POPULATION DYNAMICS OF WHITE BASS AND STRIPED BASS X WHITE BASS HYBRIDS IN LAKE CARL BLACKWELL, OKLAHOMA

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PREFACE

Striped bass *Morone saxatilis* x white bass *M. chrysops* hybrids are stocked in numerous reservoirs in Oklahoma, some of which contain populations of striped bass and (or) white bass. There is some uncertainty in the use of univariate morphometric characters, developed for use in the southeastern states, for separating the hybrid from the parental species in Oklahoma. A multivariate approach employing discriminant analysis and sheared principal component analysis was used to identify characters for separation of the three groups. A conceptual simulation model was developed for the white bass and striped bass x white bass fisheries in reservoirs.

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TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

Statement of Problems

The demand for a pelagic sport fish capable of utilizing clupeid forage fish abundant in numerous reservoirs has enhanced the popularity of striped bass, *Morone saxatilis* x white bass *M. chrysops* hybrid fisheries in many southeastern States, including Oklahoma. In many cases, this demand has resulted in striped bass, *Morone saxatilis* x white bass, *M. chrysops* hybrids being stocked into reservoirs with populations of striped bass and (or) white bass. There is concern that the hybrid, by virtue of its voracious appetite, fast growth rate, and adaptability to a wide range of habitat types, may have adverse impacts on other sport fishes such as white bass, walleye, crappie, and largemouth bass.

Since the introduction of striped bass x white bass hybrids into Oklahoma reservoirs in the late seventies, the hybrid has grown in popularity to the extent that some Oklahoma reservoirs are designated as "hybrid" reservoirs. Often these "hybrid" reservoirs also contain white bass or striped bass. In recent years there have been some problems with the use of morphometric and meristic characters that were developed for separating Oklahoma hybrids from the parental species. Univariate characters have proven to be inadequate for unambiguous separation of Morone sp. in Oklahoma reservoirs. The ability to identify accurately is necessary because of the importance of the Morone sp. to sport fishery in Oklahoma.

Fish populations are controlled by habitat limitations, density-dependent factors, and stochastic environmental variations. Most fishery management strategies are formulated to account for variations in population sizes due to density-dependent and habitat related causes but exclude variations due to stochastic events. White bass and striped bass x striped bass hybrids in Lake Carl Blackwell (Maughan et al. 1986) do not appear to be limited by habitat but may be limited by stochastic environmental factors. They also may be limited by density dependent factors because white bass and hybrids have similar ecological requirements, often occur in the same reservoirs and are often managed as one fishery. The popularity of these fish makes it important to understand the population dynamics and ecology of the two groups and their effects on other native fish populations.

Objectives

The inability to separate striped bass x white bass hybrids from both parental forms, with univariate characters, developed for use in the southeastern states, created a need for identifying groups of characters that could be used for separating the three forms. Therefore, I developed multivariate criteria for separation of the three groups. Fifty-two morphometric characters were measured on each fish with the objective of using linear discriminant function analysis and sheared principal component analysis to elucidate the morphological differences between the three groups. The goal of the analysis was to identify 'groups' of morphometric variables that would facilitate separation.

The second objective of this study was to use as much of the available information as possible to develop a conceptual model of the population dynamics of striped bass x white bass hybrids and white bass in Lake Carl Blackwell, Oklahoma. The major assumptions used in the development of this model were that the hybrid and white bass populations were constrained by density-dependent mechanisms and subject to stochastic environmental variations. The model utilizes information routinely collected in fish population surveys and if the underlying assumptions are correct, can be used to evaluate the effects of various management practices on harvest, yield, population size, and population structure.

Dissertation Format

This dissertation consists of three chapters. The last two chapters have been prepared as independent documents to be submitted for publication. References, tables, and figures for chapters II and III are included jointly at the end of the dissertation.

CHAPTER II

COMPARATIVE MORPHOLOGY OF THE WHITE BASS AND STRIPED BASS X WHITE BASS HYBRIDS IN LAKE CARL BLACKWELL, OKLAHOMA

Literature Review

Hybrids of striped bass *Morone saxatilis* and white bass *M. chrysops* crosses are of considerable interest to taxonomy, phylogeny, and management. Striped bass x white bass hybrids have been stocked into several reservoir/river systems which contain endemic white bass populations (Ware 1975) and there is concern that the hybrid may be reproducing or backcrossing with either or both of the parental species within those aquatic systems (Avise and Van Den Avyle 1984; Crawford et al. 1984).

The introduction of striped bass x white bass hybrids (hereafter referred to as the hybrid) into reservoirs has also created questions of identification among fishermen, fishery managers, game rangers, and even fishery biologists. The commonly accepted criterion for separation of the hybrid from white bass is the shape of the tooth patches on the

base of the tongue. The hybrid and striped bass are supposed to have split patches whereas the white bass has only one patch (Williams 1972). This character, however, does not accurately separate the three groups in Oklahoma. It is possible that the problem of identifying the hybrid in Oklahoma waters may be exacerbated by the fact that parental brood stock as well as fingerlings have come from locations in South Carolina, Louisiana, Illinois, and locally from Oklahoma (Harold Namminga: Oklahoma Department of Wildlife Conservation (ODWC)). This diversity of parental stock may have resulted in a diverse gene pool and high levels of phenotypic variability.

Morphometric and meristic characters of *Morone sp.* hybrids in the southeastern U.S. have been described in some detail (Bayless 1968, 1972; Harrell 1984; Kerby 1979a, 1979b; Kerby et al. 1971; Williams 1976). Harrell (1984) successfully used osteological, morphometric, and meristic characters to identify *Morone* hybrids. Kerby (1979b) compared the morphometric characters of the striped bass x white bass hybrid with those of the parental species and established some ratios which have also been used to separate the hybrid from the white bass. Kerby (1979b) found a linear relationship between most body length measurements and standard length in the striped bass x white bass hybrid as well as in the striped bass x white perch hybrid. Based partly on Kerby et al.'s (1971) data, Williams (1976) concluded that the ratios of body depth/head length and fork length/body depth could be used to separate striped bass from either white bass or striped bass x white bass hybrids. These ratios (Williams 1976) (fork length/body depth for white bass, striped bass, and the hybrid were 3.477, 4.440, and 3.460 respectively and the corresponding body depth/head length ratios were 1.198, 0.893, and 1.158) have been widely used to identify these forms. All these authors are in agreement that no single character always separates the three forms from one another. Also many of the ratios and relationships used elsewhere do not seem to be applicable to Oklahoma fish.

Since no single character can best be described as "definitive" in its power to separate the white bass from the striped bass x white bass hybrid I have proposed development of a multivariate approach. The multivariate techniques I have used in this development are the linear discriminant analysis, principal component analysis and a modified (sheared) principal component analysis.

Materials and Methods

Sample Collection and Preparation

Fish collections (gill net) were made from April to November 1985 by biologists of the Oklahoma Department of Wildlife Conservation at Fort Supply Lake, Lake Texoma, Optima Lake, Canton Lake, and the Great Salt Plains Lake. I also made gill net collections from Lake Carl Blackwell during the same period.

Known striped bass x white bass hybrids were obtained from the Southeastern Fish Culture Laboratory, United States Fish and Wildlife Service, Marion, Alabama and known striped bass were obtained from collections made in Lake Texoma, Oklahoma, by personnel of the ODWC. White bass were collected from Lake Carl Blackwell and their identity was electrophoretically verified by the ODWC's Fishery Research Laboratory. The electrophoretic identification of the white bass was done using the starch gel methods of Selander et al. (1971). The interpretation of the results follows those reported by Avise and Van Den Avyle (1984). The three enzyme loci used to confirm identification were: (i) phosphoglucoisomerase (PGI), (ii) calcium binding protein (CBP), and (iii) esterase (EST).

Upon capture, fish suitable for morphometric and meristic analyses were immediately packed on ice and the livers, to be used for electrophoresis, were immediately removed and frozen. The fish were then injected with 10% formalin (to prevent visceral deterioration) and subsequently preserved in 10% formalin.

Morphometric Measurements

Morphometric measurements were made following Hubbs and Lagler (1970). Characters chosen included those previously used in the segregation of the three groups such as the length of 2nd and 3rd dorsal spines, body depth, and head length plus numerous other characters. In all, 52 morphometric measurements (Table I) and 13 meristic counts

(Table II) were made on each fish. Standard length measurements were made to the nearest mm. All other measurements were made to the nearest 0.01 mm with electronic digital calipers. Each variable was measured four times and the average reading was recorded. Meristic variables were also counted four times and the mean recorded for each variable. Meristic counts such as number of scale rows above, below, and on the lateral line, gill raker counts, and fin ray counts were made under magnification.

Traditionally, data collected for morphometric analyses have been analyzed without much regard for allometry or the variation of allometry within populations. Growth and body form have been studied mostly by analysis of length or height and such measures have been criticized for being of limited utility in discerning shapes from sizes. Conventional measures of length commonly used in morphometric studies have been found (Bookstein et al. 1985) to be (i) aligned mostly along a few axes usually longitudunal or 'anterior-posterior' and with limited data on depth or breadth, (ii) restricted to some regions of the body with other regions receiving limited or no coverage, (iii) highly repetitious of some morphological landmarks such as the tip of the snout and end of vertebral column. Errors can also be made if measurements, (iv) are reliant on 'extremal' measurements which can be quite variable such as maximum body depth, and (v) cover too long a span thereby containing less information on localized variation than would relatively short distance measures. To overcome these objections, morphometric variables chosen for analysis in this study (Table I) represented all regions of the fish including longitudunal, tranverse, and oblique axes.

Previous studies on the identification of Morone sp. have relied heavily on ratios derived from morphometric analyses for conclusive separation. For example, Williams (1976) determined that ratios of body depth/head length and fork length/body depth were conclusive in the separation of the striped bass x white bass hybrid from either parental species. The use of ratios of morphometrics is one of three methods used to compare shapes among groups while removing the effects of size. The other methods are regression and principal component analyses. Although the use of ratios have been a long established technique for analyzing morphometric data, its reliability has been questioned because spurious variations can occur as a result of correlations between denominators and numerators as well as dependence of numerator on denominator (Atchley and Anderson 1978; Mosimann and James 1979; Hills 1978; Humphries et al. 1981). Consequently, use of ratios in morphometrics is being discouraged and methods which rely less on ratio-related measures are being encouraged. One technique commonly used to nullify the effects of size in morphmetrics has been log-transformation of data. However, log transformation does not automatically remove size-related effects on variables (Humphries et al. 1981). To overcome these difficulties, it is now recommended that multivariate techniques be used to make comparison.

Selection of variables to be included in a multivariate analysis is critical and has been based mostly on the criterion that a large number of variables be used. Considerably less importance has been attached to the functional and ecological roles of the variables chosen. I have attempted to include large numbers of variables but also to consider function and ecology in my selection of variables. In addition, I have attempted to minimize redundancy in choice of variables and to include variables from all regions of the body (Table I, II). Differences in the morphometrics between the hybrid and the parental species, if they did exist, were expected to be small hence I selected a large number of morphometric variables, encompassing most regions of the body. Many statistical tests assume homoscedasticity (equality of variance) and additivity of variance components. I do not believe this is a valid assumption, therefore, I used variable transformations and tested the distributions of the log transformed variables for goodness of fit to the normal distribution prior to use in the model. All morphometric variables were log-transformed (unless otherwise indicated to base 10) before use in the analyses (Table III).

Statistical Analyses

The weaknesses inherent in univariate methods and ratios for taxonomic analyses caused me to use a multivariate approach employing discriminant analyses, principal component analysis, and sheared principal component analysis algorithms for separating the three groups. In recent years both classical and numerical taxonomists have employed discriminant analysis in the assessment of morphometric divergence among natural populations. Discriminant analysis employs a dependent variable (species type) and a collection of independent variables, including both continuous (morphometrics) and discrete (meristic) variables. It is recommended that separate analyses be performed on morphometric and meristic variables (Bookstein et al. 1985). In my study, there were high overlaps in the ranges of the meristic variables for all three groups. These high overlaps made statistical analyses impossible; consequently, further analyses of the meristic data were discontinued. The result presented here are based entirely on morphometric data.

The discriminant functions used in this study are developed in a multidimensional space that maximizes the variability between groups (in this case species) while minimizing the variance within groups. The discriminant analysis then develops a number of canonical variates (eigen vectors) which discriminate the groups. Each variate makes its own individual contribution to the discrimination, the first contributing the greatest amount, the second the next greatest, etc. In presenting the data, the means of each of the groups are plotted along the axes of the first two or three canonical variates in order to depict the discrimination patterns. The discriminant function in its final form becomes a very powerful tool that uses the joint probabilities of combinations of variables for the best separation of the groups.

In my study, a multivariate analysis of variance (MANOVA) was first performed on the morphometric variables to test the null hypothesis of equality of the group centroids. Although MANOVA is a simple linear test, it should be conducted prior to multivariate discriminatory techniques to ensure that discrimination is not spurious. Discrimination is valid only if there is a significant difference among the group centroids (Pimental 1979). To accomplish this separation of my data, all 52 morphometric variables were analyzed iteratively using the step-wise linear discriminant analysis program BMDP07M (Jennrich and Sampson 1983). The discriminant function is constructed in a step-wise manner such that at each step the relative contribution of each variable is assessed and if it falls below some criterion level, it is deleted from the analysis. Variables which make the largest contribution to the separation of all the groups (based on the F value it generates in a one-way ANOVA) are entered first. After the first variable is entered into the discriminant function, the second variable making the next largest contribution (the one with the next largest adjusted F value) is selected, etc., until all variables are used. Weights are then assigned to each variable such that the maximum difference between the groups is produced. Statistical procedures employed in the discriminant analyses are described in detail by Green (1978), Morrison (1967), and Srivastava and Carter (1984).

In addition to indicating the relative contribution made by each variable to the overall discrimination, the scriminant function coefficient was also used to determine a variable's effect on group membership. When the value of a variable with a positive corresponding function is increased, the resultant discriminant score is increased. This tendency increases the probability of classifying the individual into the group with a higher centroid. On the other hand, increasing the value of a variable with a negative corresponding coefficient results in increased probability of classifying the individual into a group with a lower centroid.

I also used linear discriminant function analysis to test the reliability of my identification models. In applying the linear discriminant function analysis, the function is first developed, and second tested, based on the percent correct/incorrect classification of an independent sample of known specimens. The higher the percent of correct classification, the more useful the function is as a tool in the discrimination of the specimens. Individuals are assigned group membership based on the value of the classification function score. The classification function C_i for species i is given by:

$$C_i = C_{i1}V_1 + C_{i2}V_2 + C_{i3}V_3 + \ldots + C_{ij}V_j + C_{ip}V_p + C_{i0}$$

where the C_{ij}'s are the classification function coefficients, C_{i0} is a constant, and the V's are the discriminating variables. An individual is classified into the group for which it's set of V's produces the highest classification score.

Discriminant analysis is an excellent technique for depicting multivariate patterns of differences among the species but tells little of the interrelationships of the characters' overall groups. I used techniques such as factor analysis or principal component analysis (PCA) which generates factors which are often interpretable in terms of functional groups of variables to obtain such information. Factor scores may be generated for each individual, and these scores represent essentially new characters on which ANOVA and other tests may be done.

I also used principal component analysis (PCA), an ordination technique used for the analysis of the structure of multivariate observations, for investigating the morphological variations occurring in the populations. PCA has been widely used as an exploratory technique for discovering structure in morphometric and meristic data (Blackith and Reyment 1971; Smith 1973; Thorpe 1976; and Pimental 1979) and is particularly useful when no a priori patterns of interrelationships can be suggested or are suspected (Blackith and Reyment 1971). When used on morphometric and meristic data, PCA can be used to show geographic, clinal and other types of variations. The technique may be used on individual specimens since the analysis assumes very little by way of biological models (Thorpe 1976).

The goal in PCA is to reduce the original number of variables to a smaller number of variates or principal components which are expressed in terms of linear combinations of the original variables. The new variables (principal components or PCs) define independent patterns of variation among the original variables, which may be interpreted separately. The principal components are ordered in descending order of contribution to the explained variation such that PC I accounts for the maximum percentage of variance possible for the single linear combination of the original variables. Principal component II is uncorrelated with principal component I and represents a set of variables which explains the second largest amount of variation, and so on.

Shape is important in fish systematics and when used in conjunction with meristic charcters and color patterns, can serve as a very important tool for systematics and taxonomy. For example, white bass are described as being relatively more 'deep bodied' than striped bass of comparable length (Bayless 1972). I used principal component analysis to consider the effects of both size and shape since these two characters are often confounded (Humphries et al. 1981). In the analysis of a single population, the approach is quite simple because PC I is considered to be a general size factor. However, in the analysis of multigroup populations, size and shape effects often occur in the first two principal components (Humphries 1984). Consequently, an interpretation of a multigroup analysis as we have in my data would be confounded by size-dependent differences. In order to nullify the effects of size variability in morphometrics, it is necessary to develop a size-free PCA by partitioning the size effects from PC I and PC II. The result of the removal of size-related effects from PCA results in analysis of variation in shape. The technique for developing a size invariant PCA is called 'shearing' (Humphries et al. 1981). I used sheared PCA and discriminant analysis in the morphological separation of the three groups in this study.

The sheared principal component, H, is a linear combination whose coefficients equal the partial covariances adjusted for intergroup size. The value H is approximately equal to the residual obtained from PC II after regressing out intragroup size, and is uncorrelated with intragroup size.

The need for shearing is determined by examining the plot of the regular principal component scores obtained from a covariance matrix for the presence of the same trend for PC I and PC II. Such a trend is an indication of size-related effects and necessitates corrective action through shearing. Shearing is accomplished by first standardizing the scores from the original PCA to zero mean, yielding two new components PC I_z and PC II_z. The magnitude of the size effect is then computed by regressing PC II_z on S, the within group size component of Q (the covariance matrix adjusted to mean zero within each group). The estimated residual from the above regression gives an estimate of H, the sheared principal component. H can then be used as a size invariant morphometric discriminator while still maintaining all of the original variance.

Size was an important confounding effect in my data, therefore a sheared principal component analysis was performed on the log transformed morphometric data using a SAS macro program Bookstein et al. (1985). The principal components were computed using the covariance matrix method.

Results

Discriminant Analysis of Striped bass, White bass, and Striped bass x White bass hybrids

Results of the three-group linear discriminant analysis, based on 52 morphometric variables, indicate that white bass, striped bass, and striped bass x white bass hybrids are statistically separable. The seven variables which contributed significantly to the discrimination (Table IV) are:

(i) caudal peduncle length
(ii) snout length
(iii) first dorsal fin base length
(iv) pelvic fin base length
(v) pectoral to second dorsal fin distance
(vi) pectoral fin height
(vii) internasal distance

Application of stepwise discriminant analysis algorithm (BMDP07M) to unstandardized data results in a ranking of the variables in descending order of their contribution to overall discrimination. The analysis (Table IV) indicates that caudal peduncle length was the most important variable for separating the three taxonomic groups. Snout length was the next most important variable. A plot of the canonical variate or discriminant scores (Table V) shows the presence of three 'clusters' representing the three groups (Figure 1). Interpretation of the clusters in terms of the discriminant functions and the appropriate morphometric variables reveals that striped bass have longer snout lengths, caudal peduncle lengths, and internasal distance than do the other groups. Furthermore, the information indicates (Table IV; Figure 1) that for each variable along the first canonical variate, the relative morphology of the hybrid is intermediate between those of both parental species. Fish with longer pectoral fin to second dorsal fin distances have higher probability of being classified as white bass whereas those with longer snout lengths are more likely to be classified as striped bass. The group centroids also indicate that complete segregation occurs along the first canonical axis but only partially along the second axis (Table VI). Canonical variate I explains the most variation (77.71%) and the variables which load high on this axis are the most important for group separation.

Although partial separation of the three taxonomic groups was achieved by the first discriminant function, the second function only enables the separation of the striped bass x white bass hybrid from both parental groups but not the separation of the parental groups from one another (Table IV; Figure 1). The first discriminant function accounts for 77.71% of the variation (variance=A_1/A_1+A_2 where A_1 and A_2 are the eigen values for functions I and II respectively) while function II, which separates the hybrid from the two parental forms, accounts for 22.29% of the variation. Function II indicates that specimens with long base length of first dorsal fin have a higher probability of being classified as hybrids (being hybrids) than as either of the parental groups. The canonical correlation p of function j, (where $p_1 = A_1/1+A_1$, and A_1=eigen value for function I) (the correlation between the linear discriminant function and the original set of variables) is 0.9837 for function I and 0.9564 for function II (Table IV).

The results of the classification indicates that a 100% correct classification into the pre-determined number of groups (reference samples of known identities) was obtained based on the seven morphometric variables (Table VII). Although discriminant function I accounted for only 77.71% of the total variation, a complete separation of the three taxonomic groups was achieved by the model using the seven variables. Based on the results of this discriminant analysis (Table VIII) the following function was developed to classify any unknown fish into one of the three groups.

Group I=

$$-300.36035*L_1-2926.40112*L_2-1236.32837*L_3-453.61182*L_4$$

$$+6003.64063*L_5+3447.52490*L_6-3738.73706*L_7-3324.34546$$

Group II=

$$-245.57773*L_1-2666.80835*L_2-737.22559*L_3-558.96631*L_4$$

$$+5150.37891*L_5+2942.44629*L_6-3164.17896*L_7-2654.37329$$

Group III=

$$7.58869*L_1-2422.22412*L_2-1069.62012*L_3-766.17554*L_4$$

$$+5120.94141*L_5+3224.96753*L_6-3350.47729*L_7-2792.80615$$

where L_1-L_7 respectively represent the log transformed values of the variables in Table IV. In this analysis, an individual is classified into one of the three species depending on the relative magnitude of the classification function, thus: If the Group I coefficient is greater than Groups II and III coefficients, then the sample is classified as a white bass. If the Group II coefficient is greater than Groups I and III coefficients, then the sample is classified as a hybrid. If the Group III coefficient is greater than Groups I and II coefficients, then the sample is classified as a striped bass.

In order to test the accuracy of the model, the classification function was applied to an independent sample "holdout sample" of *Morone sp.* from several Oklahoma reservoirs. The result (Table IX) indicates that a 91.67% discrimination was obtained between the three forms. The classification scores indicate that the white bass and striped bass x white bass hybrids are morphologically very similar (Table X). The result also confirms the presence of two or more *Morone sp.* in some Oklahoma reservoirs.

Sheared Principal Component Analysis of White bass, Striped bass, and Striped bass x White bass hybrids

The results of principal component analysis performed on the log transformed morphomertric variables indicated the presence of three 'clusters', representing the three taxonomic groups (Figure 2). However, the scatter plot of PC I against PC II showed the presence of size-dependent distributions. Plots of PC II and PC I against log of standard length also indicated that PC I (Figure 3) and PC II (Figure 4) were both size confounded.

In order to achieve a size-free discrimination of the three groups, I sheared, (Humphries et al. 1981) the data to obtain a sheared principal component, H, (Table XI) which when plotted against PC I, removes the effect of size. After this treatment, the data on striped bass had significantly different shape components than white bass and striped bass x white bass hybrids but the latter two did not differ from one another (Figure 5). The strong morphological similarity between the white bass and the hybrid was indicated by the mean sheared PC II which are -0.358, -0.396, and -0.704 for the white bass, hybrid, and striped bass respectively. However, these values also indicated that the hybrid was morphologically intermediate between the parental species.

Morphometric similarity between white bass and hybrid was also indicated when the sheared PC II was compared with the results of the discriminant analysis. Canonical discriminant analysis indicated (Figure 1) that the three groups could be separated using variables associated with canonical variate I. However, a plot of sheared PC II plotted against the canonical variate I indicated (Figure 6) that, although white bass and hybrid can be distinguished morphologically from the striped bass, they can not be distinguished from one another. The correspondence between the results of the discriminant analysis and sheared principal components is strong (Pearson correlation coefficient=0.89, $p<0.0001$) suggesting that the results of the discriminant analysis were not significantly confounded by size. A similar examination of the relationship between sheared PC II and canonical variate II of the discriminant analysis also indicated (Figure 7) that the white bass and hybrids are statistically similar morphologically but they are collectively different from the striped bass (Pearson correlation coefficient=-0.36, $p<0.04$). The above comparisons between both multivariate classification techniques suggest that subtle differences do exist in the morphology of the three groups, but that white bass and hybrids are morphologically very similar. These analyses also suggest that differences between them may not be discernable when examined in conjunction with the striped bass.

Sheared Principal Component Analysis for White bass and Striped bass x White bass hybrids

Computation of principal components on white bass and hybrids indicates that although an oblique 'cluster' does exist due to some size confounding on PC I, it is much less pronounced in the absence of striped bass (Table XII, Figure 8) than it was with striped bass included in the data set. Shearing of PC II of this reduced data set removed the effects of size on the data and resulted in a complete morphological separation of the white bass and striped bass x white bass hybrids. This elimination of size as a factor is evidenced by the size invariant pattern exhibited by the plot of sheared PC II against log of standard length (Figure 9). A plot of the sheared PC II against PC I (Figure 10) also illustrates the ability of this procedure to separate the two groups.

In summary, white bass can be separated from hybrids on morphological grounds if striped bass are not included in the analysis. The inclusion of striped bass in the data set results in differences between white bass and hybrids being masked.

Discussion

The introduction of striped bass x white bass hybrids into reservoirs with native populations of striped bass and (or) white bass has created successful sport fisheries in several Oklahoma reservoirs. However, these introductions have also generated controversies. Some individuals believe that hybrid introductions have adversely impacted largemouth bass and white bass populations (K. E. Erickson, ODWC). Conversely, there is some evidence (Gilliland and Clady 1981) that only limited impacts have occurred.

The introductions of hybrids into warm water reservoirs have often been justified on the basis of the hybrid's ability to utilize the clupeid forage without considering the effects on other game species. However, in reality, a thorough understanding of the biological interactions between these groups is necessary before realistic management decisions can be made. The first requirement for understanding the interaction between these groups is the ability to differentiate hybrid stocks from those of the parental groups. In addition, the ability to distinguish the hybrid from the white bass, the parental group to which it is morphologically more similar, has obvious management implications. For example, in Oklahoma there are no creel limits on white bass and striped bass x white bass hybrids in most reservoirs. Thus it is imperative that the angling public as well as the fisheries biologist and game ranger be able to distinguish the two forms from the striped bass for which there is a creel limit on most Oklahoma reservoirs. The results of this study indicate that this separation is not easy and that with multivariate examination of

52 morphometric variables, the precision of the separation of the hybrid from the white bass is low. Inclusion of striped bass in the analysis further complicated the separation.

In spite of the difficulties of the separation of these forms, there are significant differences in the morphometric measurements for white bass, striped bass, and striped bass x white bass hybrids. Separation of the forms is possible with sheared principal component analysis and discriminant analysis. Estimates of the mean sheared PC II between the three groups indicate that striped bass is most different from the white bass and also that high similarity between the hybrid and white bass results in less reliable predictions of group memberships when all three groups are present. The similarity between these two groups as indicated by the mean sheared PC II between the hybrid and white bass is confounded by size-related factors but the high correlation (0.89) obtained between the size-free PCA and the discriminant analysis indicates that the results of the discrimnant analysis (unadjusted for size) are reliable and that the effects of size on the overall morphological discrimination was probably minimal.

Other authors using univariate approaches have found the hybrid to be more similar in some characteristics to either one or the other of the parents. For example, Williams (1976) determined that the mean ratio of body depth/head length of the hybrid was closer to that of the white bass than to that of the striped bass and also that the mean fork length/body length of the hybrid was also closer to that of the white bass than to that of the striped bass. Conversely, he found that mean head length/2nd anal spine length was more similar between the hybrid and striped bass than between the hybrid and white bass.

The multivariate analysis also shows that the hybrid is morphologically intermediate in some characteristics between both parental forms, but also allows us to determine what such differences mean. The distance between the pectoral fin and the second dorsal fin was longer on the average for white bass than for the other two groups and the hybrid was intermediate. This observation means that measures of shape along oblique axes are important variables for distinguishing the three groups. The longer pectoral fin to second dorsal fin distance for the white bass coupled with its greater tendency to acquire longer pectoral fin height and longer base length of pelvic fin are all indicative of morphological developments associated with the humeral region of the white bass.

That the morphological differences separating the white bass from the other groups is the greater development in the humeral region, is also corroborated in part by univariate determinations. Williams (1976) concluded that the mean body depth/head length ratio for white bass and hybrid was 1.198 and 0.893 respectively. These findings indicate that white bass may have a more developed humeral region than the other two groups. This greater development is reflected in the greater body depth for the white bass. The joint effect of the variables around the humeral region could be construed to indicate that there is a difference in the degree of rotundness of the abdominal and humeral regions of the white bass relative to those of the other two groups. This conclusion is supported by discriminant analysis because the intermediate value of the loadings for the hybrid along canonical variate II are also a relative measure of body depth and rotundness. Although canonical variate scores for the white bass indicate differences in growth and body morphology associated with rotundness and increased condition factor (a measure of allometry) relative to the striped bass, the data also indicates that striped bass have longer caudal peduncle length, snout length, and internasal distance than the white bass.

The association of variables such as caudal peduncle length and snout length on one axis imply that striped bass are more streamlined than the other two groups. Some predators such as striped bass which actively chase down their prey are characterized as having 'torpedo-shaped' fusiform body form and well developed caudal region for rapid propulsion (Moyle and Cech 1982). Conversely, the white bass which is presently found in reservoirs through out the midwest and in most of the United States (Trautman 1981) is primarily a stream dwelling fish which has been widely introduced or entrapped in reservoirs. In keeping with these differences in behavior, white bass are less fusiform and more rotund. One might hypothesize that a comparison of the predatory behavior of the white bass would reveal investment of considerably different amounts of time, energy, and effort in foraging.

Conclusions and Recommendations

The popularity of the striped bass fishery in the Chesapeake Bay, on the east coast of the United States, and in landlocked reservoirs, coupled with the importance of the white bass fishery, resulted in the development of the female striped bass x male white bass hybrid. Introduction of the hybrid has been encouraged because of its ability to utilize the clupeid forage abundant in several reservoirs, its 'fighting' ability, its rapid growth, and ability to adapt to different geographic regions and water quality conditions.

