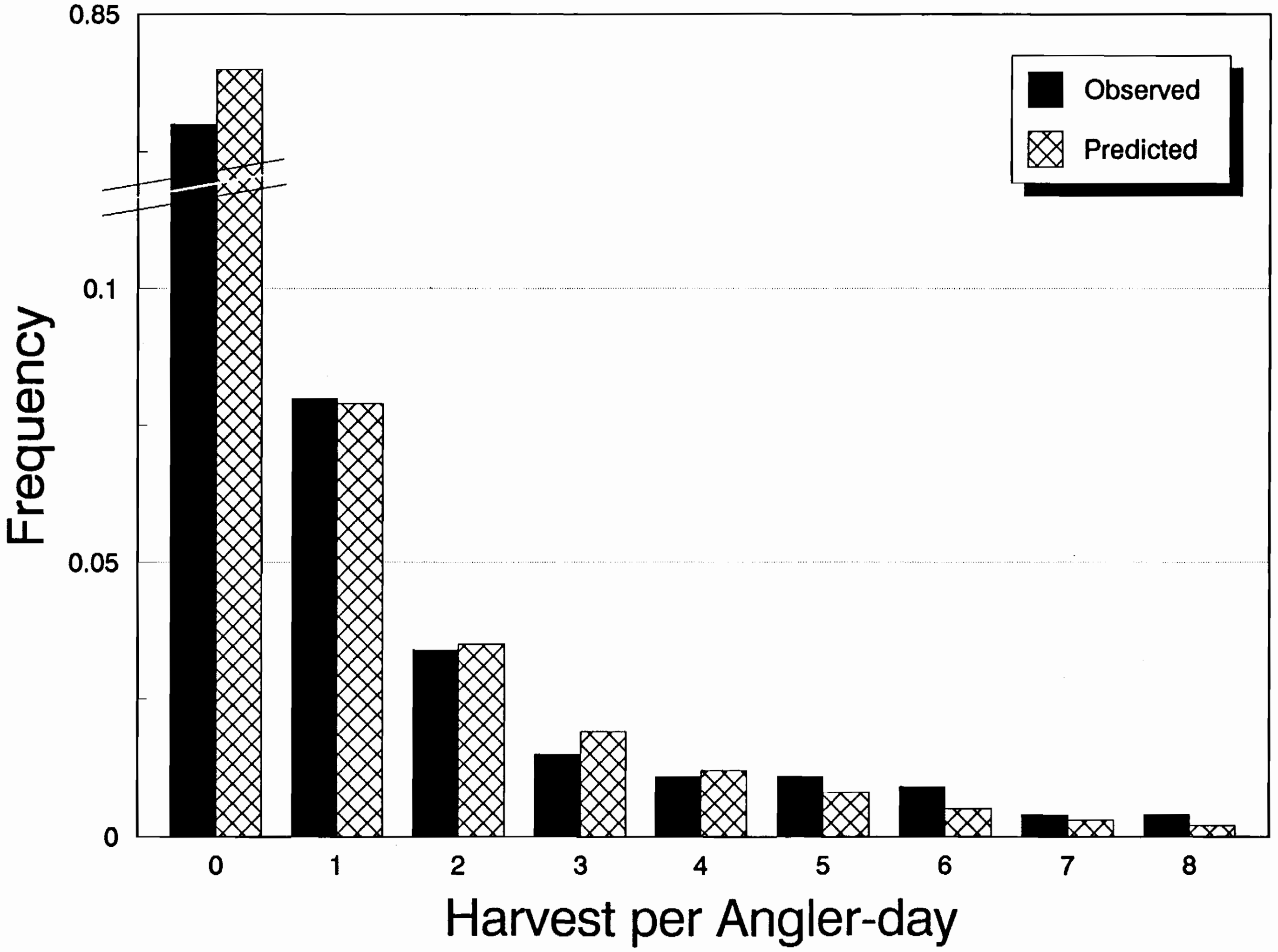


Figure 2: An example of a frequency distribution of daily number of fish harvested per angler. Data from New R., Bluestone Dam to Hinton, WV.

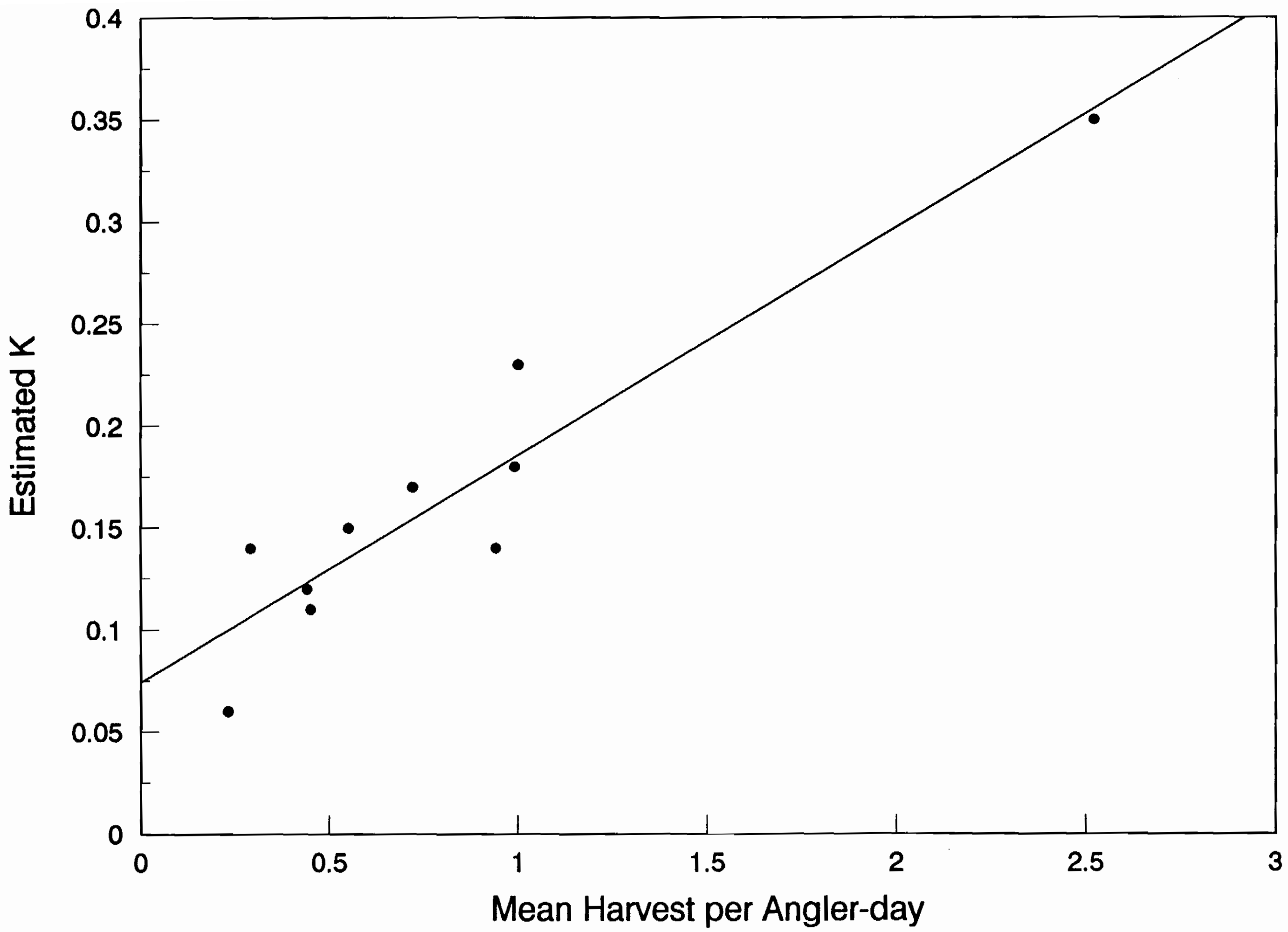


Figure 3: Relationship between mean harvest per angler-day and estimated dispersion coefficient, k, for 10 smallmouth bass fisheries.

CHAPTER 2

Simulation for Evaluating Combined Regulation Schemes in Recreational Fisheries

Introduction

Length limits are commonly used to restrict harvest or protect a specific size class that is of critical importance for reproduction or predatory control of other species. Clark et al. (1980) and Smith (1981) developed models to simulate various length limit regulations for trout and bluegill fisheries, respectively. Length limits also played a major role in Taylor's (1981) general inland fishery simulator (GIFSIM), which has been modified and applied by other researchers (Zagar and Orth 1986, Rieman and Beamesderfer 1990). Many of these models share simplifying assumptions that affect their general applicability, including constant growth independatn of density (Walters 1969, Clark et al. 1980, Jensen 1981, Taylor 1981, Clark 1983), absence of hooking mortality (Walters 1969, Jensen 1981, Taylor 1981), no size selection by anglers (Walters 1969, Clark et al. 1980, Jensen 1981, Smith 1981, Clark 1983), and no voluntary catch and release (Walters 1969, Clark et al. 1980, Jensen 1981, Smith 1981, Taylor 1981).

Creel limits are the most commonly applied regulations in recreational fisheries. Such regulations are more acceptable to some anglers than more restrictive length limits (Chipman and

Helfrich 1988) and thus are politically attractive. However, in modelling efforts creel limits have been ignored. The degree to which any such limit will benefit a fishery depends on the probability that released fish will survive. Some models allow for mortality due to the hooking of released fish (Clark 1983, Waters and Huntsman 1986).

In order to evaluate the comparative merit of different combinations of length limits and creel limits a theoretical model was developed. To maximize potential for application, the model needed to be simple, generalized, and computer implemented. In order to be realistically useful, it employs data commonly collected in addition to that which can be hypothesized from the literature, and provides for density dependent interactions. These factors were well addressed in Taylor's (1981) generalized inland fishery simulator (GIFSIM). The problem with Taylor's approach is that it uses expectations which are more cumbersome to work with than instantaneous rates. Other researchers have employed instantaneous rates (ie. Walters 1969, Clark et al. 1980, Jensen 1981, and Clark 1983).

In this study a model was created that provides a generalized approach similar to that of Taylor (1981) while employing instantaneous rates as most previous studies have. The advantage of this model's approach over previous studies is that it allows for regulation schemes that combine two harvest restrictions, length limits and creel limits.

This model is demonstrated based on the smallmouth bass fishery of the New River in West Virginia. This fishery is described in detail by Austen (1984) and Roell and Orth (1987).

Methods

An age structured, non-linear, population model employing instantaneous mortality rates was developed to compare the merit of various regulation schemes. This mathematical model was implemented as a PASCAL program on an IBM-compatible personal computer. In general, population parameters are provided as input to a population model. The population model incorporates reproductive parameters, density dependant first year survival, and instantaneous rates of fishing, hooking, and natural mortality. Simulated regulation changes impact the rates of fishing and hooking mortality. The model produces output statistics commonly used by fisheries managers. This model is depicted diagrammatically in Appendix E along with a more detailed representation of the population model which may help to clarify the model description.

Model Description

The change in numbers of fish in each cohort during a year was calculated based on mortality, growth, and number in the cohort at the end of the previous year as shown in equation 4 of Table 4 (based on Walters 1969). The number of fish recruited to age-1 each year was determined by number in the previous year's age-0 group (equations 1, 2) and the survival of age-0 fish. Age-0 survival was density dependent (equation 3) as described by the Beverton and Holt stock-recruitment function (Ricker 1975).

The production of age-0 fish, or larvae, was calculated based on egg production and hatching success (equation 1): egg production by cohort was the product of numbers, proportion of females, maturity rate, and mean fecundity of mature females of the given age (equation 2). Each simulated year began at the time of hatching of young-of-year fish. At this time each cohort was shifted to the next higher age group. Thus the cohort was assumed to have the mean length that was entered for the age group. Growth in weight was based on the length-weight regression. The mean length for each was entered into the length-weight regression and the resulting weight was used as the mean weight for the age group. Using mean length to predict mean weight in this manner introduced some error (Nielsen and Schoch 1980). Since the coefficients of variation for length at age were less than 0.10 at all ages beyond 1 with a length-weight exponent of less than 3, this error was small.

The impact of reduced creel limits was to reduce fishing mortality by a constant proportion over all ages. The predicted reduction in harvest (table 8) was based on creel survey data from the New River in West Virginia (Pierce et al. 1981) following the censoring procedure discussed in Chapter 1. This reduction was subtracted from one to get the proportion of harvest remaining. This proportion was used as the modification factor for the creel limit reduction. Based on the conclusions in chapter 1 of this document, it is more desirable to use actual data such as these rather than a theoretical distribution, when such data are available.

The reduction in fishing mortality due to length limits is a more complex modelling endeavor. The lower length associated with the length limit's protected range was standardized by subtracting the mean length for the given age and dividing by the standard deviation (Table 4, equation 8) to give the lower z-score. The upper length associated with the protected range was treated likewise (Table 4, equation 9) to give the upper z-score. These z-scores were then compared to a standard normal table to determine the probability of a higher value than each z-score. The probability of a higher value than the upper z-score was subtracted from the probability of a higher value than the lower z-score to get the probability of a value being between the two, or the probability of being within the protected range (Table 4, equation 7). The probability of being within the protected range represents the proportion of the given age group that will be protected by the length limit. This proportion was subtracted from one to give the proportion of the age group still subject to harvest, which is used as the modifying factor due to the length limit.

The modifications due to each of these types of regulations were then applied to the fishing and hooking mortality rates.

This was relatively simple since instantaneous rates were used. The initial fishing mortality rate was multiplied by the modification factors for the creel limit and length limit to yield the new rate of fishing mortality. Since the only fish subject to hooking mortality are those that can no longer be harvested due to the regulations, the hooking mortality rate is multiplied by 1 minus the product of the two modification factors. One problem that this approach induces is that the two harvest reduction factors are applied independently. In actuality, the reduction in harvest under a length limit would lessen the impact a creel limit would have. Thus, combining regulations in this model would result in over estimating the reduction in harvest.

The catch as numbers was calculated from Baranov's catch equation as in equation 20 (Ricker 1975). Yield as weight was then calculated based on catch and the length- weight regression (equation 21).

A listing of the PASCAL program used is provided as Appendix F.

Model Input Parameters

Initial model parameters were based on previous studies. Whenever possible, values were based on actual data from the New River in West Virginia (Roell and Orth 1987). The study area simulated had an area of 61.65 hectares.

Mortality (Table 5)

A maximum potential hooking mortality rate of 0.2 was used for all ages. Roell and Orth (1987) estimated total mortality for this smallmouth population, and this was held constant for simulated ages 1 through 15. A value of 20% was assumed as constant natural mortality for ages 2 through 15; it was assumed that age-1 smallmouth would not be harvested, and thus assigned all mortality for this age to natural mortality. Forney (1972) observed a maximum age of 18 for smallmouth in Lake Oneida, New York. A maximum of 15 for the New River was considered reasonable, since in warmer climates organisms often grow faster but have shorter life-spans. Thus mortality rates were increased to maximum levels after that age.

Parameters of the first year survival equation were fit based on data from Courtois Creek, Missouri (Pflieger 1966) and Roell and Orth's (1987) biomass model day-1 abundances. This resulted in a maximum recruitment of 16,666.

Reproduction (Table 6)

Carlander (1977) reported that most smallmouth mature at ages 3 to 4. Based on this we assigned all female fish age 0 to 2 as immature, all age 5 and older mature, and ages 3 and 4 as a mixture of mature and immature. In the absence of data to the contrary, a sex ratio of 1 to 1 was assumed. Egg potential (fecundity) by age and hatching success rates were estimated by Clady (1975).

Population Parameters (Table 7)

Those parameters specific to the New River population were obtained from Roell and Orth (1987). These included number at age, mean and standard deviation of length at age, and coefficients of the length-weight regression.

The model was run and initial parameters were fine tuned to provide stable age structure through deterministic simulation (no random variability in recruitment) under the initial scenario of no length limit and an eight fish per day creel limit. After 50 years of simulation, numbers in each age group had become constant throughout the maximum number of digits of precision available in the program (11 digits). Based on this, all subsequent simulations were run for 50 years to ensure that stability had been attained, and the year-50 results used to represent that scenario.

Model Outputs

Model output was generated on a yearly basis, but only the year- 50 results were used for analysis. The output represents the population immediately after the year's spawn hatches: age-0 fish are larvae and all other ages are promoted by one year. Outputs by age included numbers, harvest, yield, and catch. Other outputs included mean age and length caught; mean age and length harvested; and totals for parameters partitioned by age.

Proportional stock density (Anderson 1976) and various relative stock densities (equations 10-19) (Gabelhouse 1984) were also output. These were calculated by partitioning the number in each age group among the length categories defined by Gabelhouse (1984). Partitioning was achieved by assuming a normal distribution of lengths at each age with the given mean and standard deviation. The minimum length for stock size (180 mm) was standardized by subtracting the mean length for the given age and dividing by the standard deviation. The resulting value was compared to a standard normal table to determine the probability of a fish of the given age being stock size or larger. This probability represents the proportion of individual fish in the age group that were stock size or greater, and when multiplied by the number of fish in the age group gives the number of stock size and greater fish in the age group. This procedure was then repeated for each age group and the total number of fish stock size and larger was determined by totalling the numbers for each age group. This entire procedure was then repeated for quality (280 mm), preferred (350 mm), memorable (430 mm), and trophy (510 mm) size classes. Proportional stock density (PSD) and the various relative stock densities (RSD's) were then generated by using these numbers in equations 10 - 19 of Table 4.

A sample output is provided as appendix G.

Simulations

Combinations of various length and creel limits were simulated. Creel limits ranged from 8 (existing regulation, assumed equivalent to no regulation) to 0 (catch-and-release). Length limit regulations included minimums of 254, 279, 305, 330, 356, and 381 mm; protected slot limits of 254 - 330, 279 - 356, and 305 - 381 mm; and no length limit. All possible combinations of these creel and length limits were simulated, except that catch-and-release was only simulated once since length limits would be irrelevant when no harvest was allowed. This resulted in a total of 81 scenarios that were simulated.

Principal Components Analysis

It was realized that most of the output parameters were correlated and would respond to regulation changes in a similar manner. The number of variables for analysis could be reduced by eliminating variables that respond in a similar manner. This would result in a small set of variables that provide the maximum statistical difference between the scenarios. In order to achieve this, results of the deterministic simulations were submitted as raw data to multivariate analysis using the SAS principle components procedure (SAS 1982) using the correlation matrix. All factors with eigenvalues of one or greater were retained for interpretation. Initially, eight summarizing variables; mean age caught, mean length caught, mean age harvested, mean length harvested, total population, number caught, number harvested, and yield; and all 8 population structural indices (PSD, RSDp, RSDm, RSDt, RSDs-q, RSDq-p, RSDp-m, and RSDm-t) were entered into the procedure. The set of variables utilized was repeatedly reduced to obtain the minimum set of variables that adequately represent the variation among the scenarios.

Utility Function

A utility function provides a combination of several decision variables into a single statistic that can be compared among scenarios. The optimal scenario would provide a compromise between scenarios that best benefit different measures of the fishery. We employed a linear combination of the variables identified by the principal components analysis as giving the maximum statistical difference between the scenarios. These variables were given equal weighting, and each scaled to range between 0 and 1 based on the observed range of values in the simulations, with 0 representing the minimum and 1 representing the maximum values observed over all scenarios simulated. This approach is represented in the general equation:

$$U = \sum_{i=1}^{n} \left(a(i) \left(\frac{v(i) - \min(i)}{\max(i) - \min(i)} \right) \right)$$

where:

a(i) = weighting factor for variable i,
v(i) = value of variable i,
min(i) = minimum value for variable i, and
max(i) = maximum value for variable i.

It should be stressed that this simply serves as an example. In actual utility function application, variables would be selected and weighted bases on management objectives and utilities assigned to values corresponding to their desirability. More elaborate approaches to utility analysis are available, including optimization (Getz 1979, 1985, Reed 1980, Walters 1969, 1975, 1981), dynamic programming (Walters 1975, 1981), goal programming (Weithman and Ebert 1981), and multiattribute utility analysis (Powers and Lackey 1976, Healey 1984).

Results

Principal Components Analysis

Principal components analysis of the correlation matrix showed that 91.2% of the variation among the model runs could be represented in the first three factors (Table 9). These three factors were the only ones that warranted interpretation, since no others had eigenvalues greater than 1. The first factor included positive loadings for all population structural indices except RSDsq, which had a negative loading since it is equal to one minus the PSD. The first factor also had positive loadings for mean length and age caught, which are together as suspected since length is derived directly from age. Factor two had positive loadings for harvest and yield, and negative loadings for catch, mean length, and mean weight harvested. Factor three had positive loadings for PSD, catch, and yield, and negative loading for RSDt.