Although the hybrid fishery is over 20 years old, questions are still being raised about the ecology and management of the hybrid. The most important questions raised by the introductions into numerous streams/reservoir systems are (i) the potential ecological impacts on native populations of white bass, striped bass, largemouth bass and other species, and (ii) management problems stemming from uncertainty in stock/species identification in aquatic systems in which the hybrid coexists with one or both of the parental species. Since sound fisheries management entails accurate stock identification and assessment, the importance of unambiguous and accurate techniques for stock separation are a nesessity.

Separation of the three groups have traditionally been done on the basis of size since striped bass is the largest and white bass the smallest. Identification was also done using meristic and morphometric characters such as the number and shape of tooth patches on the base of the tongue as well as the shape and patterns of stripes on the sides of the fish and measurement ratios. In Oklahoma, these methods have been proven unreliable for separating the three groups, especially when small fish are involved. Thus a multivariate approach was employed as an aid in identification.

Separation of the three groups was possible but difficult when all three groups were analyzed simultaneously with discriminant analysis and sheared principal component analysis. When data on white bass and hybrid were analyzed the absence of data on striped bass, separation was easier. The variables which contributed significantly to the discrimination were the caudal peduncle length and the snout length. The base lengths of the first dorsal and pelvic fins were longer on the average for the hybrid and ratios involving these measurements can be used to separate the hybrid from both parental species. White bass tended to have longer pectoral to first dorsal fin distances than the other two groups whereas striped bass tended to have longer caudal peduncles and snout lengths than the other two groups. For the hybrid, the range of the above variables tended to be intermediate between those of the parents.

These variables can be used to separate the three groups when they coexist.

The application of the discriminant analysis to an independent data set, comprised of fish from several Oklahoma reservoirs, confirmed the presence of stocks of two or more *Morone* *sp*. in some reservoirs. Fort Supply reservoir, Canton reservoir, and Lake Carl Blackwell had stocks of both white bass and striped bass x white bass hybrids whereas Optima reservoir contained only striped bass x white bass hybrids.

Management implications of the findings are that fishing regulations, regarding creel limits on the three *Morone* forms, need to be reevaluated especially in lakes which contain the striped bass and one or both of the other forms. This is necessitated by the lack of a creel limit on white bass and striped bass x white bass hybrids in most reservoirs whereas there is a creel limit on striped bass in most reservoirs. The strong similarity between the three forms and their occurrence in the same bodies of water could result in high incidences of misidentification which would complicate management objectives. The inability to accurately and easily identify the white bass from the hybrids in Oklahoma waters makes enforcement of game laws difficult. Such a problem can be alleviated by managing the two species as a single fishery. Benefits from management of a mixed *Morone* *sp*. as a single fishery rather than as separate fisheries are probably high. However, application of the classification function developed in this study

(91.67% separation) suggests that the risks associated with misclassification may be acceptable in some situations. In those situations, the single-species management concept should be used. The need for joint management of the white bass and the striped bass x white bass hybrids as one fishery was recognized by the ODWC whose management guidelines (1987 Oklahoma fishing regulations) apparently addressed the problem by setting equal creel limits on both species.

Stocking the hybrid in reservoirs containing the parental species should be carefully considered because of difficulties in management of the fish populations and enforcement of game laws. Stocking of hybrids in reservoirs containing populations of white bass would entail managing both species as a single fishery (as suggested by the 1987 Oklahoma fishing regulations). Without easy methods for delineation of the various stocks and populations, management and law enforcement become problematic. Multivariate techniques are required for accurate identification of the three groups but these techniques are too complex to be used by the angling public or law enforcement officers. For these groups, the seven most distinguishing factors identified in the multivariate analysis should be used to assign group memberships. Ultimate group membership, however, can only be decided based on the value of the linear classification function coefficients.

CHAPTER III

SIMULATION MODEL OF THE POPULATION DYNAMICS OF WHITE BASS AND STRIPED BASS X WHITE BASS HYBRID IN LAKE CARL BLACKWELL, OKLAHOMA

Literature Review

Historically, interest in population dynamics models has centered on generalized, theoretical population systems. In recent years however, there has been considerable interest in modeling specific fish populations, with the practical objectives of understanding or predicting population changes (Orth 1977, Taylor 1981), or simulating the behavior of populations under various management regimes (Reed 1982, Gutreuter 1983, and Zuboy and Lackey 1975). Diverse approaches have been applied to these ends ranging from strictly empirical equations geared toward predictions (Orth 1977, Taylor 1981), to highly detailed biologically explicit models oriented towards understanding and simulation (Gutreuter 1983; Jester et al. 1977).

Empirical models can be quickly constructed from raw data with little biological know-how, may have good predictive powers under conditions similar to those in which the data were collected, but they add little to our understanding of biological processes. Highly detailed models require considerable biological knowledge and intuition, as well as large quantities of data, but their complexity and extensive mathematical structure make interpretation difficult. Grant (1986), in his critique of large-scale systems models, proposes that the most important attribute of a model is transparency, or ability to provide insight into the workings of the system with a reasonable expenditure of effort. To maintain this attribute, Grant suggests that models be aimed at specific objectives, be simple, and be constructed with a balanced blend of fact, theory, and intuition.

Natural resource conservation agencies in several southern states, including the Oklahoma Department of Wildlife Conservation, stock hybrids into reservoirs with native populations of white and (or) striped bass. The original purposes of these stockings were to (i) provide an alternative pelagic fishery to the white bass and (or) striped bass, and (ii) utilize the abundant clupeid forage present in most of these reservoirs to provide a harvestable resource. Most hybrid stockings in Oklahoma reservoirs are done every 2 to 4 years (Hicks 1978, 1979; Kleinholz 1985; Maughan et al. 1985). Creel surveys and fall gill net sampling are used to assess the standing crops and other pertinent statistics of the hybrid and white bass populations.

To provide an alternative for predicting the characteristics of these populations, I have developed a conceptual model of the population dynamics of striped bass x white bass hybrids and white bass in reservoirs. I have patterned my efforts after Orth (1977), Reed (1982), and Taylor (1981). Orth (1977) and Reed (1982) developed models for population dynamics of largemouth bass in reservoirs and Taylor (1981) modeled walleye and trout population dynamics. Although these models represent "the state of the art" in modeling single-species reservoir fisheries, they are not applicable to multispecies fisheries such as the white bass and striped bass x white bass hybrids. The goal of this model is to develop a tool for fishery biologists engaged in the management of striped bass x white bass hybrids and white bass.

The major assumptions of this model were that density-dependent effects on growth and recruitment as well as random environmental fluctuations were in effect. Consequently, population sizes of both species were constrained around pre-determined densities. Gulland (1983) criticized single species models for neglecting the interactions between species. Because white bass and hybrids are ecologically similar, often occur in the same reservoirs, and are sometimes managed jointly, I decided to model both populations under the assumption that density-dependent mechanisms (especially forage) limit the populations. Environmental fluctuations are important in regulating fish populations. In reservoirs, these fluctuations often occur in the form of variations in water level and has been shown

(Zweiacker 1972; Orth 1977) to regulate largemouth bass recruitment in Lake Carl Blackwell. I assumed that white bass and hybrid populations in Lake Carl Blackwell were subject to random environmental fluctuations, hence I introduced stochastic perturbations on the recruitment processes.

A good model is one which maximizes any two of the following properties: realism, precision, and generality (Levins 1968). Therefore, consistent with the major objectives of this study, many of the data used in implementing the model and the conclusions drawn there from are specific to striped bass x white bass hybrids and white bass in Lake Carl Blackwell, Oklahoma. However with appropriate data, the model can be adapted to simulate the population dynamics of a variety of two species fisheries consisting of a put-and-take fishery (such as the hybrid) and a naturally reproducing species.

The Model

The model I developed utilizes information from several existing models including those of Jacobsen (1983), Orth (1977), Zagar and Orth (1986), Taylor (1981), Reed (1982), Gutreuter (1983), and Walters (1969). The model is age-structured, and stochastic and utilizes the Leslie matrix algorithm (Leslie 1945) to express year class strengths.

Recruitment is generally defined as the number of fish entering the harvestable size class during the given year and has been shown (Walters 1969, Orth 1977) to be the driving factor in fish population dynamics. Dynamic pool models have shown a very strong relationship between the size of the parental stock and the number of recruits. A number of factors affect recruitment including spawning biomass, environmental factors, predation, and competition (Pitcher and Hart 1981). In addition, Nikolskey (1969) stressed the importance of population size; indicating that changes in the number of recruits are responses to factors such as fecundity, viability of eggs and larvae, mortality, and growth all of which in turn vary in a complicated manner in response to environmental changes. These factors can be grouped as either density-dependent or density-independent (Lackey and Hubert 1979).

Data on density independent factors such as environmental variability were not available for use in this model thus a density-independent stochastic component was used to estimate these factors. Long-term population statistics were also not readily available for white bass and striped bass x white bass hybrids. As a result of paucity of data on these species, the resulting model is mainly a conceptual model with the theoretical framework developed for a multispecies fishery. The model is intended to serve as a guide to fishery biologists and policy makers regarding management of these resources.

A fish population will change in biomass after one time period as a result of recruitment, growth in biomass, and mortality. This relationship can be expressed as

$$dB/Bdt=R(B)+G(B)-M(B)-F(E)+e \tag{1}$$

where B=biomass, E=fishing effort, R, G, M, and F are rates of recruitment, growth, natural mortality, and fishing mortality and e is a random error. Derivations of equations 2 through 25 follow the methods of Orth (1977), Ricker (1975), Pitcher and Hart (1981), and Gulland (1983). The instantaneous rate of total mortality (Gulland 1973) can be written as

$$dN_{ij}/dt=-Z_{ij}*N_{ij} \tag{2}$$

where Z_{ij}=instantaneous rate of total mortality for age class j of species i, and N_{ij}=population size of age class j of species i. Rearranging equation (2), we can obtain

$$dN_{ij}/N_{ij}=-Z_{ij}dt \tag{3}$$

Integrating (3) yields

$$N_{i(j+1)}=N_{ij}\ \exp^{-(Zij)} \tag{4}$$

Z_{ij} can be partitioned into fishing mortality, F_{ij}, and natural mortality, M_{ij}, thus

$$N_{i(j+1)}=N_{ij}\ \exp^{-(Fij+Mij)} \tag{5}$$

Instantaneous rate of survival can be obtained from the following relationship

$$S_{ij}=N_{i(j+1)}/N_{ij} \tag{6}$$

alternatively, S_{ij} can be derived from instantaneous total mortality rate as

$$S_{ij}=\exp^{-(Zij)} \tag{7}$$

where S_{ij}=instantaneous annual survival rate for age class j of species i. Instantaneous annual rate of growth, G_{ij}, was computed from the formula

$$G_{ij}=L_{i(j+1)}/L_{ij} \tag{8}$$

where $L_{i(j+1)}$=mean total length of age class j+1 of species i, and L_{ij}=mean total length of age class j of species i. Growth in weight can be expressed as

$$W_{i(j+1)}=W_{ij}*\exp^{(bi*Gij)} \tag{9}$$

where $W_{i(j+1)}$=mean weight of age class j+1 of species i, W_{ij}=mean weight of age class j of species i and b_i is the exponent in the length-weight relationship

$$\mathrm{Weight}=a_i*\mathrm{Length}^{bi} \tag{10}$$

Biomass B_{ij}, of age class j of species i was computed from the formula

$$B_{ij}=N_{ij}*W_{ij} \tag{11}$$

The mean number of fish in age class j of species i during the period t, t+dt is represented by the formula

$$\mathrm{NBAR}_{ij}=\int_{t}^{t+1} N_{ij}*\exp^{-(Zij)}\,dt \tag{12}$$

Integrating (12) yields

$$\mathrm{NBAR}_{ij}=(1-\exp^{(-Zij)})/Z_{ij} \tag{13}$$

Mean biomass (kg) of age class j of species i during time period t, t+dt is represented by the formula

$$\mathrm{BBAR}_{ij}=\int_{t}^{t+1} B_{ij}*(\exp^{(Gij-Zij)})*t\,dt \tag{14}$$

integrating (14) yields

$$\mathrm{BBAR}_{ij}=B_{ij}(1-\exp^{-(Zij-bi*Gij)})/(Z_{ij}-b_i*G_{ij}) \tag{15}$$

when $Z_{ij}>G_{ij}$ and

$$=B_{ij}*(\exp^{(Gij-Zij)}-1)/(G_{ij}-Z_{ij}) \tag{16}$$

when $Z_{ij}<G_{ij}$. B_{ij} is the biomass of age class j of species i at time t=0. Number of fish of age group j of species i harvested during the time period t, t+1 is represented by the formula

$$C_{ij}=F_{ij}*NBAR_{ij} \qquad (17)$$

where F_{ij} is the fishing mortality rate of age-class j of species i. Weight of fish (kg) of age group j of species i harvested during the period t, t+1 is represented by the formula

$$Y_{ij}=F_{ij}*BBAR_{ij} \qquad (18)$$

Gross production of fish of age class j of species i during the period t, t+1 is represented by the formula

$$GPROD_{ij}=b_i*G_{ij}*BBAR_{ij} \qquad (19)$$

Net production (Ricker 1975) by age class j of species i during the period t, t+1 is given by

$$NPROD_{ij}=(b_i*G_{ij}-Z_{ij})*BBAR_{ij} \qquad (20)$$

Excess of growth over natural mortality of age class j of species i during the period t, t+1 is given by

$$EXS_{ij}=(G_{ij}-M_{ij})*BBAR_{ij} \qquad (21)$$

and weight of fish of age class j of species i that die naturally is represented by the formula

$$WTMORT_{ij}=M_{ij}*BBAR_{ij} \qquad (22)$$

There is a concensus of opinion that no general or specific parental-recruitment relationship holds true for all species (Beverton and Holt 1957, Ricker 1958). Furthermore, in situations where a theoretical basis for a particular model exists, it still shows significant dispersions; indicating that factors other than parental stock may be in operation (Reynolds and Babb 1978). This indicates that other factors such as stochastic environmental perturbations may be important in determining recruitment. Assuming that the above assertion is correct, I included a stochastic component into the recruitment submodel. Biomass and other statistics of the fishery computed by the model include fish of both species within age classes I through V. Data on hybrids older than age V, and larval and young-of-the-year fish were not available hence the model is also limited to age-classes I through V.

Parameter Estimation

Growth Rates

Growth in length is a function of many factors, the most important of which are initial size and prey availability. Within any given population, smaller fish grow at a much faster rate than larger fish and at any given size this rate is usually constant (Weatherly and Rogers 1978). Conversely, prey availability is unpredictable and accurate estimates of prey availability have been considered to be one of the weak points of single-species modeling (Reed 1982). In any balanced fish community (Swingle 1950), predator numbers exert a controlling influence over prey numbers hence predators are limited by their own biomass. Prey availability is a function of predator size and numbers, prey size and numbers, prey distribution, time, energy requirements, competition, and other factors (Werner 1974). Since data on prey availability were not available for use in this model, density-dependent and stochastic effects of this factor on growth, as estimated from fish in Lake Carl Blackwell, were used to build the model.

Mean lengths-at-age data were taken from data from fish collected from Lake Carl Blackwell during 1985 and were fit to von Bertalanffy growth curves (von Bertalanffy 1938) for each species. Walford plots (Walford 1946) were obtained by plotting mean lengths at time t+1 against mean lengths at time t. The slopes of the Walford plots equals $\exp^{(-ki)}$ where k_i is the asymptotic rate of growth for species i. Ricker (1975) and Cailliet et al. (1986) give detailed descriptions of the von Bertalanffy curve and how to estimate the parameters. The simplest version of the von Bertalanffy growth formula has the form

$$L_{it}=L_{mi}(1-\exp^{-ki(ti-t0)}) \qquad (23)$$

k_i is the asymptotic growth constant for species i and t_0 is the 'age' the fish would have had at zero length if they had always grown according to the equation (t_0 genearlly has a negative value). The maximum lengths attainable by each species, L_{mi}, were obtained from the Walford plots as the points of intersection of $L_{i(t+1)}=L_{i(t+1)}$ with $L_{i(t+1)}=L_{it}$. The intercept, I_i, of the plot of $\log(L_{mi}-L_{it})$ against t enables the computation of t_0, thus

$$t_0=(I_i-\log(L_{mi}))/k_i \qquad (24)$$

The von Bertalanffy growth model for the white bass was

$$L_{it}=448*(1-\exp^{-0.48(ti-0.13)}) \qquad (25)$$

and for the hybrid, was

$$L_{it}=487*(1-\exp^{-0.53(ti-0.08)}) \qquad (26)$$

Mean lengths-at-age, and estimated annual instantaneous rates of growth for white bass and striped bass x white bass hybrid are listed in Table XIII.

Length-Weight Relationship

Length-weight relationships were determined for both species by regressing the common logarithm of weight (grams) against the log of total length (mm). The estimated constants a and b, obtained from the relationship $weight=a*length^b$ are listed in Table XIV.

Mortality Rates

Mortality in exploited fish populations comes from two sources: fishing and natural causes. In unexploited populations, natural causes are the sole source of mortality whereas in heavily exploited populations, fishing may account for a major part of the total mortality. Fishing mortality is a function of the catchability coefficient, q, and the fishing effort, f. Natural mortality estimates are less precise than fishing mortality because they can not be estimated independent of fishing mortality; thus the errors associated with fishing mortality estimates are carried over into natural mortality estimates.

Instantaneous total mortality rates, Z_{ij}, were estimated for both species by means of catch curves (Ricker 1977, Bagenal 1978) on 1985 data from Lake Carl Blackwell. The natural log of catch per unit of effort plotted against age, yields a graph with both ascending and descending arms. The descending arm represents the fully recruited age classes and its slope at various ages are taken to represent the age-specific instantaneous total mortality rates. Data on annual instantaneous rates of fishing and natural mortalities were not available for either species. Consequently, total instantaneous mortality rates were partitioned on the assumption that the fishing mortality rates for both species in Lake Carl Blackwell were slightly lower than that for the hybrid in Sooner Lake (Glass 1982). Mortality rates employed in the model are listed in Table XV.

Survival Rates

The survival rates for both species were obtained from the data used to compute instantaneous total mortality rates. Age-specific survival rate, S_{ij} is given by

$$S_{ij}=\exp^{-(Zij)} \qquad (7)$$

The age specific survival rates computed for both species and used in the modeling are listed in Table XVI.

Fecundity

Fecundity estimates for white bass were obtained from Baglin (1972), who determined age-specific fecundity rates for white bass in Lake Texoma, Oklahoma-Texas. Baglin's estimate of fecundity, derived from fish in the Washita river arm of Lake Texoma, was:

$$\text{Fecundity}=49954+71241*\text{Age} \qquad (27)$$

White bass in Lake Texoma (Baglin 1972) and Lake Carl Blackwell did not reach sexual maturity until age II. The age-specific fecundities shown in Table XVII were used in the model.

The Simulation

The model assumes an annual stocking of a fixed number of hybrid fingerlings and a self sustaining white bass population. The number of hybrid fingerlings stocked annually is at the discretion of the modeler but the survival of the stocked fish is controlled by stochastic variation of environmental parameters as well as density-dependent factors. Conversely, the white bass population is controlled by the survival of the fingerlings produced by natural reproduction of a population with a 1:1 sex ratio. Furthermore, in the modeling effort, I assumed that interactions with fish species other than between white bass and hybrids were negligible or inconsequential and that both fish species were initially absent from the reservoir. Thus 3,000 white bass fry and 10,000 striped bass x white bass fingerlings were used as 'seeds' to initiate the simulation. The population dynamics of both species were simulated for fifty years and statistics such as abundance, catch, yield, and lengths-at-age were generated on an annual basis.

Since the value of any density-dependent function is determined only when the value of the density is specified, it was necessary to determine the absolute size of the population (numbers, biomass) at equilibrium. To obtain these estimates of absolute population size at equilibrium, six stations in Lake Carl Blackwell were sampled monthly for 14 months (June 1984 to August 1985 excluding January). Sampling was done with gill nets, trap nets, and barrel nets. Constant monthly fishing efforts were expended using 12, 61 m nylon experimental gill nets (mesh sizes 2.54, 5.08, 7.62, and 10.16 cm respectively). These efforts resulted in harvests of both species that were considerably less than those from other Oklahoma reservoirs (Table XVIII). These data indicate that the absolute population size of both of these species in Lake Carl Blackwell is quite small.

To accurately determine the total standing crop or biomass in a reservoir the size of Lake Carl Blackwell (area=1369 ha) would require extensive mark-recapture data or cove rotenone data and determination of catchability coefficients for each sampling technique. These data were not available, therefore standing crop was estimated based on the sampling data available. A Morone sp. standing crop estimate of 700 kg (for both species) was employed as the upper limit beyond which density-dependent forces become operative.

Fry and Egg Survival

Since young-of-the-year survival is probably the key element determining population fluctuations in reservoir fisheries, and because weather often influences their survival, several modeling attempts have been made to include stochastic elements in predicting young-of-the-year survival (Jensen 1975; DeAngelis et al. 1980). One problem of these attempts has been the inclusion of stochastic events in predicting the survival of a pre-reproductive age class which may alter the intrinsic rate of growth of the population. Goodyear and Christensen (1984) attempted to adjust for this bias by determining a correction factor for the bias in population growth introduced by the distribution of the random variation. Even with these adjustments, estimates of survival from egg to age I is difficult to obtain. Vaughan and Saila (1976) used a Leslie matrix algorithm to compute survival rates from egg to age I as:

$$S_0=1/\sum_{i=1}^{k-1}\left(m_{i+1}\left(\prod_{j=1}^{i} * S_j\right)\right) \qquad (28)$$

where S_j=age specific survival rate, k=number of age classes, and m_i=age specific fecundity. In my study, the annual stocking rate for for hybrids was substituted for age-specific fecundity in equation (27) above. Random variation was incoporated into the term representing the probability of survival from egg through age 0 by the equation

$$S_0(_t)=S_0{*}\exp^{(R(t))} \tag{29}$$

where $S_0(t)$=probability that eggs deposited at the beginning of the year will survive to age I, and $R(_t)$=random number for year t. Initially a correction factor, C, determined by the method of Goodyear and Christensen (1984) was used to obtain a corrected survival rate of:

$$S_0(_t)=S_0{*}\exp^{(R(t)+C)} \tag{30}$$

However, since the model was subject to density-dependent constraints the true effects of the correction factor were masked. Consequently, the correction factor, C, was dropped from the model. In its place, a subroutine developed by Orth (1977) was adapted for use in computing survival rates of age 0 white bass and hybrids.

Stochasticity

The ability of any model to provide reliable predictions depends on several uncertaintities associated with the modeling process. Uncertaintities in modeling can result from three sources (i) errors in the model construction, (ii) uncertainty in the model parameters, and (iii) variability of the natural system (O'Neill et al. 1979). In this context the density-dependent models contain virtually no bias compared to those inherent in the density-independent Leslie matrix models where wide deviations occur.

Understanding large-scale fluctuations due to variations in year-class strengths have been the recipient of considerable effort (Ward and Larkin 1964). In some cases, year-class size has been determined by density-dependent processes within the population. However, random fluctuations and their effects on recruitment are also important. Adjustments for these random effects is often done by multiplying the survival factor by a random variable (Allan and Basasibwaki 1974).

In order to account for random variability in recruitment, a stochastic component was introduced into the model developed in this study. The survival rates of white bass eggs and stocked hybrid fingerling to age I were then estimated (equation (29)) by multiplying the original rates by the exponent of a normally distributed random variate of mean of 1 and standard deviation supplied by the user. Thus the modeler could incorporate some realistic degree of fluctuation in the young-of-the-year population sizes.

Density-Dependent Effects on Young-of-the-Year Survival

Most fish populations adjust to increased mortality or excessive survival through one or more compensatory mechanisms. Density-dependent mechanisms have been incorporated into Leslie matrix models for mortality rates (Walters 1969; LMS 1975) and stock recruitment (Ricker type) models (Hess et al. 1975). In addition a model designed to predict the long-term impact of man-induced mortality on the population must incoporate some form of negative feedback mechanism (Gulland 1983).

Three problems confront the modeler when the Leslie matrix is used to model fish populations. They are (i) selection of age-specific parameter(s) that are assumed to be density-dependent, (ii) selection of a function relating a density-dependent parameter to some index of population size, and (iii) selection of numerical values for the parameters in this function. Density-dependent effects can be modeled in terms of (i) recruitment, (ii) mortality (fishing and natural), and (iii) survival of age-class 0. Survival rates for age class 0 are very difficult to obtain directly (Vaughan and Saila 1976;). However, young-of-the-year survival is the most important parameter in determining reservoirs fisheries population dynamics (Orth 1977), and it is important to consider the effects of density-dependence on this factor.

In my model, the function which describes the density-dependent effects on white bass egg and stocked hybrid fry survival is given by:

$$F(S(_t))=F(B(_t)) \tag{31}$$

where $F(S(_t))$ is the egg survival coefficient and $F(B(_t))$ is the density-dependent term. The model can be reduced to a piecewise form:

$$F(S(_t))=\begin{cases} D_1 \text{ if } B(_t)<=B_d \\ \\ D_2 \text{ if } B(_t)>B_d \end{cases} \tag{32}$$

where D_1 and D_2 are density-dependent coefficients for the survival of white bass eggs and stocked hybrid fingerlings to age I, $B(_t)$ is the total Morone sp. biomass, and B_d is a pre-determined carrying capacity.

Density-dependent feedback mechanism in the form of negative exponential function was incoporated into the model. The survival of both species to age I was considered to be under some form of density dependence and was fit with the relationship:

Density dependent coefficient

$$=ADEN_i*\exp^{-(BDENi*Total\ biomass)} \quad (33)$$

where $ADEN_i$, $BDEN_i$ are arbitrarily determined constants and total biomass is the combined biomass for both species (Table XIX). The constants $ADEN_i$ and $BDEN_i$ were determined from iterations in which total biomass values were used along with various combinations of $ADEN_i$ and $BDEN_i$. The final constants were chosen from among the group which yielded density dependent coefficients between 0 and 1 and were similar to those reported for other species (Zagar and Orth 1986; Taylor 1981).

Density-Dependent Effects on Growth

Factors affecting growth of adult fishes include forage availability, overcrowding (both inter- and intra-specific), genetics, and environmental suitability. High density in fish populations can result in reduced fecundity (LeCren 1965), reduced growth (Gulland 1983), and higher mortality of early life history stages through predation, starvation, cannibalism, and competition for space and other resources.

In my study, the effects of density on the growth of the two species were incoporated into the model via a feedback mechanism that enhanced growth at low densities and retarded it at high densities (Table XIX). The proportion of growth, PG_{ij}, achieved at any given total biomass is given by:

$$PG_{ij}= \begin{cases} PG*\exp^{+(bl*\text{total biomass})} \\ \quad (PG=0.9 \text{ if total biomass}>700 \text{ kg}) \\ \\ PG*\exp^{+(bl*\text{total biomass})} \\ \quad (PG=1.05 \text{ if total biomass}<=700 \text{ kg}) \end{cases} \qquad (34)$$

Consequently, the proportion of growth, PG_{ij}, computed under any given population biomass is applied to the instantaneous rate of growth, G_{ij}, and the corrected instantaneous rate of growth is provided thus:

$$\text{New } G_{ij}=G_{ij}*PG_{ij} \qquad (35)$$

The corrected rate was used in all computations in the model. PG is constrained to between 0.90 to 1.05 implying that growth can be retarded by about 10% or enhanced by 5% as a result of density-dependent effects.

The effects of high density on growth were examined in the field by comparing the annual variations in body lengths and weights. Annual lengths-at-age data were used to compute proportional stock density (Anderson 1976). Proportional stock density (PSD) is an index developed for assessing the quality of sport fisheries and is expressed as the ratio of number of fish in the population that are at least of stock length to the number that are at least of quality length. Quality and stock lengths employed in the simulation were derived from Gabelhouse (1984). Populations with higher PSDs have greater proportions of bigger fish than populations with lower PSDs.

Model Input and Output

Input into the model consists of: (i) number of age classes in each species, (ii) number of years the simulation is to run, (iii) year to commence simulation, (iv) number of hybrid fry to be stocked annually, (v) age-specific fecundity for white bass, (vi) age-specific instantaneous survival rates for each species, (vii) age-specific frequency of each species, (viii) age-specific mean lengths and mean weights for each species, (ix) age-specific instantaneous total, fishing, and natural mortality rates for each species, and (x) age-specific instantaneous rates of growth for each species.

Model output consists of: (i) Age-specific frequency of each species in the population, (ii) age-specific catch, yield, and biomass of each species during each year of simulation, (iii) age-specific mean lengths and weights for each species during each year of simulation, and (iv) proportional stock density (PSD) (Anderson 1976) for each species during each year of simulation. Input codes for variables and parameters used in the model are listed in Table XX.

Model Implementation

Factors which influence the usefulness of a model include the ease and extent of the distribution of the language in which the program was written, the codes used and their degree of relatedness to the actual variables, program documentation, and system requirements such as computer time and memory allocation requirements. In order to make this model easily accessible to as many potential users as possible, I (i) used a modular approach by isolating key segments into subroutines, (ii) used arrays, thereby making it easier to vary population parameters from one reservoir to another as well as vary the number of age classes (iii) allow the user to modify the density-dependent effects and stochasticity by modifying the appropriate parameters. This model was written in FORTRAN 77 and was run on an IBM 3081K mainframe computer system at Oklahoma State University.

Model Validation

As indicated earlier, one of the benefits derived from population modeling is the synthesis of knowledge and information from different facets of the ecosystem into a workable 'package'.If the assumptions made in initial model development are correct, this package allows for the testing of the interactions between different facets of the system; the ultimate goal of which is to optimize the allocation of resources and the evaluation of alternative management practices.

Model validation is a two-step process involving first, the testing of the various relationships in the model and secondly, evaluating the joint action of these relationships which define the structure of the model. The object of testing a model is to determine whether the model can adequately account for as much of the behavior of the real system as possible. However, lack of data for all sets of conditions in the system is often the reason for modeling in the first place. Such was the case for the white bass and striped bass x white bass hybrid populations in Lake Carl Blackwell. Consequently, formal and rigorous testing of the results of this model could not be undertaken. The results presented here are the types that can be generally obtained from the model. Comparisons with actual data are made when such comparisons enhance the validity of the model. The model should serve as a prototype for building similar two-species models and testing various multispecies reservoir fishery management hypotheses. A flow chart of the program for this model is shown in Appendix C and the program listing is shown in Appendix D.

Results

Population size

Fifty-year simulations, constrained by density-dependent mechanisms and subjected to stochastic variations, produced stable populations of white bass and striped bass x white bass hybrids (Table XXI). However, population size fluctuated widely during the early years and continued to fluctuate thereafter due to the stochastic variation and the compensatory responses to high density (Figure 11). The total annual population size (excluding young-of-the-year) ranged from 2704 to 4386 fish. The inverse relationship between growth rate and population size implies that reductions in population density when they are at high levels brings about much greater growth changes than when population densities are low.

Various scenarios were simulated to determine what annual stocking rate of striped bass x white bass hybrid would be required to maintain an equilibrium with the white bass population. The results of one such simulation (Table XXI; Figure 11) indicates that 10,000 hybrid fingerling stocked annually would maintain the population in equilibrium. This simulation as well as others to be described later, rely on the successful natural reproduction of white bass to sustain that population. In this simulation, white bass were initially more abundant in the population than the hybrids but by the thirteenth year of the simulation the hybrid population had surpassed that of the white bass. In all simulations, the white bass population was less variable than that of the hybrid even though both populations were subjected to the same degree of stochastic perturbations. Wide fluctuations in the hybrid population is especially apparent during simulation years 23 to 36 (Figure 11).

Biomass

Biomass can be used to express the quality of a fishery since it is a function of both size and number of fish in the population. A balanced fishery (Swingle 1950) is one with an abundance of intermediate size fishes rather than one with too many small or too few large fishes. A carrying capacity of 700 kg of *Morone sp.* was imposed on the lake hence total biomass fluctuated about that point (Table XXI; Figure 12). The white bass biomass were higher than that of the hybrid during most of the simulation.

Fecundity

The density-dependent compensatory mechanism built into the model was such that only a given percentage of the theoretical fecundity was realized each year. Such an approach may be realistic since the expected number of eggs, based on standard age-fecundity or weight-fecundity relationships is often not achieved when resources such as food and space are limiting. Such requirements are assumed to be limiting under density-dependence thus the resulting effect is decrease in white bass fecundity. Annual fecundity as well as model predicted fertility indicate that fecundity declined during the early years of the simulation but increased thereafter (Table XXII; Figure 13). White bass realized only 35 to 47% of their theoretical fecundity as a result of the density-dependent constraints imposed by the entire Morone sp. populations biomass.

Percent of White bass in the Population

One of the goals of a multispecies fishery that depends on natural reproduction of one of the species for propagation, is the achievement of acceptable and sustainable yield. The goal of my model, which calls for an annual stocking of hybrid fingerlings, is the maintenance of a viable two-species fishery. The model indicated that white bass and hybrid populations can be maintained within a predictable proportion of the total population. White bass populations constituted 48 to 66% of the total population (excluding larval fish and young-of-the-year) during any given year (Table XXII; Figure 14). The proportion of either species in the population could be varied by the modeler, through suitable choice of parameters, to suit the needs of the fishery.

Percent Survival of Stocked Hybrid Fingerling

The density-dependent constraints imposed on hybrid fingerling survival resulted (Table XXII; Figure 15) in only 2 to 5% annual survival through the 'critical' period of development. Larval survival is the key to successful development of fish populations and has been shown to account for variability in year-class strengths in some reservoir fish populations. These values of survival estimated by the model seem to be low for Lake Carl Blackwell since Kleinholz (1985) estimated that mortality of hybrid fry stocked in Lake Carl Blackwell ranged from 1 to 5% and that young-of-the-year mortality ranged from 40 to 50%. Kleinholz (1984) concluded that hybrid fry mortality is highest at stocking and is most common in small reservoirs with inadequate forage. Huner (1985) concluded that survival rates in excess of 50% for pond-raised hybrid fry were good. Hence higher mortality rates than those estimated by Kleinholz might be expected in resevoirs.

Harvest

Annual harvest estimates obtained from the simulation ranged from 217 to 397 for the white bass and 244 to 387 for the hybrid (Table XXIII; Figure 16). This level of harvest is small compared to those obtained in other reservoirs the size of Lake Carl Blackwell. However, angling for white bass and hybrids in Lake Carl Blackwell has traditionally resulted in poorer catches than in surrounding reservoirs. One of the assumptions of the model was that annual age-specific fishing mortality rates (Table XV) were constant. Estimated instantaneous fishing mortality rates were higher for the hybrid (0.09 to 0.77) than for the white bass (0.03 to 0.55). On the average, harvest was greater for the hybrid than for the white bass during most of the simulated years and based on the population parameters employed in the modeling, 5 to 10% of the white bass and 6 to 14% of the hybrid (ages I-V) are removed by anglers.

Yield

Yield in fisheries is a reflection of both numbers and weight of fish caught. In commercial fisheries it is also a measure of the energetic contribution of the fish to man's nutritional needs and represents that portion of the biomass that is harvested by man. The yield curves of both species were quite similar to the harvest curves. This similarity is not unexpected since constant annual age-specific fishing mortality rates were employed in the modeling and both species had similar age-specific mean weights. The mean annual yields ranged from 110 to 171 kg for the white bass and from 109 to 186, kg for the hybrid after the model had stabilized (Table XXIII; Figure 17). Thus the combined annual yield for the Morone sp. fishery ranged from 241 to 333 kg.

Proportional Stock Density

In addition to expressing harvest in terms of weight and numbers, fishing quality has been variously expressed in terms of population indices such as forage/carnivorous (F/C) ratio or balance (Swingle 1950), young/carnivorous (Y/C) ratio (Swingle 1950), proportional stock density (PSD) (Anderson 1976; 1978), and relative stock density (RSD) (Anderson 1980). Proportional stock density, the proportion of quality length fish that are also at least of stock length, has become popular among biologists as a convenient method of expressing population structure. The simulation indicated that both species had annual PSD's ranging from 41 to 58 for the white bass and from 31 to 61 for the hybrid (Table XXIII; Figure 18). The PSD's of 100 which were obtained during the early part of the simulation are not representative since the populations were not in equilibrium at that time.

Alternative Hybrid Stocking Rates

One of the most important advantages of models is that they facilitate the quick, inexpensive simulation of management scenarios that are impossible to test or implement in the real system. In keeping with the primary objectives of this study, the effects of various hybrid fingerling stocking rates were simulated. The stocking rate of 10,000 fish was used as a baseline and the behavior of the system under stocking rates of 15,000 and 5,000 fish were examined for stability, yield and other parameters previously discussed. The rationale for testing different annual stocking rates was to determine which rates would produce persistent and satisfactory yield of both species to the fishery at the least cost.

A 50-year simulation with an annual stocking rate of 15,000 hybrid fingerlings (all other parameters remaining unchanged) indicated that the hybrid population was consistently higher relative to that of the white bass than at the base stocking rate (Table XXIV; Figure 19). The total Morone sp. population size was slightly higher ($p<0.05$) at this stocking rate (mean annual=3,600 fish) than at the baseline stocking rate (mean annual=3,100 fish). However, the 50% increase in hybrid stocking rate also resulted in a corresponding significant decrease in the white bass population ($p<0.05$)

Under the 15,000 fingerling stocking rate, the simulated annual total biomass (Table XXIV; Figure 20) was similar ($p>0.05$) to that at the 10,000 stocking rate but that of white bass significantly lower ($p<0.05$). White bass fecundity was lower ($p<0.05$) at higher total population density than at lower population density but the proportion of white bass eggs which hatched as a result of density dependence remained essentially unchanged (Table XXV; Figure 21). The proportion of white bass in the population was lower ($p<0.05$) at high hybrid stocking density than at the baseline rate (Table XXV; Figure 22). At the baseline hybrid stocking rate, white bass constituted 48 to 66% of the entire population but at the higher rate, they made up only 34 to 52%. This difference indicates that a 50% increase in hybrid stocking rate does not translate into a corresponding decrease in the proportion of white bass in the population. The proportion of stocked hybrid fingerling that died annually from density-dependent causes remained essentially unchanged (Table XXV; Figure 23) under both stocking rates. The justification for increasing the hybrid stocking rate is to increase fish harvest and yield. To this end, the increase in hybrid population size resulted in higher ($p<0.0001$) harvests (Table XXVI; Figure 24) and yield ($p<0.05$) (Table XXVI; Figure 25) resulting in an annual mean hybrid harvest of 366 fish weighing 260 kg. Growth of both species were retarded at high total population densities and were enhanced at lower densities by an amount proportional to the total population biomass. The increased hybrid population size might be expected to result in lower hybrid average size as well as lower PSD. Conversely, white bass might be expected to obtain larger average sizes and have higher PSDs as their population size decreased. However, the density-dependent effects on growth operated on the entire Morone population not each species individually. Consequently, differences in PSD between the two groups were not observed (Table XXVI; Figure 26).

A 50% decrease in hybrid fingerling stocking rate resulted in a decrease ($p<0.05$) in the number of hybrids in the total population (Table XXVII; Figure 27) but the survival rate of stocked hybrid fingerling remained unchanged (Table XXVIII; Figure 28). A persistent and sustainable fishery resulted at the lower stocking rate but the contribution of hybrid to the overall fishery was reduced to about 33% of that of the white bass. The reduced stocking rate did not result in lower overall Morone biomass but did result in a substantial decrease ($p<0.0001$) in hybrid biomass (Table XXVII; Figure 29).

White bass fecundity increased with decreased stocking of hybrids. However, the percentage of eggs that hatched remained essentially unchanged (Table XXVIII; Figure 30) because of the compensatory feedback mechanism. Decreased hybrid stocking rates resulted in a 16% increase in the proportion of white bass in the population (Table XXVIII; Figure 31). The simulated annual harvest (Table XXIX; Figure 32) and yield (Table XXIX; Figure 33) of white bass did not increase in proportion to the 50% stocking decrease of striped bass x white bass hybrid. Also the PSD increased only slightly at the lower stocking density (Table XXIX; Figure 34). In summary, the lower overall Morone sp. population size brought on by reduced hybrid stocking resulted in an increased PSD for both species and a corresponding increase in the quality of the fishery.

Slot-Length Limits

Various measures have been adopted to ensure adequate representation of fish of desirable sizes within the population. One of these measures is the slot-length limit whereby only fish within certain size-classes are harvested. The effects of restricting fishing to age classes II through IV were tested for both species and the result indicated that significant differences ($p<0.05$) in annual harvests were observed as a result of the size restriction (Table XXX). However, no differences in yield ($p>0.05$) occurred (Table XXX). The relatively small contributions made by age-classes I and V to the fishery might explain the lack of significant differences in yield. Despite their relatively large numbers, fishes in age-class I have traditionally not contributed much to sport fisheries because of their small sizes. On the other hand, older and larger fishes are in greater demand but their numbers are usually low; hence both age-classes do not significantly contribute to the yield.

Growth in Length

There were very few changes in lengths-at-age for the white bass (Figure 35) or the hybrid (Figure 36) in the simulations. Compensatory growth occurred when the biomass dropped below 700 kg and compensation was reflected as a 5%

increase in the instantaneous rate of growth. Conversely, a 10% reduction in the instantaneous rate of growth occurred when biomass exceeded of 700. In summary, the density of the _Morone_ _sp._ fluctuated widely but these fluctuations were not reflected in the growth patterns of either species.

Discussion

When two species share a common limiting resource, one of the species will be excluded from the resource unless the species can subdivide the use of that resource (Gause 1934; Neyman et al. 1956). This subdivision is achieved when each species excludes their competitor from part of their 'fundamental niches'. The exact requirement for stable coexistence is that each species must inhibit its own growth more than it inhibits that of the other species. This requirement is commonly called the Lotka-Volterra model. One property of the Lotka-Volterra model is that total population size of the combined system is larger than that of each individual group or species. This property served as the basis for my model. I assumed that the total population size attained by the _Morone_ _sp._ fishery was greater than that of each of the two forms. This assumption dictated that the marginal resources 'empty niches' that are not utilized by either form when they were alone in the system would be used to some extent when both forms were in coexistence.

The major assumptions of this model were that density-dependent effects on recruitment and growth as well as random environmental fluctuations were in effect. However, it is widely accepted that the degree to which recruitment depends on density is one of the more important problems of fishery research. The stock-recruitment process appears to be the main mechanism by which fish populations maintain themselves at around the level they do rather than continuously declining or expanding (Cushing 1977). However, there is also evidence (Parrish 1973; Gulland 1983) that recruitment to most fish stocks bears no obvious relation to the abundance of the parent stock. Rather, it is clear that recruitment in those stocks is governed mostly by environmental factors at some early stage in the life history of the species.

In recognition of the possible manifestations of density-dependence and stochastic environmental fluctuations on fish populations in reservoirs, I made the model flexible in order to accommodate situations other than those in which density-dependence and stochastic perturbations are both operative. Thus the model can be used for populations where either density-dependence or stochastic environmental fluctuations are known or suspected to occur as well as for populations where none of the above mechanisms are operative. In order to nullify the effects of density-dependence, lines 98 to 106 of the program (Appendix D) should be modified such that the value of 1.0 is returned for the coefficients of interest. For example, division of the fecundity coefficient (EGGDEN) by itself (lines 100-103) nullifies density-dependence on recruitment while division of the random number (RANDEV) by itself (line 179) nullifies random fluctuations in the model.

Although a time interval of one year was assumed in this model, it could be modified to simulate population changes on a monthly, seasonal, or on the basis of any other time interval. With those modifications, the model response will undoubtedly better reflect the environmental and biological events that occur in nature. Environmental changes, such as seasonal floods, and biological events, such as incresed population sizes during the spawning season, could be examined in greater detail. However, such models are rather complex and entail collection of large amounts of data.

Mortality and growth are the two main density-dependent effects on fish populations. Mortality will have the greatest effects early in life, particularly the larval and immediately post-larval stages. Conversely, growth tends to become increasingly important as a fish ages. There are density-dependent growth effects early in life, but it is among adult fish that the influence of population density in growth is most apparent. The simplest form of density regulation for a fish population, density-dependent growth of the adults, occurs because they grow in weight by an order of magnitude subsequent to maturation. The density-dependent mortality of early life stages may operate directly through intraspecific competition for a limited resource such as food or space or indirectly by lengthening developmental time and thereby increasing vulnerability. White bass in Oklahoma spawn from late March to May and because striped bass x white bass hybrids are also stocked in reservoirs at this time there is potential for competition between white bass larvae and those of striped bass x white bass hybrids.

Changes in growth rates and in densities are customarily explained in terms of changes in food supply (Weatherly and Rogers 1978). Beverton and Holt (1957) explain the relationships thus: "the variation of growth with density in fish populations is perhaps the best established of the density-dependent effects ..."

One of the reasons for hybrid introduction was its fast growth rate and voracious appetite for clupeids (Williams 1972). Several studies have suggested broader and more aggressive use of these resources by the hybrid than by the white bass (Keith 1986, citing K. E. Erickson, (ODWC)). If these suggestions are true (Maughan et al. 1986; Gleason 1982) hybrids should have a greater impact on the white bass than vice versa. My model is designed to give such a result. Striped bass x white bass hybrids have been considered to be serious competitors to some segments of white bass populations (Kleinholz 1985) and have been suggested to have severe impacts on the community structures of some populations (Keith 1986). However, there are also indications that the detrimental effects of hybrid bass populations on the endemic sport fishes may have been overemphasized (Harper and Namminga 1986).

White bass and striped bass x white bass hybrid populations were modeled using different age-specific survival and mortality constants. Keeping rates and parameters constant during simulations is easy and convenient and allows the modeler to simultaneously test the relationships between various components of the system. However, in the real system, the mortality and survival rates vary annually. The population sizes of the two species predicted by the model, reflect density-dependent effects as well as stochastic processes. White bass had slightly higher survival rates of young-of-the-year than hybrids and higher survival was reflected in the higher numbers of white bass in the baseline simulations. Higher survival rates of hybrids might be explained by food habits. Although white bass and striped bass x white bass hybrid have very similar food requirements (Kleinholz 1985), the hybrid has been shown to be the more voracious feeder (Keith 1986). Optimal foraging theory would suggest that competition between white bass and hybrids might force the white bass to accept a broader forage base than the hybrid would be required to accept. The wider niche breadth of the white bass relative to that of the hybrid would however be reflected in the higher levels of variability observed in the hybrid populations since both populations were subjected to the same levels of stochasticity.

The creation of numerous impoundments in Oklahoma has restricted the habitat suitable for spawning white bass;

they must travel upstream to spawn (Trautman 1981). This requirement for stream spawning sites means white bass recruitment is strongly tied to water level fluctuation. In years of poor white bass recruitment, or in systems where natural spawning is sporadic, stocking of hybrids could be used to buffer the loss of the white bass fishery. Stocking strategies for the hybrid would be different in systems where natural reproduction of white bass were adequate and consistent.

The assumption that the hybrid and white bass interact with one another implies that the population structure of one of the species can be deduced once knowledge of the other is available. However, actual knowledge of the community structure of each of these populations is very valuable since it enables additional definition to be added to the model. Population sizes and the associated age structures of reservoir fish populations were obtained in my study in routine fish sampling. However data to be input into the model can be obtained either empirically or estimated from the literature.

In the model, harvest and yield are dependent upon population size and fishing mortality rates. Hence the trend exibited by these two parameters in the simulations parallels those of the population sizes. Although this modeling exercise was made on the assumption that fishing and natural mortality rates were constant from year to year, these factors are rarely constant. The assumption of constant fishing and natural mortality rates allows the evaluation of the effects of fishing on the population structure but additional insight could be obtained by measurements of these parameters over shorter time intervals and incoporation of these measurements into the model.

Yield is a function of fishing effort as well as growth. In populations with low growth relative to mortality, sustained yields are lower than in expanding populations with younger age-classes. The production (net and gross) from a fishery is a function of the difference between growth and mortality and is higher when growth rate is high relative to mortality. In the real system, mortality is easier to manipulate than growth, and is generally the factor used to increase fish yield and production. In theory, manipulation of mortality allows us to alter the size and age structure of the populations to suit fishery needs.

The white bass fishery is very popular in Oklahoma and th the introduction of hybrids into Oklahoma reservoirs, the popularities of both species have increased. Gilliland (1981) reported that the enthusiastic support for hybrid fishery in Oklahoma is due to the rapid growth of the fish, ease of capture, and large size relative to the white bass.

The harvest and yield curves derived from my model are comparatively lower than those of most small lakes in Oklahoma (Glass 1982; Gilliland 1981; Glass and Maughan 1985). In addition, the fishing mortality rates employed in my model were lower than those encountered in other studies (Glass and Maughan 1985). Lower harvest rates than those estimated by Glass and Maughan (1985) may however be reasonable, because their data came primarily from harvest in a heated effluent canal. Predicted returns from the fishery ranged from 0.08-0.14 kg/ha for the hybrids and 0.08-0.15 kg/ha for the white bass. Axon and Whitehurst (1985) determined from a national creel survey that mean harvest rates for hybrids in 1978 and 1982 were 0.7 kg/ha and 3.0 kg/ha for mixed fisheries of hybrids and striped bass. The yields predicted by the model probably reflect the low productivity and angling rates prevalent in the reservoir.

In my simulations, yields of both populations tend to reach equilibrium. Higher fishing or natural mortality on any one species can be observed to result in compensatory growth by both species and a predictable level of output from the fishery.

In the real system, the imposition of slot-length limits on one or both species might be instituted to accomplish changes in both yield and harvest of the target population. For example, slot-length limits might be imposed on populations with low PSDs. Using my model, the effects of the restriction on both the community structures and the fisheries could be evaluated. There are currently no creel limits on white bass and striped bass x white bass hybrids in most Oklahoma reservoirs. On the other hand, there are certain size restrictions on the *Morone sp.* fishery in some Oklahoma reservoirs. Consequently, the inability to distinguish accurately white bass from hybrids makes enforcement of length limits and (or) creel limits difficult in Oklahoma reservoirs which contain two or more of the Morone sp. Use of the model would allow avoidance of the identification problem by enabling the researcher to test the effects of length limits or other regulations on one or both species.

It is generally accepted that fecundity is independent of adult population size (LeCren 1965) since it is thought that population regulating mechanisms act mainly during the first few weeks after hatching. However, annual variations in fecundity have been related to population density. These conflicting interpretations have led to the concept of fecundity and fertility. In my simulations, the fertility of white bass relative to the fecundity fluctuated from 35 to 48% in response to the density dependent processes. Reduction in fecundity as a result of forage and resource limitation is not uncommon since McFadden et al. (1965) reported that brown trout from infertile streams had lower growth, and fecundity and Wydoski and Cooper (1966) reported 16% difference in brown trout fecundity between oductive and unproductive streams.

Factors which affect fecundity can be density-dependent as well as density-independent. Only the density-dependent effects were considered in this model and these factors include age, size, weight, food supply, and age at first spawning. The tenets on which this model was built include the assumptions that forage was limiting and that growth reduction, resulting from food shortage, are translated into lower fecundity. The compensatory mortality processes which control white bass fecundity are also assumed to control survival of stocked hybrid fingerling during the first few weeks of life. Major density-dependent sources of mortality to fingerlings include cannibalism, predation, and competition for food and space. The overall effects of these processes on the fingerlings result in annual survival rates of 2 to 5%.

The model did not individually consider the density-independent factors affecting growth and other physiological processes such as temperature, turbidity, water level fluctuations, and wave action. The effects of these actions on fish recruitment processes can be modeled directly (Orth 1977) or indirectly estimated using stochastic processes (Taylor 1981). The second approach was used in my model. Water level fluctuations in Lake Carl Blackwell play a significant role in determining the level of recruitment for largemouth bass (Zweiacker 1972; Summerfelt and Shirley 1978) and Orth (1977) used water level fluctuations to predict year-class-strengths of largemouth bass in Lake Carl Blackwell. Therefore my modeling approach may not accurately assess the importance of these factors in Lake Carl Blackwell.

Many practical applications of single species models assume that the world is deterministic. One example of this assumption in action is in the concept of maximum sustainable yield (MSY) (May 1978). In the actual fishery, management strategies can, however, be significantly modified by the presence of environmental randomness and unpredictability. By acknowledging the reality of environmental stochasticity, we are forced to consider the dynamics of populations and to consider trade-offs between limits such as MSY and the fluctuations in the yield. Therefore, there seems to be some need to incoporate environmental stochasicity in the absence of real data into management models in fisheries ecology (May et al. 1979).

The degree of stochasticity utilized in this model is set by the user. This approach makes the model flexible enough for use in reservoir systems with different levels of environmental fluctuation. The model could also be adjusted to produce periodic stochastic variations during simulation. This modification would be useful in terms of modeling the effects of drought or flood on fish productivity in reservoirs.

The model developed in my study emphasizes an alternative approach to the management of multispecies fisheries in reservoirs. The future demand for varied recreational fisheries coupled with the diminishing availability of water resources, especially around major population centers, will necessitate management strategies such as those suggested by this model. Kerby et al. (1983) and Massingill et al. (1983) concluded that in view of the high survival, growth, and production capabilities of the hybrid it could be used for commercial aquaculture and in fee-fishing ponds. Attributes of this model such as the response to high densities, typical of most culture situations, would make it attractive for use in simulating such situations. The use of hybrids such as the striped bass x white bass, walleye x sauger, and muskellunge x northern pike as well as their parental species might be heightened if management strategies suggested by this model are adopted and developed. The model has demonstrated that stable and sustainable populations of two ecologically similar species can be managed simultaneously both as separate stocks and as a joint fishery. Although the model considered five age classes of each species, it can be altered to include any number of age-classes. This model was developed to serve as a guide for managing multispecicies fisheries consisting of a put-and-take species and a naturally reproducing species. Since data for adequate testing of the model are not available, the model can only serve as a prototype upon which future management-oriented two-species models can be based.

Model Limitations

Applied models are built with the sole objectives of solving specific problems. In the course of model building, problems do arise which were not considered in the initial analysis. Such problems are often in the form of assumptions about the data or processes being modeled. The limitations of this model include lack of long-term data base of both populations. Lack of long-term data makes estimates of parameters less than accurate and precludes testing of the results. Paucity of data on certain aspects of the population dynamics of these important sport fishes are also highlighted by the model. The identification of these aspects should stimulate more research in those areas. The model also includes assumptions of constant annual age-specific rates of fecundity, growth, survival, and mortality. Obviously these assumptions are not technically correct. Additional empirical information would increase the reliability of the model. Another limitation of my effort is that I assumed an equal number of age-classes in each stock. To overcome this problem, the model has been constructed so that it can be modified to accommodate a different number of age-classes in each species.

Conclusions

The use of models to predict fish yield and population dynamics is becoming an essential component of fisheries management. Models are needed because biological systems, especially warm water fisheries, are very complex and compartmentalization of information into various interacting units enhances understanding. Models are cost effective and require considerably less time to develop than would be required to conduct research in the real systems. Models usually work better when they are simple and describe non-interacting single species populations but since such populations rarely exist in nature, modeling attempts have been made to describe major interactions in some multi-species systems. The model I have developed is designed to explain the workings of a warm water fishery consisting of two top-level predators. My goal in developing this model was to help fishery biologists answer questions such as those related to harvest, yield, length limits, overcrowding, and random effects on year-class strengths. Interspecific competition and density-dependent control of animal populations as well as stochastic variations in environmental paramerters were the major assumptions upon which the model was built. Density-dependence appears to be a reasonable assumption in this model since significant diet overlap was reported (Kleinholz 1985) for both species in Lake Carl Blackwell. Fluctuations in environmental parameters, especially water level, has been determined to be an important factor controlling largemouth bass recruitment in Lake Carl Blackwell (Summerfelt and Shirley 1978; Zweiacker 1972; Orth 1977). If one accepts these assumptions, the model can be used to simulate relevant decision alternatives confronting fishery managers.

The model is presented as a foundation upon which other models can be built. It demonstrates the effects that recruitment or exploitation on one species-stock can have on the other species-stock when both stocks are under density-dependent constraints. It also illustrates the importance of recruitment to population structure as well as the effects of stochastic variation and density-dependence on recruitment. Multispecies fisheries can be managed as different stocks but when the species are potential competitors, as in this case, sound management decisions must consider the ramifications of species interactions. This model was not validated due to the lack of data on the species considered but it can be modified and the concepts and procedures adapted for use in other fisheries where adequate data for testing, evaluation, and implementation exist.

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APPENDIXES

APPENDIX A

TABLES

Table I. Morphometric Variables Employed in the Multivariate Discrimination of White bass, Striped bass, and Striped bass x White bass hybrids.

VARIABLE
Standard Length
Post-Pectoral Length
Post-Pelvic Length
Pre-Dorsal Length
Caudal Peduncle Length
Pre-Pelvic Length
Head Length
Snout Length
Post-Orbital Head Length
Upper Jaw Length
Lower Jaw Length
Base Length of First Dorsal Fin
Pre-Nasal Length
Second Dorsal Spine Length
Second Anal Spine Length
Pectoral Fins Insertion Distance
Pelvic Fins Insertion Distance
Head Width at Pre-Opercle
Head Depth at Occiput
Head Depth at Pupil
Head Depth at Nostril
Head Width at Pupil
Nasal to Opercular Spine Distance
Posterior of second Dorsal Fin to Posterior of Caudal Peduncle at Lateral Line
Third anal Spine Length
Base Length of Anal Fin
First Dorsal Fin Height
Orbital Length
Base Length of Pectoral Fin
Base Length of Pelvic Fin
Nasal to First Dorsal Fin Distance
Pelvic Fin to Pectoral Fin Distance
Pectoral Fin to Anterior of Second Dorsal Fin
Pectoral Fin to First Dorsal Fin Distance
Pelvic Fin to First Dorsal Fin Distance
Anterior of Anal Fin to Anterior of First Dorsal Fin
Anterior of Anal Fin to Posterior of First Dorsal Fin
Posterior of Anal Fin to Anterior of First Dorsal Fin
Posterior of Anal Fin to Posterior of First Dorsal Fin
Anterior of Anal Fin to Posterior of Second Dorsal Fin
Posterior of Anal Fin to Posterior of Second Dorsal Fin
Base Length of Second Dorsal Fin

(Table I Continued)

Anal Fin Height
Pelvic Fin Height
Pectoral Fin Height
Caudal Peduncle Height
Orbit to Preopercle Distance
Preopercle to Opercle Distance
Eye Diameter
Inter-Nasal Distance
Posterior of Second Dorsal Fin to Pectoral Fin Distance
Body Depth at Third Dorsal Spine

Table II. Meristic Variables Counted on White bass, Striped bass, and Striped bass x White bass hybrids.

VARIABLE
Number of Scales on Lateral Line
Number of Scales Above Lateral Line
Number of Scales Below Lateral Line
Number of Rays on First Dorsal Fin
Number of Spines on Second Dorsal Fin
Number of Rays on Second Dorsal Fin
Number of Rays on Pelvic Fin
Number of Rays on Pectoral Fin
Number of Rays on Anal Fin
Number of Branchiostegal Rays
Number of Upper Gill Rakers
Number of Lower Gill Rakers
Number of Rays on Caudal Fin

Table III. Means and Standard Deviations of Morphometric Variables Used in the Multivariate Discrimination of Striped bass, White bass, and Striped bass x White bass Hybrids.