Closer investigation of the factors allowed for reduction of the number of variables used to eliminate redundancies (Table 10). The first factor was a contrast of mean length caught, mean length harvested, PSD, and RSD-trophy against harvest (in number): showing the tradeoff between large fish vs. many fish harvested. In factor two total harvest and yield are contrasted against mean length harvested and catch: high output fisheries vs. quality fisheries (bigger fish harvested, high rate of catch and release). Factor three contrasts PSD, catch, and yield against RSD-trophy: distinguishing trophy fisheries from other quality fisheries.

The results of these seven variables from the final principal components analysis (mean length caught, mean length harvested, PSD, RSD-trophy, harvest, yield, and catch) were used to represent the different scenarios in all further analyses.

Fishery Parameters

The simulated values of these seven variables are displayed for the various scenarios in Figures 4 - 10 and Appendix E. The figures omit the middle slot and intermediate minimum length limits for clarity: values for these would fall between the extremes displayed in the graph for that type of length limit. The variables display two general patterns. One pattern is having the highest value under the most restrictive scenario, catch and release, and is exemplified by catch, mean length caught, PSD, and RSD-t (Figures 4 - 7), all of which reflect quality. All of these variables exhibit maxima under a creel limit of zero, and at higher creel limits have highest values under a 381 mm minimum length limit and lowest values with no length limit. RSD-trophy (Figure 7) appears to be very sensitive to any harvest, which agrees with expectations based on field studies (Clady et al. 1975).

Mean length harvested (Figure 8) also reflects quality, but is dependent on fish being harvested, and thus has a value of zero under catch and release. It is highest under a 381 mm minimum, and lowest under no length limit and the slot length limits, which show essentially identical response in this variable. There is little difference in mean length harvested over creel limits from 8 to 1, but under all length regulation alternatives this mean is slightly higher at lower creel limits.

The remaining two variables, harvest and yield, are measures of quantity output by the fishery. As such they would be expected to exhibit patterns quite different from the other five variables. Harvest (Figure 9), as might be expected, shows a pattern that increases at higher creel limits and is minimized by the most restrictive length limits. It is interesting to note the behavior of this variable with no length regulation. It is initially very close to the slot limit results, but it attains a maximum at a creel limit of 2 and then declines slightly at higher creel limits. The highest harvest appears under a 254 to 330 mm slot length limit and a creel limit of 8. In part, yield (Figure 10) follows a pattern similar to that of the first set of variables mentioned above, except for the zero value under catch and release. Otherwise, its highest values are under a 381 mm minimum and lowest under no length limit. Values decline at higher creel limits for the slot limits. This decline is also seen in the lower minimum length limits, but as the minimum increases there is a transition toward higher yield at higher creel limits, resulting in a maximum overall yield occurring with a 381 mm minimum length limit and a creel limit of 8.

Utility Function

The seven most important variables for statistically separating the different scenarios as indicated by principal components analysis were combined in a utility function to provide an example of this approach. Utility scores were generated using equal weighting and scaling each variable to a range of 0 to 1 by subtracting the minimum value observed in the simulations and dividing by the difference between the minimum and maximum values. Results of these calculations are given for selected regulation scenarios in Figure 11; all utility scores are given in Appendix H. Based this sample utility function, a creel limit of 1 and a 381 mm minimum length limit is the best scenario, but at values of 1 or greater, creel limit changes have less impact than minimum length limits. Thus, a 381 mm minimum gave the highest utility scores at any creel limit.

Comparative Data

A few parameters beyond these seven were generated for selected regulation scenarios for comparison to field studies. Selected regulation scenarios included those frequently seen (effectively unregulated, 305 mm minimum, catch and release) and the predicted optimum length limit (381 mm minimum) based on the sample utility function. Number of smallmouth bass per hectare by age group is given for these 4 scenarios in Table 11. There is great variability in age-0, but age-1 is relatively less variable due to the density dependant control of first year survival. A great difference can also be seen in the maximum age that fish survive to under the different regulations. Table 12 shows total number and biomass of smallmouth bass per hectare under these 4 scenarios.

Discussion

Principal Components Analysis

Principal components analysis allowed recognition of redundant variables, and reduction of the set of variables that statistically separate the scenarios to seven variables. All of these variables can be readily estimated from techniques in common use in fisheries agencies. The structural indices, PSD and RSD-trophy, can be determined from length frequencies generated from routine population sampling techniques, such as electrofishing. The other five parameters, catch, mean length caught, harvest, mean length harvested, and yield might be estimated from creel survey data. Yield, harvest, and mean length harvested are commonly estimated in this manner. Catch and mean length caught would be less reliable, since they would necessitate reliance on angler recall which introduces problems with reliability and bias. Values of these two variables varied among scenarios in a similar manner to the structural indices, but were contrasted in at least one principal component. It might be useful to attempt monitoring these catch related parameters in situations where the benefits of catch and release fishing were emphasized. This analysis also gives an indication of what variables are most sensitive to regulation changes. These seven variables would therefore be those with high sensitivity to regulation changes since they maximize the difference among the regulation scenarios.

Utility Function

An example was given above of the use of a utility function. It was not intended that this specific formula, which provided uniform scaling and weighting of the included variables, be used to generate management recommendations. The goals of the manager of a particular fishery should determine the inclusion, weighting, and scaling of variables. One generality that can be drawn from either the utility function or the individual variables, is that the results of slot limits are more similar to no length limit than the minimum length limits are. This is likely a spurious conclusion that is an artifact of the model structure. The rational behind imposing slot length limits rather than minimums assumed the density is limiting growth. Since the model assumes constant growth, it is clear that slot length limits would have less than the desired effect.

Comparative Data

The results exhibit an intuitive pattern. However, the true test of the usefulness of the model is comparison to real world fisheries. Density, PSD, and biomass of smallmouth bass are presented for a variety of fisheries in Tables 13, 14, and 15. Additionally, Table 16 displays angler harvest statistics from several streams. Detailed comparison of these data to those generated by the model provides insight into the strengths and shortcomings of this model's predictions for the New River, West

Virginia, smallmouth bass fishery. They can be compared to determine if the model output values are within the range of field estimates for smallmouth fisheries. These data can also be used to see if the predicted changes in model output due to regulation changes are similar to the changes evoked by similar regulation changes in field studies.

The Fish Population

PSD's provide an index of the quality of the size range in a fish population based on the length frequency of individual fish in the population. PSD's in stream smallmouth bass populations are highly variable. Anderson and Weithman (1978) gave a desirable PSD for balanced smallmouth bass populations of 30 to 60%. Values observed for stream smallmouth populations often fell below this range. Available estimates (Tables 13 - 15) range from 3% on the New River in Virginia (Austen 1984) to 42% on the Turkey River in Iowa (Paragamian 1984a). Model predictions ranged from 12% under no regulation to 50% under catch and release (Figure 6, Tables 13 - 15). Nine of the effectively unregulated fisheries (no length limit, creel limit of 8 /day or greater) in Table 15 had an average value of 20%, with the lowest value being 4% on the New River in West Virginia (Austen 1984). In light of this, the predicted value of 12% under no regulations seems reasonable, especially given the sensitivity of PSD to recruitment variability and sampling bias.

Density from smallmouth bass population estimates vary greatly depending in part on whether or not early age classes are included. Estimates, based on all fish (Table 13), were only available from the Maquoketa River in Iowa. Under no special regulations, the estimate of 1204 smallmouth bass per hectare was on the same order of magnitude as the model's prediction of 3027. These values are not really comparable, since it is unlikely that a field sample collecting some portion of the young-of-year during the summer could reflect the model's exact enumeration of larvae at hatching. The prediction of 3027 does look quite good when compared with the 3587 used in Roell and Orth's (1987) energetics modelling of the study pool on the New River, West Virginia. Values based on fish approximately age I and older (Table 14) ranged from 118 on the Plover River in Wisconsin (Paragamian and Coble 1975) to 361 on the Galena River in Wisconsin, bracketing the model's estimate of 207, which compared well to Roell and Orth's estimate of 254 for the New River, West Virginia. Studies of smallmouth bass age II and older (Table 15) in streams yielded values ranging from 62 on Pats Creek in Wisconsin to 136 on the Galena River in Wisconsin (Forbes 1989) under unregulated conditions, marginally including the model estimate of 62.

Smallmouth bass total biomass (Tables 13 - 15) is less sensitive than density to inclusion of early age classes, since these fish are small enough that they constitute little of the total biomass. The lowest value reported on an unregulated fisherywas 8.2 kilograms per hectare on Courtois Creek in Missouri; additionally Nebish Lake in Wisconsin had a value of 3.1 (Serns 1984). A maximum value of 56.1 was reported from Pats Creek in Wisconsin (Forbes 1989). The model's prediction of 9.3 for effectively unregulated fell in the lower end of the observed range. The model's prediction of 11.5 kg/ha was much lower than that reported by Roell and Orth (1987), but they reported annual mean biomass from their energetics modelling, while this model's output represents standing biomass at the beginning of the year.

The Fishery

A pressure estimate of 185 hours per hectare on the New River in West Virginia (Pierce et al. 1981) 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 16). The fisheries included receive a wide range of pressure levels. These range from 69 hours per hectare on the Current River in Missouri (Fleener 1973) to 925 on the Maquoketa River in Iowa (Paragamian 1984a).

Model results exhibit a catch rate (total catch / hour) of 0.20 smallmouth bass per hour. This falls well within the observed range of 0.05 (Maquoketa River, Paragamian 1984a) to 1.33 (New River, Austen and Orth 1984). This value is quite close to the 0.28 found by Pierce et al. (1981) in the study that the pressure estimate was taken from. The model predicts a yield of 5.5 kilograms per hectare, which is also well within the observed range of 1.2 (New River, Wollitz 1968) to 24.0 (Shenandoah River, Kauffman 1983). Estimated smallmouth bass harvest, 36.7 per hectare, was just within the range of 4.1 (Current River, Fleener 1973) to 39.2 (Maquoketa River, Paragamian 1984a).

Harvest Regulation

The purpose of developing this model was to predict changes in the fishery and fish population due to a change to more restrictive harvest regulation schemes. This is particularly desirable in the case study, since relatively few evaluations of harvest regulations have been conducted in smallmouth fisheries. Most studies of innovative harvest regulation have been confined to largemouth bass fisheries. These results are likely to be inapplicable to smallmouth bass streams, due to differences in the two species and the habitats involved. The model results can be compared to the few studies that have evaluated smallmouth harvest regulation.

The most commonly employed regulation in smallmouth bass fisheries is a 305 mm minimum length limit. It can be compared to an unregulated situation on the same stream in several studies. It must be remembered that the actual results of the regulation change will depend on the response of growth and mortality patterns to the increased density of the smallmouth population.

The model predicts an increase in PSD from 12 to 34 if this regulation is imposed. Field studies (Table 15) have shown PSD to increase (Fajen 1975a, 1975b, Paragamian 1984a, 1984b). Kauffman and Smith (1987)observed a decrease which they explained was due to increased total mortality, and Austen (1984) saw little change and attributed this increased mortality and decreased growth rate. Density is predicted to increase over two-fold, from 62 to 141 per hectare, while the only study showing change in density showed a large decline from 116 to 31 (Paragamian 1984a, 1984b) which was explained by weak year classes due to a prior recruitment failure. Biomass is predicted to increase from 9.3 to 37.9. The studies that compare biomass tend to agree with this (table 15): Fajen (1975a, 1981) reported higher biomass under this length limit, while Paragamian (1984a, 1984b) observed just the opposite, due to the low density subsequent to the weak year classes mentioned previously. Serns (1984) reported increases in both density and biomass when a 203 mm length limit was imposed on Nebish Lake in Wisconsin. Catch rate is predicted to increase from 0.20 to 0.58 smallmouth bass per hour. Paragamian (1984a, 1984b) observed an increase from 0.05 to 0.22 (Table 16); Austen and Orth (1984), Fleener (1974a), and Fleener (1974b) also observed higher catch rates. Yield is predicted to increase from 5.5 to 12.9 kilograms per hectare. A slight increase in yield (Table 16) was reported by Fleener (1974a) and Fajen (1981) and a very slight decline was reported by Fleener (1974b). Harvest is predicted to decline from 36.7 to 20.6 fish per hectare. Marked declines in harvest (Table 12) were reported by Paragamian (1984a, 1984b), Fleener (1974b), and Fleener (1974a). A slight increase in harvest is seen on Courtois Creek (Fajen 1975, 1981), but is likely a relict of the intervening years under a catch and release regulation. The model predicts an increase in the mean length of smallmouth harvested form 216.5 to 360.5 mm (Appendix H). Austen (1984) also observed an increase in mean length harvested.

The model results compare favorably to the field study results of imposing a 305 mm minimum length limit. The contradictory results evident in some studies can be explained by changes in mortality patterns, density dependent growth, and chance occurrences, such as recruitment failures (Paragamian 1984a, 1984b). This provides good support for the theoretical premises this model is based on.

After fishing was prohibited for 22 years in Big Buffalo Creek in Missouri, PSD, density, and biomass were among the very highest reported in the literature (Reed and Rabeni 1989). Similar results were exhibited by the model under the catch and release scenario (Table 15, 16). This also suggests that the model results are reasonable.

Assumptions

In any theoretical simulation certain things are assumed to be true. Before any firm conclusions are drawn from the results of this study, some of the assumptions made must be considered. Assumptions were made about angler behavior, fish behavior, and fish biology.

The behavior of anglers influences a fishery management scenario through their harvest behavior and regulation compliance. It is assumed that anglers are not more or less size selective under certain regulation schemes. The assumption is also made that anglers will not begin to voluntarily release fish. It was also assumed that regulation compliance would be perfect. While these behavioral assumptions may be unrealistic, presently little is known that would allow modelling them more realistically. Any behaviors present under the unrestrictive situation would be intrinsically included in the simulations, and thus are assumed not to change under different regulations.

Fish behavior changes can impact the effectiveness of a harvest regulation. Fishing mortality is dependent on the probability of fish being caught. It is assumed that fish behavior does not change under a regulation in such a way as to alter this probability. By age group, this probability is assumed to be proportional to numbers in the age group.

The biology of the fish population can also have a severe effect on the results of a regulation. The most obvious population parameter to impair the effectiveness of a regulation is growth rate. Growth rate change is often cited as the reason regulations fail to achieve the desired results (Paragamian 1984a, 1984b, Austen and Orth 1988). A comparison of growth rates in several smallmouth bass fisheries allowing comparison of regulated and unregulated situations is provided in Table 17. In this model it was assumed that growth rates remain constant over time and under varying densities and harvest regulations. This would only be the case if competition for food never became a limiting factor, rather that mortality is the limitation. A 305 mm minimum appeared to decrease growth (Austen 1984, Fajen 1981, Paragamian 1984a, 1984b), have no clear impact (Kauffman 1983), or increase growth (Kauffman and Smith 1987). A 280 to 330 mm slot (Kauffman and Smith 1987) and a 203 mm minimum (Serns 1984) seemed to improve growth. These varied responses of growth rates to regulation changes may reflect size specific differences in the availability of energetically optimal prey organisms. Smallmouth bass in the New River have high growth rates (Roell and Orth 1987), possibly indicating a highly abundant prey base. Austen and Orth (1988) cite high mortality as a possible cause of failure of Virginia's length limit, suggesting it as the possible limitation on the fishery.

Austen and Orth (1985) observed a difference in food habits between the regulated and unregulated river sections, but it is unclear if this is due to the regulation or some external influence, such as habitat differences. Roell and Orth (1987) found that smallmouth bass age 2 and older ate predominantly crayfish, even in the face of competition with rock bass, flathead catfish, and commercial bait harvesters. This suggests that Austen and Orth's (1985) finding that smallmouth bass in the Virginia section ate predominantly insects might be a result of differences in natural availability rather than a function of the harvest regulation, and thus be a causative agent to the regulation's failure. The availability of crayfish as a larger food item would increase the growth rates of larger smallmouth bass, and crayfish are known to be the preferred food of smallmouth bass (Coble 1975, Kilambi et al 1977, Austen and Orth 1985, Roell and Orth 1987).

It is likely that the assumption of no change in growth was invalid, especially considering the large increases in density and biomass predicted under the more restrictive model scenarios. If growth rates were depressed by density, results of regulations would be less dramatic. Catch rate would likely remain unchanged or increase due to fish remaining in the protected size range for a longer period. All other output variables would decline slightly with the greatest impact being on yield. Thus the large changes predicted would be less dramatic, but it is anticipated that the direction of the change would be similar.

A great deal of assumption was involved in generating the first year survival function. The Beverton-Holt function was assumed to be an appropriate model. Through manipulation of data from the New River using survival patterns from other studies a point, the current situation, was generated through which the curve would pass. Since it must also pass through the origin, two points were available. Still, any one of an infinite number of curves would pass through these two points. The one that was arbitrarily selected placed the current point on a steeply increasing portion of the curve, where changes in population have a great effect on recruitment. This was done to highlight the changes due to new regulations. It is more likely that the population is farther up on the curve where recruitment is less sensitive to changes in density. If this is the case, the magnitude of the changes in the fishery would be less. Specifically, changes in density, biomass, catch, harvest, and yield would be less pronounced. Response of the other variables would be relatively unchanged, since they are related to the size structure of the population rather than to numbers.

In addition to growth and recruitment, several other input parameters are assumed to remain constant. Most of these parameters were generalized from the literature, so it is also an assumption that they are correct for this particular fish population. No information was available to evaluate the validity of these assumptions.

TABLES: CHAPTER 2

Table 4. Equations used in model.

Survival		
Eggs→ *Larvae*	$L_j = E_j \times \text{HATCH}$	[1]
	$E_j = \sum_{i=0}^{n} N_{i,j} \times S_i \times MAT_i \times C_i$	[2]
Larvae→Age-1	$N_{1,j+1} = \dfrac{1}{(a + (\dfrac{b}{L_j}) + v)}$	[3]
Age-1→Age-2,...Age-n-1→Age-n	$N_{i+1,j+1} = N_{i,j} \times e^{-(F_i + M_i + H_i)}$	[4]
Harvest Regulations	$F_i = F'_i \times R_i \times \text{MOD}$	[5]
	$H_i = H'_i \times (1 - R_i \times \text{MOD})$	[6]
	$R_i = 1 - [P(z > z^-_{1,i}) - P(z > z^+_{2,i})]$	[7]
	$z^-_{1,i} = \dfrac{(L^*_1 - \bar{L}_i)}{S_i}$	[8]
	$z^+_{2,i} = \dfrac{(L^*_2 - \bar{L}_i)}{S_i}$	[9]
Assessing Balance	$N^*_k = \sum_{i=0}^{n} P(z < z_{k,i}) \times N_{i,1}$	[10]
	$z_{k,i} = \dfrac{(L^*_k - \bar{L}_i)}{S_i}$	[11]
	$\text{PSD} = \dfrac{N^*_{\text{Quality}}}{N^*_{\text{Stock}}}$	[12]
	$\text{RSD}_P = \dfrac{N^*_{\text{Preferred}}}{N^*_{\text{Stock}}}$	[13]
	$\text{RSD}_M = \dfrac{N^*_{\text{Memorable}}}{N^*_{\text{Stock}}}$	[14]
	$\text{RSD}_T = \dfrac{N^*_{\text{Trophy}}}{N^*_{\text{Stock}}}$	[15]
	$\text{RSD}_{S \rightarrow Q} = \dfrac{(N^*_{\text{Stock}} - N^*_{\text{Quality}})}{N^*_{\text{Stock}}}$	[16]

Table 4. (*continued*).

Assessing Balance (*continued*)	$\mathrm{RSD}_{\mathrm{Q} \rightarrow \mathrm{P}} = \frac{(N^{*}_{\mathrm{Quality}} - N^{*}_{\mathrm{Preferred}})}{N^{*}_{\mathrm{Stock}}}$	[17]
	$\mathrm{RSD}_{\mathrm{P} \rightarrow \mathrm{M}} = \frac{(N^{*}_{\mathrm{Preferred}} - N^{*}_{\mathrm{Memorable}})}{N^{*}_{\mathrm{Stock}}}$	[18]
	$\mathrm{RSD}_{\mathrm{M} \rightarrow \mathrm{T}} = \frac{(N^{*}_{\mathrm{Memorable}} - N^{*}_{\mathrm{Trophy}})}{N^{*}_{\mathrm{Stock}}}$	[19]
Catch and Yield	$C_{\mathrm{i,j}} = \frac{N_{\mathrm{i,j}} \times F_{\mathrm{i}} \times (1 - e^{-(F_{\mathrm{i}} + M_{\mathrm{i}} + H_{\mathrm{i}})})}{F_{\mathrm{i}} + M_{\mathrm{i}} + H_{\mathrm{i}}}$	[20]
	$Y_{\mathrm{i,j}} = C_{\mathrm{i,j}} \times w \times L_{\mathrm{i}}^{y}$	[21]
	$\overline{\mathrm{Age}_{\mathrm{j}}} = \frac{\sum_{i=0}^{n} i \times C_{\mathrm{i,j}}}{\sum_{i=0}^{n} C_{\mathrm{i,j}}}$	[22]
	$\mathrm{CR}_{\mathrm{j}} = \sum_{i=0}^{n} \frac{F'_{\mathrm{i}} \times N_{\mathrm{i,j}} \times (1 - e^{-(F_{\mathrm{i}} + M_{\mathrm{i}} + H_{\mathrm{i}})})}{F_{\mathrm{i}} + M_{\mathrm{i}} + H_{\mathrm{i}}}$	[23]

Variables used in equations.