	SPECIES					
	WHITE BASS		HYBRID		STRIPED BASS	
VARIABLE	MEAN	SD	MEAN	SD	MEAN	SD
Std Len	140.12	79.64	169.17	17.95	269.19	53.42
Post-Pect Len	97.22	58.12	118.53	13.63	185.04	37.00
Post-Pelv Len	83.03	49.27	103.38	11.47	165.61	35.88
Pre-Dor Len	59.31	34.50	68.08	7.15	109.30	20.87
Caud Pedun Len	27.73	14.00	31.74	2.80	54.79	10.51
Pre-Pelv Len	53.81	30.29	63.60	7.97	99.21	18.75
Head Len	44.77	24.29	52.49	5.14	86.42	16.48
Snout Len	11.28	6.91	13.95	1.87	23.61	5.08
Post-Orb Head Len	21.07	12.20	23.93	2.64	40.99	8.39
Upper Jaw Len	18.01	10.05	20.85	2.06	34.22	6.92
Lower Jaw Len	23.86	12.92	26.73	2.50	44.40	8.90
Base Len 1st Dor Fin	33.06	19.26	42.17	5.81	57.43	11.98
Pre-Nasal Len	11.77	6.68	14.42	1.41	23.14	4.65
2nd Dor Spine Len	8.52	3.10	10.91	3.21	17.19	3.29
2nd Anal Spine Len	14.84	7.25	14.39	2.18	15.75	2.05
Pect Fin Insert Dist	17.66	11.38	21.81	3.31	33.14	6.97
Pelv Fin Insert Dist	11.05	6.78	11.76	1.63	16.89	3.46
Head Width at Pre-Opercle	21.82	13.35	25.04	2.81	37.07	7.74
Head Depth at Occiput	35.14	21.56	39.93	4.76	57.72	11.29
Head Depth at Pupil	24.38	13.58	26.28	2.55	39.43	7.65
Head Depth at Nostril	17.23	9.03	18.33	1.82	28.33	5.67
Head Width at Pupil	18.01	10.84	21.02	2.41	29.69	6.62
Nasal-Operc Spine Dist	33.29	17.78	39.07	3.87	64.57	12.34
Post of 2nd Dors Fin -Post Caud Pedun Len at Lat Line	29.52	15.37	34.07	3.32	56.65	11.41
3rd Anal Spine Len	16.94	8.85	16.50	2.08	23.96	3.25
Base Len of Anal Fin	23.04	12.93	29.89	8.37	36.19	6.63
1st Dor Fin Height	24.48	14.40	30.63	4.00	42.07	7.39
Orbital Len	12.50	5.73	13.95	1.24	19.49	3.14
Base Len of Pect Fin	6.31	3.98	7.22	0.85	10.82	2.02
Base Len of Pelv Fin	7.57	5.03	8.14	1.08	9.97	2.01

(Table III Continued)

Nasal-1st Dor Fin Dist	47.69	27.98	53.51	5.37	85.85	16.62
Pelv Fin-Pect Fin Dist	9.28	5.99	12.62	2.06	17.35	3.49
Pect Fin-Ant of 2nd Dor Fin	63.70	29.61	65.60	8.64	93.40	18.30
Pect Fin-1st Dors Fin Dist	32.01	20.91	37.89	4.33	50.87	9.50
Pelv Fin-1st Dors Fin Dist	41.93	26.01	51.72	6.45	68.42	12.68
Ant of Anal Fin-Ant of 1st Dor Fin	60.00	37.03	74.59	8.72	105.76	20.65
Ant of Anal Fin-Post of 1st Dor Fin	42.11	27.03	51.34	6.28	66.37	12.18
Post of Anal Fin-Ant of 1st Dor Fin	70.41	41.92	87.16	10.47	126.55	25.34
Post of Anal Fin-Post of 1st Dor Fin	42.74	26.28	51.97	5.99	75.46	14.57
Ant of Anal Fin-Post of 2nd Dor Fin	37.09	22.54	44.26	6.30	55.78	10.06
Post of Anal Fin-Post of 2nd Dors Fin	23.27	14.03	28.21	3.51	36.53	6.25
Base Len of 2nd Dors Fin	24.08	13.57	31.21	3.31	47.02	11.25
Anal Fin Height	27.85	15.70	31.61	3.81	39.44	6.79
Pelvic Fin Height	29.92	17.66	33.53	3.96	48.07	8.95
Pectoral Fin Height	26.05	16.32	27.66	3.00	44.84	8.88
Caud Peduncle Height	17.89	10.59	19.43	2.79	26.56	4.73
Orbit-Preoper Dist	14.89	8.69	18.21	2.03	30.00	6.41
Preoper-Operc Dist	16.26	8.46	18.65	2.22	28.11	5.05
Eye Diameter	10.01	3.83	10.32	0.66	14.38	1.78
Internasal Distance	7.69	4.22	9.98	0.92	14.37	3.14
Post of 2nd Dor Fin-Pect Fin Dist	71.56	44.31	88.99	11.21	133.75	28.54
Body Depth at 3rd Dor Spine	42.43	27.72	52.19	7.27	69.03	13.13

Table IV. Significant Morphometric Variables and Linear Discriminant Function Coefficients for Separating White bass, Striped bass, and Striped bass x White bass hybrids.

VARIABLE	FUNCTION I	FUNCTION II
Caudal Peduncle Length	-25.23	17.10
Snout Length	-39.85	5.30
Base Length of First Dorsal Fin	-9.60	-53.45
Base Length of Pelvic Fin	25.18	-10.71
Pectoral Fin to Second Dorsal Fin Distance	66.31	43.98
Pectoral Fin Height	14.21	49.81
Internasal Distance	-27.44	-45.96
Constant	-35.93	-47.96
Eigen Value	29.91	8.58
Variance	77.71	22.29
Canonical Correlation	0.9837	0.9564

Table V. Canonical Variate Scores from the Discriminant Analysis of Morphometric Characters on White bass, Striped bass, and Striped bass x White bass hybrids.

CAN VAR I	CAN VAR II
WHITE BASS	
9.47	2.19
9.62	3.02
9.31	1.02
7.78	1.55
8.43	1.96
10.29	1.15
8.43	1.49
8.31	2.53
HYBRID	
1.44	-6.31
0.33	-5.91
3.69	-4.07
1.35	-6.59
2.06	-7.29
-0.60	-6.52
STRIPED BASS	
-3.24	1.28
-4.22	0.85
-2.53	1.54
-3.11	0.81
-4.50	1.66
-4.86	0.68
-3.54	-2.05
-3.61	0.57
-3.15	1.77
-3.17	1.73
-2.92	1.36
-2.64	-0.72
-4.41	2.38
-5.24	1.32
-3.46	1.08
-5.46	2.66

(Table V Continued)

-3.83	1.00
-3.29	1.85
-3.07	1.18
-4.24	-0.52
-5.43	1.35

Table VI. Group Centroids of The Linear Discriminant Functions of Morphometric Variables for White bass, Striped bass, and Striped bass x White bass hybrids.

SPECIES	FUNCTION I	FUNCTION II
White bass	8.96	1.86
Hybrid	1.38	-6.11
Striped bass	-3.81	1.04

Table VII. Classification Matrix for the Discriminant Function Analysis of Morphometric variables for White bass, Striped bass, and Striped bass x White bass hybrids.

SPECIES	PERCENT CORRECT	NUMBER CLASSIFIED INTO GROUP		
		White bass	Hybrid	Striped bass
White bass	100.00	8	0	0
Hybrid	100.00	0	6	0
Striped bass	100.00	0	0	21
Total	100.00	8	6	21

Table VIII. Classification Function Coefficients for White bass, Striped bass, and Striped bass x White bass hybrids, and Using log Transformation of the Variables Listed.

	CLASSIFICATION FUNCTIONS		
VARIABLE	White bass	Hybrid	Striped bass
Caudal Peduncle Length	-300.36035	-245.57773	7.58869
Snout Length	-2926.40112	-2666.80835	-2422.22412
Base Length of First Dorsal Fin	-1236.32837	-737.22559	-1069.62012
Base Length of Pelv Fin	-453.61182	-558.96631	-766.17554
Pectoral Fin to Second Dorsal Fin Distance	6003.64063	5150.37891	5120.94141
Pectoral Fin Height	3447.52490	2942.44629	3224.96753
Internasal Distance	-3738.73706	-3164.17896	-3350.47729
Constant	-3324.34546	-2654.37329	-2792.80615

Table IX. Classification Matrix for the Discriminant Analysis of Morphometric variables for Independent samples of White bass, Striped bass, and Striped bass x White bass hybrids from some Oklahoma Reservoirs.

SPECIES	PERCENT CORRECT	NUMBER CLASSIFIED INTO GROUP		
		White bass	Hybrid	Striped bass
White bass	83.33	10	2	0
Hybrid	91.67	1	11	0
Striped bass	100.00	0	0	10
Total	91.67	11	13	10

Table X. Classification Scores of Independent *Morone sp.* samples from selected Reservoirs in Oklahoma. (Initial ID W=white bass, H=hybrid, S=striped bass, and * indicates misclassification).

		Classification Scores			
Sample Number	Initial ID	White bass	Hybrid	Striped bass	Source
6	H	2897.21	2905.52	2882.11	Canton
12	H	2395.11	2441.76	2429.13	Canton
30	H	2502.24	2561.09	2526.51	Optima
42	H	2664.74	2698.88	2672.42	Ft Supply
48	W	2283.02	2352.33	2302.00	Canton
49	W*	2963.97	2965.59	2935.24	Lake Carl Blackwell
50	W	2900.60	2892.24	2852.15	Lake Carl Blackwell
54	H	2387.43	2449.13	2438.28	Canton
66	H*	3322.33	3265.85	3236.69	Lake Carl Blackwell
72	H	2293.38	2374.22	2359.23	Optima
90	W	3318.17	3262.00	3226.53	Ft Supply
96	H*	3239.21	3212.70	3196.02	Great Salt Plains
102	W	3192.29	3184.87	3189.32	Lake Carl Blackwell
132	S	2702.32	2738.90	2776.71	Texoma
138	S	2615.38	2680.74	2696.27	Texoma
150	S	2790.24	2826.25	2862.48	Texoma
151	S	2658.41	2716.91	2747.06	Texoma

Table XI. Principal Components and Sheared Principal Components of Morphometric Variables for White bass, Striped bass, and Striped bass x White bass hybrids.

PC I	PC II	SHEARED PC II
	WHITE BASS	
-9.484	0.528744	-0.37131
-9.334	0.501355	-0.38426
-9.012	0.489265	-0.36587
-8.638	0.430311	-0.38899
-8.744	0.457625	-0.37188
-8.696	0.446527	-0.37843
-12.098	0.858304	-0.29119
-12.256	0.841580	-0.32273
	HYBRID	
-10.822	0.655348	-0.37201
-10.284	0.573694	-0.40228
-10.871	0.638500	-0.39335
-10.913	0.628016	-0.40776
-10.881	0.640886	-0.39200
-10.007	0.542992	-0.40656
	STSRIPED BAS	
-10.837	0.371968	-0.65463
-12.034	0.346425	-0.79305
-11.857	0.465040	-0.65864
-11.193	0.403952	-0.65649
-12.151	0.465972	-0.68549
-12.349	0.452464	-0.71751
-12.250	0.462904	-0.69784
-13.054	0.436173	-0.80031
-11.107	0.370680	-0.68141
-11.907	0.435280	-0.69281
-11.080	0.373522	-0.67597
-10.484	0.309862	-0.68284
-12.074	0.432741	-0.71113
-11.276	0.408512	-0.65979
-12.238	0.443347	-0.71617
-12.213	0.412074	-0.74476

(Table XI Continued)

-12.294	0.418861	-0.74572
-11.900	0.469803	-0.65998
-11.668	0.411261	-0.69411
-12.207	0.432132	-0.72431
-11.885	0.395072	-0.73064

Table XII. Principal Components and Sheared Principal Components of Morphometric Variables for White bass and Striped bass x White bass hybrids.

PC I	PC II	SHEARED PC II
	WHITE BASS	
-9.47835	0.301442	-0.00662
-9.32603	0.268224	-0.03486
-9.00412	0.283347	-0.00930
-8.62563	0.238411	-0.04190
-8.73361	0.283782	-0.00008
-8.68569	0.286446	0.00414
	HYBRID	
-12.11130	0.385777	-0.00786
-12.26600	0.393404	-0.00526
-10.82460	0.110387	-0.24122
-10.27870	0.100694	-0.23317
-10.86960	0.151670	-0.20143
-10.91100	0.103046	-0.25136
-10.88090	0.091252	-0.26216
-9.99984	0.141415	-0.18343

Table XIII. Mean Lengths-at-Age, and Estimated Annual Instantaneous Rates of Growth for White bass and Striped bass x White bass hybrids in Lake Carl Blackwell, Oklahoma, during 1985.

	White bass		Hybrid	
Age	Mean length	Growth rate	Mean length	Growth rate
I	153	0.549	188	0.503
II	265	0.234	311	0.208
III	335	0.121	383	0.106
IV	378	0.067	426	0.057
V	404	0.000	451	0.000

Table XIV. Constants Obtained from Length-Weight Relationships for White bass and Striped bass x White bass hybrids in Lake Carl Blackwell, Oklahoma, during 1985 (Numbers in parentheses indicate standard errors).

N	$\log_{10}a$	b	R^2	Species
83	-5.03 (0.18)	3.05 (0.07)	0.9561	White bass
104	-5.54 (0.12)	3.26 (0.05)	0.9791	Hybrid

Table XV. Age-specific Instantaneous Total, Fishing, and Natural Mortality Rates for White bass and Striped bass x White bass hybrids in Lake Carl Blackwell, Oklahoma during 1985.

	White bass			Hybrid		
Age	Total	Fishing	Natural	Total	Fishing	Natural
I	0.55	0.03	0.52	0.69	0.09	0.60
II	0.97	0.39	0.58	1.09	0.61	0.48
III	0.73	0.40	0.33	1.22	0.71	0.51
IV	0.96	0.55	0.41	1.21	0.53	0.68
V	1.21	0.39	0.82	1.61	0.77	0.84

Table XVI. Age-specific Instantantaneous Survival Rates for White bass and Striped bass x White bass hybrids in Lake Carl Blackwell, Oklahoma during 1985.

Age	White bass	Hybrid
I	0.53	0.43
II	0.60	0.70
III	0.44	0.56
IV	0.25	0.17
V	0.00	0.00

Table XVII. Age-specific Fecundity for White bass in the Washita River arm of Lake Texoma (Baglin 1972).

Age	Fecundity
0	0
I	0
II	192436
III	263677
IV	334918
V	406159

Table XVIII. Monthly Harvests of White bass and Striped bass x White bass hybrids in Lake Carl Blackwell, Oklahoma from June 1984-August 1985.

	1984	
Month	White bass	Hybrid
June	10	9
July	13	8
August	2	12
September	6	15
October	3	8
November	9	9
December	31	29
	1985	
February	18	56
March	11	17
April	13	13
May	4	3
June	1	6
July	34	8
August	2	1

Table XIX. Constants Used to Simulate the Effects of Density-dependence on Fecundity, Percent Survival of Stocked hybrid Fingerlings, and Proportion of Growth.**

	Biomass (kg)			
	>=700		<700	
Density effect	A	B	A	B
Fecundity	0.70	-5.0×10^{-7}	0.95	-5.0×10^{-7}
Hybrid survival	0.04	-5.0×10^{-4}	0.08	-5.0×10^{-4}
Prop of Growth	0.90	-5.0×10^{-7}	1.05	-5.0×10^{-7}

** Models are of the form

density effect=A*exp$^{(B*\text{total biomass})}$.

Table XX. Input Data Requirements and Codes for Variables and Parameters Used in Modeling Population Dynamics of White bass and Striped bass x White bass hybrids in Lake Carl Blackwell, Oklahoma.

Name	Usage	Default Value
K	Number of age classes in each species (assume equal number)	None
NYR	Number of years simulation is to run	None
JYEAR	Year simulation is to start	None
HSTOCK	Number of hybrid fingerlings stocked annually	None
WSURV$_i$,HSURV$_i$	Age-specific survival rates for white bass and hybrid, respectively	None
FERT$_i$	Age specific fecundity for white bass	None
WN$_i$,HN$_i$	Number of white bass and hybrid in each age class respectively	None
WLEN$_i$,HLEN$_i$	Age-specific mean lengths for white bass and hybrids respectively	None
WG$_i$,HG$_i$	Age-specific instantaneous mean	None

(Table XX Continued)

	rates of growth for white bass and hybrid respectively	
WWT_i,HWT_i	Age-specific mean weights for white bass and hybrid respectively	None
WZ_i,HZ_i	Age-specific instantaneous total mortality rates for white bass and hybrid respectively	None
$WFMORT_i$,$HFMORT_i$	Age-specific fishing mortality rates for white bass and hybrid respectively	None
$WNMORT_i$,$HNMORT_i$	Age-specific natural mortality rates for white bass and hybrid respectively	None
WVIVE,HVIVE	Annual survival rate for white bass from egg to age I and survival of hybrid fingerling to age I	None
WAWT,HAWT	Constant a in the relationship: Weight=a*Length^b for white bass and hybrid respectively	None
WBWT,HBWT	Constant b in the relationship: Weight=a*Length^b for white bass and hybrid respectively	None
GENDER	Sex ratio for white bass in the population	0.5
A_1,B_1	Constants in the relationship: Egg density=a_1*exp$^{-(\text{bl*total biomass})}$ for white bass	None
A_{11}	Constant A_{11} in the relationship: Egg density=a_{11}*exp$^{-(\text{bl*total biomass})}$ for white bass	None
A_2,B_2	Constants in the relationship: Survival=a_2*exp$^{-(\text{b2*total biomass})}$ for stocked hybrid fingerling	None
A_3	Constants in the relationship: Survival=a_3*exp$^{-(\text{b2*total biomass})}$ for stocked hybrid fingerling	None
A_4	Constant in the relationship: Prop. of growth=a_4*exp$^{-(\text{bl*total biomass})}$ for white bass and hybrid	None
A_5	Constant in the relationship: Prop. of growth=a_5*exp$^{-(\text{bl*total biomass})}$ for white bass and hybrid	None
RANDEV	Normally distributed random variate with mean=1 and user supplied std. dev	None

(Table XX Continued)

WTOT,HTOT	Annual total population size for white bass and hybrid respectively	None
TOT	Total population size (both species)	None
$WAVLEN_i$,$HAVLEN_i$	Mean annual lengths-at-age for white bass and hybrid respectively	None
$WAVWT_i$,$HAVWT_i$	Mean annual weights-at-age for white bass and hybrid respectively	None
$WBIOMS_i$,$HBIOMS_i$	Annual age-specific biomass for white bass and hybrid respectively	None
WTOTBI,HTOTBI	Total annual biomass for white bass and hybrid respectively	None
SUMBIO	Total annual mean biomass (both species)	None
$WAVBIO_i$,$HAVBIO_i$	Mean annual age-specific biomass for white bass and hybrid respectively	None
STKSUV	Density-dependent hybrid fingerling survival rate	None
EGGDEN	Density-dependent fecundity coefficient for white bass	None
PG	Density-dependent growth coefficient for both species	None
$WCATCH_i$,$HCATCH_i$	Age-specific harvest for white bass and hybrid respectively	None
$WYIELD_i$,$HYIELD_i$	Age-specific yield for white bass and hybrid respectively	None
$WGPROD_i$,$HGPROD_i$	Age-specific gross production for white bass and hybrid respectively	None
$WNEPRO_i$,$HNEPRO_i$	Age-specific net production for white bass and hybrid respectively	None
WSTK,HSTK	Annual number of white bass and hybrid of stock size respectively	None
WQUAL,HQUAL	Annual number of white bass and hybrid of quality size respectively	None
WPSD,HPSD	Proportional stock density for white bass and hybrid respectively	None
WYLD,HYLD	Total annual yield tor white bass and hybrid respectively	None
WHAVST,HHAVST	Total annual harvest for white bass and hybrid respectively	None
YOYCF	Random effects on white bass egg survival and hybrid fingerling survival	None
HATCH	'Fertility' or observed fecundity of white bass due to density-dependence	None
SUMEGG	Total theoretical white bass fecundity	None
WRATIO	Annual percentage of reproductive potential achieved by white bass	None
PERCEN	Annual percentage of adult	None

(Table XX Continued)

	white bass in entire population	
HYBFRY	Density-dependent annual hybrid fingerling survival percentage	None
$CLUTCH_i$	Age-specific total annual white bass fecundity	None
FAMILY	White bass fertility	None

Table XXI. Simulated Annual Population Size and Biomass (kg) of White bass and Striped bass x White bass hybrids in Lake Carl Blackwell, Oklahoma.

	POPULATION SIZE			BIOMASS		
YEAR	TOTAL	WHITE BASS	HYBRID	TOTAL	WHITE BASS	HYBRID
00	3000	3000	0	601	601	0
01	2877	1590	1287	921	527	395
02	3202	2130	1072	924	640	284
03	3054	1955	1099	885	542	343
04	2907	1850	1057	853	529	324
05	2707	1737	970	738	458	279
06	2688	1676	1012	708	444	264
07	2840	1710	1130	704	425	278
08	2598	1528	1070	661	394	267
09	3455	1756	1699	804	416	388
10	2932	1592	1340	723	396	327
11	2704	1491	1213	703	376	327
12	2597	1436	1161	644	347	297
13	3455	1658	1797	749	371	378
14	3063	1582	1481	701	369	331
15	2868	1514	1354	708	363	345
16	2807	1516	1291	670	350	320
17	3410	1657	1752	730	365	365
18	2974	1556	1417	676	360	316
19	3917	1868	2048	830	397	432
20	3152	1656	1495	747	389	358
21	3140	1749	1390	745	394	351
22	2925	1667	1258	678	377	301
23	3601	1863	1738	744	400	345
24	3067	1694	1373	687	387	300

(Table XXI Continued)

25	3908	1984	1924	816	418	398
26	3394	1880	1514	762	417	345
27	3019	1751	1268	728	408	320
28	3146	1859	1287	693	399	294
29	3716	1982	1733	747	418	329
30	3049	1740	1309	689	403	286
31	4112	2149	1963	825	434	391
32	3445	1953	1491	766	433	333
33	3511	2099	1412	783	450	333
34	3242	1983	1259	727	436	291
35	3547	2216	1331	739	459	280
36	3331	2088	1243	713	453	259
37	3166	1997	1169	703	447	256
38	3363	2107	1256	702	441	261
39	3681	2287	1394	736	464	272
40	3177	1999	1179	707	453	255
41	3459	2185	1274	726	457	270
42	3276	2066	1210	699	445	254
43	4355	2478	1877	812	485	328
44	3640	2214	1426	780	483	297
45	3709	2340	1369	814	497	317
46	3350	2161	1189	748	472	276
47	3365	2211	1154	718	471	247
48	3468	2249	1219	705	466	239
49	3272	2107	1164	700	461	239
50	4386	2536	1851	812	491	321
51	3838	2368	1470	802	503	299

Table XXII. Simulated Annual White bass Fecundity, Fertility, Percentage of Egg Hatch, Percentage of White bass in the Population, and Percent Survival of Hybrid Fingerlings in Lake Carl Blackwell, Oklahoma.

	WHITE BASS				HYBRID
YEAR	FECUNDITY	FERTILITY	% HATCH	%WHITE BASS	%SURV.
00	0	0	0.000	100.000	4.946
01	305972992	107041200	34.984	55.269	1.914
02	251389616	87945712	34.984	66.512	1.911

(Table XXII Continued)

03	260379200	91092368	34.984	64.015	1.970
04	234123376	81908208	34.985	63.644	2.022
05	221948320	77653248	34.987	64.168	2.217
06	216414304	75718176	34.988	62.354	2.270
07	203563680	71222192	34.988	60.211	2.278
08	206355792	97986624	47.484	58.818	4.716
09	189887088	66433744	34.986	50.813	2.102
10	208297104	72877600	34.987	54.308	2.243
11	198275328	69371952	34.988	55.138	2.280
12	183943776	87345136	47.485	55.301	4.779
13	174237648	60960320	34.987	47.990	2.197
14	195556896	68420912	34.988	51.660	2.284
15	196643616	68800880	34.988	52.797	2.271
16	187536544	89049984	47.484	54.012	4.680
17	183313104	64136128	34.987	48.605	2.230
18	197931360	93985584	47.484	52.341	4.657
19	193355616	67646384	34.985	47.703	2.060
20	222113600	77710704	34.987	52.553	2.201
21	208362112	72899552	34.987	55.715	2.203
22	211478928	100418432	47.484	56.989	4.652
23	204221552	71450928	34.987	51.733	2.205
24	222462000	105633152	47.484	55.239	4.618
25	211718176	74071104	34.986	50.774	2.082
26	236009760	82571936	34.987	55.392	2.175
27	232753600	81434096	34.987	57.999	2.234
28	216854880	102970352	47.484	59.104	4.595
29	222888768	77981904	34.987	53.350	2.200
30	238428368	113214416	47.484	57.058	4.608
31	219416064	76763920	34.986	52.263	2.067
32	252922064	88488784	34.987	56.708	2.167
33	243687344	85257152	34.986	59.771	2.138
34	254165152	88925456	34.987	61.167	2.236
35	244440752	85522656	34.987	62.466	2.215
36	264646896	92593392	34.988	62.696	2.262
37	259008848	90621216	34.988	63.080	2.280
38	245845600	86015728	34.988	62.643	2.281
39	252994624	88515520	34.987	62.140	2.220
40	275077632	96243104	34.988	62.899	2.271
41.	252672096	88403088	34.987	63.177	2.237
42	261641296	124236176	47.483	63.074	4.574
43	253219856	88590928	34.986	56.905	2.089
44	294090496	102891488	34.986	60.830	2.142
45	279260672	97701440	34.986	63.087	2.086
46	283347712	99134592	34.987	64.518	2.198
47	266299696	93171408	34.987	65.707	2.252
48	266815376	93352448	34.988	64.838	2.275
49	273325824	129784304	47.483	64.411	4.570
50	260396080	91101616	34.986	57.806	2.089
51	299966720	104946240	34.986	61.698	2.106

Table XXIII. Simulated Annual Harvest, Yield (kg), and Proportional Stock Density (PSD) of White bass and Striped bass x White bass hybrids in Lake Carl Blackwell, Oklahoma.

YEAR	WHITE BASS			HYBRID		
	HARVEST	YIELD	PSD	HARVEST	YIELD	PSD
00	69	18	100	0	0	0
01	397	205	100	84	36	100
02	298	173	100	239	99	100
03	325	184	100	273	163	100
04	271	155	100	239	141	100
05	277	146	100	209	124	100
06	260	141	100	204	109	100
07	250	132	100	222	113	100
08	250	130	100	237	121	51
09	235	123	100	274	136	100
10	256	130	55	327	155	59
11	238	123	54	301	169	57
12	223	115	52	253	138	52
13	217	110	43	277	134	29
14	243	119	53	348	156	55
15	239	120	54	335	180	57
16	229	115	50	286	152	52
17	227	113	46	293	143	33
18	244	119	54	339	154	57
19	243	119	43	365	179	36
20	273	132	57	387	183	64
21	254	126	48	332	186	55
22	260	127	53	279	144	53
23	253	123	45	289	138	33
24	274	131	56	335	149	58
25	263	128	44	351	172	37
26	293	140	53	370	171	60
27	280	138	55	322	176	59
28	267	130	47	269	138	48
29	277	133	47	289	132	33
30	290	139	58	333	148	61
31	275	133	41	346	167	35
32	313	147	55	370	168	61
33	299	144	48	331	177	53
34	313	149	53	286	143	55
35	302	145	45	266	133	43
36	327	153	54	271	125	50
37	313	151	53	265	129	52
38	303	145	48	256	122	45
39	316	148	46	271	123	42

(Table XXIII Continued)

40	335	157	58	282	131	56
41	310	149	47	267	131	47
42	321	152	53	260	122	50
43	318	148	42	301	130	31
44	364	167	57	360	153	61
45	340	163	49	328	170	55
46	346	165	54	275	139	56
47	323	155	49	242	123	47
48	331	155	49	244	110	44
49	332	157	54	256	118	50
50	328	153	42	297	127	31
51	372	171	54	358	151	58

Table XXIV. Simulated Annual Population Size and Biomass (kg) of White bass and Striped bass x White bass hybrids in Lake Carl Blackwell, Oklahoma. (Output with 50% increase in Hybrid Fingerling Stocking Rate).

	POPULATION SIZE			BIOMASS		
YEAR	TOTAL	WHITE BASS	HYBRID	TOTAL	WHITE BASS	HYBRID
00	3000	3000	0	601	601	0
01	3520	1590	1930	1119	527	592
02	3625	2130	1495	1034	640	394
03	3493	1955	1538	1029	542	487
04	3297	1850	1447	976	529	447
05	3050	1737	1313	838	458	380
06	3063	1676	1387	804	444	360
07	3270	1710	1560	808	425	383
08	3006	1528	1478	762	393	368
09	3038	1496	1542	752	371	381
10	3061	1455	1606	730	350	380
11	2854	1322	1533	689	326	363
12	3945	1497	2447	846	337	509
13	3314	1370	1944	772	327	446
14	3449	1459	1990	818	332	486
15	3105	1345	1760	747	316	431
16	3064	1354	1709	709	311	398
17	2922	1266	1656	661	292	369

(Table XXIV Continued)

18	4253	1507	2746	832	315	517
19	3522	1385	2137	776	313	463
20	3326	1363	1963	797	312	485
21	3268	1387	1880	748	304	444
22	3056	1331	1725	685	298	386
23	4043	1482	2561	786	310	476
24	3373	1351	2022	740	305	434
25	3273	1347	1925	756	301	456
26	3273	1373	1900	720	294	426
27	2900	1240	1659	653	283	370
28	4487	1572	2915	815	306	509
29	3466	1344	2122	751	303	448
30	3194	1297	1898	765	296	469
31	3151	1312	1839	704	280	424
32	3051	1287	1764	650	278	372
33	4592	1577	3014	809	303	506
34	3637	1398	2239	775	309	466
35	3904	1613	2291	854	329	525
36	3476	1514	1962	781	325	456
38	3352	1525	1828	687	316	371
39	5271	1974	3297	900	365	535
40	3810	1615	2195	834	367	467
41	3962	1819	2143	900	380	520
42	3549	1715	1835	802	367	435
43	3448	1746	1702	740	372	368
44	3351	1670	1682	697	357	340
45	4812	2020	2792	861	391	470
46	3793	1751	2042	812	387	425
47	3813	1843	1969	851	392	459
48	3748	1871	1878	802	386	416
49	3402	1753	1648	741	384	357
50	3504	1784	1720	724	375	348
51	3607	1798	1809	734	376	358

Table XXV. Simulated Annual White bass Fecundity, Fertility, Percentage of Egg Hatch, Percentage of White bass in the Population, and Percent Survival of Hybrid Fingerlings in Lake Carl Blackwell, Oklahoma. (Output with 50% Increase in Hybrid Fingerling Stocking Rate).

	WHITE BASS				HYBRID
YEAR	FECUNDITY	FERTILITY	% HATCH	% WHITE BAS	%SURVIVAL
00	0	0	0.000	99.999	4.946
01	305972992	107030624	34.980	45.167	1.634
02	251389616	87940832	34.982	58.754	1.749
03	260379200	91085808	34.982	55.966	1.756
04	234123376	81903168	34.983	56.116	1.832
05	221948320	77649344	34.985	56.939	2.046
06	216414304	75714528	34.986	54.717	2.102
07	203563680	71218480	34.986	52.292	2.096
08	206355792	72196992	34.987	50.833	2.174
09	189887088	66435472	34.987	49.248	2.192
10	181779408	63599536	34.987	47.525	2.230
11	176442880	83781456	47.484	46.308	4.609
12	162941328	57005312	34.985	37.958	2.033
13	177991408	62272912	34.986	41.340	2.156
14	170261536	59567152	34.986	42.302	2.080
15	176466064	61740032	34.987	43.323	2.200
16	166225952	58158432	34.988	44.209	2.268
17	163931856	77841888	47.484	43.329	4.715
18	155552768	54420784	34.985	35.438	2.055
19	177999536	62275648	34.986	39.317	2.150
20	173223856	60604160	34.986	40.984	2.113
21	167343104	58548160	34.987	42.455	2.199
22	167597824	79581696	47.484	43.544	4.626
23	162751728	56940704	34.986	36.651	2.133
24	177872272	62232256	34.987	40.045	2.214
25	168432080	58928912	34.987	41.174	2.184
26	164115216	57419632	34.987	41.944	2.248
27	165729472	78695792	47.484	42.777	4.746
28	153598016	53737376	34.986	35.037	2.084
29	184272832	64471248	34.987	38.783	2.193
30	170643008	59702176	34.987	40.591	2.168
31	159408544	55773328	34.988	41.628	2.277
32	157495040	74785792	47.485	42.188	4.755
33	156259744	54668768	34.986	34.352	2.094
34	187167856	65483344	34.986	38.448	2.151
35	177019648	61930400	34.985	41.318	2.020
36	192856976	67473552	34.986	43.554	2.141

(Table XXV Continued)

37	186982832	65420752	34.988	46.121	2.267
38	177976640	84509856	47.484	45.482	4.618
39	183388592	64157120	34.984	37.450	1.947
40	231398800	80955776	34.985	42.391	2.052
41	209422096	73264736	34.984	45.918	1.947
42	218232288	76350656	34.986	48.314	2.106
43	209620944	73340176	34.987	50.636	2.213
44	211665664	100506112	47.483	49.821	4.579
45	205729536	71974304	34.985	41.976	2.008
46	238456640	83425936	34.986	46.163	2.090
47	221678512	77554432	34.985	48.347	2.025
48	223065264	78041520	34.986	49.903	2.106
49	226336816	79188544	34.987	51.544	2.212
50	216292896	75675104	34.987	50.910	2.242
51	216856384	75871856	34.987	49.844	2.224

Table XXVI. Simulated Annual Harvest, Yield (kg), and Proportional Stock Density (PSD) of White bass and Striped bass x White bass hybrids in Lake Carl Blackwell, Oklahoma. (Output with 50% Increase in Hybrid Fingerling Stocking Rate).

YEAR	WHITE BASS			HYBRID		
	HARVEST	YIELD	PSD	HARVEST	YIELD	PSD
00	69	18	100	0	0	0
01	397	205	100	125	53	100
02	298	173	100	352	146	100
03	325	184	100	388	236	100
04	271	155	100	330	195	100
05	277	146	100	283	170	100
06	260	141	100	278	148	100
07	250	131	100	305	155	100
08	250	130	100	328	167	51
09	229	120	51	327	172	47
10	222	114	51	330	167	46
11	213	109	55	335	169	50
12	202	102	44	390	183	31
13	219	108	55	473	216	58
14	209	104	48	452	242	51
15	216	107	55	403	208	55

(Table XXVI Continued)

16	202	101	50	365	192	48
17	200	99	54	354	172	49
18	195	95	42	424	188	29
19	220	105	55	528	230	59
20	210	103	52	488	260	58
21	206	101	49	409	212	52
22	204	99	52	371	189	49
23	203	97	45	419	185	32
24	218	104	56	497	219	59
25	204	100	51	460	240	55
26	202	98	49	403	202	50
27	200	97	56	374	187	52
28	195	92	40	437	187	27
29	227	106	59	546	231	63
30	204	100	53	488	262	60
31	196	95	49	395	203	51
32	192	92	51	363	180	46
33	199	92	41	453	184	28
34	231	107	58	576	242	62
35	219	104	45	533	277	53
36	238	112	54	456	228	57
37	225	108	53	389	204	53
38	220	105	48	364	172	44
39	236	108	39	476	189	26
40	284	130	63	611	254	69
41	256	123	46	531	287	57
42	269	127	53	420	216	57
43	255	121	50	361	187	47
44	261	122	53	354	162	48
45	258	121	42	432	180	29
46	293	135	58	529	223	63
47	270	129	49	477	249	55
48	276	130	49	404	200	51
49	274	130	54	367	183	51
50	265	126	50	356	166	46
51	267	126	50	369	168	45

Table XXVII. Simulated Annual Population Size and Biomass (kg) of White bass and Striped bass x White bass hybrids in Lake Carl Blackwell, Oklahoma.(Output with 50% Decrease in Hybrid Fingerling Stocking Rate).

	POPULATION SIZE			BIOMASS		
YEAR	TOTAL	WHITE	HYBRID	TOTAL	WHITE	HYBRID
00	3000	3000	0	601	601	0
01	2233	1590	643	724	527	197
02	2711	2130	581	794	640	154
03	2550	1955	595	725	542	183
04	2435	1850	585	707	530	177
05	2281	1737	544	614	458	156
06	2834	1960	873	729	506	223
07	2581	1860	720	670	484	186
08	2904	1986	919	761	512	248
09	2524	1814	710	676	478	198
10	3100	2137	963	779	526	253
11	2503	1812	691	667	480	187
12	3048	2120	927	764	522	242
13	2653	1932	721	680	490	190
14	3499	2443	1056	830	570	260
15	2852	2100	751	733	537	196
16	2871	2183	688	732	539	192
17	2646	2036	610	658	497	161
18	3352	2427	925	749	547	202
19	2957	2225	731	701	533	169
20	2871	2193	679	704	529	176
21	2896	2234	662	675	512	163
22	3428	2506	922	743	551	192
23	2937	2235	701	695	534	161
24	3603	2638	964	790	577	213
25	3107	2376	731	734	558	176
26	3199	2511	687	738	567	171
27	2848	2255	593	673	528	144
28	3839	2871	967	776	589	187
29	3161	2452	709	726	571	155
30	3002	2366	636	719	558	161
31	3022	2396	626	674	527	148
32	3693	2764	930	744	570	174
33	3416	2654	762	738	580	158
34	3306	2609	697	753	586	167
35	3611	2896	715	763	602	161
36	3361	2736	625	742	603	139
37	3186	2612	574	715	587	128
38	3374	2756	619	712	583	130

(Table XXVII Continued)

39	3684	2996	688	746	611	135
40	3199	2616	583	722	596	126
41	3491	2861	629	736	601	134
42	3305	2706	599	712	586	126
43	3360	2753	607	715	589	126
44	3231	2639	592	694	570	123
45	4140	3191	948	787	622	165
46	3468	2765	703	762	615	147
47	3590	2914	676	781	623	158
48	3611	2958	653	759	615	144
49	3345	2774	572	734	610	124
50	3407	2822	585	716	596	120
51	3453	2843	610	719	597	122

Table XXVIII. Simulated Annual White bass Fecundity, Fertility, Percentage of Egg Hatch, Percentage of White bass in the Population, and Percent Survival of Hybrid Fingerlings in Lake Carl Blackwell, OKlahoma. (Output with 50% Decrease in Hybrid Fingerling Stocking Rate).

	WHITE BASS				HYBRID
YEAR	FECUNDITY	FERTILITY	%HATCH	%WHITE BASS	%SURV.
00	0	0	0.000	100.000	4.946
01	305972992	107051760	34.987	71.192	2.241
02	251389616	87951424	34.986	78.580	2.119
03	260379200	91099664	34.987	76.656	2.239
04	234123376	81914192	34.988	75.972	2.272
05	221948320	105393072	47.485	76.156	4.896
06	216414304	75717392	34.987	69.185	2.233
07	232529136	110414320	47.484	72.086	4.681
08	230086688	80499680	34.987	68.368	2.176
09	240682560	114285552	47.484	71.877	4.658
10	225258432	78809712	34.986	68.929	2.145
11	252660944	119973920	47.484	72.383	4.692
12	229409424	80262592	34.987	69.567	2.170
13	251721792	119527200	47.484	72.811	4.645
14	240010032	83968640	34.985	69.827	2.059
15	287629312	100633360	34.987	73.658	2.226
16	267284272	93515264	34.987	76.042	2.228

(Table XXVIII Continued)

17	264690192	125686464	47.484	76.928	4.726
18	249458592	87277808	34.987	72.398	2.198
19	286014976	100070112	34.988	75.264	2.282
20	279134976	97662816	34.988	76.360	2.277
21	269343232	127894832	47.484	77.140	4.661
22	269670656	94349648	34.987	73.112	2.208
23	299219712	142079792	47.483	76.118	4.589
24	281910272	98629584	34.986	73.230	2.126
25	313626624	109729008	34.987	76.476	2.223
26	296219136	103638432	34.987	78.509	2.217
27	303589632	144156464	47.484	79.193	4.671
28	280065792	97984992	34.986	74.803	2.151
29	335449344	117364624	34.987	77.557	2.238
30	312078592	109188224	34.987	78.811	2.250
31	291090944	138221440	47.484	79.289	4.665
32	287587840	100618304	34.987	74.828	2.206
33	327508736	114585728	34.987	77.683	2.216
34	331217152	115882272	34.987	78.927	2.190
35	321635584	112529472	34.987	80.201	2.172
36	345782528	120978976	34.987	81.394	2.209
37	338084352	118287232	34.987	81.977	2.258
38	322455040	112819056	34.988	81.669	2.262
39	331032832	115818224	34.987	81.335	2.201
40	360224256	126032864	34.987	81.789	2.244
41	330782976	115731440	34.987	81.967	2.221
42	342884864	119966960	34.988	81.888	2.263
43	331861248	116109904	34.987	81.945	2.258
44	334748160	158950080	47.483	81.679	4.593
45	324503808	113531600	34.986	77.095	2.131
46	376840192	131843712	34.987	79.741	2.174
47	350509568	122630368	34.986	81.162	2.142
48	352916224	123473792	34.987	81.927	2.180
49	357964544	125241584	34.987	82.905	2.223
50	342158848	119712688	34.987	82.828	2.255
51	342994176	120004752	34.987	82.334	2.250

Table XXIX. Simulated Annual Harvest, Yield (kg) and Proportional Stock Density (PSD) of White bass and Striped bass x White bass hybrids in Lake Carl Blackwell, Oklahoma. (Output with 50% Decrease in Hybrid Fingerling Stocking Rate).

YEAR	WHITE BASS			HYBRID		
	HARVEST	YIELD	PSD	HARVEST	YIELD	PSD
00	69	18	100	0	0	0
01	397	205	100	42	18	100
02	298	173	100	122	51	100
03	325	184	100	145	85	100
04	271	155	100	131	77	100
05	277	146	100	117	69	100
06	267	146	100	135	69	100
07	287	151	100	170	83	100
08	284	152	100	180	100	100
09	294	156	100	178	95	100
10	280	149	100	173	98	100
11	309	161	100	179	91	100
12	283	150	100	172	98	100
13	311	161	100	176	89	100
14	302	157	100	182	99	100
15	356	180	100	197	97	65
16	323	169	50	169	100	56
17	324	166	54	137	75	54
18	311	158	42	145	72	29
19	355	175	55	177	80	58
20	338	172	52	166	91	57
21	331	167	49	143	76	51
22	336	167	45	152	73	32
23	367	179	57	176	81	60
24	351	175	43	180	92	38
25	386	189	56	183	88	62
26	361	180	48	160	88	53
27	371	182	56	137	70	56
28	352	172	40	148	69	28
29	414	197	59	180	78	62
30	373	187	53	162	88	59
31	357	177	49	133	69	50
32	359	173	43	145	66	30
33	408	191	53	181	77	56
34	404	196	52	172	89	57
35	400	193	45	150	76	48
36	424	202	53	139	69	51
37	410	198	53	130	64	52
38	397	192	48	125	60	45

(Table XXIX Continued)

39	413	194	46	133	60	42
40	439	207	58	139	65	56
41	406	196	47	132	65	47
42	421	200	53	129	61	50
43	405	193	50	128	61	47
44	411	195	53	128	60	49
45	408	191	42	150	64	30
46	463	214	59	180	77	62
47	426	205	49	163	85	55
48	437	206	49	139	69	50
49	434	206	54	128	64	51
51	422	199	50	125	57	46

Table XXX. Simulated Annual Harvest, Yield (kg) and Proportional Stock Density (PSD) of White bass and Striped bass x White bass hybrids in Lake Carl Blackwell, Oklahoma. (Output With No Fishing Mortality For Ages I and V of Both Species).

YEAR	WHITE BASS			HYBRID		
	HARVEST	YIELD	PSD	HARVEST	YIELD	PSD
00	0	0	100	0	0	0
01	397	205	100	0	0	100
02	271	166	100	204	86	100
03	304	179	100	239	151	100
04	227	120	100	206	130	100
05	258	142	100	161	93	100
06	232	126	100	161	90	100
07	222	119	100	173	94	100
08	227	118	100	196	104	51
09	206	110	100	191	108	100
10	234	119	55	283	137	59
11	216	112	54	257	150	57
12	202	106	52	209	120	52
13	187	96	43	180	96	29
14	220	109	53	297	137	55
15	218	110	54	289	162	57
16	206	106	50	237	134	52
17	199	100	46	201	106	33
18	221	109	54	290	135	57
19	213	108	43	271	152	36
20	251	122	57	343	165	64

(Table XXX Continued)

21	226	114	48	276	158	55
22	236	117	53	232	126	53
23	221	109	45	197	102	33
24	251	122	56	289	132	59
25	230	115	44	263	146	37
26	266	129	53	321	153	60
27	254	125	55	273	150	59
28	239	120	47	218	121	49
29	244	117	55	198	98	50
30	230	113	46	199	102	33
31	249	120	53	279	127	55
32	236	116	43	264	141	36
33	282	134	53	339	158	60
34	273	133	52	292	159	58
35	269	132	46	235	128	48
36	288	136	53	217	105	51
37	280	136	53	214	109	52
38	266	131	40	199	103	29
39	325	150	51	319	136	55
40	338	162	57	314	166	64
41	308	153	47	236	133	52
42	316	149	53	193	95	50
43	306	146	50	190	94	46
44	315	151	53	200	99	48
45	297	143	49	199	99	46
46	305	145	54	207	101	51
47	284	137	49	198	100	46
48	288	138	49	202	99	45
49	294	139	54	215	104	51
50	280	135	50	208	106	47
51	280	134	50	207	102	46

APPENDIX B

FIGURES

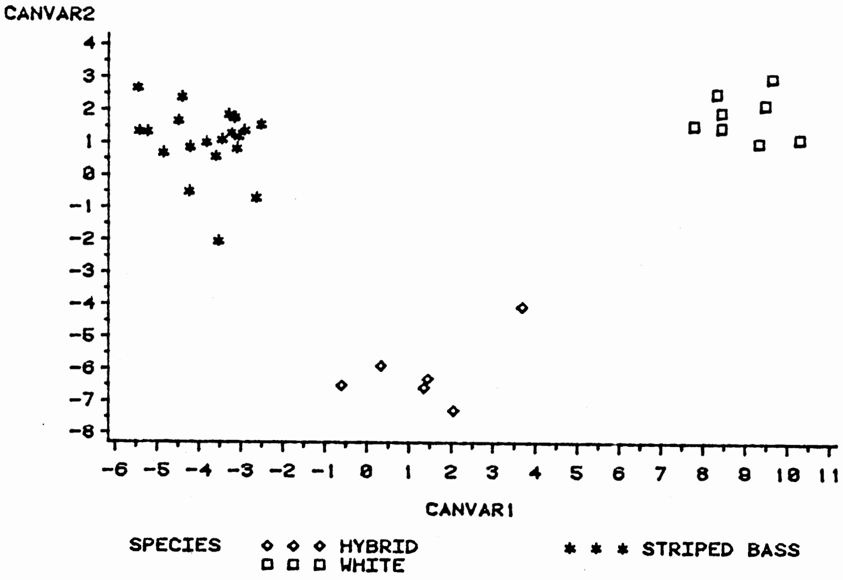


Figure 1. Plot of Discriminant Scores for White Bass Striped bass, and Striped bass x White bass hybrids

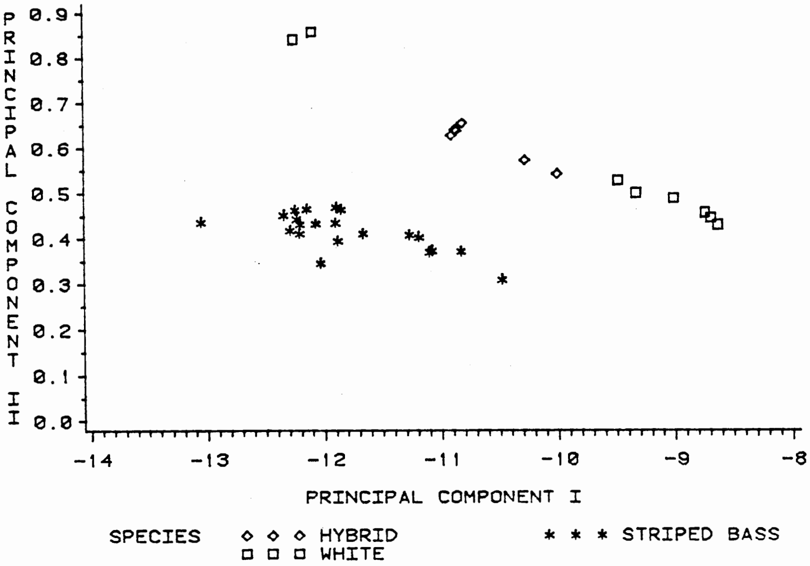


Figure 2. Plot of Principal Component II against Principal Component I for White bass, Striped bass, and Striped bass x White bass hybrids

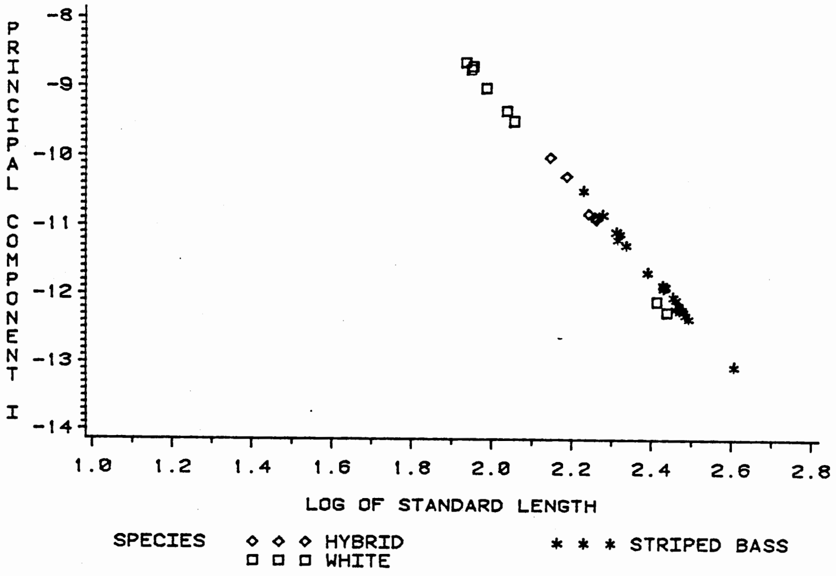


Figure 3. Plot of Principal Component I against $\log_{10}$ of Standard Length for White bass Striped bass, and Striped bass x White bass hybrids

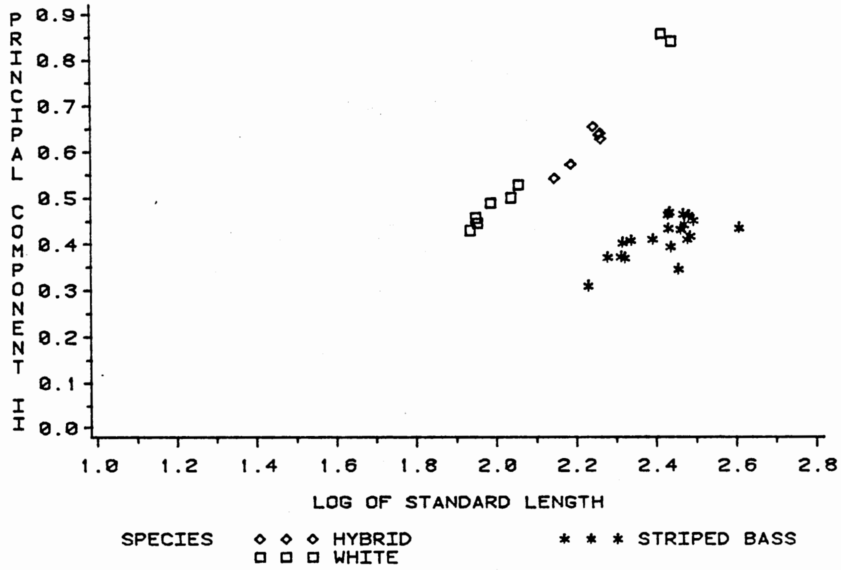


Figure 4. Plot of Principal Component II against $\log_{10}$ of Standard Length for White bass, Striped bass, and Striped bass x White bass hybrids

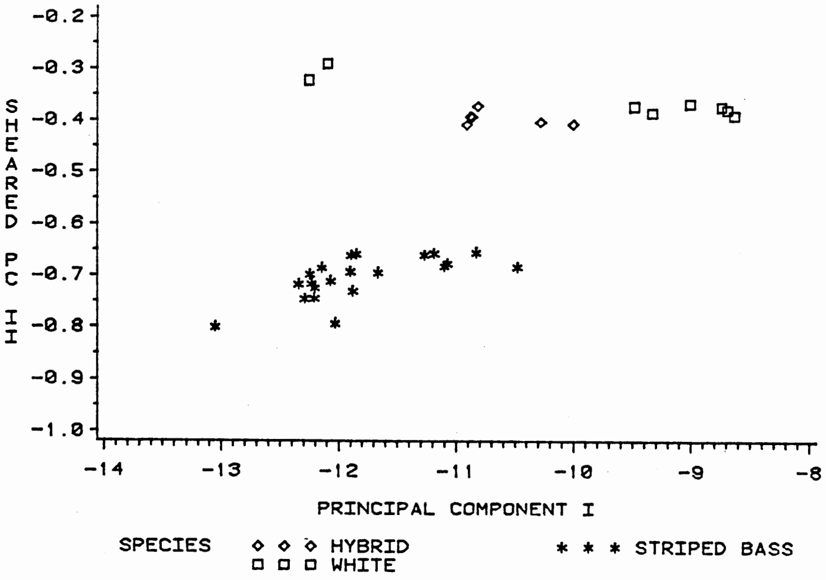


Figure 5. Plot of Sheared Principal Component II against Principal Component I for White bass, Striped bass, and Striped bass x White bass hybrids

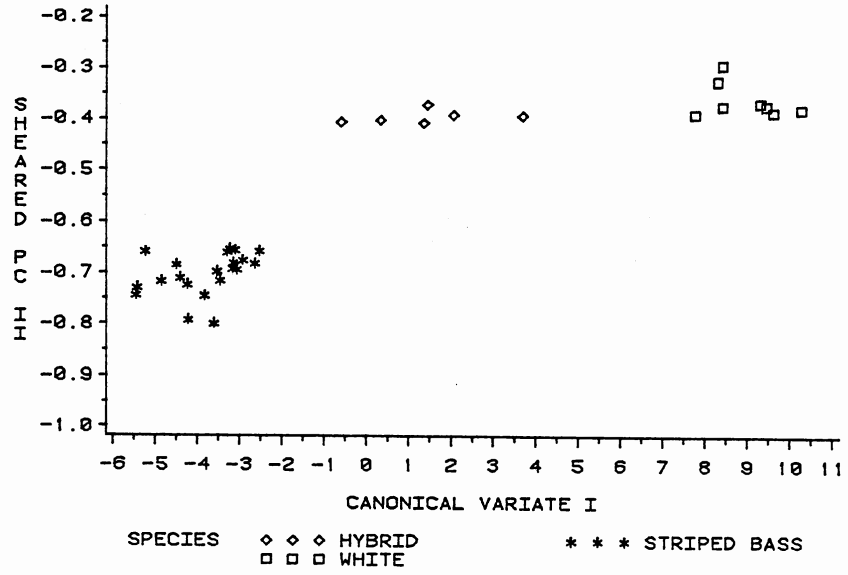


Figure 6. Plot of Sheared Principal Component II against Canonical Variate I for White bass, Striped bass, and Striped bass x White bass hybrids

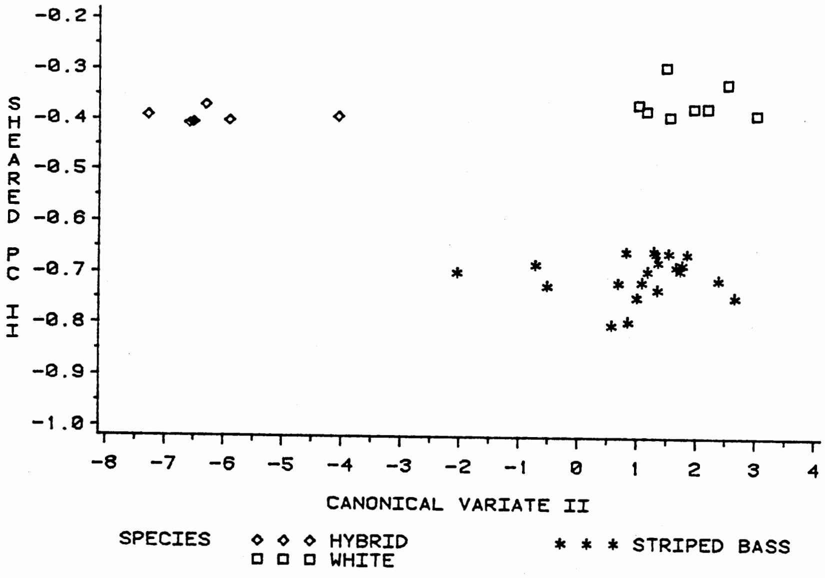


Figure 7. Plot of Sheared Principal Component II against Canonical Variate II for White bass, Striped bass, and Striped bass x White bass hybrids

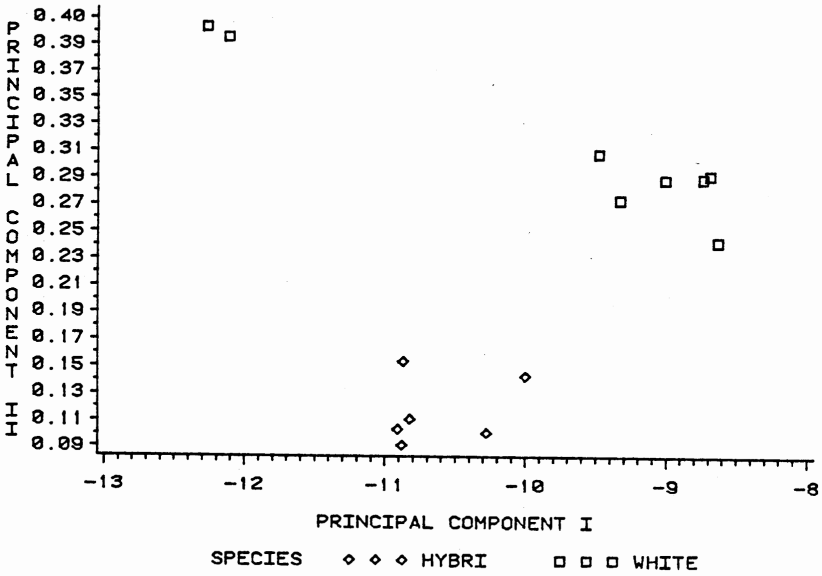


Figure 8. Plot of Principal Component II against Principal Component I for White bass and Striped bass x White bass hybrids

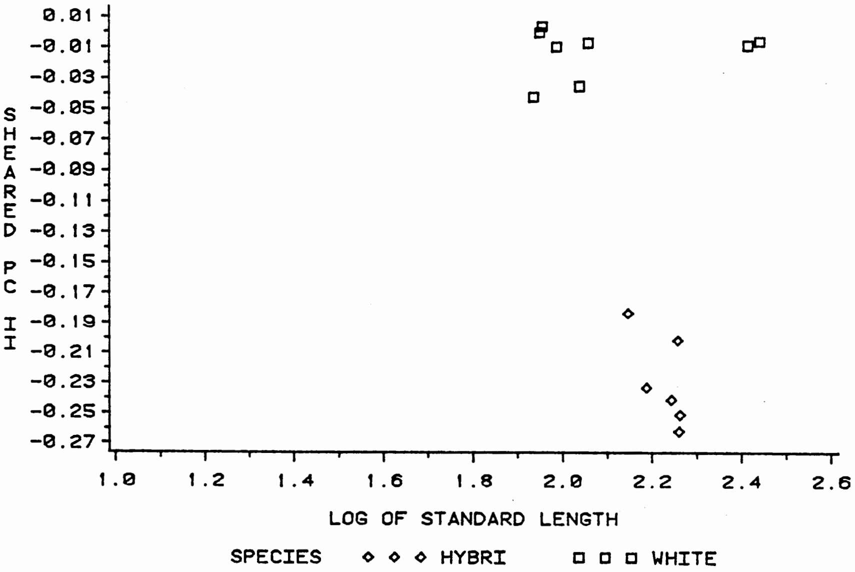


Figure 9. Plot of Principal Component II against log of Standard Length for White bass and Striped bass x White bass hybrids