$N_{\mathrm{i,j}}$	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 proportion of total egg potential.
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.

Table 4. (*continued*).

n	The maximum age group.
F'_i	Potential fishing mortality rate for the i^{th} age group, assuming no harvest regulation.
F_i	Realized fishing mortality rate for the i^{th} age group, accounting for the effect of harvest regulation.
H'_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 the effect of allowed harvest.
M_i	Natural mortality rate for the i^{th} age group.
R_i	Factor for reduction in harvest in the i^{th} age group due to the effect of length limits (expressed as proportion of unregulated F_i remaining).
MOD	Overall reduction in harvest due to the effect of a creel limit (expressed as proportion of unregulated F_i remaining).
$P(z > z_{k,i})$	The probability, based on the standard normal distribution, of z, a random variate, being greater than $z_{k,i}$, the critical value.
$z_{1,i}$	The value on the standard normal distribution corresponding to the minimum length in the protected length range.
$z^{+}_{2,i}$	The value on the standard normal distribution corresponding to the maximum length in the protected length range.
$z_{k,i}$	The value on the standard normal distribution corresponding to the the minimum length of one of the stock density length groups (Gabelhouse 1984).
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 (Gabelhouse 1984), specifically the k^{th} group.
$\bar{L}_i$	The mean length of the i^{th} age class.

Table 4. (*continued*).

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', and 'Trophy'.
PSD	Proportional stock density.
RSD_P	The relative stock density of fish preferred size and larger.
RSD_M	The relative stock density of fish memorable size and larger.
RSD_T	The relative stock density of fish trophy size and larger.
$RSD_{S\rightarrow Q}$	The relative stock density of fish between stock and quality size.
$RSD_{Q\rightarrow P}$	The relative stock density of fish between quality and preferred size.
$RSD_{P\rightarrow M}$	The relative stock density of fish between preferred and memorable size.
$RSD_{M\rightarrow T}$	The relative stock density of fish between memorable and trophy size.
$C_{i,j}$	Number of fish harvested (catch) in the i^{th} age group in year j.
$Y_{i,j}$	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.
$\overline{Age}_j$	Mean age harvested in year j.
CR_j	Number of fish caught, but not necessarily harvested, in year j.

Table 5: Mortality parameter inputs derived from Roell and Orth (1987).

Age	Fishing Mort.	Natural Mort.
1	0	1.20
2	1.01	0.19
3	1.01	0.19
4	1.01	0.19
5	1.01	0.19
6	1.01	0.19
7	1.01	0.19
8	1.01	0.19
9	1.01	0.19
10	1.01	0.19
11	1.01	0.19
12	1.01	0.19
13	1.01	0.19
14	1.01	0.19
15	1.01	0.19
16	4.09	1
17	4.09	1
18	4.09	1
19	4.09	1
20	4.09	1

1st Year Survival Coefficients used in equation 3 of Table 4:

A	0.00006
B	9.0

Table 6: Reproductive parameters used as model inputs (Clady 1975, Carlander 1977). Used in equations 1 and 2 of Table 4.

Age	Maturity	Egg Cont.
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 7: Population parameters for smallmouth bass in the New River, West Virginia (Roell and Orth 1987), and used as model input parameters.

Age	Number*	Mean Length	SD Length
0	210847	5	1
1	10853	106	16
2	3256	190	16
3	977	252	20
4	293	313	29
5	88	387	42
6	26	459	42
7	8	524	42
8	2	548	42
9	1	560	42
10	0	575	42
11	0	585	42
12	0	590	42
13	0	593	42
14	0	595	42
15	0	596	42
16	0	597	42
17	0	598	42
18	0	599	42
19	0	600	42
20	0	600	42

*Number in study pool (61.65 hectares).

Length-Weight Regression (used in equation 21 of Table 4):

Linear Coefficient	0.00001285
Exponential Coefficient	2.994

Table 8: Predicted harvest reduction (shown as proportion of unregulated fishing mortality) due to creel limit reduction, based on data from the New River, West Virginia (Pierce et al. 1981), and proportion of fishing mortality remaining. Sections are as follows: 1 - upper New River (above Bluestone Lake), 2 - Bluestone Dam to Hinton, and 3 - Hinton to Sandstone Falls.

	New Creel Limit								
Section	0	1	2	3	4	5	6	7	8
1	1.000	0.576	0.322	0.203	0.119	0.076	0.042	0.008	0.000
2	1.000	0.581	0.366	0.236	0.141	0.073	0.031	0.010	0.000
3	1.000	0.593	0.333	0.188	0.103	0.051	0.020	0.006	0.000
Mean	1.000	0.583	0.340	0.209	0.121	0.067	0.031	0.008	0.000
Proportion Remaining	0.000	0.417	0.660	0.791	0.879	0.933	0.969	0.992	1.000

Table 9: Factor pattern from principal components analysis of 16 variables output by model. Singularity of data matrix due to high correlation of variables precluded interpretation of these factors.

Variable	Factor 1	Factor 2	Factor 3
Yield	0.31559	-0.66351	0.35267
Catch	0.21897	-0.51181	-0.62511
Mean Length Caught	0.93868	0.27426	0.13003
Mean Age Caught	0.94989	0.24549	0.11788
Harvest	-0.39605	-0.37408	0.74859
Mean Length Harvested	0.30021	0.53686	-0.68750
Mean Age Harvested	0.34723	0.61090	-0.61014
PSD	0.97016	-0.19412	-0.08701
RSD-Preferred	0.91858	0.27118	0.27345
RSD-Memorable	0.63930	0.65650	0.38710
RSD-Trophy	0.47292	0.79995	0.33842
RSD-Stock-Quality	-0.97106	0.19412	0.08701
RSD-Quality-Preferred	0.66578	-0.57548	-0.40560
RSD-Preferred-Memorable	0.75999	-0.61797	-0.12813
RSD-Memorable-Trophy	0.88823	-0.10149	-0.36995
Population (N)	0.79524	-0.52578	0.06943
Eigenvalue	8.09929	3.85867	2.62816
Cumulative Proportion	0.5062	0.7474	0.9116

Table 10: Factor pattern from principal components analysis of the seven selected variables. Factor 1 contrasts mean length caught, mean length harvested, PSD, and RSD-trophy against numbers. Factor 2 contrasts harvest and yield against catch and mean length harvested. Factor 3 contrasts PSD, catch, and yield against RSD-trophy.

Variable	Factor 1	Factor 2	Factor 3
Mean Length Caught	0.96282	0.09679	0.19983
Harvest	-0.46749	0.84522	-0.02824
Mean Length Harvested	0.46585	-0.67650	-0.08855
PSD	0.73988	0.02736	0.63983
RSD-Trophy	0.83405	0.15553	-0.48970
Catch	-0.09197	-0.50289	0.75190
Yield	-0.02511	0.63663	0.65906
Eigenvalue	4.34668	1.97480	1.82100
Cumulative Proportion	0.4830	0.7024	0.9047

Table 11: Predicted number of smallmouth bass per hectare by age group for selected regulation scenarios. Numbers represent population in spring after hatching of larvae. All scenarios except catch & release were also regulated by a creel limit of 8 per day, which was considered to have no effect.

	Number per Hectare			
Age	unregulated	305 mm minimum	381 mm minimum	catch & release
0	2820	19146	30541	62955
1	145	240	250	260
2	44	59	62	64
3	13	40	42	43
4	4	27	28	29
5	1	11	19	20
6	0	3	8	13
7	0	1	2	9
8	0	0	1	6
9	0	0	0	4
10	0	0	0	3
11	0	0	0	2
12	0	0	0	1
13	0	0	0	1
14	0	0	0	1
15	0	0	0	0

Table 12: Total density and biomass of smallmouth bass of all ages under selected regulation scenarios. Numbers represent population in spring after hatching of larvae.

regulation	density (#/ha)	biomass (kg/ha)
none	3027	11.5
12 inch minimum	19527	41.5
15 inch minimum	30954	58.4
catch & release	63413	118.0

Table 13: Smallmouth bass population statistics calculated based on all sizes of smallmouth bass from selected streams.

Stream, State	Ref.	Density (#/ha)	PSD	Biomass (kg/ha)	Regs.
Field estimates:					
Maquoketa R., IA*	1	1204	17	33.0	none
Maquoketa R., IA*	2	103	25	11.5	B
New River, WV**	3	3587		24.3	none
Simulation results:					
New River, WV	4	3027	12	11.5	none
New River, WV	4	19527	34	41.5	B
New River, WV	4	30954	40	58.4	C
New River, WV	4	63413	50	118.0	E

* Field estimates later in spring and summer probably do not accurately reflect springtime abundance including larvae.

**Annual mean biomass.

References:

1. Paragamian 1984a
2. Paragamian 1984b
3. Roell and Orth 1987
4. this model

Regulations:

A. 203mm minimum
B. 305mm minimum
C. 381mm minimum
D. 280-330mm slot
E. catch & release
F. no fishing
none: includes those with creel limits of 8 or more per day

Table 14: Smallmouth bass population statistics based on fish approximately age-1 and older from selected streams.

Stream, State	Ref.	Density (#/ha)	PSD	Biomass (kg/ha)	Regs.
Field estimates:					
Huzzah Cr., MO	1	58	17	9.0	?
Galena R., WI	2	361		42.6	none
Pats Cr., WI	2	170		19.6	none
Plover R., WI	3	118		17.5	none
Red Cedar R., WI	3	132		15.1	none
New River, WV	4	254			none
Simulation results:					
New River, WV	5	207	12	11.5	none
New River, WV	5	381	34	41.5	B
New River, WV	5	413	40	58.4	C
New River, WV	5	458	50	117.9	E

References:

1. Fleener 1974a
2. Forbes 1989
3. Paragamian and Coble 1975
4. Roell and Orth 1987
5. this model

Regulations:

A. 203mm minimum
B. 305mm minimum
C. 381mm minimum
D. 280-330mm slot
E. catch & release
F. no fishing
none: includes those with creel limits of 8 or more per day

Table 15: Smallmouth bass population statistics based on fish approximately age-2 and older from selected populations.

Stream, State	Ref.	Density (#/ha)	PSD	Biomass (kg/ha)	Regs.
Field estimates:					
Coffins Grove Cr., IA	1		10		none
Turkey R., IA	1		42		none
Upper Iowa R., IA	1		19		none
Volga R., IA	1		24		none
Big Buffalo Cr., MO	2	138	41	28.9	F
Jack's Fork R., MO	3	134	28	27.2	B
Glover Cr., OK	4		19		none
Galena R., WI	5	136		32.7	none
Pats Cr., WI	5	62		56.1	none
Maquoketa R., IA	1	116	17	13.8	none
Maquoketa R., IA	6	31	25	8.4	B
Courtois Cr., MO	7	56	20	8.2	none
Courtois Cr., MO	8	76	34	16.1	B
Courtois Cr., MO	9			15.8	B
Shenandoah R., VA	10		13		B
Shenandoah R., VA	10		22		D
Shenandoah R., VA	10		28		none
New R., VA	11		3		B
New R., WV	11		4		none
Nebish Lake, WI	12	20		3.1	none
Nebish Lake, WI	12	36		5.5	A
Simulation results:					
New River, WV	13	62	12	9.3	none
New River, WV	13	141	34	37.9	B
New River, WV	13	163	40	54.6	C
New River, WV	13	198	50	114.0	E

(continued on next page)

Table 15: (continued)

References:

1. Paragamian 1984a
2. Reed and Rabeni 1989
3. McClendon and Rabeni 1987
4. Orth et al. 1983
5. Forbes 1989
6. Paragamian 1984b
7. Fajen 1975a, Funk 1975
8. Fajen 1975b
9. Fajen 1981
10. Kauffman and Smith 1987
11. Austen 1984
12. Serns 1984
13. this model

Regulations:

A. 203mm minimum
B. 305mm minimum
C. 381mm minimum
D. 280-330mm slot
E. catch & release
F. no fishing
none: includes those with creel limits of 8 or more per day

Table 16: Angler harvest statistics for selected smallmouth bass stream fisheries.

Stream, State	Ref.	Regs:	Pressure hr/ha	Catch #/hr	Yield kg/ha	Harvest #/ha
Field estimates:						
Maquoketa R., IA	1	none	925	0.05	7.7	39.2
	2	B	830	0.22	8.0	12.8
Middle Fork Kentucky R., KY	3	?	121		14.8	
Potomac R., MD	4	?	81		4.3	
Big Piney R., MO	5	none	156	0.03	3.3	9.0
	5	B	169	0.10	2.8	4.8
Courtois Cr., MO	6	none	367	0.10	9.8	21.1
	6	A	283	0.20	0	0
	7	B	234		10.8	24.8
Current R., MO	8	?	69	0.09	2.0	4.1
Huzzah Cr., MO	9	none	413	0.08	8.7	34.1
	9	B	333		8.6	14.6
	7	B	148		4.6	10.9
Niangua R., MO	10	?	94		1.5	
Shenandoah R., VA	11	none	227			
	11	B	219			
New R., VA	12	none	133	0.09	1.2	12.0
New R., WV	13	none	185	0.28		29.8
New R., VA	14	B		1.33		
New R., WV	14	none		1.05		
Plover R., WI	15	none	318	0.07	5.6	
Galena R., WI	16	C,D	221	0.32	8.2	31.1
Simulation results:						
New R., WV	17	none	185*	0.20	5.5	36.7
New R., WV	17	A	185*	0.90	0	0
New R., WV	17	B	185*	0.58	12.9	20.6
New R., WV	17	C	185*	0.22	6.1	38.8
New R., WV	17	E	185*	0.71	14.9	14.2

*Based on Pierce et al. 1981.

(continued on next page)

Table 16: (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. Wollitz 1968
13. Pierce et al. 1981
14. Austen and Orth 1984
15. Paragamian 1973
16. Forbes 1989
17. this model

Regulations:

A. catch and release
B. 305mm minimum
C. 5/day creel limit
D. closed season from March 1 through 1st Sat. in May
E. 381mm minimum
none: includes those with creel limits of 8 or more per day

Table 17: Selected length at age data for smallmouth bass from studies comparing harvest regulations.

						Age					
Ref.	1	2	3	4	5	6	7	8	9	10	Regs.
1	89	175	221	265	324	388					none
	111	189	246	290	324	356	450				A
	103	187	245	300	352	395	414	437			B
2	86	145	208	251	292	358	399	396	432		none
	86	150	213	274	345	404	442	429	452		C
3	96	187	244	331	447	484	524	589			none
	107	176	236	281	312	344	365	410	440		A
4			225	307							none
			242	291							A
5	79	150	213	272	330	381					none
	79	145	201	244	284	333					A
6	97	178	259	330	406	439	475	493	500	521	none
7	94	155	221	279	343	404	414	406	432		A
8	106	190	252	313	387	459	524	548			none

References:

1. Kauffman and Smith 1987
2. Serns 1984
3. Austen 1984
4. Kauffman 1983
5. Fajen 1981
6. Paragamian 1984a
7. Paragamian 1984b
8. model inputs (Roell and Orth 1987)

Regulations:

A. 305mm minimum
B. 280-330mm slot
C. 203mm minimum
none: includes those
with creel
limits of 8 or
more per day

FIGURES: CHAPTER 2

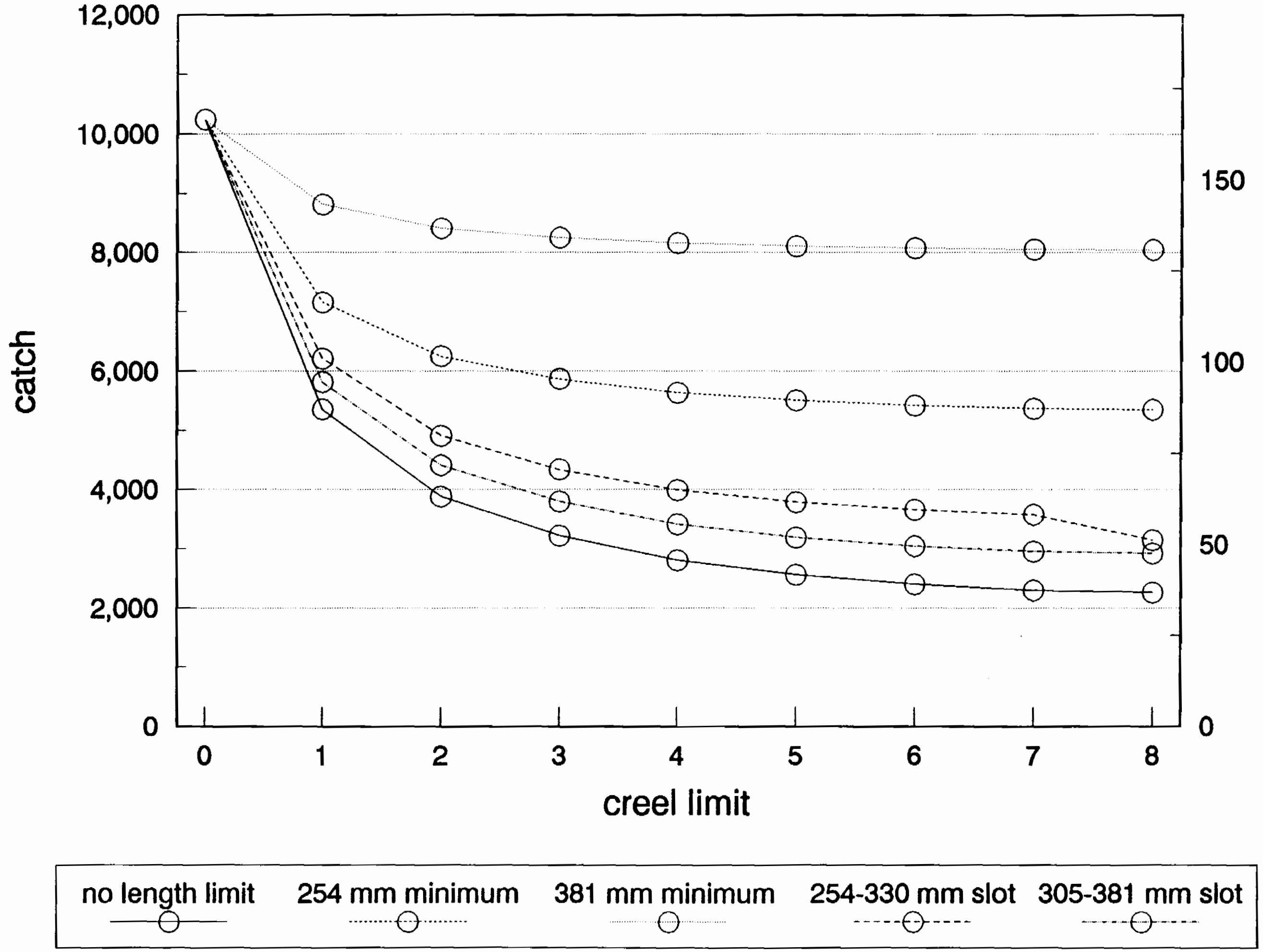


Figure 4: Number of smallmouth bass caught, whether kept or not, under selected combinations of simulated regulations.

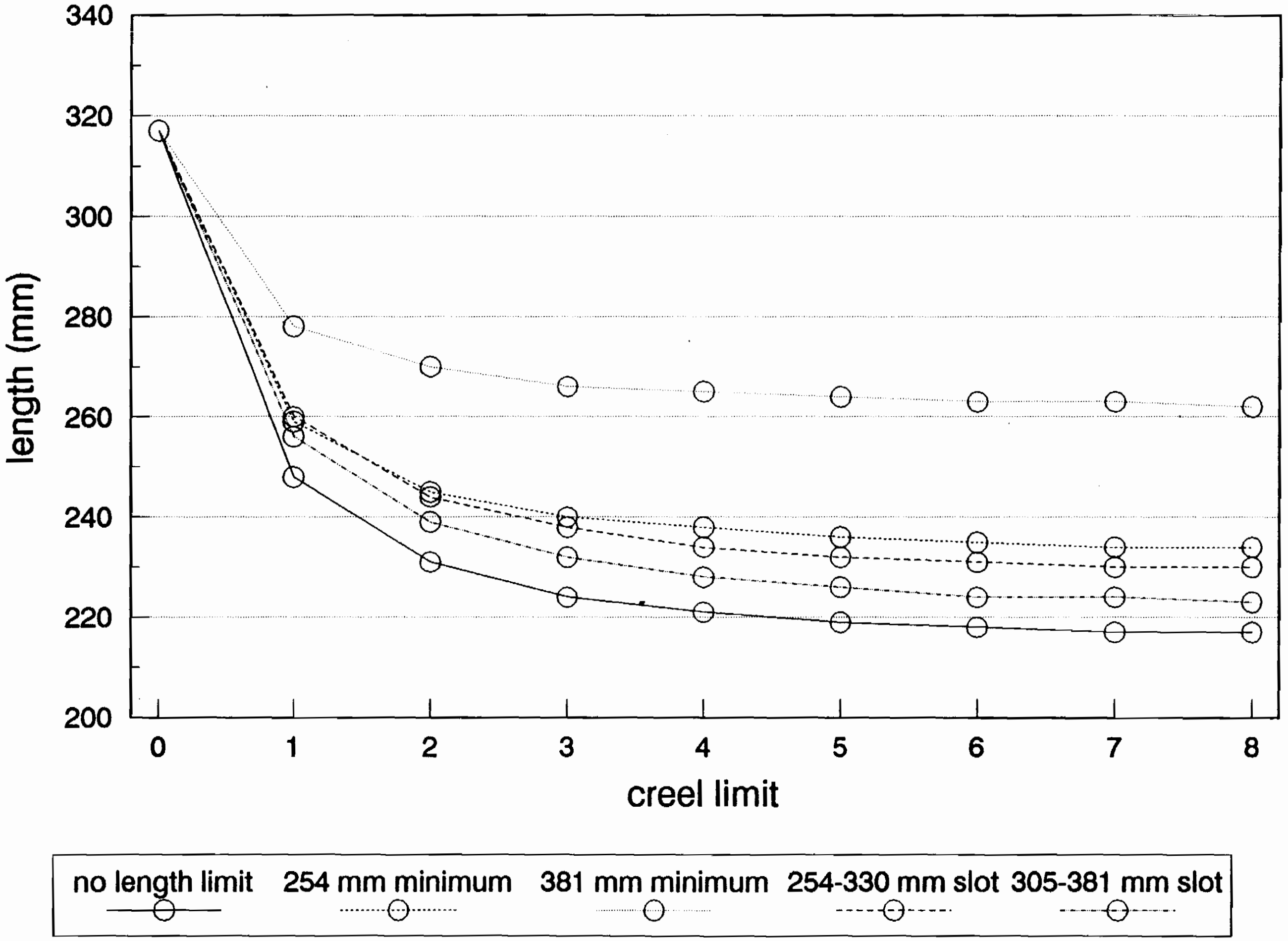


Figure 5: Mean length in millimeters of smallmouth bass caught, whether kept or not, under selected combinations of simulated regulations.

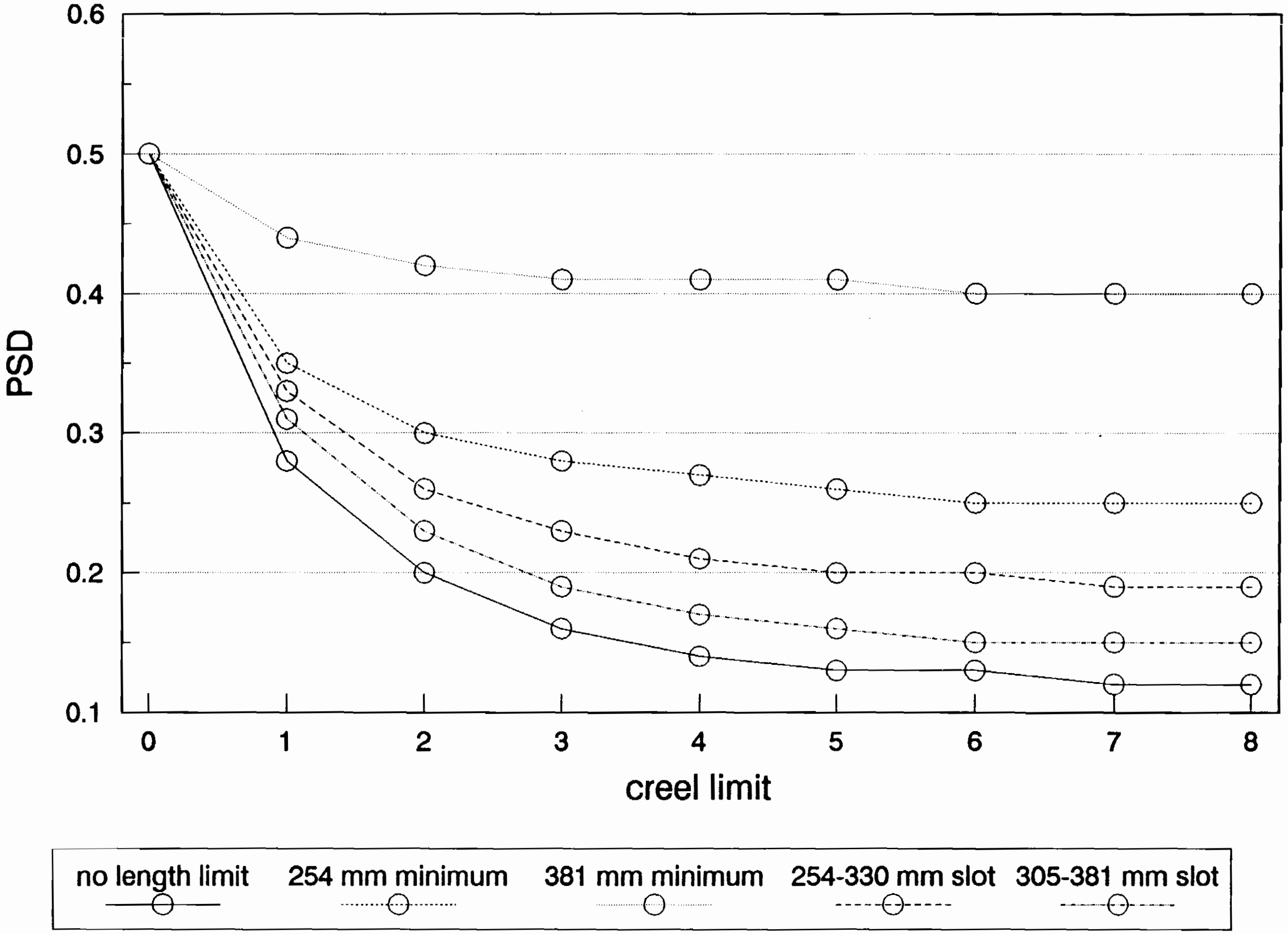


Figure 6: Proportional stock density of smallmouth bass under selected combinations of simulated regulations.

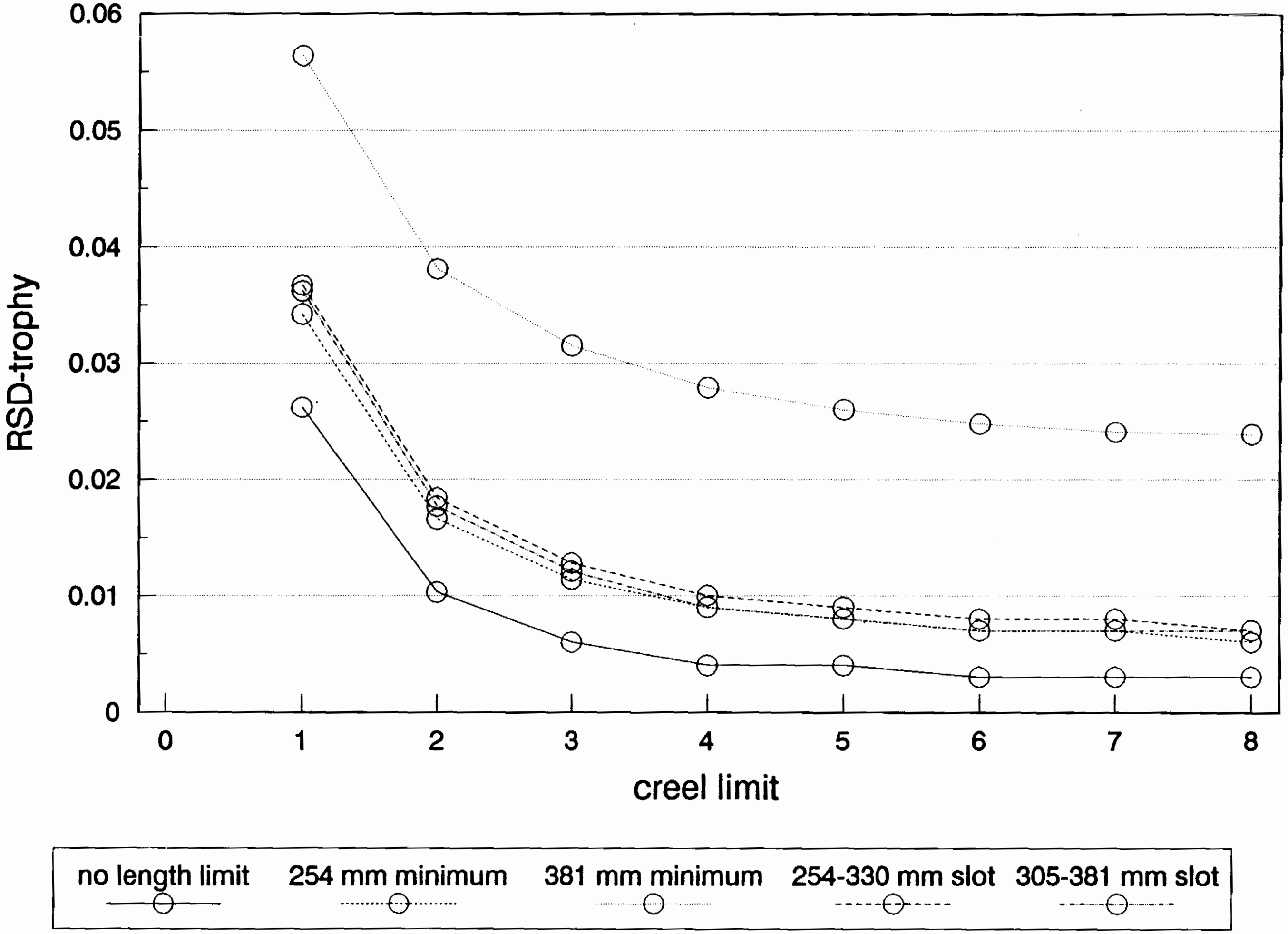


Figure 7: Relative stock density of smallmouth bass trophy size (510 mm) and larger under selected combinations of simulated regulations. RSD-t = 0.1325 for a creel limit of 0.

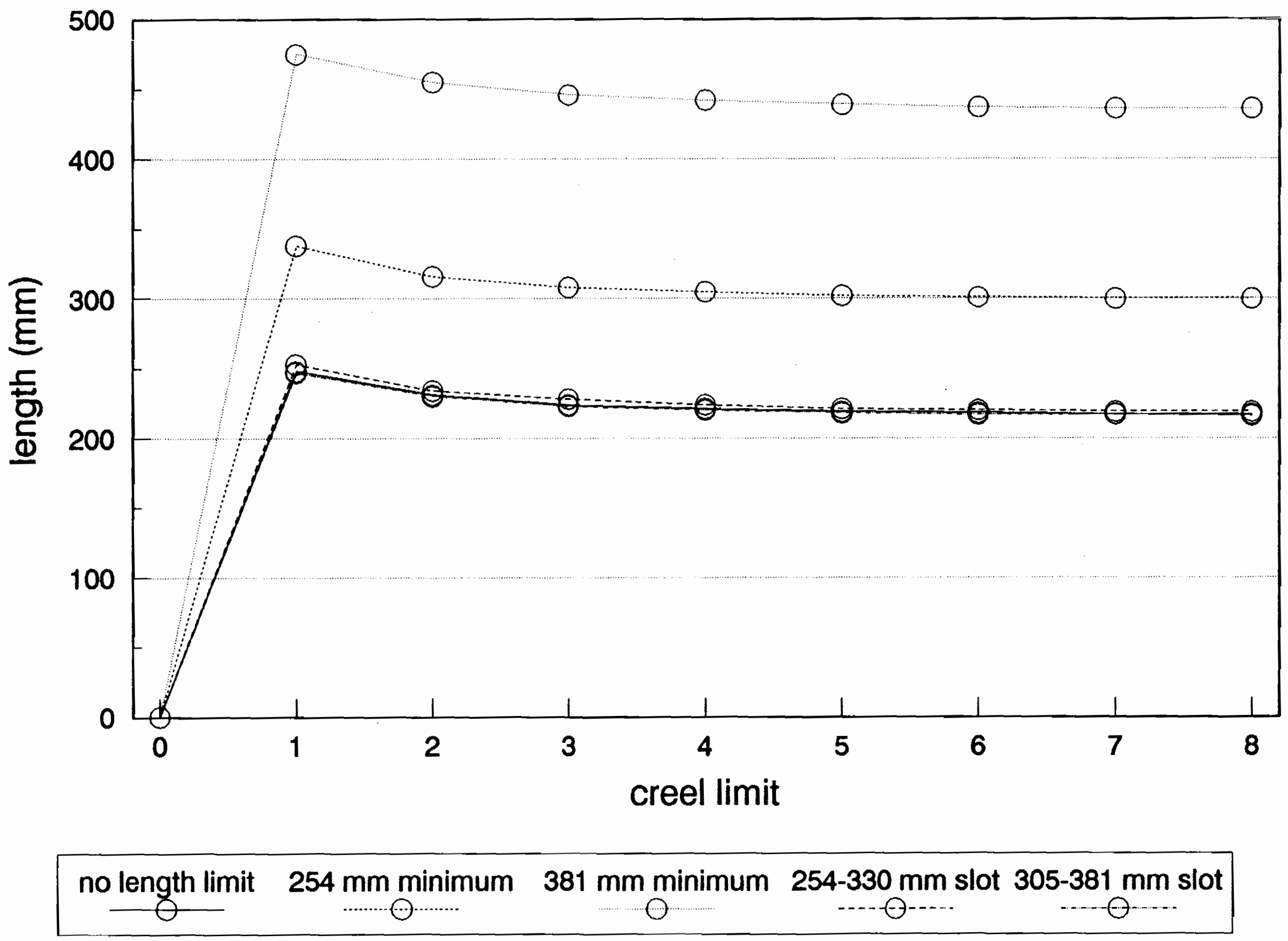


Figure 8: Mean length in millimeters of smallmouth bass harvested under selected combinations of simulated regulations.

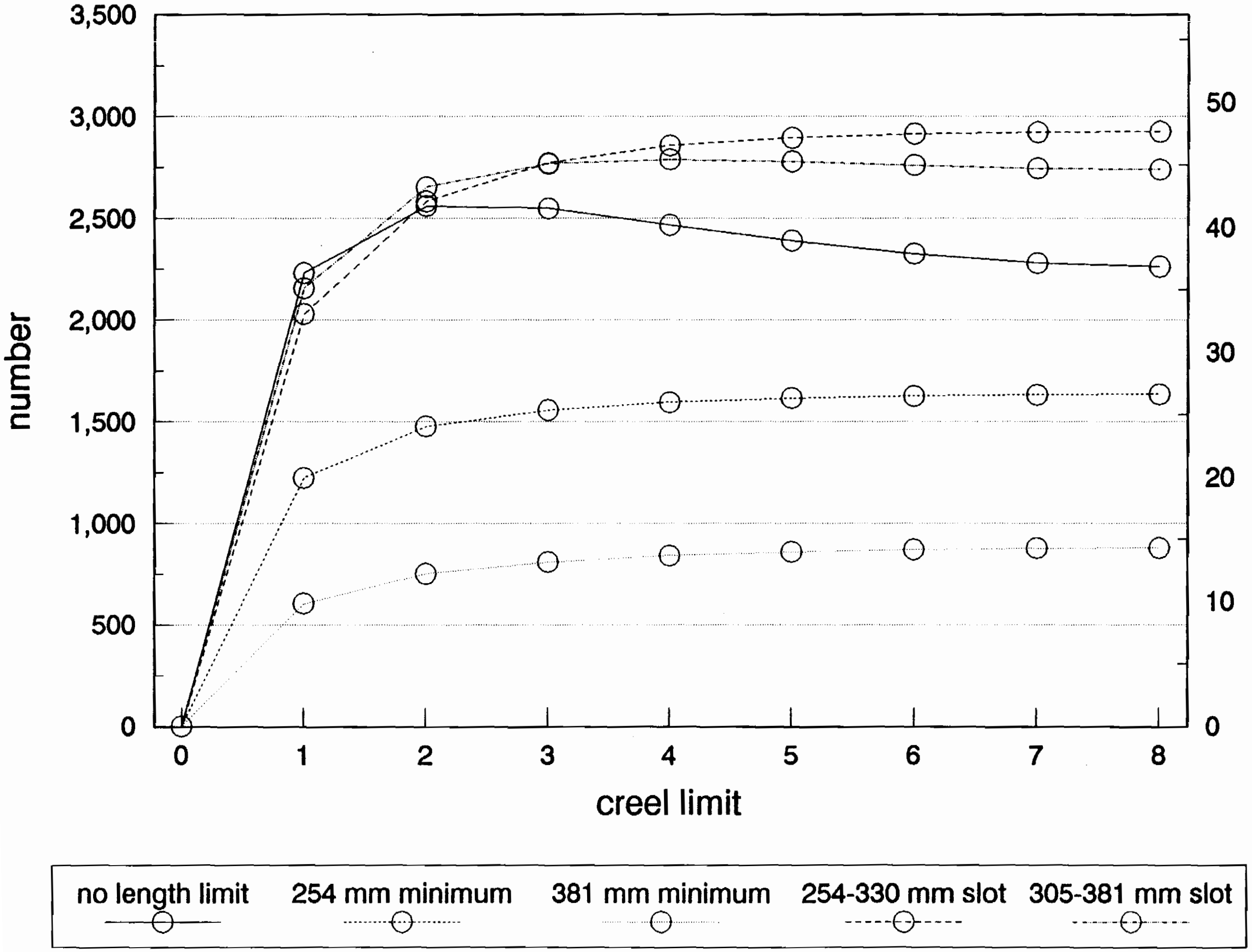


Figure 9: Number of smallmouth bass harvested under selected combinations of simulated regulations.

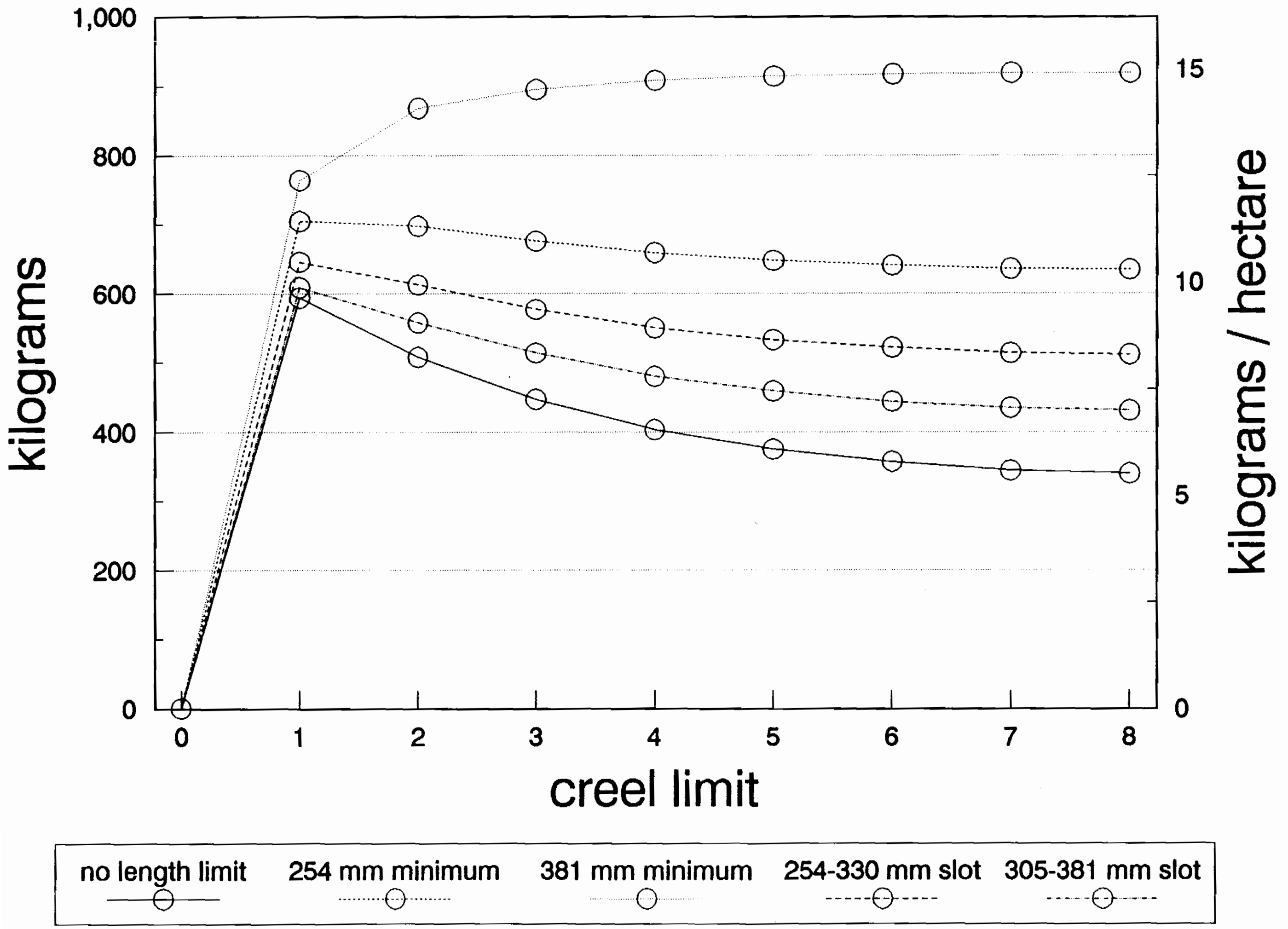


Figure 10: Yield in kilograms of smallmouth bass under selected combinations of simulated regulations.