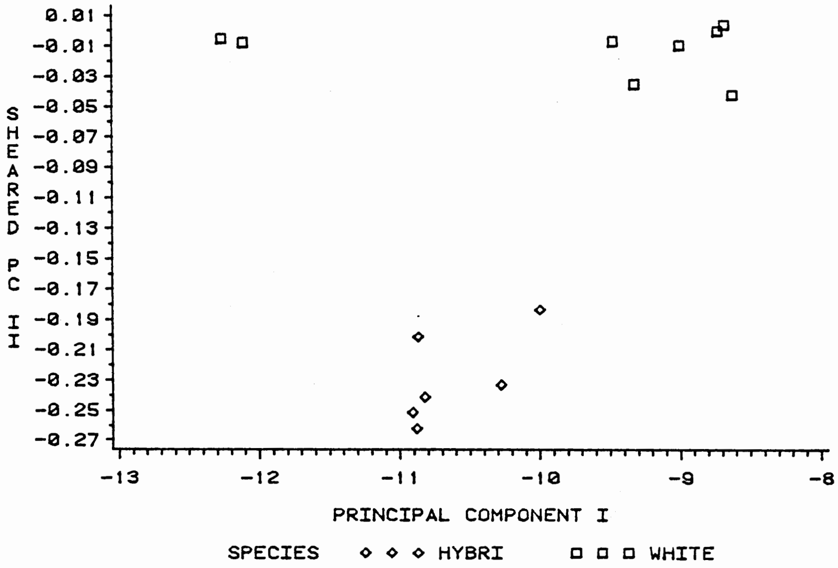


Figure 10. Plot of Principal Component II against Principal Component I for White bass and Striped bass x White bass hybrids

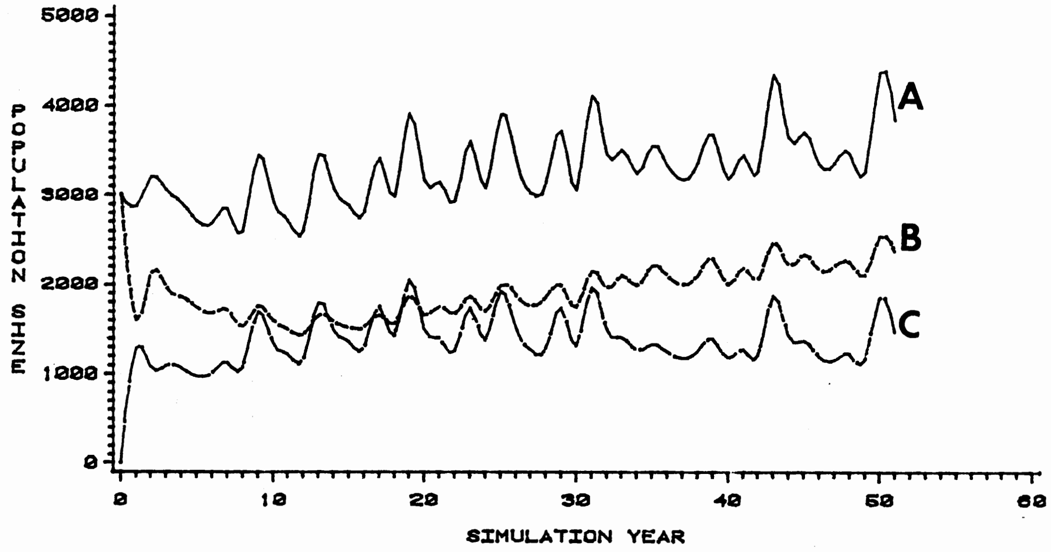


Figure 11. Simulated Total, White bass, and Striped bass x White bass hybrids population sizes (**Annual Hybrid Stocking Rate is 10,000 A=TOTAL, B=WHITE BASS, C=HYBRID**)

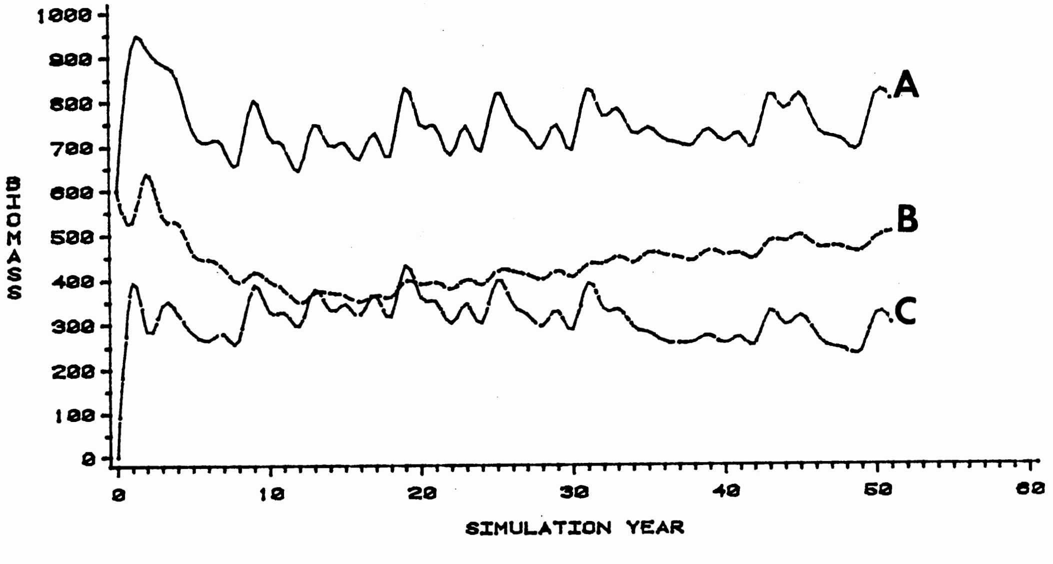


Figure 12. Simulated Total, White bass, and Striped bass x White bass hybrids Annual Biomass (**Annual Hybrid Stocking Rate is 10,000 A=TOTAL, B=WHITE BASS, C=HYBRID**)

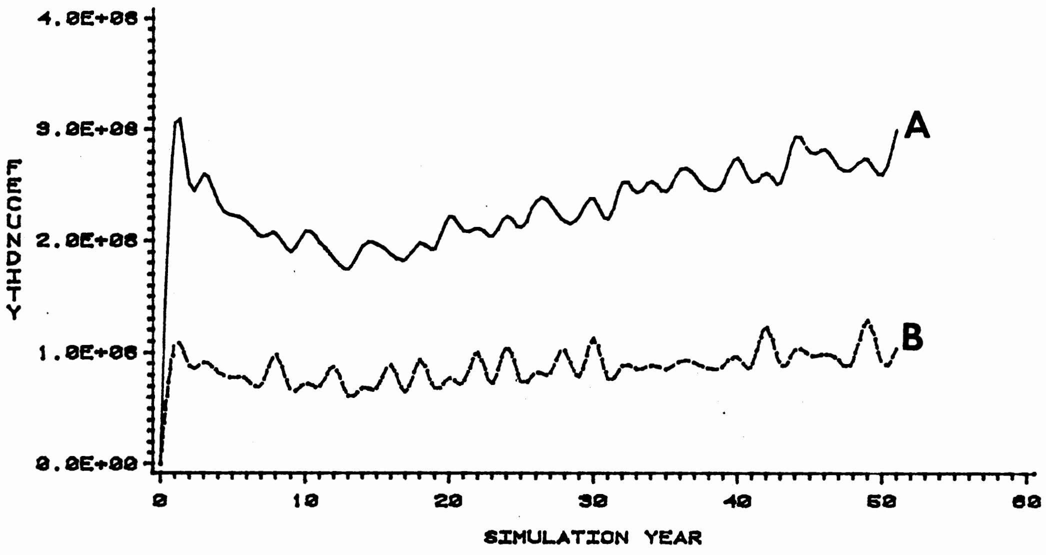


Figure 13. Simulated Fecundity and Fertility Estimates for White bass (**Annual Hybrid Stocking Rate is 10,000 A=FECUNDITY, B=FERTILITY**)

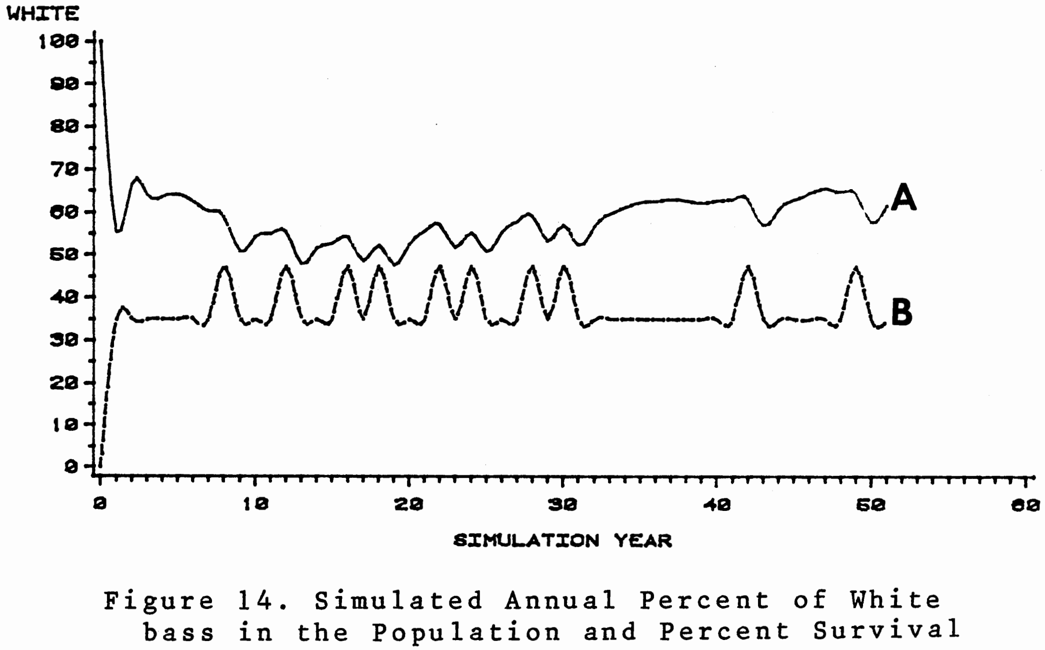


Figure 14. Simulated Annual Percent of White bass in the Population and Percent Survival of White bass to Age I (**Annual Hybrid Stocking Rate is 10,000 A=% WHITE BASS, B=% WHITE BASS SURV.**)

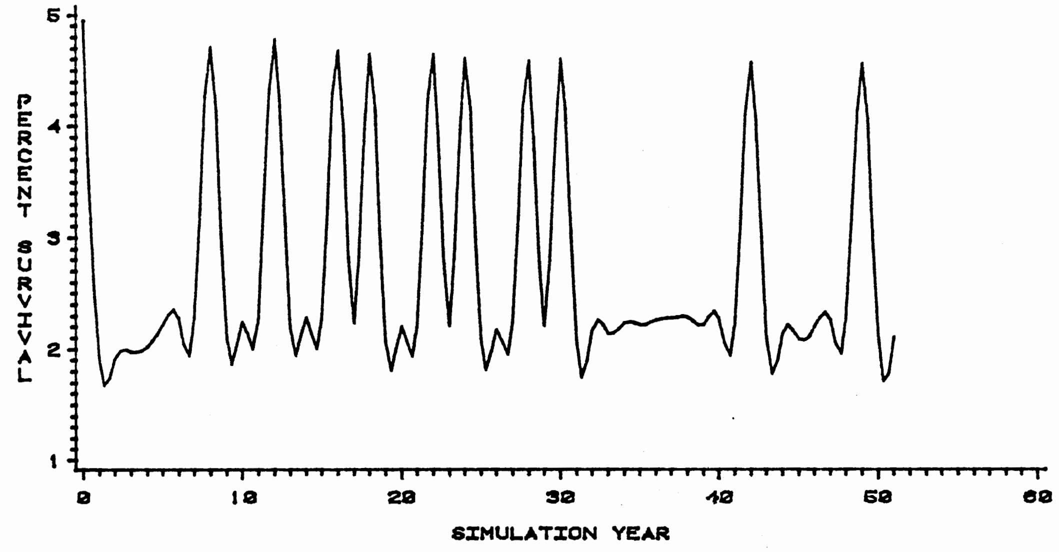


Figure 15. Simulated Annual Survival Rate of Stocked Striped bass x White bass hybrids **(Annual Hybrid Stocking Rate is 10,000)**

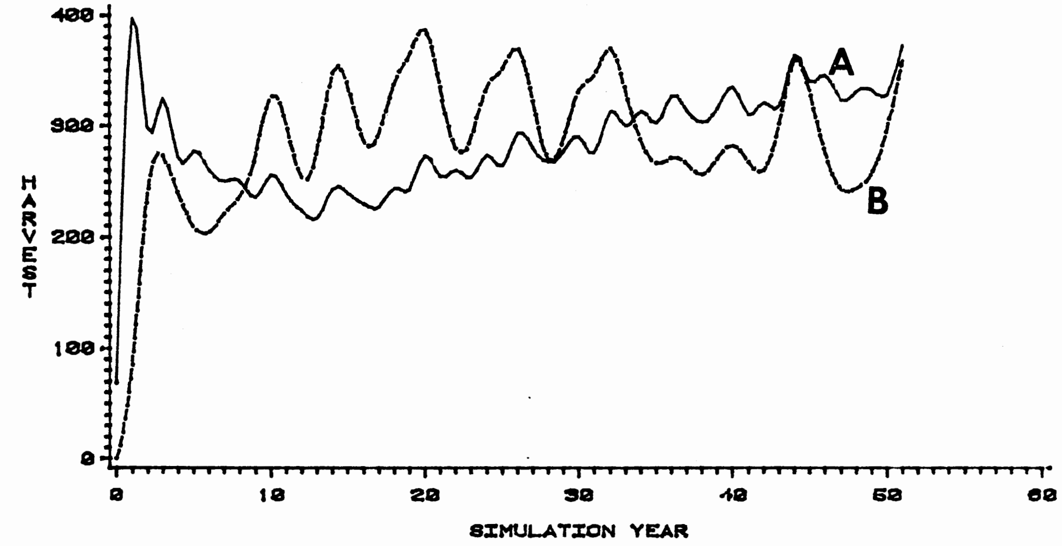


Figure 16. Simulated Annual Harvest of White bass and Striped bass x White bass hybrids **(Annual Hybrid Stocking Rate is 10,000 A=WHITE BASS, B=HYBRID)**

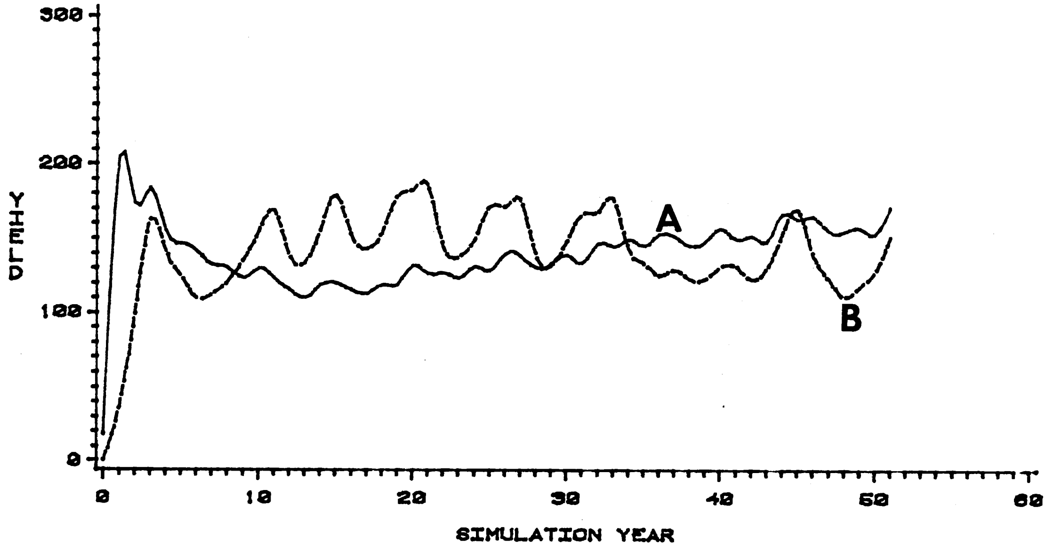


Figure 17. Simulated Annual Yield of White bass and Striped bass x White bass hybrids **(Annual Hybrid Stocking Rate is 10,000 A=WHITE BASS, B=HYBRID)**

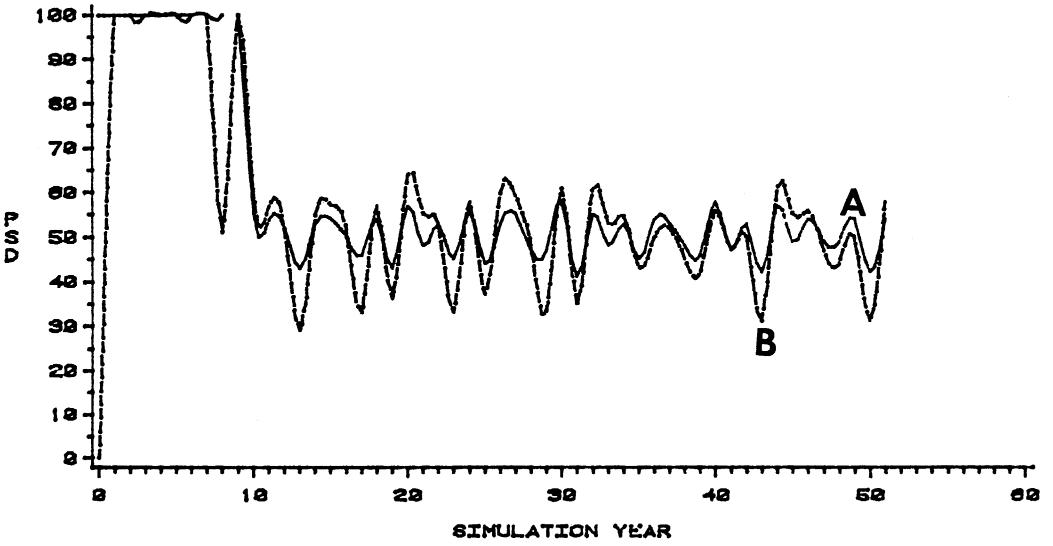


Figure 18. Simulated Annual Proportional Stock Density of White bass and Striped bass x White bass hybrids **(Annual Hybrid Stocking Rate is 10,000 A=WHITE BASS, B=HYBRID)**

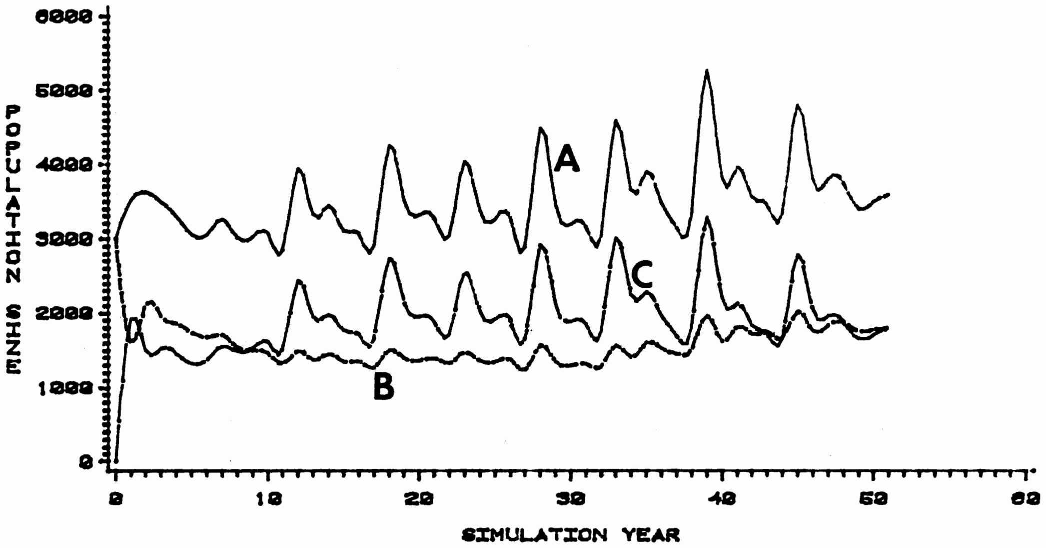


Figure 19. Simulated Total, White bass, and Striped bass x White bass hybrids population sizes **(Annual Hybrid Stocking Rate is 15,000 A=TOTAL, B=WHITE BASS, C=HYBRID)**

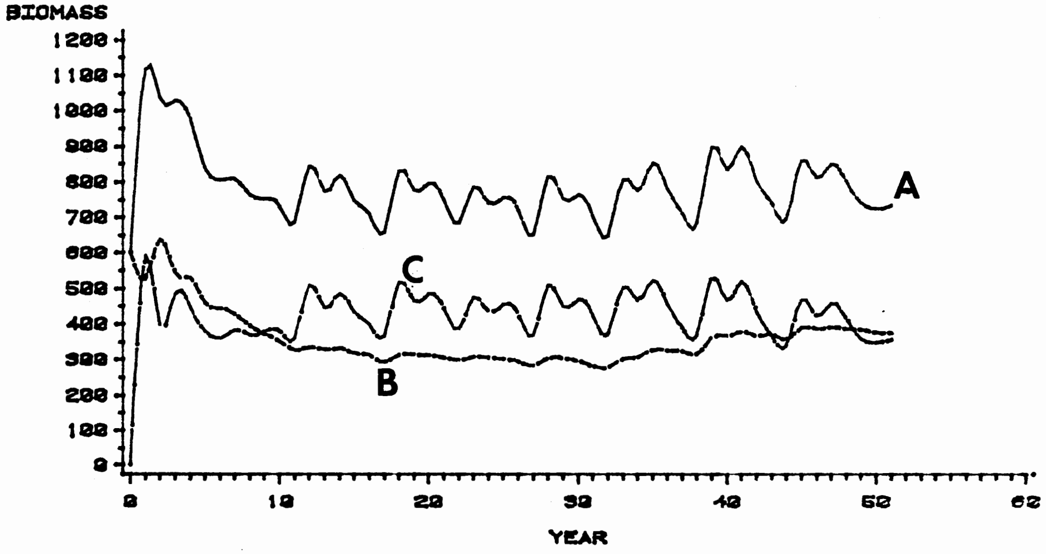


Figure 20. Simulated Total, White bass, and Striped bass x White bass hybrids Annual Biomass **(Annual Hybrid Stocking Rate is 15,000 A=TOTAL, B=WHITE BASS, C=HYBRID)**

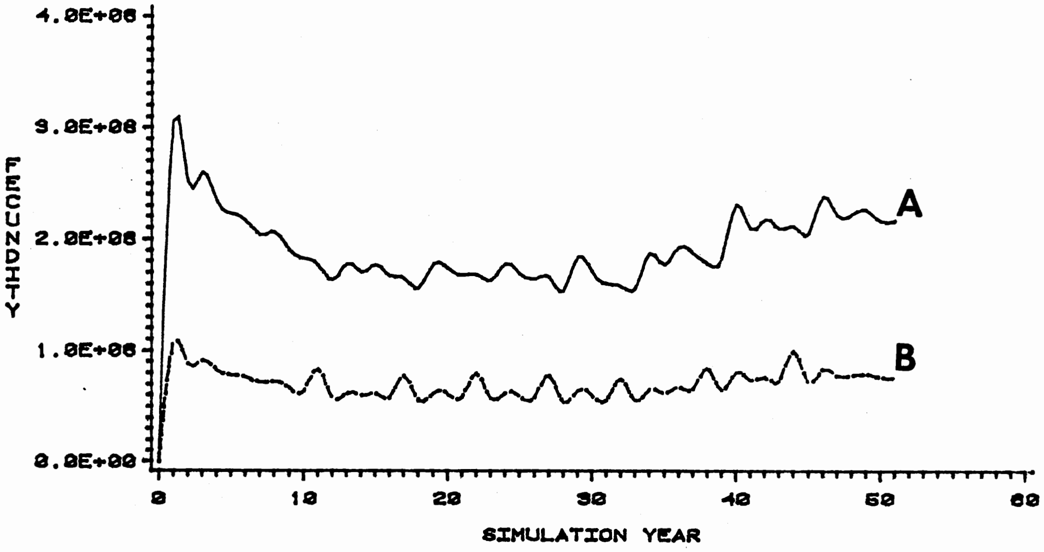


Figure 21. Simulated Fecundity and Fertility Estimates for White bass (**Annual Hybrid Stocking Rate is 15,000 A=FECUNDITY, B=FERTILITY**)

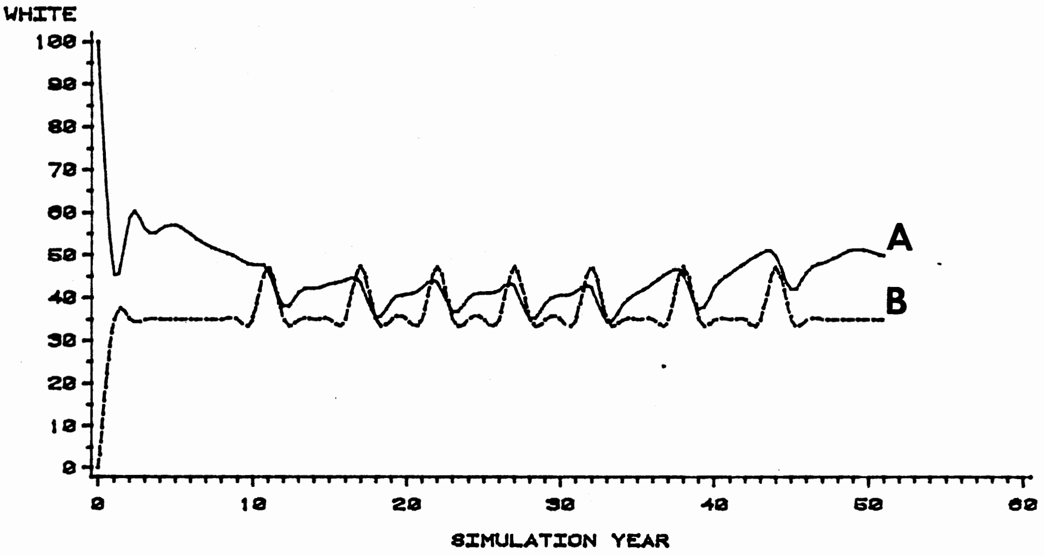


Figure 22. Simulated Annual Percent of White bass in the Population and Percent Survival of White bass to Age I (**Annual Hybrid Stocking Rate is 15,000 A=% WHITE BASS, B=% WHITE BASS SURV.**)

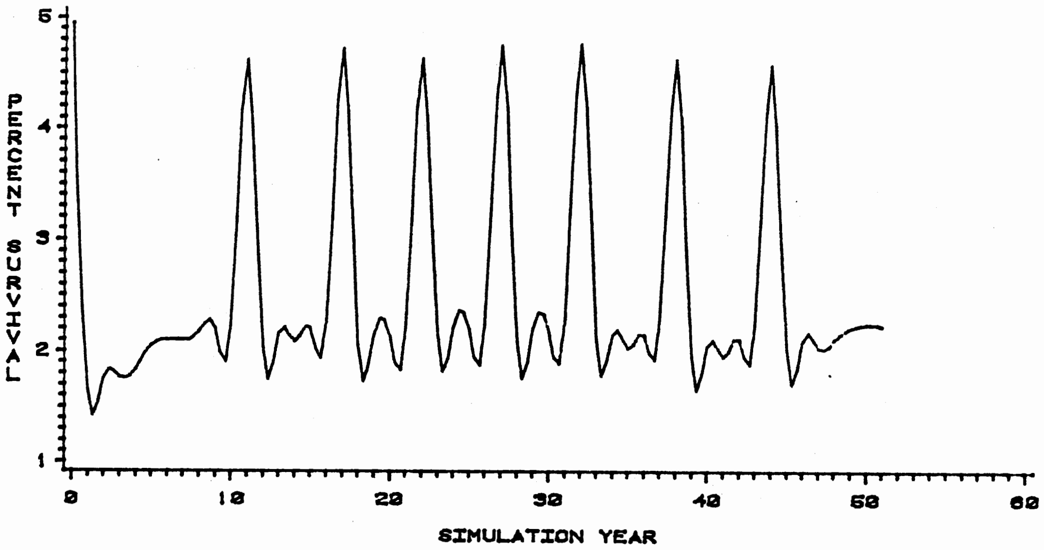


Figure 23. Simulated Annual Survival Rate of Stocked Striped bass x White bass hybrids **(Annual Hybrid Stocking Rate is 15,000)**

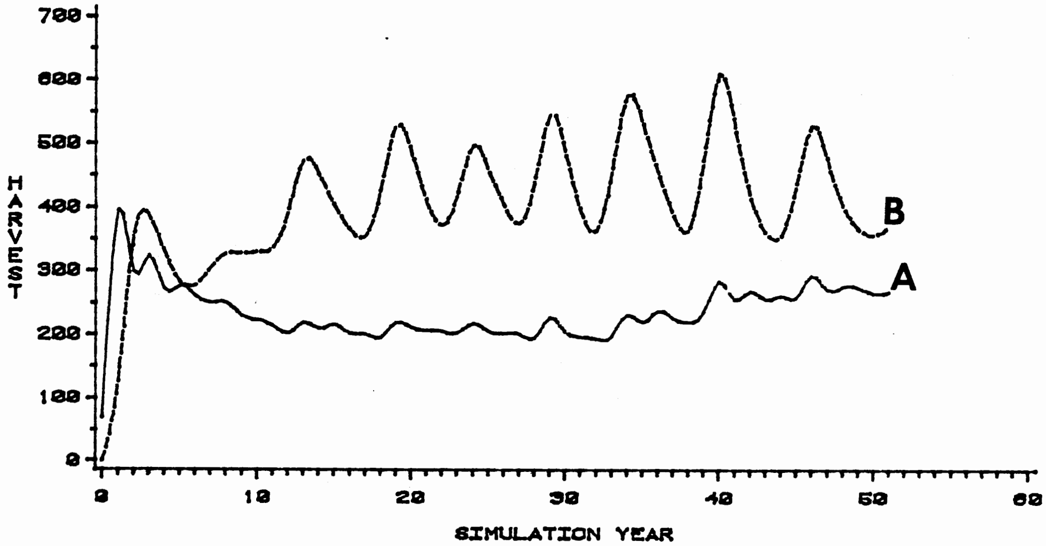


Figure 24. Simulated Annual Harvest of White bass and Striped bass x White bass hybrids **(Annual Hybrid Stocking Rate is 15,000 A=WHITE BASS, B=HYBRID)**