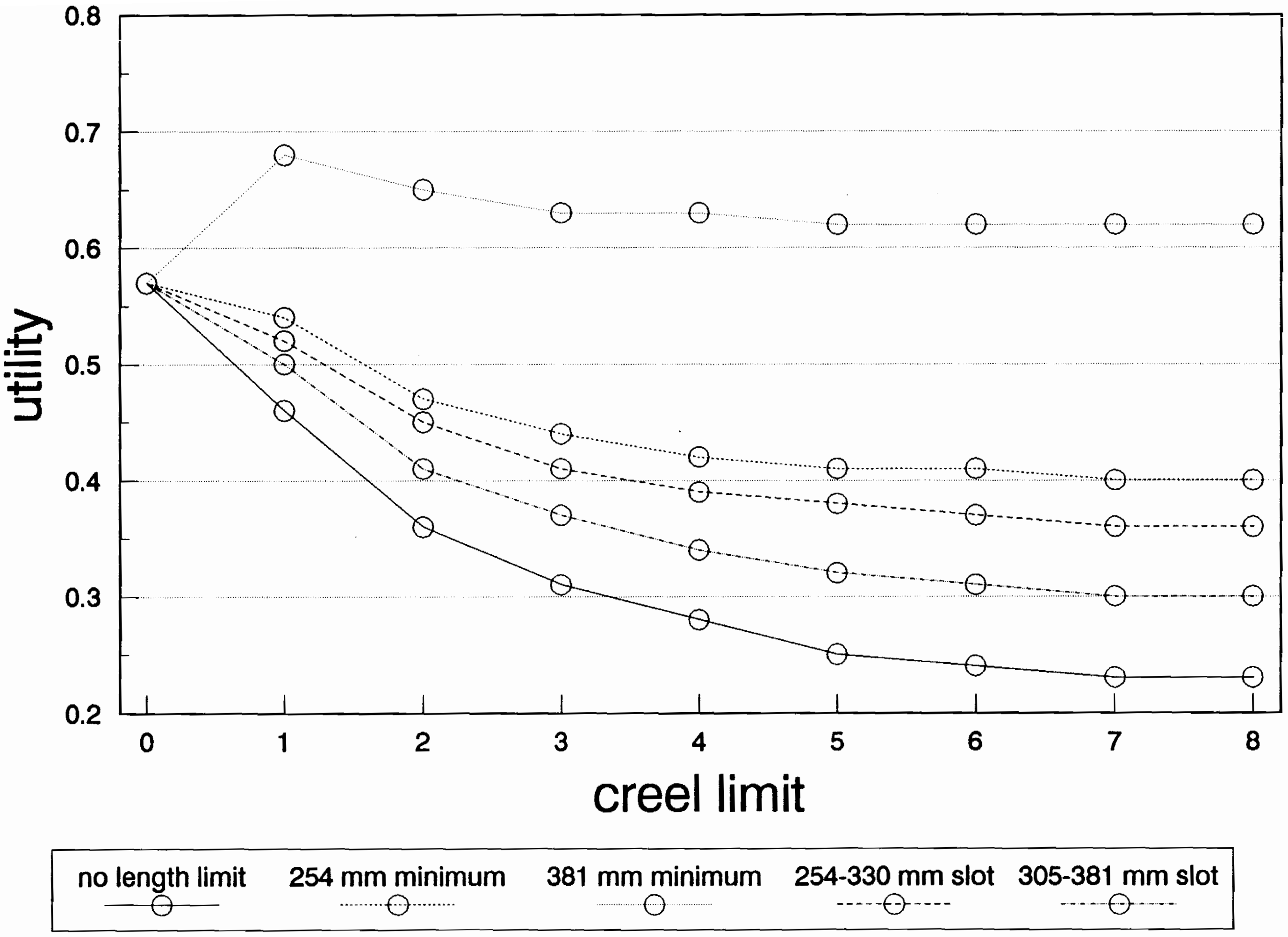


Figure 11: Utility scores under selected combinations of simulated regulations.

Conclusion

Models are very useful as theoretical representations of a complex system. They have been applied to commercial and recreational fisheries, as well as many other disciplines. This study demonstrates the utility of modelling to the responsible stewardship of fisheries resources.

In chapter 1, the frequency distribution of daily angler harvest was explored. The negative binomial distribution was hypothesized to characterize this frequency distribution. Some similarity was found between the harvest in different fisheries for smallmouth bass. In eight of the ten cases explored, the negative binomial represented the harvest frequency distribution well. In the remaining two cases, the poor fit of the negative binomial could be explained by problems with the creel survey methodologies and as an artifact of the procedure for generating the fitted distribution. Predicted reductions in harvest based on the negative binomial underestimated the potential reduction in harvest due to creel limit reductions. It was concluded that the negative binomial would serve as a useful model of daily angler harvest in situations where data was limited. It was obvious, due to the underestimation of harvest reductions based on the negative binomial, that the use of reliable field data when available was preferred. Since the three data sets from the New River seemed reliable and allowed calculating a mean with very low variance, the actual frequency distributions were employed for modelling creel limit reductions in Chapter 2.

A computer implemented simulation model employing instantaneous rates was developed for recreational fisheries in Chapter 2. This model expanded on existing approaches by simulating two potential harvest regulations, creel limits and length limits, and what interactive effects they would have on the fishery. In order to demonstrate this modelling approach, simulations were conducted based on data from the smallmouth bass fishery of the New River, West Virginia. Model inputs were derived from specific data on the River, as well as from existing literature on the species. Simulation results were compared to field studies comparing different regulation schemes. There were quantative differences in the effects of specific regulation changes between the model and field data. However, these differences could be explained by changes in mortality patterns, density effects on growth rate, violation of other model assumptions, and chance events, such as recruitment failure in one case. In general, comparison of the model results to field data support the validity of the model's predictions tempered by consideration of its assumptions.

Model predictions indicate that the size structure of the smallmouth bass population and the quality of the fishery in the New River, West Virginia, could be improved through more restrictive regulations. However, careful consideration should be given to Austen's (1984) observation that mortality was higher under a 305 mm minimum length limit on the Virginia section of the River compared to the West Virginia section with no length limit. A careful look should also be given to the results of Virginia's current slot length limit regulation to see if improved growth results.

This study displays the application of many numeric techniques to a particular fishery situation. Some of these include characterizing a frequency distributions, simulation modelling, principal components analysis, and utility analysis. In most situation it will not be necessary to used all of these techniques, but this study provides a demonstration of the applicability of each of these individually. It is only hoped that some part or parts of this may prove useful in the wise management of particular fisheries resources.

LITERATURE CITED

Anderson, R. O. 1976. Management of small warm water impoundments. Fisheries 1(6):5-7, 26-28.

Argue, A. W., R. Hilborn, R. M. Peterman, M. J. Stanley, and C. J. Walters. 1983. The Strait of Georgia chinook and coho fishery. Bulletin 211 in Fisheries and Aquatic Sciences, Canadian Department of Fisheries and Oceans, Ottawa, Ontario.

Austen, D. J. 1984. Evaluation of the effects of a 305-mm minimum length limit on the smallmouth bass populations in the New River. Master's Thesis, Virginia Polytechnic Institute and State University, Blacksburg.

Austen, D. J. and D. J. Orth. 1984. Angler catches from New River, Virginia and West Virginia, in relation to minimum length limit regulations. Proceedings of the Annual Conference Southeastern Association Fish and Wildlife Agencies 38:520-531.

Austen, D. J. and D. J. Orth. 1985. Food utilization by riverine smallmouth bass in relation to minimum length limits. Proceedings of the Annual Conference Southeastern Association Fish and Wildlife Agencies 39:97-107.

Austen, D. J. and D. J. Orth. 1988. Evaluation of a 305-mm minimum-length limit for smallmouth bass in the New River, Virginia and West Virginia. North American Journal of Fisheries Management 8:231-239.

Barnhart, R. A., and T. D. Roelofs, editors. 1977. Catch-and-release fishing as a management tool. California Cooperative Fishery Research Unit, Arcata.

Beverton, R. J. H. and S. J. Holt. 1957. On the dynamics of exploited fish populations. Ministry of Agriculture, Fisheries, and Food, London. Fisheries Investigations Series 2, Volume 19. 533pp.

Carlander, K. D. 1977. Handbook of freshwater fishery biology. Volume 2. Iowa State University Press. Ames.

Chipman, B. D. and L. A. Helfrich. 1988. Recreational specializations and motivations of Virginia river anglers. North American Journal of Fisheries Management 8:390-398.

Clady, M. D. 1975. Early survival and recruitment of smallmouth bass in northern Michigan. Journal of Wildlife Management. 39(1):194-200.

Clady, M. D., D. E. Campbell, and G. P. Cooper. 1975. Effects of trophy angling on unexploited populations of smallmouth bass. Pages 231-239 in R. H. Stroud and H. Clepper, editors. 1975. Black bass biology and management. Sport Fishing Institute, Washington, D. C.

Clark, R. D., Jr., G. R. Alexander, and H. Gowing. 1980. Mathematical description of trout stream fisheries. Transactions of the American Fisheries Society. 109:587-602.

Clark, R. D., Jr. 1983. Potential effects of voluntary catch and release of fish on recreational fisheries. North American Journal of Fisheries Management. 3:306-314.

Coble, D. W. 1975. Smallmouth bass. Pages 21-33 in R. H. Stroud and H.Clepper, editors. 1975. Black bass biology and management. Sport Fishing Institute, Washington, D. C.

DeAngelis, D. L. and C. C. Coutant. 1979. Growth rates and size distributions of first-year smallmouth bass populations: some conclusions from experiments and a model. Transactions of the American Fisheries Society. 108:137-141.

Elliott, J. M. 1977. Some methods for the statistical analysis of samples of benthic invertebrates, second edition. Scientific Publication Number 25. Freshwater Biological Association, Cumbria, England.

Fajen, O. F. 1975a. The standing crop of smallmouth bass and associated species in Courtois Creek. Pages 231-239 in R. H. Stroud and H. Clepper, editors. 1975. Black bass biology and management. Sport Fishing Institute, Washington, D. C.

Fajen, O. F. 1975b. The effect of a "fish-for-fun" regulation on black bass upon the standing crop of fish in Courtois Creek. Missouri Department of Conservation. Dingell-Johnson Project F-1-R-24, Study 11, Columbia.

Fajen, O. F. 1981. An evaluation of the 12-inch minimum length limit on black bass in streams. Missouri Department of Conservation. Dingell-Johnson Project F-1-R-30, S-23.

Fleener, G. G. 1973. Harvest of fish from the Current River. Missouri Department of Conservation. Dingell-Johnson Project F-1-R-21, Study 10, Columbia.

Fleener, G. G. 1974a. Harvest of fish from Huzzah Creek. Missouri Department of Conservation. Dingell-Johnson Project F-1-R-23, Study 12, Columbia.

Fleener, G. G. 1974b. Harvest of fish from the Big Piney River. Missouri Department of Conservation. Dingell-Johnson Project F-1-R-22, Study 2, Columbia.

Fleener, G. G. 1975. Harvest of smallmouth bass and associated species in Courtois Creek. Pages 250-256 in R. H. Stroud and H. Clepper, editors. 1975. Black bass biology and management. Sport Fishing Institute, Washington, D. C.

Forbes, A. M. 1989. Population dynamics of smallmouth bass (Micropterus dolomieui) in the Galena (Fever) River and one of its tributaries. Technical Bulletin No. 165. Wisconsin Department of Natural Resources, Madison.

Forney, J. L. 1972. Biology and management of smallmouth bass (Micropterus dolomieui) in Oneida Lake, New York. New York Fish and Game Journal. 19:132-154.

Funk, J. L. 1975. Evaluation of the smallmouth bass population and fishery in Courtois Creek. Pages 257-269 in R. H. Stroud and H. Clepper, editors. 1975. Black bass biology and management. Sport Fishing Institute, Washington, D. C.

Funk, J. L. and G. G. Fleener. 1966. Evaluation of a year-round open fishing season upon a smallmouth bass stream, Niangua River, Missouri. Missouri Department of Conservation Division of Fisheries, D-J Series No. 2. Dingell-Johnson Project F-1-R, Columbia.

Funk, J. L., and G. G. Fleener. 1974. The fishery of a Missouri Ozark stream, Big Piney River, and the effects of stocking fingerling smallmouth bass. Transactions of the American Fisheries Society. 103:757-771.

Gabelhouse, D. W., Jr. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management 4:273-285.

Getz, W. M. 1980. Harvesting models and stock recruitment curves in fisheries management. Pages 284-304 in Getz, W. M., editor. Mathematical modelling in biology and ecology. Springer-Verlag, Berlin, Germany.

Getz, W. M. 1985. Optimal feedback strategies for managing multicohort populations. Journal of Optimization Theory and applications. 46:505-514.

Gutreuter, S. J. and R. O. Anderson. 1985.Importance of body size to the recruitment process in largemouth bass populations. Transactions of the American Fisheries Society. 114:317-327.

Hampton, J. and J. Majkowski. 1986. Computer simulations of future southern bluefin tuna parental biomass, recruitment, and catches under the 1982 fishing regime. North American Journal of Fisheries Management 6:77-87.

Healey, M. C. 1984. Multiattribute analysis and the concept of optimum yield. Canadian Journal of Fisheries and Aquatic Sciences. 41:1393-1406.

Hicks, C. E., L. C. Belusz, D. J. Witter, and P. S. Haverland. 1983. Application of angler attitudes and motives to management strategies at Missouri's trout parks. Fisheries. 8(5):2-7.

Hilborn, R., C. J. Walters, R. M. Peterman, and M. J. Stanley. 1984. Models and fisheries: a case study in implementation. North American Journal of Fisheries Management. 4:9-14.

Hughes, T. P. 1983. Population dynamics based on individual size rather than age: a general model with a coral reef example. American Naturalist. 123:778-795.

Jensen, A. L. 1981. Optimum size limits for trout fisheries. Canadian Journal of Fisheries and Aquatic Sciences. 38:657-661.

Kauffman, J. 1983. Effects of a smallmouth bass minimum size limit on the Shenandoah River sport fishery. Proceedings of the Annual Conference Southeastern Association Fish and Wildlife Agencies 37:459-467.

Kauffman, J. W. and P. P. Smith. 1987. Shenandoah Size Limit Studies. Virginia Commission of Game and Inland Fisheries. Dingell-Johnson Project F-45-R, Richmond.

Kilambi, R. V., W. R. Robison, and J. C. Adams. 1977. Growth, mortality, food habits, and fecundity of the Buffalo River smallmouth bass. Proceedings of the Arkansas Academy of Science. 31:62-65.

Lackey, R. T. 1978. Fisheries management theory. Special Publication 11. American Fisheries Society, Bethesda, Maryland.

Lewis, G. E. 1985. Shenandoah River creel survey performance report. West Virginia Department of Natural Resources, Federal Aid Project F-10-R-28, Charleston.

McClendon, D. D. and C. F. Rabeni. 1987. Physical and biological variables useful in predicting population characteristics of smallmouth bass and rock bass in an Ozark stream. North American Journal of Fisheries Management 7:46-56.

Morris, W., editor. 1980. The American heritage dictionary of the English language. Houghton Mifflin Company, Boston, Massachusetts.

Nielsen, L. A. and W. F. Schoch. 1980. Errors in estimating mean weight and other statistics from mean length. Transactions of the American Fisheries Society. 109:319-322.

Orth, D. J., D. D. Oakey, and O. E. Maughan. 1983. Population characteristics of smallmouth bass in Glover Creek, southeast Oklahoma. Proceedings of the Oklahoma Academy of Science 63:37-41.

Paragamian, V. L. 1973. Population characteristics of smallmouth bass (Micropterus dolomieui) in the Plover and Red Cedar Rivers, Wisconsin. Master's Thesis, University of Wisconsin, Stevens Point.

Paragamian, V. L. 1984a. Population characteristics of smallmouth bass in five Iowa streams and management recommendations. North American Journal of Fisheries Management 4:497-506.

Paragamian, V. L. 1984b. Evaluation of a 12.0-inch minimum length limit on smallmouth bass in the Maquoketa River, Iowa. North American Journal of Fisheries Management 4:507-513.

Paragamian, V. L. and D. W. Coble. 1975. Vital statistics of smallmouth bass in two Wisconsin rivers, and other waters. Journal of Wildlife Management. 39:201-210.

Pflieger, W. L. 1966. Reproduction of smallmouth bass (Micropterus dolomieui) in a small Ozark stream. American Midland Naturalist. 76(2):410-419.

Pielou, E. C. 1977. Mathematical ecology. John Wiley and Sons, New York.

Pierce, B. E., C. W. Stihler, and J. E. Reed. 1981. A recreational use survey of a section of the New River below Bluestone Dam in West Virginia. In house report. West Virginia Department of Natural Resources, Charleston.

Ploskey, G. R. and R. M. Jenkins. 1982. Biomass model of reservoir fish and fish-food interactions, with implications for management. North American Journal of Fisheries Management 2:105-121.

Porch, C. E., I. 1988. Dynamic trends trends of fisheries regulated by small daily bag limits. Master's Thesis, University of Miami, Miami, Florida.

Powers, J. E. and R. T. Lackey. 1976. A multiattribute utility function for management of a recreational resource. Virginia Journal of Science. 27(4):191-198.

Redmond, L. C. 1986. The history and development of warmwater harvest regulations. Pages 186-195 in G. E. Hall and M. J. Van Den Avyle, editors. Reservoir Management: Strategies for the 80's. American Fisheries Society. Bethesda, Maryland.

Reed, W. J. 1980. Optimum age-specific harvesting in a nonlinear population model. Biometrics. 36:579-593.

Reed, M. S. and C. F. Rabeni. 1989. Characteristics of an unexploited smallmouth bass population in a Missouri Ozark stream. North American Journal of Fisheries Management 9:420-426.

Renyard, T. S. and R. Hilborn. 1986. Sports angler preferences for alternative regulatory methods. Canadian Journal of Fisheries and Aquatic Sciences. 43:240-242.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin 191. Fisheries Research Board of Canada. Ottawa.

Rieman, B. E. and R. C. Beamesderfer. 1990. Dynamics of a northern squawfish population and the potential to reduce predation on juvenile salmonids in a Columbia River reservoir. North American Journal of Fisheries Management 10:228-241.

Roell, M. J. and D. J. Orth. 1987. Investigation of commercial invertebrate bait harvest in the New River, West Virginia. West Virginia Department of Natural Resources. National Marine Fisheries Service Project No. 3-380-R-1, Charleston.

SAS (Statistical Analysis System). 1982. SAS user's guide: statistics. SAS Institute, Cary, North Carolina.

Sanderson, A. E. 1958. Smallmouth bass management in the Potomac River basin. Transactions of the 23rd North American Wildlife Conference:248-262.

Serns, S. L. 1984. An 8-inch length limit on smallmouth bass: effects on the sport fisheries and populations of smallmouth bass and yellow perch in Nebish Lake, Wisconsin. Technical Bulletin No. 148. Wisconsin Department of Natural Resources, Madison.

Smith, K. D. 1981. A general numerical model for evaluating size limit regulations with application to Michigan bluegill. Research Report Number 1897. Michigan Department of Natural Resources.

Snedecor, G. W., and W. G. Cochran. 1967. Statistical Methods. Iowa State University Press, Ames.

Taylor, M. W. 1981. A generalized inland fishery simulator for management biologists. North American Journal of Fisheries Management. 1:60-72.

Turner, W. R. 1967. A pre- and post-impoundment survey of Middle Fork of the Kentucky River. Fisheries Bulletin 51, Kentucky Department of Fish and Wildlife Resources, Frankfort.

Walpole, R. E. and R. H. Myers. 1989. Probability and statistics for engineers and scientists. Macmillan Publishing Company, New York.

Walters, C. J. 1969. A generalized computer simulation model for fish population studies. Transactions of the American Fisheries Society. 98:505-512.

Walters, C. J. 1975. Optimal harvest strategies for salmon in relation to environmental variability and uncertain production parameters. Canadian Journal of Fisheries and Aquatic Sciences. 32:1777-1784.

Walters, C. J. 1981. Optimum escapements in the face of alternative recruitment hypotheses. Canadian Journal of Fisheries and Aquatic sciences. 38:678-689.

Waters, J. R. and G. R. Huntsman. 1986. Incorporating mortality from catch and release into yield-per-recruit analyses of minimum-size limits. North American Journal of Fisheries Management. 6:463-471.

Weithman, S. E. and R. J. Ebert. 1981. Goal programming to assist in decision making. Fisheries. 6(1):5-8.

Williams, F. M. 1984. A fish population model for instream flow assessment. Research Project Technical Completion Report A-059-PA. Institute for Research on Land and Water Resources, Pennsylvania State University, University Park, Pennsylvania.

Williamson, E., and M. H. Bretherton. 1963. Tables of the negative binomial probability distribution. John Wiley and Sons, Ltd., London.

Wollitz, R. E. 1968.Smallmouth bass stream investigations. Virginia Commission of Game and Inland Fisheries. Dingell-Johnson Project F-14-R-5, Richmond.

Zagar, A. J. and D. J. Orth. 1986. Evaluation of harvest regulations for largemouth bass populations in reservoirs: a computer simulation. Pages 218-226 in G. E. Hall and M. J. Van Den Avyle, editors. Reservoir Fisheries Management: Strategies for the 80's. Reservoir Committee, Southern Division American Fisheries Society, Bethesda, Maryland.

Zuboy,J. R. and R. T. Lackey. 1975. A computer simulation of a multispecies centrarchid population complex. Virginia Journal of Science. 26(1):13-19.

APPENDICES

Appendix A: Angler Harvest Frequency Distributions

Upper New River, WV:

Harvest/	Observed		Predicted	
angler-day	Number	Frequency*	Number*	Frequency*
0	189	0.791	191	0.800
1	20	0.084	23	0.095
2	16	0.067	10	0.042
3	4	0.017	6	0.024
4	5	0.021	4	0.015
5	1	0.004	2	0.010
6	0	0.000	2	0.006
7	3	0.013	1	0.004
8	1	0.004	1	0.003

*Discrepencies due to rounding.

New River, Bluestone to Hinton, WV:

Harvest/	Observed		Predicted	
angler-day	Number	Frequency*	Number*	Frequency*
0	386	0.828	390	0.836
1	39	0.084	37	0.079
2	16	0.034	16	0.035
3	7	0.015	9	0.019
4	5	0.011	5	0.012
5	5	0.011	4	0.008
6	4	0.009	2	0.005
7	2	0.004	2	0.003
8	2	0.004	1	0.002

*Discrepencies due to rounding.

Appendix A: (continued)

New River, Hinton to Sandstone Falls, WV:

Harvest/ angler-day	Observed Number	Observed Frequency*	Predicted Number*	Predicted Frequency*
0	280	0.662	295	0.697
1	52	0.123	54	0.129
2	40	0.095	27	0.064
3	21	0.050	16	0.039
4	12	0.028	11	0.025
5	7	0.017	7	0.017
6	6	0.014	5	0.012
7	3	0.007	4	0.009
8	2	0.005	3	0.007

*Discrepencies due to rounding.

Shenandoah River, WV:

Harvest/ angler-day	Observed Number	Observed Frequency*	Predicted Number*	Predicted Frequency*
0	344	0.454	562	0.741
1	218	0.288	82	0.108
2	77	0.102	41	0.054
3	53	0.070	25	0.033
4	30	0.040	17	0.022
5	16	0.021	12	0.016
6	4	0.005	9	0.012
7	7	0.009	7	0.009
8	9	0.012	5	0.007

*Discrepencies due to rounding.

Appendix A: (continued)

Shenandoah River, Section A, VA 1984:

Harvest/ angler-day	Observed Number	Frequency*	Predicted Number*	Frequency*
0	265	0.904	267	0.910
1	13	0.044	13	0.045
2	5	0.017	6	0.019
3	3	0.010	3	0.010
4	2	0.007	2	0.006
5	2	0.007	1	0.004
6	0	0.000	1	0.003
7	1	0.003	1	0.002
8	2	0.007	0	0.001

*Discrepencies due to rounding.

Shenandoah River, Section A, VA 1985:

Harvest/ angler-day	Observed Number	Frequency*	Predicted Number*	Frequency*
0	266	0.847	268	0.855
1	25	0.080	26	0.082
2	8	0.025	10	0.031
3	5	0.016	5	0.015
4	4	0.013	2	0.008
5	5	0.016	1	0.004
6	1	0.003	1	0.003
7	0	0.000	0	0.001
8	0	0.000	0	0.001

*Discrepencies due to rounding.

Appendix A: (continued)

Shenandoah River, Section B, VA 1984:

Harvest/ angler-day	Observed Number	Observed Frequency*	Predicted Number*	Predicted Frequency*
0	113	0.384	165	0.562
1	44	0.150	43	0.148
2	52	0.177	26	0.088
3	24	0.082	18	0.060
4	25	0.085	13	0.044
5	9	0.031	10	0.034
6	12	0.041	8	0.026
7	9	0.031	6	0.021
8	6	0.020	5	0.017

*Discrepencies due to rounding.

Shenandoah River, Section B, VA 1985:

Harvest/ angler-day	Observed Number	Observed Frequency*	Predicted Number*	Predicted Frequency*
0	318	0.750	326	0.768
1	38	0.090	44	0.104
2	26	0.061	21	0.049
3	17	0.040	12	0.029
4	12	0.028	8	0.018
5	4	0.009	5	0.012
6	4	0.009	4	0.009
7	4	0.009	3	0.006
8	1	0.002	2	0.004

*Discrepencies due to rounding.

Appendix A: (continued)

Shenandoah River, Section C, VA 1984:

Harvest/ angler-day	Observed Number	Observed Frequency*	Predicted Number*	Predicted Frequency*
0	214	0.746	223	0.776
1	28	0.098	26	0.092
2	10	0.035	13	0.046
3	10	0.035	8	0.028
4	8	0.028	6	0.019
5	9	0.031	4	0.014
6	3	0.010	3	0.010
7	1	0.003	2	0.008
8	4	0.014	2	0.006

*Discrepencies due to rounding.

Shenandoah River, Section C, VA 1985:

Harvest/ angler-day	Observed Number	Observed Frequency*	Predicted Number*	Predicted Frequency*
0	194	0.833	196	0.844
1	17	0.073	17	0.074
2	5	0.021	8	0.033
3	6	0.026	4	0.017
4	3	0.013	3	0.012
5	4	0.017	2	0.008
6	3	0.013	1	0.005
7	1	0.004	1	0.004
8	0	0.000	1	0.003

*Discrepencies due to rounding.

Appendix B: Negative Binomial PASCAL Program Listing

```
PROGRAM NEGBIN(INPUT,OUTPUT,LISTFILE);
     {this program accepts a frequency distribution of up to 100
     groups, calculates an expected distribution using a negative
     binomial, and preforms a chi-square goodness of fit test}

CONST
     DEV='LISTING';

TYPE
     DISTRIBUTION= ARRAY[0..100] OF REAL;


VAR
     loop: char;
     TITLE: STRING[80];
     IMDONE: CHAR;
     LISTFILE: TEXT;
     CHICOUNT, MAX, I, GROUP: INTEGER;
     MEAN, N, VARIANCE, KHAT, CHISQ: REAL;
     DIST, DISTF, NEWDIST, NEWDISTF: DISTRIBUTION;

{****************************************************************}

PROCEDURE ENTERDATA(VAR N:real;var MAX: INTEGER; VAR DIST,
     DISTF:DISTRIBUTION);

{this procedure gets the total number of observations, the number
of groups, and the observed distribution.  it also calculates the
observed probability distribution.}

VAR  TOTAL: REAL;
     I: INTEGER;

BEGIN {ENTERDATA}
     WRITELN('ENTER THE NUMBER OF GROUPS');
     READLN(MAX);
     MAX:=MAX-1;
     TOTAL:=0;
     FOR I:=0 TO MAX DO
     BEGIN {FOR}
          WRITE('ENTER COUNT FOR GROUP ');
          WRITELN(I);
          READLN(DIST[I]);
          TOTAL:=TOTAL+DIST[I];
     END; {FOR}
     N:=TOTAL;
```

Appendix B: (continued)

```
     FOR I:=0 TO MAX DO
          DISTF[I]:=DIST[I]/N;
END; {ENTERDATA}

{*****************************************************************}

PROCEDURE STATISTICS(N:real; MAX: INTEGER; DIST: DISTRIBUTION;
     VAR MEAN, VARIANCE: REAL);

VAR  I: INTEGER;
     TOT, TOTSQ: REAL;

BEGIN {STATISTICS}
     TOT:=0;
     TOTSQ:=0;
     FOR I:=1 TO MAX DO
     BEGIN {FOR}
          TOT:=TOT+(I*DIST[I]);
          TOTSQ:=TOTSQ+(I*I*DIST[I]);
     END; {FOR}
     MEAN:=TOT/N;
     VARIANCE:=(1/(N-1))*(TOTSQ-((1/N)*TOT*TOT));
END; {STATISTICS}

{*****************************************************************}

PROCEDURE KESTIMATE(N:real; MAX: INTEGER; MEAN,VARIANCE: REAL;
     DIST: DISTRIBUTION; VAR KHAT: REAL);

VAR  A:DISTRIBUTION;
     DIFF, DIFF1, DIFF2, WIDTH, TEMP: REAL;
     I, FLAG: INTEGER;

{-----------------------------------------------------------------}

PROCEDURE CALCDIFF(DIST,A: DISTRIBUTION; KHAT,MEAN,n: REAL;
     MAX: INTEGER; VAR DIFF:REAL);

VAR  I:INTEGER;
     LEFT, RIGHT: REAL;

BEGIN {CALCDIFF}
     LEFT:=N*LN(1+MEAN/KHAT);
     RIGHT:=0;
     FOR I:=0 TO MAX DO
     BEGIN {FOR}
```

Appendix B: (continued)

```
          RIGHT:=RIGHT+(A[I]/(KHAT+I));
     END; {FOR}
     DIFF:=LEFT-RIGHT;
END; {CALCDIFF}

{-----------------------------------------------------------------}

BEGIN {KESTIMATE}
     KHAT:=(MEAN*MEAN)/((VARIANCE*VARIANCE)-MEAN);
     WIDTH:=1;
     TEMP:=N;
     FOR I:=0 TO MAX DO
     BEGIN {FOR}
          A[I]:=TEMP-DIST[I];
          TEMP:=A[I];
     END; {FOR}
     CALCDIFF(DIST,A,KHAT,MEAN,N,MAX,DIFF);
     FLAG:=0;
     WHILE ((DIFF>0.0001) AND (FLAG<2)) DO
     BEGIN {WHILE}
          TEMP:=KHAT-(WIDTH/2);
          IF TEMP < 1.0E-25 THEN
                BEGIN{THEN}
                        TEMP:=1.0E-30;
                        FLAG:=FLAG+1;
                END;{THEN}
          CALCDIFF(DIST,A,TEMP,MEAN,N,MAX,DIFF1);
          TEMP:=KHAT+(WIDTH/2);
          CALCDIFF(DIST,A,TEMP,MEAN,N,MAX,DIFF2);
          IF ((DIFF1 > 0) AND (DIFF < 0)) OR ((DIFF > 0)
               AND (DIFF1 < 0))
          THEN
          BEGIN{THEN}
               IF ABS(DIFF1) < ABS(DIFF)
               THEN
               BEGIN{THEN}
                    KHAT:=KHAT-(WIDTH/2);
               END; {THEN}
          END {THEN}
          ELSE
          BEGIN {ELSE}
               IF ((DIFF2 > 0) AND (DIFF < 0))
                    OR ((DIFF > 0) AND (DIFF2 < 0))
               THEN
               BEGIN{THEN}
                    IF ABS(DIFF2) < ABS(DIFF)
```

Appendix B: (continued)

```
                    THEN
                    BEGIN{THEN}
                         KHAT:=KHAT+(WIDTH/2);
                    END; {THEN}
               END {THEN}
               ELSE
               BEGIN {ELSE}
                    IF (ABS(DIFF1) < ABS(DIFF))
                         AND (ABS(DIFF1) < ABS(DIFF2))
                    THEN
                    BEGIN {THEN}
                         KHAT:=KHAT-(WIDTH/2);
                    END {THEN}
                    ELSE
                    BEGIN {ELSE}
                         IF (ABS(DIFF2) < ABS(DIFF))
                              AND (ABS(DIFF2) < ABS(DIFF1))
                         THEN
                         BEGIN {THEN}
                              KHAT:=KHAT+(WIDTH/2);
                         END; {THEN}
                    END; {ELSE}
               END; {ELSE}
          END; {ELSE}
          WIDTH:=WIDTH/2;
     END; {WHILE}
     IF FLAG>1 THEN
        BEGIN{THEN}
           KHAT:=0;
           WRITELN(LISTFILE,'MAX. LIKELIHOOD EQUATION DOESN'T
               CONVERGE!');
           WRITELN(LISTFILE,'THE DISTRIBUTION MAY BE A LOG-
               SERIES.');
           WRITELN(LISTFILE);
        END;{THEN}
END; {KESTIMATE}

{*****************************************************************}

PROCEDURE CALCDISTRIB(N:real; MAX: INTEGER; DIST: DISTRIBUTION;
     MEAN,VARIANCE,KHAT:REAL; VAR NEWDIST,NEWDISTF:DISTRIBUTION);

VAR  I,J: INTEGER;
     ALPHA,TOP,BOTTOM,LEFT,RIGHT,TOPTERM,BOTTOMTERM,SUM: REAL;

BEGIN {CALCDISTRIB}
```

Appendix B: (continued)

```
     LEFT:=EXP(-KHAT*LN(1+(MEAN/KHAT)));
     SUM:=0;
     FOR I:=1 TO MAX 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];
          NEWDIST[I]:=NEWDISTF[I]*N;
     END; {FOR}
     NEWDISTF[0]:=1-SUM;
     NEWDIST[0]:=NEWDISTF[0]*N;
END; {CALCDISTRIB}

{****************************************************************}

PROCEDURE CALCCHISQ(MAX:INTEGER; DIST,NEWDIST: DISTRIBUTION;
     VAR CHISQ: REAL; VAR GROUP: INTEGER);

VAR I,Z,P:INTEGER;TEMPDIST,NEWTEMP:DISTRIBUTION;

BEGIN {CALCCHISQ}
     I:=0;
     Z:=0;
     CHISQ:=0;
     WHILE Z=0 DO
     BEGIN {WHILE}
          IF NEWDIST[I]<5
               THEN
               BEGIN{THEN}
                    TEMPDIST[I]:=0;
                    NEWTEMP[I]:=0;
```

Appendix B: (continued)

```
                    FOR P:= I TO MAX DO
                        BEGIN{FOR}
                             TEMPDIST[I]:=TEMPDIST[I]+DIST[P];
                             NEWTEMP[I]:=NEWTEMP[I]+NEWDIST[P];
                        END{FOR};
                    Z:=1;
                END{THEN}
                ELSE
                BEGIN{ELSE}
                     TEMPDIST[I]:=DIST[I];
                     NEWTEMP[I]:=NEWDIST[I];
                END{ELSE};
          IF NEWTEMP[I]=0 THEN CHISQ:=9999
                ELSE CHISQ:=CHISQ+(SQR(TEMPDIST[I]-NEWTEMP[I])
                    /NEWTEMP[I]);
          I:=I+1;
          GROUP:=I;
     END; {WHILE}
END; {CALCCHISQ}

{*****************************************************************}

PROCEDURE ERRORCALC(MAX:INTEGER; DIST, NEWDIST: DISTRIBUTION);

VAR  I, J, T: INTEGER; ERROR, SUM1, SUM2, TOTHARV: REAL;

BEGIN{ERRORCALC}
        TOTHARV:=0;
        FOR I:=0 TO MAX DO
        BEGIN{FOR}
                TOTHARV:=TOTHARV+(I*DIST[I]);
        END{FOR};
        WRITELN(LISTFILE,'TOTAL HARVEST = ',TOTHARV);
        WRITELN(LISTFILE);
        WRITELN(LISTFILE,'LIMIT   % OBS RED    % PRED RED    ERROR');
        FOR I:=0 TO MAX DO
        BEGIN{FOR}
                SUM1:=0;
                SUM2:=0;
                T:=0;
                FOR J:=I TO MAX DO
                BEGIN{FOR}
                        SUM1:=SUM1+(T*DIST[J]);
                        SUM2:=SUM2+(T*NEWDIST[J]);
                        T:=T+1;
                END{FOR};
```

Appendix B: (continued)

```
                SUM1:=SUM1/TOTHARV;
                SUM2:=SUM2/TOTHARV;
                ERROR:=SUM1-SUM2;
                WRITELN(LISTFILE,I,SUM1,SUM2,ERROR);
        END{FOR};
END{ERRORCALC};

{*****************************************************************}

BEGIN {MAIN PROGRAM}
     ASSIGN(LISTFILE,DEV);
     REWRITE(LISTFILE);
     ENTERDATA(N,MAX,DIST,DISTF);
     STATISTICS(N,MAX,DIST,MEAN,VARIANCE);
     LOOP:='Y';
     WRITELN('ENTER A TITLE FOR REPORT:');
     READLN(TITLE);
     WRITELN(LISTFILE,TITLE);
     WRITELN(LISTFILE);
   WHILE LOOP = 'Y' DO
   BEGIN{WHILE};
     writeln('THE MEAN IS ',MEAN,' WHAT VALUE DO YOU WANT TO USE?');
     READLN(MEAN);
     KESTIMATE(N,MAX,MEAN,VARIANCE,DIST,KHAT);
     WRITELN(LISTFILE,'NUMBER OF OBSERVATIONS = ',N);
     WRITELN(LISTFILE,'MEAN = ',MEAN,'VARIANCE = ',VARIANCE);
     IF KHAT<0 THEN KHAT:=0.01;
     CALCDISTRIB(N,MAX,DIST,MEAN,VARIANCE,KHAT,NEWDIST,NEWDISTF);
     CALCCHISQ(MAX,DIST,NEWDIST,CHISQ,GROUP);
     WRITELN('CHISQ= ',CHISQ,' ...REPEAT LOOP?');
     READLN(LOOP);
     IF LOOP = 'y' THEN LOOP:='Y';
   END{WHILE};
     WRITELN(LISTFILE,'MAXIMUM LIKELIHOOD ESTIMATE OF K = ',KHAT);
     WRITELN(LISTFILE);
     WRITE(LISTFILE,'GROUP     OBSERVED      FREQ');
     WRITELN(LISTFILE,'           EXPECTED           FREQ');
     FOR I:=0 TO MAX DO
     BEGIN {FOR}
          WRITELN(LISTFILE,I,DIST[I],DISTF[I],NEWDIST[I],
               NEWDISTF[I]);
          END; {FOR}
          WRITELN(LISTFILE);
          WRITE(LISTFILE,'FOR GOODNESS OF FIT TEST,
               CHI-SQUARED (WITH ',GROUP-3);
          WRITELN(LISTFILE,'DF)= ',CHISQ);
```

Appendix B: (continued)

```
          WRITE(LISTFILE,'THE CHI-SQUARE HAS n-3 df; where n is');
          WRITELN(LISTFILE,GROUP,' the # of groups, lumping
               those');
          WRITELN(LISTFILE,GROUP,' in the tail with less than
               5 obs.');
          WRITELN(LISTFILE);
          ERRORCALC(MAX,DIST,NEWDIST);

     WRITELN('ENTER ANY CHARACTER TO EXIT PROGRAM');
     READ(IMDONE);
     CLOSE(LISTFILE);
END. {MAIN PROGRAM}
```