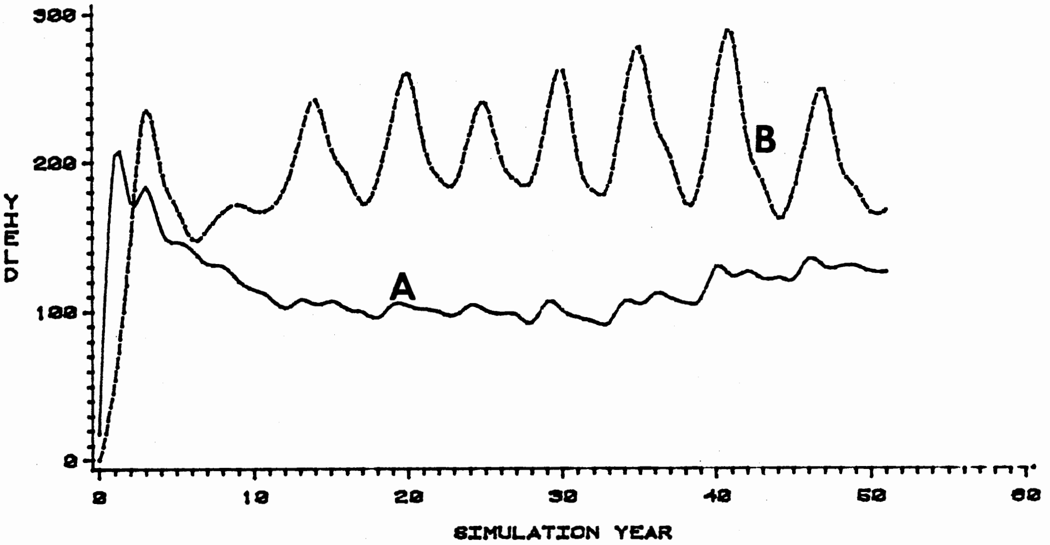


Figure 25. Simulated Annual Yield of White bass and Striped bass x White bass hybrids **(Annual Hybrid Stocking Rate is 15,000 A=WHITE BASS, B=HYBRID)**

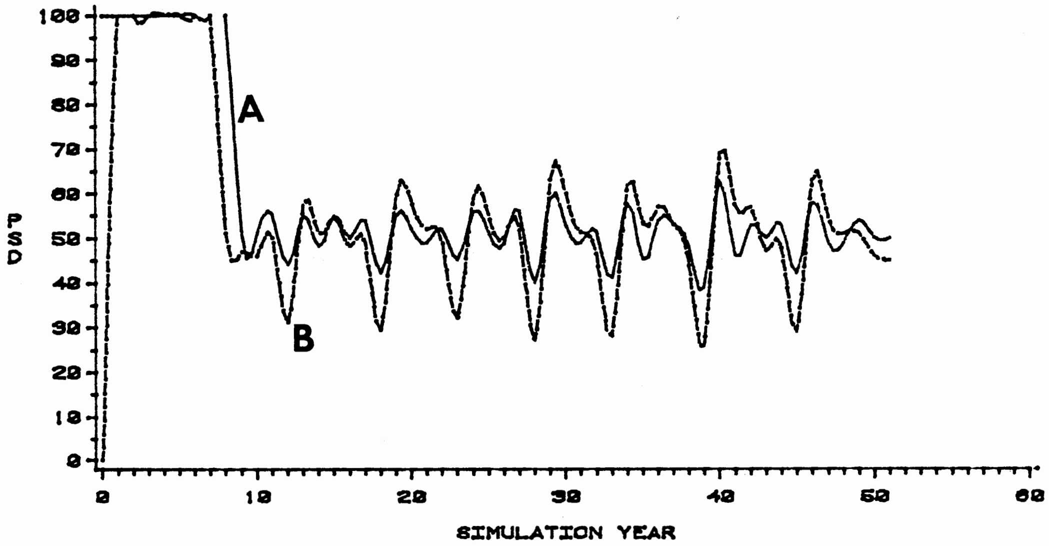


Figure 26. Simulated Annual Proportional Stock Density of White bass and Striped bass x White bass hybrids **(Annual Hybrid Stocking Rate is 15,000 A=WHITE BASS, B=HYBRID)**

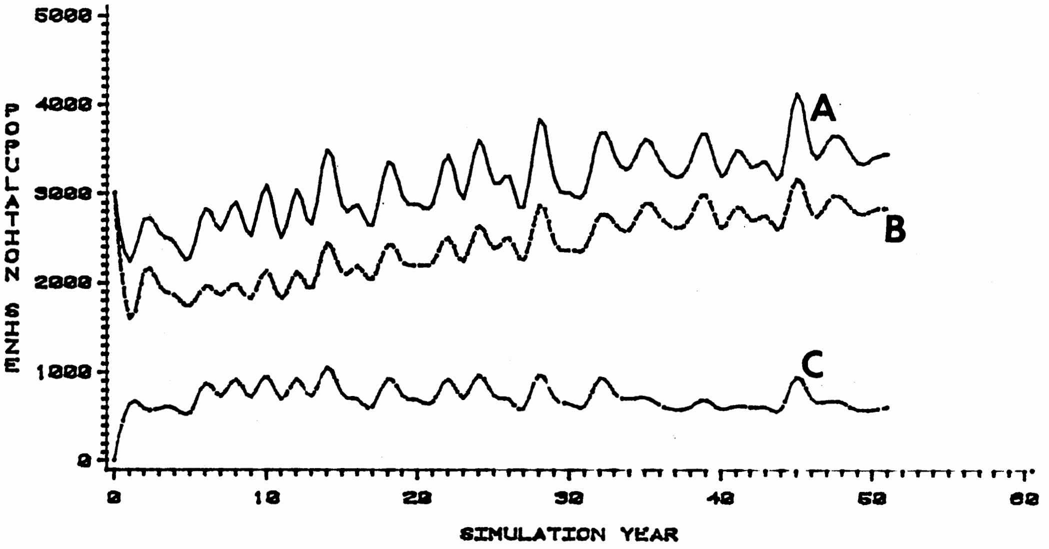


Figure 27. Simulated Total, White bass, and Striped bass x White bass hybrids population sizes **(Annual Hybrid Stocking Rate is 5,000 A=TOTAL, B=WHITE BASS, C=HYBRID)**

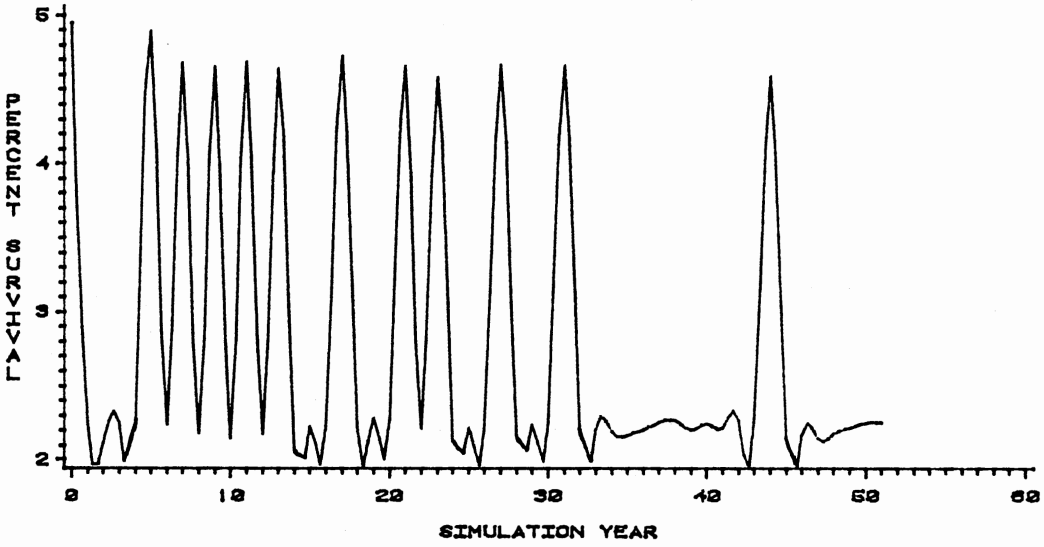


Figure 28. Simulated Annual Survival Rate of Stocked Striped bass x White bass hybrids **(Annual Hybrid Stocking Rate is 5,000)**

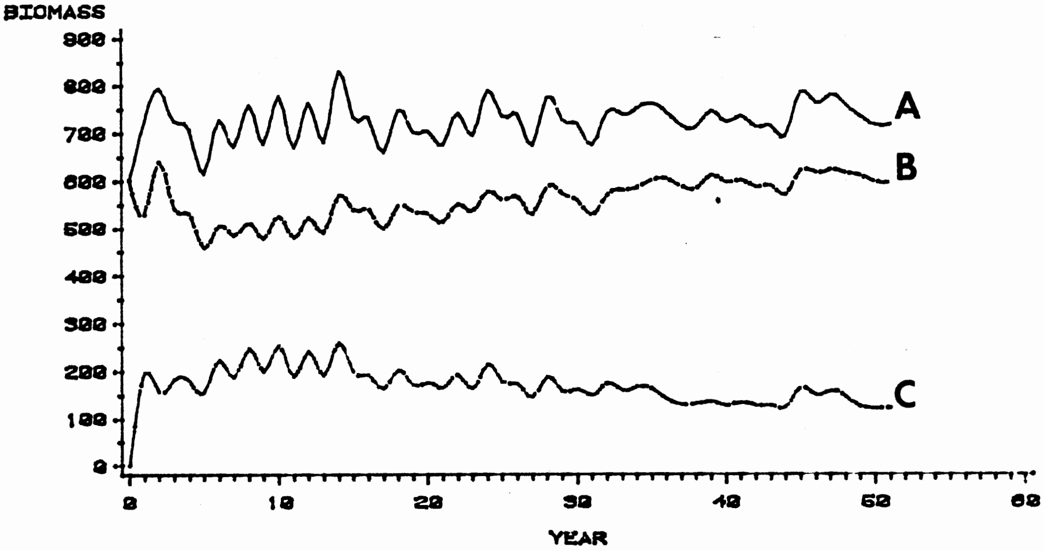


Figure 29. Simulated Total, White bass, and Striped bass x White bass hybrids Annual Biomass (**Annual Hybrid Stocking Rate is 5,000 A=TOTAL, B=WHITE BASS, C=HYBRID**)

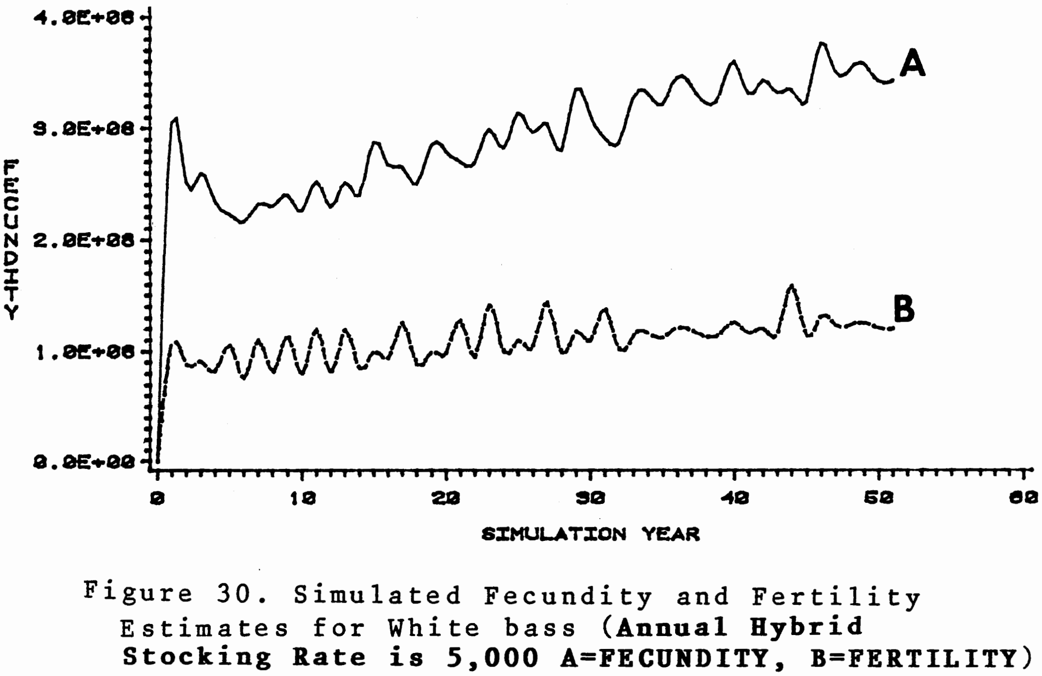


Figure 30. Simulated Fecundity and Fertility Estimates for White bass (**Annual Hybrid Stocking Rate is 5,000 A=FECUNDITY, B=FERTILITY**)

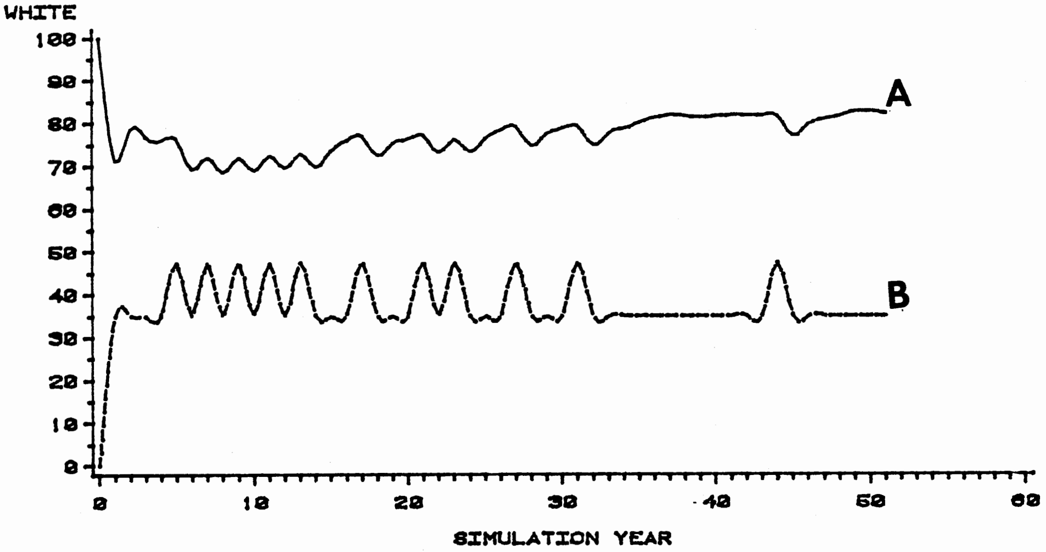


Figure 31. Simulated Annual Percent of White bass in the Population and Percent Survival of White bass to Age I (**Annual Hybrid Stocking Rate is 5,000 A=% WHITE BASS, B=% WHITE BASS SURV.**)

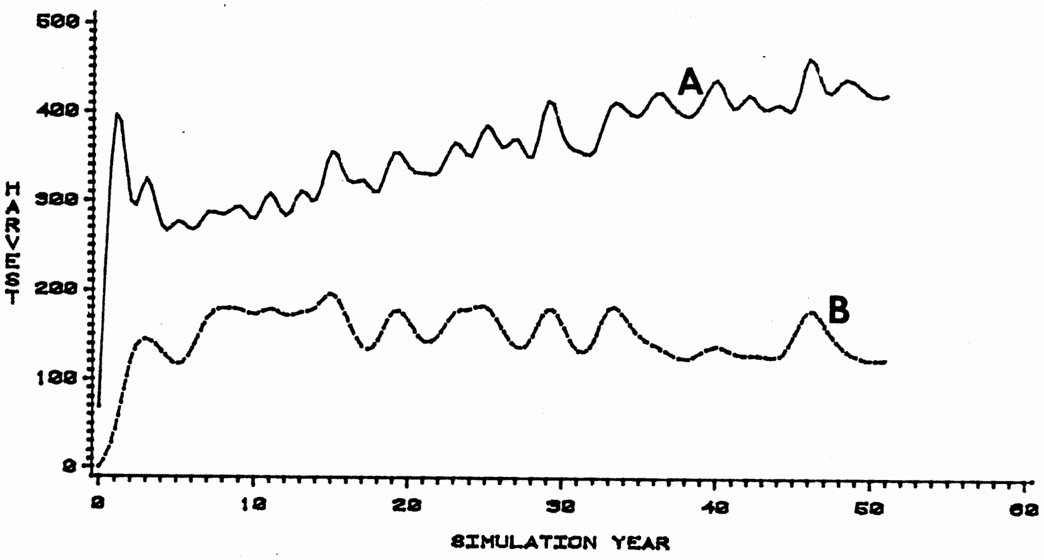


Figure 32. Simulated Annual Harvest of White bass and Striped bass x White bass hybrids (**Annual Hybrid Stocking Rate is 5,000 A=WHITE BASS, B=HYBRID**)

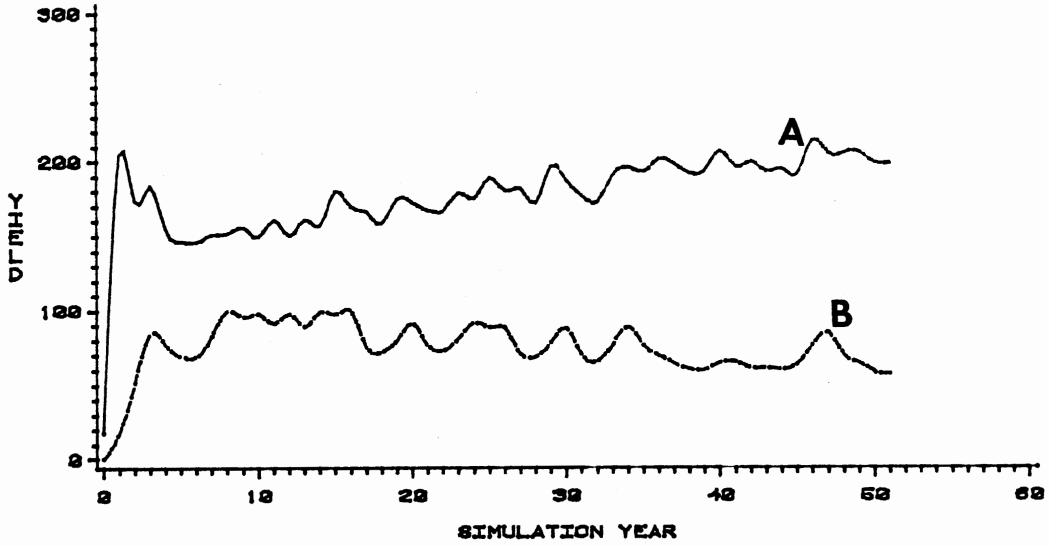


Figure 33. Simulated Annual Yield of White bass and Striped bass x White bass hybrids (**Annual Hybrid Stocking Rate is 5,000 A=WHITE BASS, B=HYBRID**)

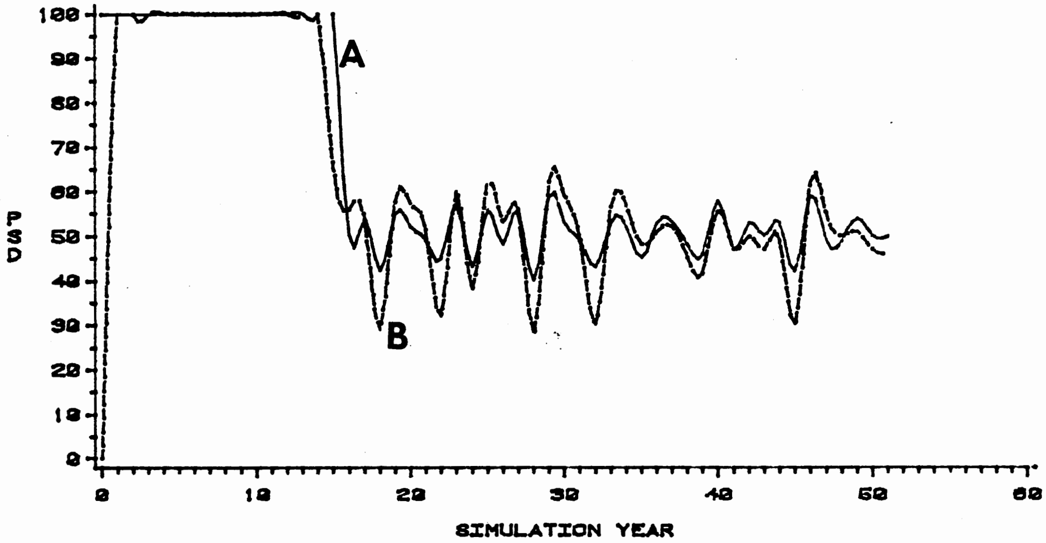


Figure 34. Simulated Annual Proportional Stock Density of White bass and Striped bass x White bass hybrids (**Annual Hybrid Stocking Rate is 5,000 A=WHITE BASS, B=HYBRID**)

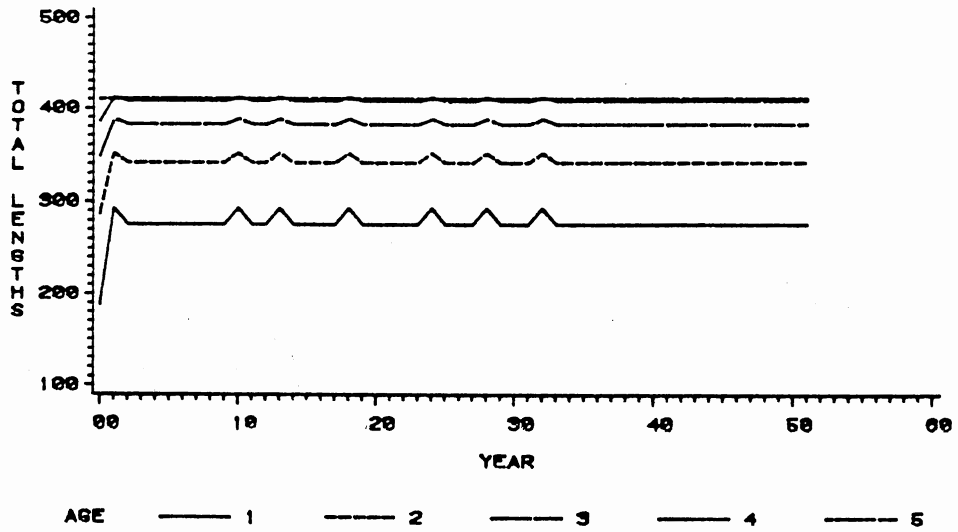


Figure 35. Simulated Annual Lengths-at-Age for White bass (**Annual Hybrid Stocking Rate is 10,000**)

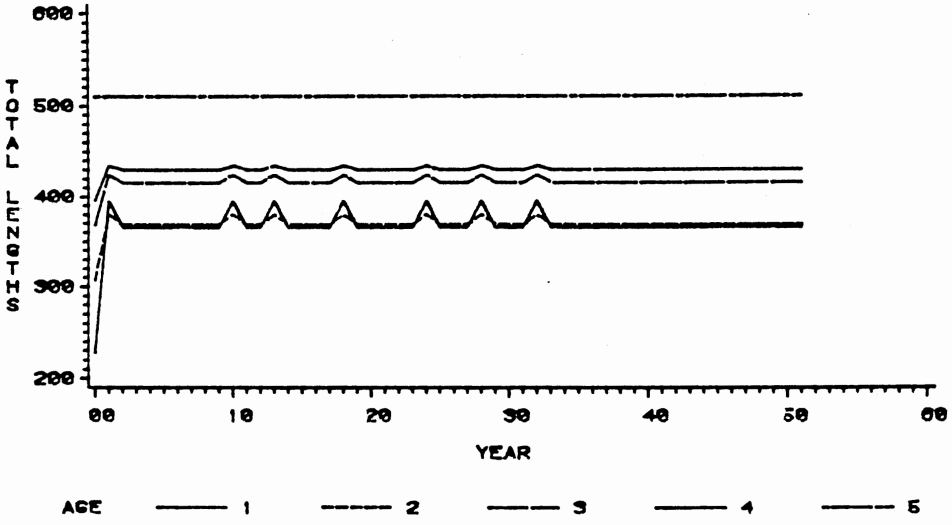
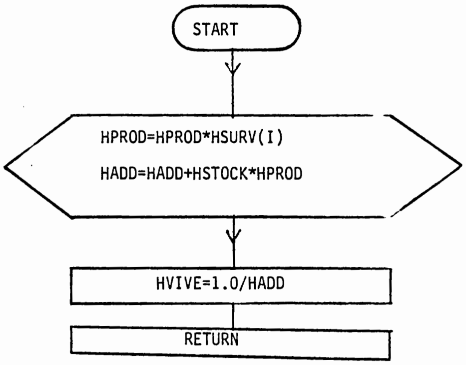


Figure 36. Simulated Annual Lengths-at-Age for Striped bass x White bass hybrids (**Annual Hybrid Stocking Rate is 10,000**)

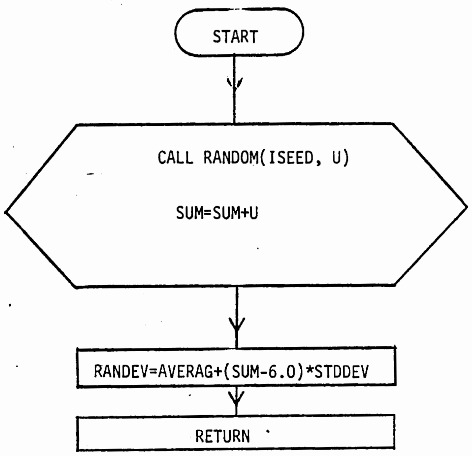
APPENDIX C

LOGIC FLOW CHART OF PROGRAM FOR SIMULATING THE POPULATION DYNAMICS OF WHITE BASS AND STRIPED BASS X WHITE BASS HYBRIDS IN LAKE CARL BLACKWELL, OKLAHOMA

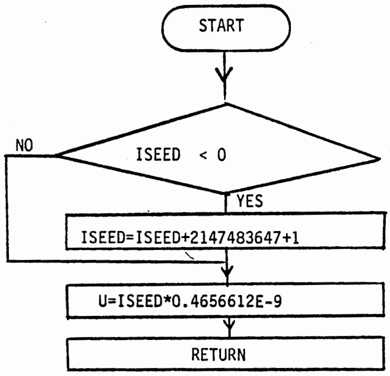
SUBROUTINE HYBRID(HVIVE)