Appendix C: Sample Negative Binomial Input and Output

Input:

```
ENTER THE TOTAL NUMBER OF OBSERVATIONS
500
ENTER THE NUMBER OF GROUPS
9
ENTER COUNT FOR GROUP 1
150
ENTER COUNT FOR GROUP 2
75
ENTER COUNT FOR GROUP 3
45
ENTER COUNT FOR GROUP 4
23
ENTER COUNT FOR GROUP 5
12
ENTER COUNT FOR GROUP 6
5
ENTER COUNT FOR GROUP 7
2
ENTER COUNT FOR GROUP 8
1
ENTER A TITLE FOR THE REPORT:
** SAMPLE REPORT **
ENTER ANY CHARACTER TO EXIT PROGRAM
```

Appendix C: (continued)

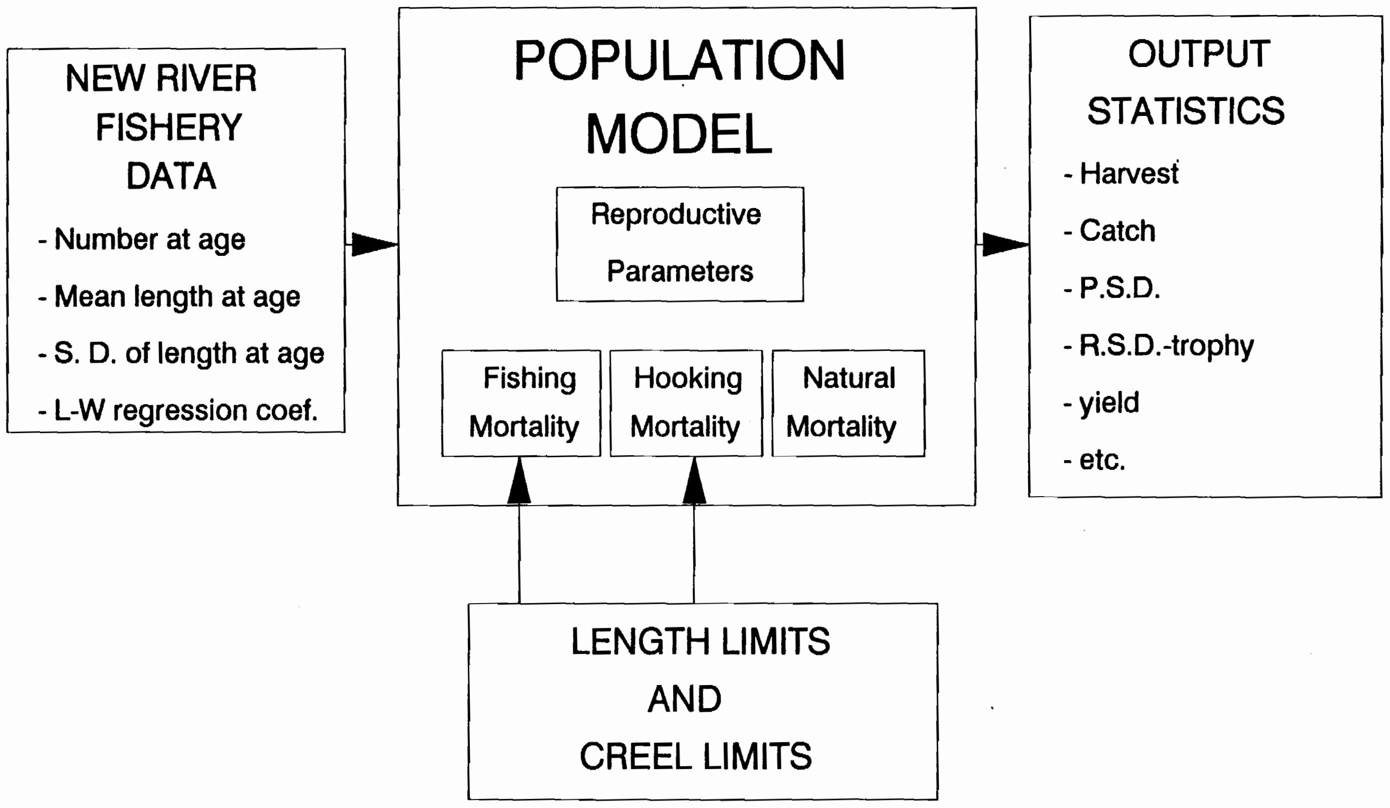
Output:

```
** SAMPLE REPORT **

NUMBER OF OBSERVATIONS = 500
MEAN =    1.2780000000E+00VARIANCE =   2.1009178357E+00
MAXIMUM LIKELIHOOD ESTIMATE OF K =   5.2084155938E-01

GROUP      OBSERVED        FREQ
0  1.8700000000E+02  3.7400000000E-01
1  1.5000000000E+02  3.0000000000E-01
2  7.5000000000E+01  1.5000000000E-01
3  4.5000000000E+01  9.0000000000E-02
4  2.3000000000E+01  4.6000000000E-02
5  1.2000000000E+01  2.4000000000E-02
6  5.0000000000E+00  1.0000000000E-02
7  2.0000000000E+00  4.0000000000E-03
8  1.0000000000E+00  2.0000000000E-03

GROUP      EXPECTED              FREQ
0  2.6985479344E+02  5.3970958689E-01
1  9.7017747786E+01  1.9403549557E-01
2  5.2413493282E+01  1.0482698656E-01
3  3.1289984088E+01  6.2579968177E-02
4  1.9567249109E+01  3.9134498218E-02
5  1.2569470919E+01  2.5138941838E-02
6  8.2169183580E+00  1.6433836716E-02
7  5.4381667609E+00  1.0876333522E-02
8  3.6321762533E+00  7.2643525067E-03

FOR GOODNESS OF FIT TEST, CHI-SQUARED (WITH 6DF)=   7.6082385314E+01
THE CHI-SQUARE VALUE WAS CALCULATED BASED ON 9 GROUPS.

TOTAL HARVEST =   6.3900000000E+02

LIMIT   % OBS RED       % PRED RED     ERROR
0  1.0000000000E+00  8.6581709726E-01  1.3418290274E-01
1  5.1017214397E-01  5.0565245476E-01  4.5196892161E-03
2  2.5508607199E-01  2.9731527358E-01 -4.2229201596E-02
3  1.1737089202E-01  1.7100233855E-01 -5.3631446528E-02
4  5.0078247261E-02  9.3656514759E-02 -4.3578267498E-02
5  1.8779342723E-02  4.6932364068E-02 -2.8153021345E-02
6  6.2597809077E-03  1.9878746898E-02 -1.3618965990E-02
7  1.5649452269E-03  7.5229143010E-03 -5.9579690750E-03
8  0.0000000000E+00  0.0000000000E+00  0.0000000000E+00
```

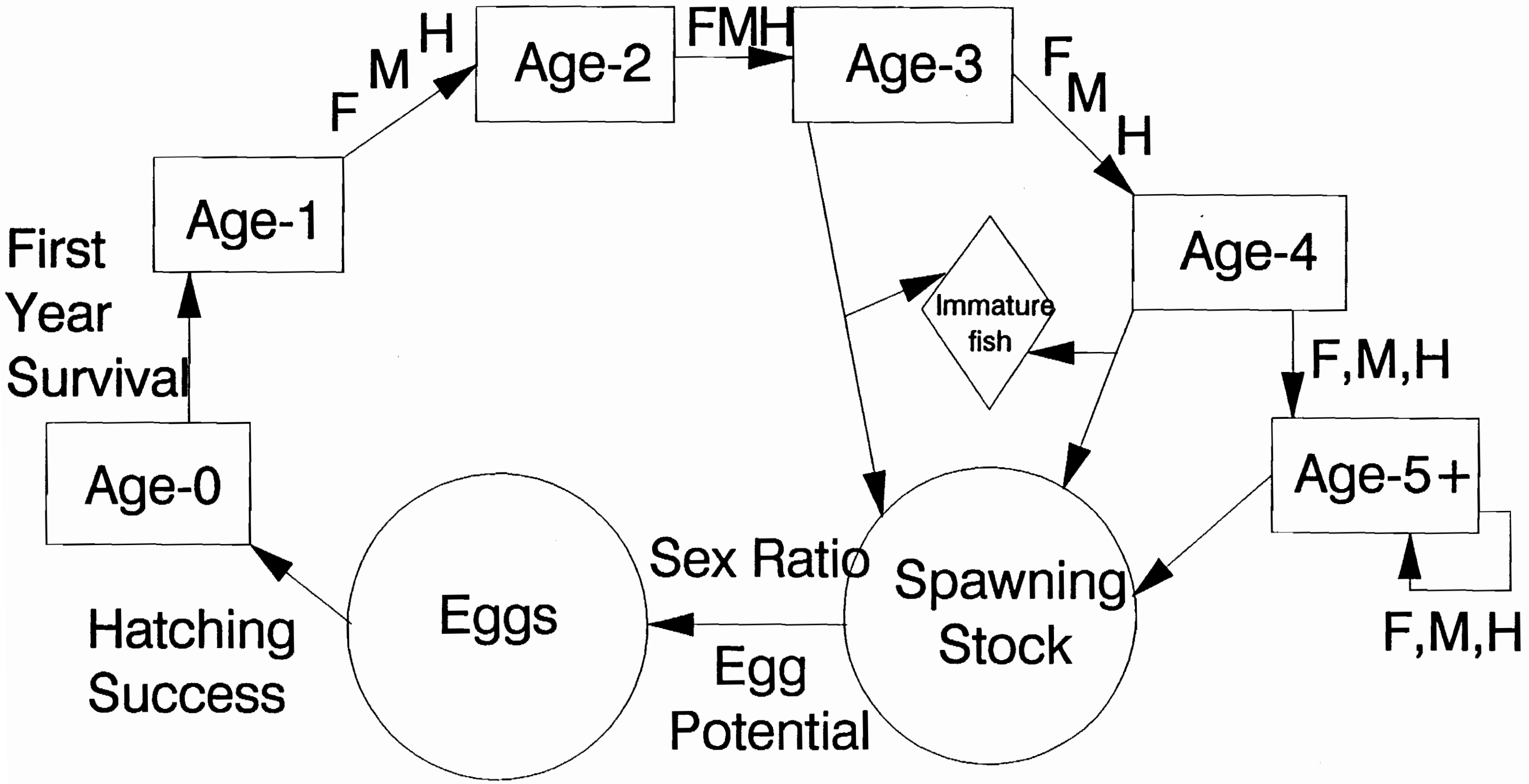
Appendix D: Chi-Square Goodness of Fit Tests

Stream Reach, State and Year	p - Value	Significant?
Upper New R., WV 1981	$0.1 < p < 0.25$	No
New R., WV above Hinton 1981	$0.25 < p < 0.5$	No
New R., WV above Sandstone Falls 1981	$0.1 < p < 0.25$	No
Shenandoah R., WV 1985	$p < 0.05$	Yes
Shenandoah R., VA section A 1984	$0.25 < p < 0.5$	No
Shenandoah R., VA section A 1985	$0.05 < p < 0.1$	No
Shenandoah R., VA section B 1984	$p < 0.05$	Yes
Shenandoah R., VA section B 1985	$0.1 < p < 0.25$	No
Shenandoah R., VA section C 1984	$0.1 < p < 0.25$	No
Shenandoah R., VA section C 1985	$0.05 < p < 0.1$	No

Appendix E: Diagrams of Model



Appendix E: (continued) Diagram of computer model.



Appendix E: (continued) Detail of population model.

Appendix F: Model PASCAL Program Listing

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

     {A population model for simulating the effects of creel
      limits, length limits, and combinations of the two.
      This program employs a differential equation approach, and
      partitions mortality into that due to natural causes,
      harvest, and the hooking mortality of released fish.  It is
      assumed that all legal fish will be retained and all
      illegal fish will be released.  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}
```

Appendix F: (continued)

```
     N:ARRAYDIST; {# IN AGE GROUP I AT END OF YEAR J}
     F:DISTRIBUTION; {INSTANEOUS RATE OF FISHING MORTALITY FOR AGE
                      GROUP I}
     M:DISTRIBUTION; {INSTANEOUS RATE OF NATURAL MORTALITY FOR AGE
                      GROUP I}
     H:DISTRIBUTION; {INSTANEOUS RATE OF HOOKING MORTALITY FOR AGE
                      GROUP I}
     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}
     SDREC:REAL; {STANDARD DEVIATION OF RECRUITMENT}
     NORMAL:NORMDIST; {RIGHT TAIL AREAS FOR INDEXED NORMAL DIST'N}
     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}
```

Appendix F: (continued)

```
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;
```

Appendix F: (continued)

```
     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}
     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 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}
```

Appendix F: (continued)

```
     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 SDREC:REAL {STANDARD DEVIATION OF RECRUITMENT}
);

{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}
```

Appendix F: (continued)

```
     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,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,SDREC);
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}
     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 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
```

Appendix F: (continued)

```
                                 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 SDREC:REAL {STANDARD DEVIATION OF RECRUITMENT}
);

{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 LINEAR COEF. OF DENSITY-DEP. 1ST-YR.
          SURVIVAL-');
     READLN(COEFA);
     WRITELN(INFILE,COEFA);
     WRITELN('ENTER EXP. 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]);
```

Appendix F: (continued)

```
          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);
          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('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');
```

Appendix F: (continued)

```
     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 STANDARD DEVIATION OF RECRUITMENT');
     READLN(SDREC);
     WRITELN(INFILE,SDREC);
     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}
     VAR M:DISTRIBUTION; {INSTANEOUS RATE OF NATURAL MORTALITY FOR
                          AGE GROUP I}
     VAR H:DISTRIBUTION; {INSTANEOUS RATE OF HOOKING MORTALITY FOR
                          AGE GROUP I}
```

Appendix F: (continued)

```
     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 SDREC:REAL {STANDARD DEVIATION OF RECRUITMENT}
);

{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,'COEFFFICIENTS 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}
```

Appendix F: (continued)

```
    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,'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]);
```

Appendix F: (continued)

```
     WRITELN(LIST,'     PREFERRED SIZE= ',LENGTH[3]);
     WRITELN(LIST,'     MEMORABLE SIZE= ',LENGTH[4]);
     WRITELN(LIST,'     TROPHY SIZE=    ',LENGTH[5]);
     WRITELN(LIST);
     WRITELN(LIST,'COEFFICIENTSFROM L-W REGRESSION');
     WRITELN(LIST,'COELW= ',COELW,' EXPLW= ',EXPLW);
     WRITELN(LIST);
     WRITELN(LIST,'STD DEV OF RECRUITMENT = ',SDREC);
     WRITELN(LIST);
END; {PRNTDATA}

{*****************************************************************}

PROCEDURE REGS(
     VAR LIST:TEXT; {OUTPUT FILE}
     VAR F:DISTRIBUTION; {INSTANEOUS RATE OF FISHING MORTALITY FOR
                          AGE GROUP I}
     VAR H:DISTRIBUTION; {INSTANEOUS RATE OF HOOKING MORTALITY FOR
                          AGE GROUP I}
     NORMAL:NORMDIST {RIGHT TAIL AREAS FOR STD. NORMAL}
);

{THIS PROCEDURE PROVIDES FOR IMPOSING EITHER LENGTH OR CREEL
 LIMIT REGULATIONS ON THE FISHERY, AND PREFORMS THE NECESSARY
 MODIFICATIONS TO THE RATES OF FISHING AND HOOKING MORTALITY.}

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}
```

Appendix F: (continued)

```
     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;
```

Appendix F: (continued)

```
               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;
          WRITELN(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}

{-----------------------------------------------------------------}
```

Appendix F: (continued)

```
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 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}
```

Appendix F: (continued)

```
          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]);
          WRITE(LIST,REDUCE[I]);
     END; {FOR}
     WRITELN(LIST);
END; {LENGTHLIMIT}

{-----------------------------------------------------------------}

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;
     {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 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);
     {APPLY MODIFICATIONS TO FISHING MORTALITY VECTOR}
     WRITELN(LIST,'THE MODIFIED FISHING MORTALITY RATES ARE:');
     FOR I:=0 TO 20 DO
     BEGIN{FOR}
          F[I]:=F[I]*REDUCE[I]*REDUCTION;
          WRITELN(LIST,F[I]);
     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
```

Appendix F: (continued)

```
      THESE ASSUMPTIONS COULD BE 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 SHOULD BE MODIFIED
      TO REFLECT THE REDUCED HARVEST DUE TO REGULATIONS.}
     WRITELN(LIST,'THE MODIFIED HOOKING MORTALITY RATES ARE:');
     FOR I:=0 TO 20 DO
     BEGIN{FOR}
          H[I]:=H[I]*(1-(REDUCE[I]*REDUCTION));
          WRITELN(LIST,H[I]);
     END; {FOR}
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};

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

Appendix F: (continued)

```
FUNCTION FIRSTYEAR(
     NO:REAL; {# IN AGE GROUP AT START OF YEAR}
     COEFA:REAL;{LINEAR COEFFICIENT OF DENSITY DEPENDENT SURVIVAL}
     COEFB:REAL; {EXPONENTIAL "  "   "   "   "   "      "   "    "}
     SDREC:REAL {STANDARD DEVIATION OF RECRUITMENT}
     ) : 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, SDREC}
     SUM:=0;
     FOR I:=1 TO 12 DO
     BEGIN{FOR}
          RX:=RANDOM;
          SUM:=SUM+RX;
     END; {END}
     V:=(SUM-6)*SDREC;
     {APPLY RANDOM VARIABILITY SUCH THAT FIRSTYEAR IS DISTRIBUTED
      IN A LOG-NORMAL FASHION}
     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};
```

Appendix F: (continued)

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

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;
```

Appendix F: (continued)

```
               IF INDEX > 72 THEN INDEX:=72;
               GSTOCK[K]:=GSTOCK[K]+N[I,0]*NORMAL[INDEX];
          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('PSD UNDEFINED');
          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
```

Appendix F: (continued)

```
 (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:REAL; {A TERM IN THE CATCH EQUATION}
     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];
          AGEC:=(N[I,0]*F[I]*(1-EXP(-MORT)))/MORT;
          TOTC:=TOTC+AGEC;
          TOTCI:=TOTCI+AGEC*I;
          WRITELN(LIST,AGEC);
     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 19 DO
     BEGIN{FOR}
          MORT:=F[I]+M[I]+H[I];
          CTERM:=EXP(LN(COELW)+EXPLW*LN(LGTHAGE[I]));
          AGEY:=(N[I,0]*F[I]*(1-EXP(-MORT))*CTERM)/MORT;
          TOTY:=TOTY+AGEY;
```

Appendix F: (continued)

```
          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,SEX,MAT,EC,HATCH,
               COEFA,COEFB,LGTHAGE,SDAGE,LENGTH,COELW,EXPLW,SDREC)
          ELSE ENTERDATA(INFILE,N,F,M,H,SEX,MAT,EC,HATCH,COEFA,
               COEFB,LGTHAGE,SDAGE,LENGTH,COELW,EXPLW,SDREC);
     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,SEX,MAT,EC,HATCH,COEFA,COEFB,LGTHAGE,
          SDAGE,LENGTH,COELW,EXPLW,SDREC);
     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,H,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}
```

Appendix F: (continued)

```
WRITELN('RUNNING SIMULATION FOR YEAR - ',X);
WRITELN(LIST);
WRITE(LIST,'*****************************************');
WRITELN(LIST,'**************************');
WRITELN(LIST);
WRITELN(LIST,'YEAR = ',X);
WRITELN(LIST);
WRITE('. ');
N[0,1]:=LARVAE(N,SEX,MAT,EC,HATCH);
WRITE('. ');
N[1,1]:=FIRSTYEAR(N[0,0],COEFA,COEFB,SDREC);
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};
```

Appendix F: (continued)

```
          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 G: Sample Model Output

```
SAMPLE TITLE

INITIAL DATA


HATCHING SUCCESS RATE=  9.9434150000E-02

COEFFFICIENTS FOR DENSITY-DEP. 1ST YR. SURVIVAL
COEFA=  6.0000000000E-05COEFB=  9.0000000000E+00

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

AGE SPECIFIC MATURITY RATES
AGE=0MATURITY=  0.0000000000E+00
AGE=1MATURITY=  0.0000000000E+00
AGE=2MATURITY=  0.0000000000E+00
AGE=3MATURITY=  4.0000000000E-01
AGE=4MATURITY=  6.0000000000E-01
AGE=5MATURITY=  1.0000000000E+00
AGE=6MATURITY=  1.0000000000E+00
AGE=7MATURITY=  1.0000000000E+00
AGE=8MATURITY=  1.0000000000E+00
AGE=9MATURITY=  1.0000000000E+00
AGE=10MATURITY=  1.0000000000E+00
AGE=11MATURITY=  1.0000000000E+00
```

Appendix G: (continued)

```
AGE=12MATURITY=  1.0000000000E+00
AGE=13MATURITY=  1.0000000000E+00
AGE=14MATURITY=  1.0000000000E+00
AGE=15MATURITY=  1.0000000000E+00
AGE=16MATURITY=  1.0000000000E+00
AGE=17MATURITY=  1.0000000000E+00
AGE=18MATURITY=  1.0000000000E+00
AGE=19MATURITY=  1.0000000000E+00
AGE=20MATURITY=  1.0000000000E+00

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

FISHING MORTALITY RATES BY AGE
AGE=0F=  0.0000000000E+00
AGE=1F=  0.0000000000E+00
AGE=2F=  1.0147770000E+00
AGE=3F=  1.0147770000E+00
AGE=4F=  1.0147770000E+00
AGE=5F=  1.0147770000E+00
AGE=6F=  1.0147770000E+00
AGE=7F=  1.0147770000E+00
AGE=8F=  1.0147770000E+00
AGE=9F=  1.0147770000E+00
AGE=10F=  1.0147770000E+00
AGE=11F=  1.0147770000E+00
```

Appendix G: (continued)

```
AGE=12F=  1.0147770000E+00
AGE=13F=  1.0147770000E+00
AGE=14F=  1.0147770000E+00
AGE=15F=  1.0147770000E+00
AGE=16F=  4.0934840000E+00
AGE=17F=  4.0934840000E+00
AGE=18F=  4.0934830000E+00
AGE=19F=  4.0934840000E+00
AGE=20F=  4.0934840000E+00

NATURAL MORTALITY BY AGE
AGE=0M=  1.2039720000E+00
AGE=1M=  1.2039720000E+00
AGE=2M=  1.8919500000E-01
AGE=3M=  1.8919500000E-01
AGE=4M=  1.8919500000E-01
AGE=5M=  1.8919500000E-01
AGE=6M=  1.8919500000E-01
AGE=7M=  1.8919500000E-01
AGE=8M=  1.8919500000E-01
AGE=9M=  1.8919500000E-01
AGE=10M=  1.8919500000E-01
AGE=11M=  1.8919500000E-01
AGE=12M=  1.8919500000E-01
AGE=13M=  1.8919500000E-01
AGE=14M=  1.8919500000E-01
AGE=15M=  1.8919500000E-01
AGE=16M=  1.0000000000E+01
AGE=17M=  1.0000000000E+01
AGE=18M=  1.0000000000E+01
AGE=19M=  1.0000000000E+01
AGE=20M=  1.0000000000E+01

HOOKING MORTALITY BY AGE
AGE=0H=  2.0000000000E-01
AGE=1H=  2.0000000000E-01
AGE=2H=  2.0000000000E-01
AGE=3H=  2.0000000000E-01
AGE=4H=  2.0000000000E-01
AGE=5H=  2.0000000000E-01
AGE=6H=  2.0000000000E-01
AGE=7H=  2.0000000000E-01
AGE=8H=  2.0000000000E-01
AGE=9H=  2.0000000000E-01
AGE=10H=  2.0000000000E-01
AGE=11H=  2.0000000000E-01
```

Appendix G: (continued)

```
AGE=12H=  2.0000000000E-01
AGE=13H=  2.0000000000E-01
AGE=14H=  2.0000000000E-01
AGE=15H=  2.0000000000E-01
AGE=16H=  2.0000000000E-01
AGE=17H=  2.0000000000E-01
AGE=18H=  2.0000000000E-01
AGE=19H=  2.0000000000E-01
AGE=20H=  2.0000000000E-01

INITIAL NUMBERS BY AGE CLASS
  2.1084710834E+05
  1.0852576093E+04
  3.2557758633E+03
  9.7673352601E+02
  2.9302023639E+02
  8.7906111722E+01
  2.6371844379E+01
  7.9115572308E+00
  2.3734688677E+00
  7.1204138921E-01
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00

MEAN LENGTH AT AGE
  5.0000000000E+00
  1.0600000000E+02
  1.9000000000E+02
  2.5200000000E+02
  3.1300000000E+02
  3.8700000000E+02
  4.5900000000E+02
  5.2400000000E+02
  5.4800000000E+02
  5.6000000000E+02
  5.7500000000E+02
  5.8500000000E+02
```

Appendix G: (continued)

```
   5.9000000000E+02
   5.9300000000E+02
   5.9500000000E+02
   5.9600000000E+02
   5.9700000000E+02
   5.9800000000E+02
   5.9900000000E+02
   6.0000000000E+02
   6.0000000000E+02

STANDARD DEVIATION OF LENGTH AT AGE
   1.0000000000E+00
   1.6000000000E+01
   1.6000000000E+01
   2.0000000000E+01
   2.9000000000E+01
   4.2000000000E+01
   4.2000000000E+01
   4.2000000000E+01
   4.2000000000E+01
   4.2000000000E+01
   4.2000000000E+01
   4.2000000000E+01
   4.2000000000E+01
   4.2000000000E+01
   4.2000000000E+01
   4.2000000000E+01
   4.2000000000E+01
   4.2000000000E+01
   4.2000000000E+01
   4.2000000000E+01
   4.2000000000E+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

COEFFICIENTSFROM L-W REGRESSION
COELW=    1.2850000000E-05 EXPLW=    2.9940000000E+00

STD DEV OF RECRUITMENT =    0.0000000000E+00
```

Appendix G: (continued)

```
PSD AND RSD VALUES
PSD=  1.2159085430E-01
RSD-P=  3.6546361601E-02
RSD-M=  1.1927570342E-02
RSD-T=  2.8361610093E-03
RSD-SQ=  8.7840914570E-01
RSD-QP=  8.5044492697E-02
RSD-PM=  2.4618791259E-02
RSD-MT=  9.0914093329E-03

 CATCH(HARVEST) VECTOR=
  0.0000000000E+00
  0.0000000000E+00
  1.7752403715E+03
  5.3257252968E+02
  1.5977185628E+02
  4.7931579133E+01
  1.4379479663E+01
  4.3138460347E+00
  1.2941547365E+00
  3.8824681839E-01
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00

 TOTAL HARVEST=   2.5358920638E+03

MEAN AGE HARVESTED =   2.4280469189E+00
MEAN LENGTH HARVESTED =   2.1653890897E+02

 YIELD VECTOR=
  0.0000000000E+00
  0.0000000000E+00
  1.5161723585E+05
  1.0594369319E+05
  6.0822344292E+04
  3.4445420766E+04
  1.7223185497E+04
  7.6814930424E+03
```

Appendix G: (continued)

```
  2.6351074322E+03
  8.4350174611E+02
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00

 TOTAL YIELD=   3.8121198182E+05


CREEL LIMIT = 4
YOU ESTIMATED REDUCTION IN HARVEST OF   8.0000000000E-01
     TIMES THE PREVIOUS HARVEST.


FISH MAY NOT BETWEEN THE LENGTHS OF   1.2500000000E+02
                                AND   3.0000000000E+02.
THE MODIFICATION FACTORS FOR F ARE:
  1.0000000000E+00
  8.8490000000E-01
  0.0000000000E+00
  8.1999999984E-03
  6.5540000000E-01
  9.8210000000E-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
  1.0000000000E+00
  1.0000000000E+00
  1.0000000000E+00
  1.0000000000E+00
```

Appendix G: (continued)

```
THE MODIFIED FISHING MORTALITY RATES ARE:
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  6.6569371187E-03
  5.3206787664E-01
  7.9728999336E-01
  8.1182160000E-01
  8.1182160000E-01
  8.1182160000E-01
  8.1182160000E-01
  8.1182160000E-01
  8.1182160000E-01
  8.1182160000E-01
  8.1182160000E-01
  8.1182160000E-01
  8.1182160000E-01
  3.2747872000E+00
  3.2747872000E+00
  3.2747864000E+00
  3.2747872000E+00
  3.2747872000E+00
THE MODIFIED HOOKING MORTALITY RATES ARE:
  4.0000000000E-02
  5.8416000000E-02
  2.0000000000E-01
  1.9868800000E-01
  9.5136000000E-02
  4.2864000000E-02
  4.0000000000E-02
  4.0000000000E-02
  4.0000000000E-02
  4.0000000000E-02
  4.0000000000E-02
  4.0000000000E-02
  4.0000000000E-02
  4.0000000000E-02
  4.0000000000E-02
  4.0000000000E-02
  4.0000000000E-02
  4.0000000000E-02
  4.0000000000E-02
  4.0000000000E-02
  4.0000000000E-02
```

Appendix G: (continued)

```
DOING A 1 YEAR SIMULATION

******************************************************************

YEAR = 1

NUMBERS BY AGE GROUP
  2.1084716848E+05
  9.7385246857E+03
  3.0710345129E+03
  2.2061206426E+03
  6.5830867386E+02
  1.2952096969E+02
  3.1403531015E+01
  9.3117806980E+00
  2.7935355925E+00
  8.3806127747E-01
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00

TOTAL =   2.2669502488E+05

PSD AND RSD VALUES
PSD=  1.7473036910E-01
RSD-P=  4.0554756521E-02
RSD-M=  1.0853478800E-02
RSD-T=  2.3989669560E-03
RSD-SQ=  8.2526963089E-01
RSD-QP=  1.3417561258E-01
RSD-PM=  2.9701277721E-02
RSD-MT=  8.4545118441E-03

 CATCH(HARVEST) VECTOR=
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  1.2135106797E+01
```

Appendix G: (continued)

```
  2.3939353241E+02
  6.4482663807E+01
  1.5842421874E+01
  4.6975978002E+00
  1.4092800378E+00
  4.2278431389E-01
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00

 TOTAL HARVEST=   3.3838338704E+02

MEAN AGE HARVESTED =   4.3128883980E+00
MEAN LENGTH HARVESTED =   3.3615374145E+02

 YIELD VECTOR=
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  2.4140149176E+03
  9.1132920333E+04
  4.6339647620E+04
  1.8975441189E+04
  8.3648244578E+03
  2.8695210835E+03
  9.1853761603E+02
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00

 TOTAL YIELD=   1.7101490722E+05
```

Appendix G: (continued)

```
CATCH VECTOR (NOT NECESSARILY HARVESTED)
  0.0000000000E+00
  0.0000000000E+00
  2.5815481590E+03
  1.8498638414E+03
  4.5657905938E+02
  8.2072426187E+01
  1.9803027343E+01
  5.8719972503E+00
  1.7616000473E+00
  5.2848039236E-01
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00
  0.0000000000E+00

TOTAL CATCH =    1.3128137479E+04
MEAN AGE CAUGHT =    2.6266631414E+00
MEAN LENGTH CAUGHT =    2.2885311476E+02
```

Appendix H: Model Results

Catch (number):

Length	Creel Limit								
Limit	0	1	2	3	4	5	6	7	8
None	10239	5349	3879	3221	2805	2560	2399	2297	2262
Minimums:									
254 mm	10239	7159	6247	5863	5634	5501	5418	5365	5348
280 mm	10239	7728	7006	6709	6534	6436	6372	6333	6320
305 mm	10239	8034	7406	7149	6999	6914	6860	6827	6657
330 mm	10239	8357	7824	7608	7482	7411	7366	7338	7329
356 mm	10239	8629	8181	8001	7892	7838	7802	7779	7771
381 mm	10239	8807	8409	8250	8158	8107	8074	8054	8047
Slots:									
254 mm-330 mm	10239	6205	4905	4338	3990	3789	3659	3577	3549
280 mm-356 mm	10239	5927	4557	3957	3588	3373	3233	3145	3114
305 mm-381 mm	10239	5809	4409	3794	3412	3189	3043	2951	2919

Appendix H: (continued)

Mean Length (mm) Caught:

Length Limit	Creel Limit								
	0	1	2	3	4	5	6	7	8
None	316.6	247.7	230.6	224.2	220.6	218.7	217.5	216.8	216.5
Minimums:									
254 mm	316.6	259.0	245.4	240.3	237.5	236.0	235.0	234.4	234.2
280 mm	316.6	264.2	252.1	247.6	245.1	243.8	242.9	242.4	242.2
305 mm	316.6	267.7	256.4	252.3	249.9	248.6	247.9	247.4	247.2
330 mm	316.6	271.8	261.6	257.8	255.7	254.5	253.8	253.4	253.2
356 mm	316.6	275.6	266.2	262.8	260.9	259.8	259.1	258.8	258.6
381 mm	316.6	278.4	269.6	266.3	264.6	263.6	262.9	262.6	262.4
Slots:									
254 mm-330 mm	316.6	259.5	244.1	237.8	234.2	232.1	230.8	230.0	229.8
280 mm-356 mm	316.6	257.4	240.8	234.0	230.0	227.9	226.5	225.6	225.3
305 mm-381 mm	316.6	256.2	239.0	232.0	228.0	225.8	224.4	223.5	223.2

Appendix H: (continued)

Harvest (number):

Length Limit	0	1	2	3	4	5	6	7	8
	Creel Limit								
None	0	2231	2560	2548	2466	2389	2325	2279	2262
Minimums:									
254 mm	0	1223	1475	1555	1594	1614	1625	1631	1634
280 mm	0	1013	1236	1314	1356	1378	1392	1400	1403
305 mm	0	899	1105	1180	1221	1243	1257	1265	1268
330 mm	0	777	963	1032	1071	1093	1106	1114	1117
356 mm	0	673	835	897	932	951	963	970	973
381 mm	0	604	751	808	840	858	869	876	878
Slots:									
254 mm-330 mm	0	2028	2583	2771	2857	2895	2914	2923	2926
280 mm-356 mm	0	2122	2644	2787	2832	2840	2836	2830	2828
305 mm-381 mm	0	2156	2653	2768	2788	2778	2761	2746	2740

Appendix H: (continued)

Mean Length (mm) Harvested:

Length Limit	Creel Limit 0	1	2	3	4	5	6	7	8
None	0	247.7	230.6	224.2	220.6	218.7	217.5	216.8	216.5
Minimums:									
254 mm	0	338.1	316.0	308.4	304.5	302.2	300.9	300.0	299.7
280 mm	0	377.5	355.6	347.2	342.6	340.0	338.3	337.4	337.0
305 mm	0	400.7	379.2	370.8	366.0	363.4	361.8	360.8	360.5
330 mm	0	427.7	405.9	397.5	392.6	390.0	388.3	387.4	387.0
356 mm	0	455.9	434.5	426.2	421.6	418.9	417.3	416.3	416.0
381 mm	0	474.6	454.7	446.3	441.7	439.1	437.4	436.4	436.0
Slots:									
254 mm-330 mm	0	252.9	234.4	227.5	223.5	221.4	220.1	219.3	219.1
280 mm-356 mm	0	248.2	231.0	224.5	220.9	219.0	217.8	217.0	216.8
305 mm-381 mm	0	246.8	230.1	223.8	220.3	218.4	217.2	216.5	216.3

Appendix H: (continued)

Proportional Stock Density:

Length	Creel Limit								
Limit	0	1	2	3	4	5	6	7	8
None	0.4987	0.2752	0.1951	0.1624	0.1436	0.1333	0.1269	0.1229	0.1216
Minimums:									
254 mm	0.4987	0.3518	0.3007	0.2790	0.2661	0.2588	0.2541	0.2512	0.2503
280 mm	0.4987	0.3830	0.3454	0.3298	0.3207	0.3156	0.3123	0.3103	0.3096
305 mm	0.4987	0.3991	0.3673	0.3542	0.3466	0.3423	0.3396	0.3379	0.3373
330 mm	0.4987	0.4156	0.3897	0.3790	0.3728	0.3693	0.3671	0.3657	0.3652
356 mm	0.4987	0.4291	0.4081	0.3996	0.3947	0.3919	0.3902	0.3891	0.3887
381 mm	0.4987	0.4375	0.4193	0.4119	0.4077	0.4053	0.4037	0.4028	0.4025
Slots:									
254 mm-330 mm	0.4987	0.3317	0.2634	0.2323	0.2133	0.2024	0.1954	0.1910	0.1895
280 mm-356 mm	0.4987	0.3134	0.2373	0.2035	0.1832	0.1717	0.1644	0.1598	0.1583
305 mm-381 mm	0.4987	0.3051	0.2262	0.1916	0.1711	0.1596	0.1523	0.1478	0.1462

Appendix H: (continued)

Relative Stock Density of Trophy Fish:

Length Limit	Creel Limit 0	1	2	3	4	5	6	7	8
None	0.1325	0.0262	0.0103	6E-03	4E-03	4E-03	3E-03	3E-03	3E-03
Minimums:									
254 mm	0.1325	0.0342	0.0166	0.0114	9E-03	8E-03	7E-03	7E-03	6E-03
280 mm	0.1325	0.0384	0.0201	0.0145	0.0117	0.0103	9E-03	9E-03	9E-03
305 mm	0.1325	0.0419	0.0234	0.0174	0.0143	0.0128	0.0119	0.0113	0.0111
330 mm	0.1325	0.0468	0.028	0.0217	0.0184	0.0167	0.0157	0.015	0.0148
356 mm	0.1325	0.0519	0.0332	0.0267	0.0232	0.0213	0.0202	0.0195	0.0193
381 mm	0.1325	0.0564	0.0381	0.0315	0.0279	0.026	0.0248	0.0241	0.0239
Slots:									
254 mm-330 mm	0.1325	0.0367	0.0184	0.0128	0.01	9E-03	8E-03	8E-03	7E-03
280 mm-356 mm	0.1325	0.0363	0.0179	0.0123	1E-02	8E-03	8E-03	7E-03	7E-03
305 mm-381 mm	0.1325	0.0362	0.0177	0.0121	9E-03	8E-03	7E-03	7E-03	7E-03

Appendix H: (continued)

Yield (kg) in study pool (61.65 ha):

Length Limit	Creel Limit								
	0	1	2	3	4	5	6	7	8
None	0	593814	507666	446989	402787	375389	356599	344372	340078
Minimums:									
254 mm	0	705052	698420	676104	659232	647900	640761	636183	634590
280 mm	0	742166	768698	760926	752803	747008	742230	739632	738717
305 mm	0	757489	804587	805417	801484	798408	796017	794375	793786
330 mm	0	768920	839596	850908	853002	853404	853189	852882	852746
356 mm	0	771409	862820	884071	892926	896045	898088	899179	899523
381 mm	0	763843	867919	895442	908202	914184	916858	918835	919481
Slots:									
254 mm-330 mm	0	645993	612518	576570	549500	532855	521512	514173	511605
280 mm-356 mm	0	621878	576643	534747	503380	483821	470407	461684	458622
305 mm-381 mm	0	608871	558379	513539	479878	458715	444139	434630	431287

Appendix H: (continued)

Utility Scores:

Length Limit	Creel Limit								
	0	1	2	3	4	5	6	7	8
None	0.5714	0.4595	0.3585	0.3087	0.2751	0.2546	0.2406	0.2317	0.2284
Minimums:									
254 mm	0.5714	0.5412	0.4713	0.4414	0.4238	0.4136	0.4072	0.4032	0.4018
280 mm	0.5714	0.5826	0.5264	0.5027	0.4888	0.4811	0.4759	0.4729	0.4719
305 mm	0.5714	0.6068	0.5579	0.5372	0.5247	0.5179	0.5137	0.5109	0.5071
330 mm	0.5714	0.6341	0.5929	0.5752	0.5648	0.5589	0.5553	0.5530	0.5521
356 mm	0.5714	0.6589	0.6246	0.6099	0.6013	0.5962	0.5931	0.5913	0.5906
381 mm	0.5714	0.6753	0.6459	0.6328	0.6253	0.6210	0.6179	0.6164	0.6157
Slots:									
254 mm- 330 mm	0.5714	0.5244	0.4495	0.4139	0.3910	0.3775	0.3685	0.3629	0.3610
280 mm- 356 mm	0.5714	0.5085	0.4245	0.3835	0.3568	0.3408	0.3302	0.3231	0.3208
305 mm- 381 mm	0.5714	0.5006	0.4121	0.3686	0.3400	0.3226	0.3110	0.3034	0.3008

VITA

Brian Keith Wagner was born on April 4, 1964 in Lawrence, Kansas. He graduated from Lawrence High School in May, 1982. Brian then attended the University of Kansas, in Lawrence, where he graduated from the College of Liberal Arts and Sciences with highest distinction and was granted a Bachelor of Science degree in Systematics and Ecology in May, 1986. During this period, Brian also spent three summers as a District Fisheries Aide with the Kansas Fish and Game Commission. Brian recently completed requirements for a Master of Science degree in Fisheries Science from the Department of Fisheries and Wildlife Sciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. Brian has been employed for the past two years as Assistant Fisheries Research Biologist with the Arkansas Game and Fish Commission.

Brian K. Wagner

Brian K. Wagner