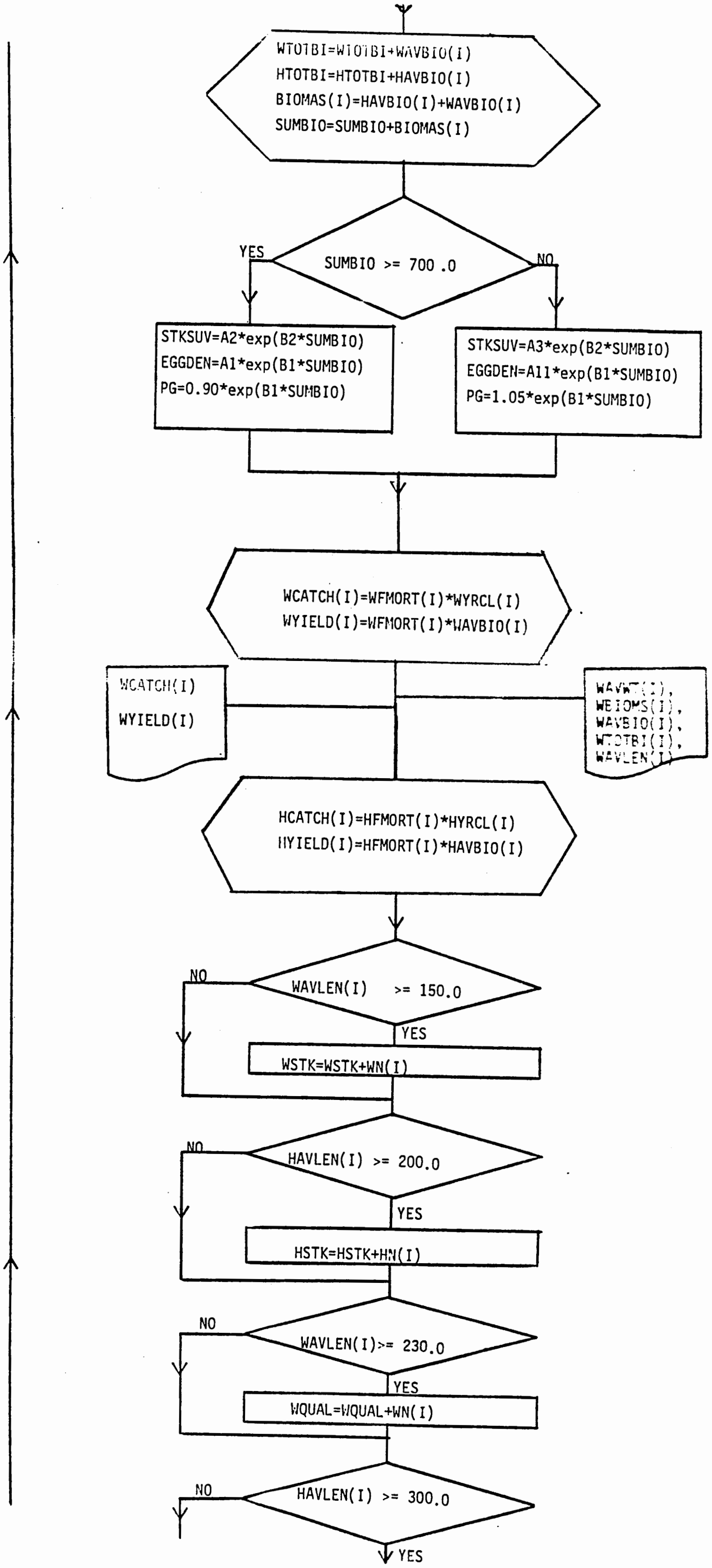


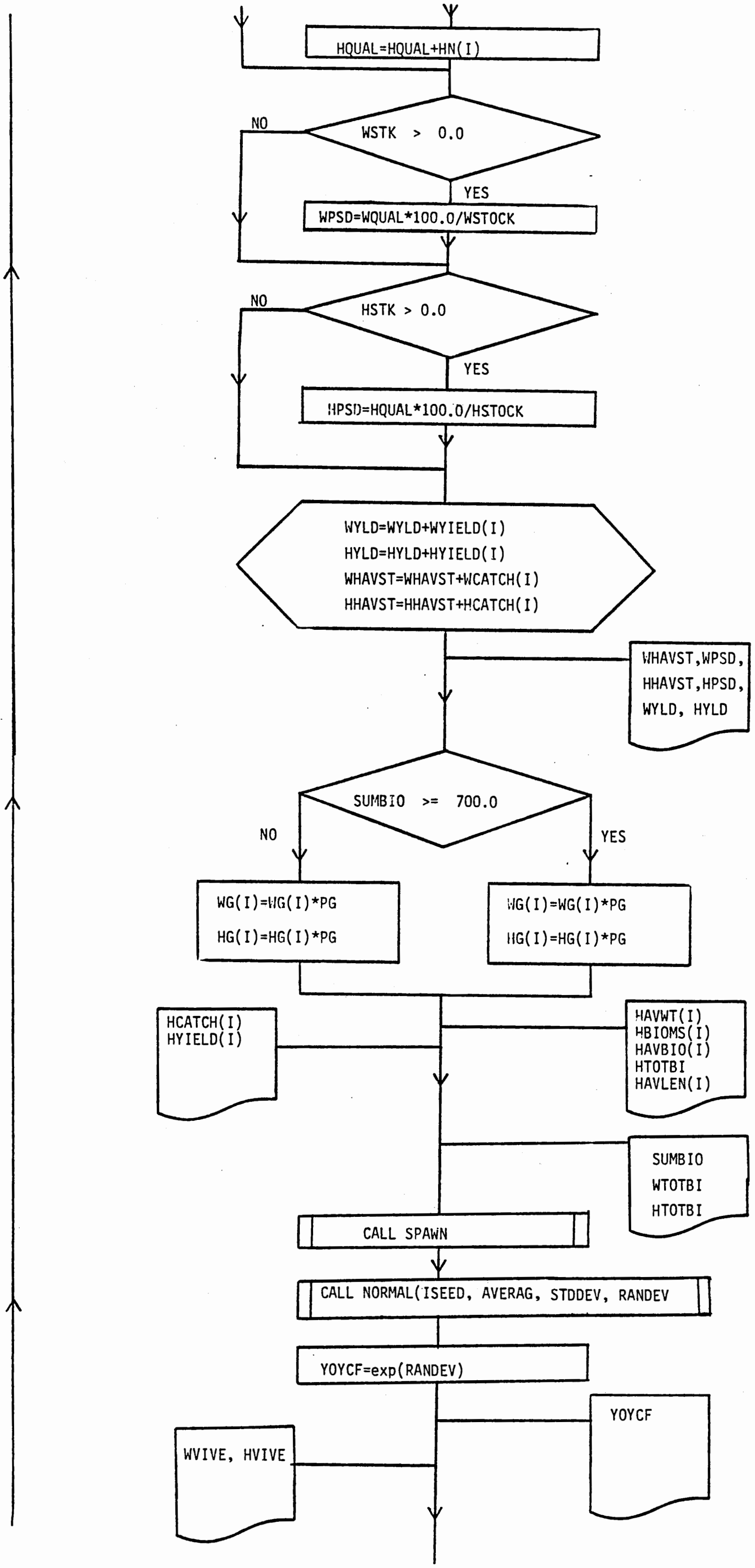
SUBROUTINE NORMAL(ISEED, AVERAG, STDDEV, RANDEV)

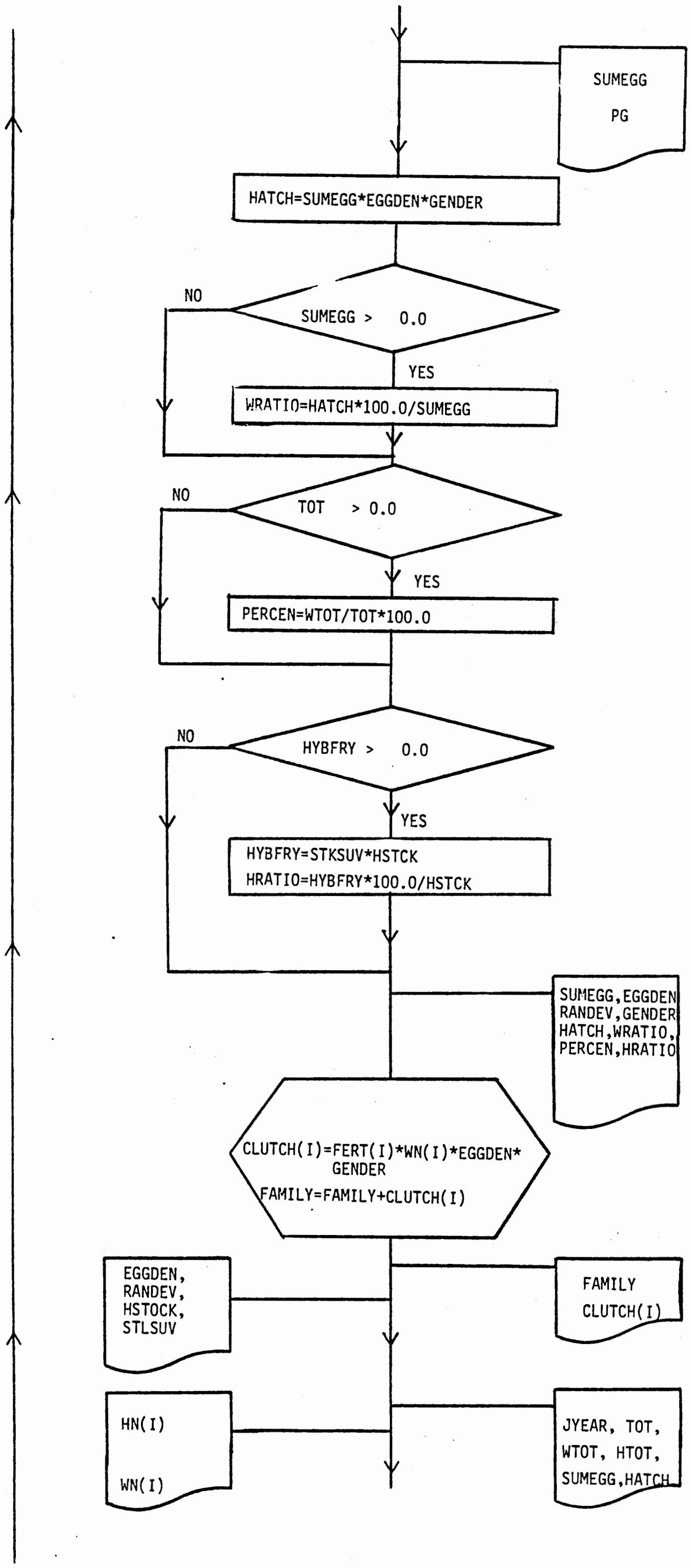


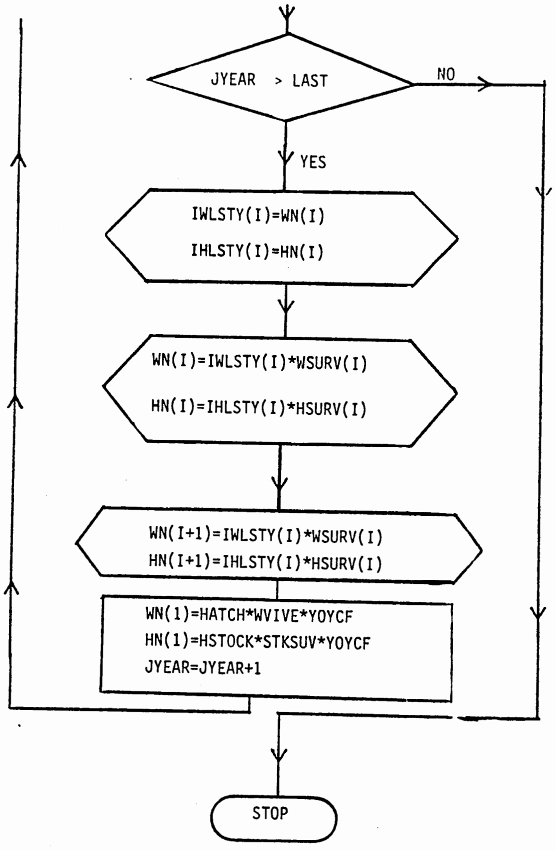
SUBROUTINE RANDOM(ISEED, U)



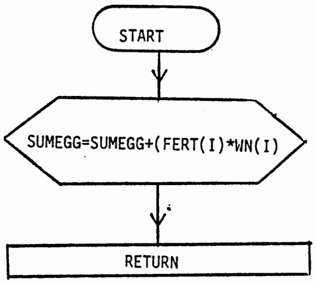

WTOTBI=WTOTBI+WAVBIO(I)
HTOTBI=HTOTBI+HAVBIO(I)
BIOMAS(I)=HAVBIO(I)+WAVBIO(I)
SUMBIO=SUMBIO+BIOMAS(I)
YES
SUMBIO >= 700 .0
NO
STKSUV=A2*exp(B2*SUMBIO)
EGGDEN=A1*exp(B1*SUMBIO)
PG=0.90*exp(B1*SUMBIO)
STKSUV=A3*exp(B2*SUMBIO)
EGGDEN=A11*exp(B1*SUMBIO)
PG=1.05*exp(B1*SUMBIO)
WCATCH(I)=WFMORT(I)*WYRCL(I)
WYIELD(I)=WFMORT(I)*WAVBIO(I)
WCATCH(I)
WYIELD(I)
WAVWT(I),
WBIOMS(I),
WAVBIO(I),
WTOTBI(I),
WAVLEN(I)
HCATCH(I)=HFMORT(I)*HYRCL(I)
HYIELD(I)=HFMORT(I)*HAVBIO(I)
NO
WAVLEN(I) >= 150.0
YES
WSTK=WSTK+WN(I)
NO
HAVLEN(I) >= 200.0
YES
HSTK=HSTK+HN(I)
NO
WAVLEN(I)>= 230.0
YES
WQUAL=WQUAL+WN(I)
NO
HAVLEN(I) >= 300.0
YES


HQUAL=HQUAL+HN(I)
NO
WSTK > 0.0
YES
WPSD=WQUAL*100.0/WSTOCK
NO
HSTK > 0.0
YES
HPSD=HQUAL*100.0/HSTOCK
WYLD=WYLD+WYIELD(I)
HYLD=HYLD+HYIELD(I)
WHAVST=WHAVST+WCATCH(I)
HHAVST=HHAVST+HCATCH(I)
WHAVST,WPSD,
HHAVST,HPSD,
WYLD, HYLD
SUMBIO >= 700.0
NO
YES
WG(I)=WG(I)*PG
HG(I)=HG(I)*PG
WG(I)=WG(I)*PG
HG(I)=HG(I)*PG
HCATCH(I)
HYIELD(I)
HAVWT(I)
HBIOMS(I)
HAVBIO(I)
HTOTBI
HAVLEN(I)
SUMBIO
WTOTBI
HTOTBI
CALL SPAWN
CALL NORMAL(ISEED, AVERAG, STDDEV, RANDEV
YOYCF=exp(RANDEV)
YOYCF
WVIVE, HVIVE

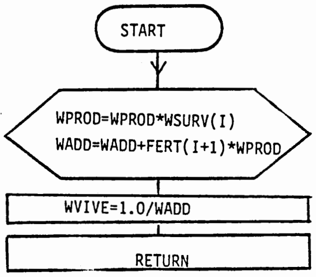

SUMEGG
PG
HATCH=SUMEGG*EGGDEN*GENDER
NO
SUMEGG > 0.0
YES
WRATIO=HATCH*100.0/SUMEGG
NO
TOT > 0.0
YES
PERCEN=WTOT/TOT*100.0
NO
HYBFRY > 0.0
YES
HYBFRY=STKSUV*HSTCK
HRATIO=HYBFRY*100.0/HSTCK
SUMEGG,EGGDEN
RANDEV,GENDER
HATCH,WRATIO,
PERCEN,HRATIO
CLUTCH(I)=FERT(I)*WN(I)*EGGDEN*
GENDER
FAMILY=FAMILY+CLUTCH(I)
EGGDEN,
RANDEV,
HSTOCK,
STLSUV
FAMILY
CLUTCH(I)
HN(I)
WN(I)
JYEAR, TOT,
WTOT, HTOT,
SUMEGG,HATCH

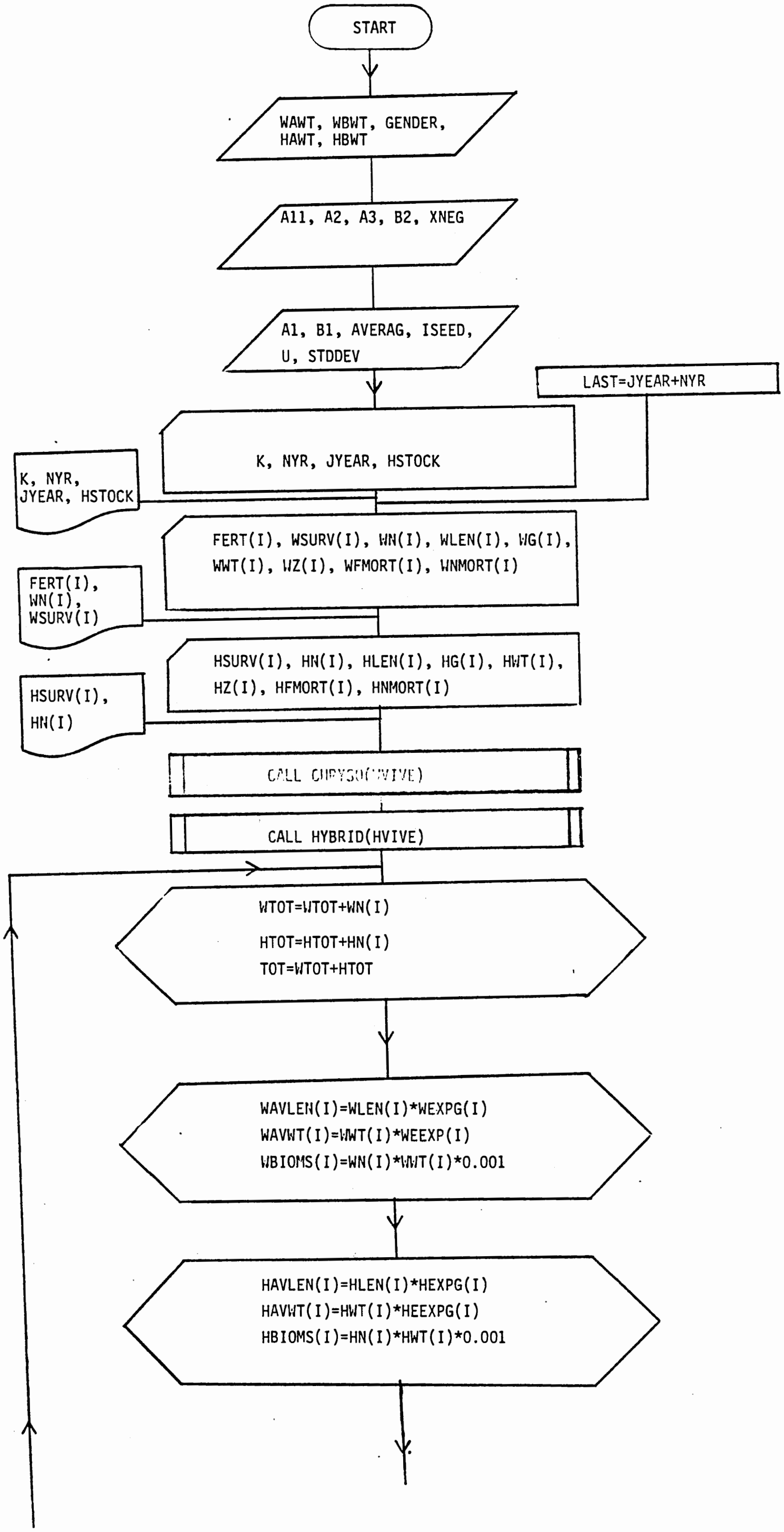


SUBROUTINE SPAWN



SUBROUTINE CHRYSO(WVIVE)




START
WAWT, WBWT, GENDER, HAWT, HBWT
A11, A2, A3, B2, XNEG
A1, B1, AVERAG, ISEED, U, STDDEV
LAST=JYEAR+NYR
K, NYR, JYEAR, HSTOCK
K, NYR, JYEAR, HSTOCK
FERT(I), WSURV(I), WN(I), WLEN(I), WG(I), WWT(I), WZ(I), WFMORT(I), WNMORT(I)
FERT(I), WN(I), WSURV(I)
HSURV(I), HN(I), HLEN(I), HG(I), HWT(I), HZ(I), HFMORT(I), HNMORT(I)
HSURV(I), HN(I)
CALL CHRYSO(WVIVE)
CALL HYBRID(HVIVE)
WTOT=WTOT+WN(I)
HTOT=HTOT+HN(I)
TOT=WTOT+HTOT
WAVLEN(I)=WLEN(I)*WEXPG(I)
WAVWT(I)=WWT(I)*WEEXP(I)
WBIOMS(I)=WN(I)*WWT(I)*0.001
HAVLEN(I)=HLEN(I)*HEXPG(I)
HAVWT(I)=HWT(I)*HEEXPG(I)
HBIOMS(I)=HN(I)*HWT(I)*0.001

APPENDIX D

LISTING OF COMPUTER PROGRAM FOR SIMULATING THE POPULATION DYNAMICS OF WHITE BASS AND STRIPED BASS X WHITE BASS HYBRIDS IN LAKE CARL BLACKWELL, OKLAHOMA

```
LEVEL 1.4.1 (MAY 1985)           VS FORTRAN          DATE: FEB 23, 1987    TIME: 10:23:54                PAGE:     1

REQUESTED OPTIONS (EXECUTE): LANGLVL(77),OPT(3)

OPTIONS IN EFFECT:  NOLIST NOMAP NOXREF NOGOSTMT NODECK   SOURCE NOTERM   OBJECT FIXED  NOTEST NOTRMFLG   SRCFLG
                    NOSYM NORENT   SDUMP AUTODBL(NONE)   NOSXM   IL
                      OPT(3) LANGLVL(77) NOFIPS   FLAG(I)  NAME(MAIN  )  LINECOUNT(60)      CHARLEN(500)

               *....*...1.........2.........3.........4.........5.........6.........7.*.......8

ISN        1         COMMON/YOA/K,WN(5),HN(5),TOT,WTOT,HTOT,WSURV(5),HSURV(5),JYEAR
ISN        2         COMMON/YOB/FERT(5),SUMEGG,WCATCH(5),HCATCH(5),WBG(5),HBG(5)
ISN        3         COMMON/YOC/WZ(5),HZ(5),WZZEXP(5),HZZEXP(5),WZEXP(5),HZEXP(5)
ISN        4         COMMON/YOD/WZUPER(5),HZUPER(5),WZDENM(5),HZDENM(5),WAVBIO(5)
ISN        5         COMMON/YOE/HAVBIO(5),WBIOMS(5),HBIOMS(5),WG(5),HG(5),WAVWT(5)
ISN        6         COMMON/YOF/HAVWT(5),WWT(5),HWT(5),WFMORT(5),HFMORT(5),WNMORT(5)
ISN        7         COMMON/YOG/HNMORT(5),WYIELD(5),HYIELD(5),WEEXP(5),HEEXP(5)
ISN        8         COMMON/YOH/WLEN(5),HLEN(5),WJEXP(5),HJEXP(5),WGPROD(5),HSTOCK
ISN        9         COMMON/YOI/HGPROD(5),WNEPRO(5),HNEPRO(5),WYRCL(5),HYRCL(5)
ISN       10         COMMON/YOJ/CLUTCH(5),TOTBIO,WTOTBI,HTOTBI,FAMILY,WWF(5),HWF(5)
ISN       11         COMMON/YOK/WEXPG(5),HEXPG(5),HAVLEN(5),WAVLEN(5),SUMBIO
ISN       12         COMMON/YOL/EGGDEN,RANDEV,HATCH,WREXP(5),HREXP(5),BIOMAS(5)
ISN       13         COMMON/YOM/HYBBIO,WHIBIO,WRATIO,YOYCF,HRATIO,HYBFRY
ISN       14         COMMON/YON/WRG(5),WLLEN(6),WSLOPE(5),WINT(5),WWET(5),WINTC
ISN       15         COMMON/YOO/HRG(5),HLLEN(6),HSLOPE(5),HINT(5),HWET(5),HINTC
ISN       16         COMMON/YOP/WSTK,HSTK,WQUAL,HQUAL,WPSD,HPSD,WYLD,HYLD,HHAVST,WHAVST
ISN       17         COMMON/YOQ/WNP,WGP,HNP,HGP
ISN       18         DIMENSION IWLSTY(5),IHLSTY(5)
               C
               C      ENTER CONSTANTS FOR SIMULATION HERE
               CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
               C                                                                 C
               C    THIS PROGRAM SIMULATES THE DYNAMICS OF STRIPED BASS X WHITE  C
               C    BASS HYBRID AND WHITE BASS POPULATIONS OVER TIME IN TERMS OF C
               C    NUMBER OF FISH IN VARIOUS AGE CLASSES, YIELD, GROWTH         C
               C    HARVEST, BIOMASS, AND PROPORTIONAL STOCK DENSITY             C
               C    THE MODEL USED IN THE SIMULATION IS AGE-STRUCTURED           C
               C    AND INCOPORATES STOCHASTIC ELEMENTS AS WELL AS DENSITY-      C
               C    DEPENDENT COMPENSATORY MECHANISM.                            C
               C                                                                 C
               C    THE FOLLOWING ASSUMPTIONS WERE USED IN THE MODEL             C
               C                                                                 C
               C            (1) THE RATE OF GROWTH IN LENGTH IS                  C
               C                DENSITY-DEPENDENT                                C
               C                                                                 C
               C            (2) FISHING, AND NATURAL MORTALITY RATES AS WELL     C
               C                AS SURVIVAL AND FECUNDITY RATES ARE CONSTANT     C
               C                FROM YEAR TO YEAR                                C
               C                                                                 C
               C            (3) DENSITY-DEPENDENCE OPERATES TO REDUCE WHITE BASS C
               C                FECUNDITY AS WELL AS TO INCREASE HYBRID          C
               C                FINGERLING AND WHITE BASS FRY MORTALITY          C
               C                                                                 C
               C            (4) CARRYING CAPACITY OF THE RESERVOIR IS FIXED      C
               C                AND DENSITY-DEPENDENCE MECHANISMS ARE TRIGGERED  C
               C                WHEN CARRYING CAPACITY EXCEEDS OPTIMUM           C
               C                                                                 C
               C            (5) FIXED NUMBER OF HYBRID FINGERLING ARE STOCKED    C
               C                ANNUALLY                                         C
               C                                                                 C
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LEVEL 1.4.1 (MAY 1985)          VS FORTRAN          DATE: FEB 23, 1987    TIME: 10:23:54      NAME: MAIN     PAGE:      2
               *....*...1.........2.........3.........4.........5.........6.........7.*.......8
               C            (6) HYBRID FINGERLING AND WHITE BASS FRY SURVIVAL    C
               C                SURVIVAL IS ALSO SUBJECT TO STOCHASTIC VARIATION C
               C                                                                 C
               CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
               C                                                                 C
               C          TO USE THIS PROGRAM THE FOLLOWING INFORMATION  MUST   C
               C          BE PROVIDED IN THE APPROPRIATE FORMAT:                 C
               C                                                                 C
               C            (1) THE NUMBER OF AGE CLASSES FOR EACH SPECIES       C
               C                                                                 C
               C            (2) THE NUMBER OF YEARS SIMUATION IS TO RUN          C
               C                                                                 C
               C            (3) ANNUAL HYBRID FINGERLING STOCKING RATE           C
               C                                                                 C
               C            (4) AGE-SPECIFIC WHITE BASS FECUNDITY, SURVIVAL      C
               C                RATES, MEAN LENGTHS, INSTANTANEOUS GROWTH RATES, C
               C                AND FISHING AND NATURAL MORTALITY RATES.         C
               C                                                                 C
               C            (5) AGE-SPECIFIC HYBRID STOCKING RATE, SURVIVAL      C
               C                RATES, MEAN LENGTHS, INSTANTANEOUS GROWTH RATES  C
               C                MEAN WEIGHTS, AND FISHING AND NATURAL MORTALITY  C
               C                RATES                                            C
               C                                                                 C
               C            (6) CONSTANTS IN WEIGHT-LENGTH REGRESSION            C
               C                                                                 C
               C            (7) CONSTANTS IN DENSITY-DEPENDENT EFFECTS ON        C
               C                  (I) WHITE BASS FECUNDITY                       C
               C                  (II) STOCKED HYBRID FINGERLING SURVIVAL RATE   C
               C                  (III) PROPORTION OF GROWTH OF ADULT FISH       C
               C                                                                 C
               C                                                                 C
               CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
               C
               C THIS PROGRAM SEGMENT FUNCTIONS TO READ IN DATA AND ALLOCATION   C
               C OF STORAGE FOR THE SOME OF THE ARRAYS USED IN THE SIMULATION    C
               C THE VARIABLE NAMES ARE:                                         C
               C                                                                 C
               C   VARIABLE NAME               USAGE                             C
               C                                                                 C
               C   K              NUMBER OF AGE CLASSES FOR BOTH SPECIES         C
               C   NYR            NUMBER OF YEARS TO SIMULATE                    C
               C   JYEAR          YEAR TO COMMENCE SIMULATION                    C
               C   HSTOCK         ANNUAL HYBRID FINGERLING STOCKING RATE         C
               C   WAWT.WBWT ,    CONSTANTS 'A & B' IN WHITE BASS LENGTH-WEIGHT C
               C                  REGRESSION                                     C
               C   HAWT.HBWT      CONSTANTS 'A & B' IN HYBRID LENGTH-WEIGHT      C
               C                  REGRESSION                                     C
               C   A11, B1,A1     CONSTANTS IN WHITE BASS DENSITY-DEPENDENT      C
               C                  FECUNDITY RATE                                 C
               C   A2,B2,A3       CONSTANTS IN HYBRID FINGERLING DENSITY         C
               C                  DEPENDENT SURVIVAL RATE                        C
               C   FERT(I)        AGE-SPECIFIC WHITE BASS FECUNDITY              C
               C   WSURV(I)       AGE-SPECIFIC WHITE BASS SURVIVAL RATE          C
               C   WN(I)          AGE-SPECIFIC WHITE BASS POPULATION SIZE        C
               C   WLEN(I)        AGE-SPECIFIC WHITE BASS MEAN LENGTH            C
               C   WG(I)          AGE-SPECIFIC WHITE BASS INSTANTANEOUS GROWTH   C
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LEVEL 1.4.1 (MAY 1985)          VS FORTRAN          DATE: FEB 23, 1987    TIME: 10:23:54       NAME: MAIN     PAGE:      3
                      *....*...1.........2.........3.........4.........5.........6.........7.*.......8

                      C                   RATE                                             C
                      C     WWT(I)        AGE-SPECIFIC WHITE BASS MEAN WEIGHT              C
                      C     WZ(I)         AGE-SPECIFIC WHITE BASS TOTAL MORTALITY RATE     C
                      C     WFMORT(I)     AGE-SPECIFIC WHITE BASS FISHING MORTALITY RATEC
                      C     WNMORT(I)     AGE-SPECIFIC WHITE BASS NATURAL MORTALITY RATEC
                      C     HSURV(I)      AGE-SPECIFIC HYBRID SURVIVAL RATE                C
                      C     HN(I)         AGE-SPECIFIC HYBRID POPULATION SIZE              C
                      C     HLEN(I)       AGE-SPECIFIC HYBRID MEAN LENGTH                  C
                      C     HG(I)         AGE-SPECIFIC HYBRID INSTANTANEOUS GROWTH RATE C
                      C     HWT(I)        AGE-SPECIFIC HYBRID MEAN WEIGHT                  C
                      C     HZ(I)         AGE-SPECIFIC HYBRID TOTAL MORTALITY RATE         C
                      C     HFMORT(I)     AGE-SPECIFIC HYBRID FISHING MORTALITY RATE       C
                      C     HNMORT(I)     AGE-SPECIFIC HYBRID NATURAL MORTALITY RATE       C
                      C                                                                    C
                      CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
ISN       19                DATA WAWT,WBWT,HAWT,HBWT/0.000003,3.26,0.000009,3.05/
ISN       20                DATA A2,A3,B2,A11,GENDER,XNEG/0.04,0.08,-0.0008,0.95,0.5,-1.0/
ISN       21                DATA A1,B1,AVERAG,STDDEV,U,ISEED/0.70,-0.0000005,1.0,0.085,0.5,5/
                      C          READ INPUT DATA FOR AGE GROUPS, YEARS, YEAR
ISN       22                  READ (1,1,END=781) K, NYR, JYEAR, HSTOCK
ISN       23          1       FORMAT(I1,1X,I2,1X,I4,1X,F7.1)
ISN       24                  PRINT 1001, K, NYR, JYEAR, HSTOCK
ISN       25          1001  FORMAT(1H0,I1,1X,I2,1X,I4,5X,F8.1,5X,'#CLASS,#YR,BEGIN,STOCK')
ISN       26                   LAST=JYEAR+NYR
                      C           READ DATA FOR FECUNDITY,SURVIVAL, SAMPLE SIZE, GROWTH, WEIGHT,
                      C         TOTAL MORTALITY, FISHING MORTALITY, AND NATURAL MORTALITY
ISN       27                  READ (2,2)(FERT(I), WSURV(I), WN(I), WLEN(I), WG(I), WWT(I),
                            $  WZ(I), WFMORT(I), WNMORT(I), I=1,K)
ISN       28          2     FORMAT (F8.1,1X,F4.2,1X,F6.0,1X,F5.1,1X,F5.3,1X,F6.1,
                            $            1X,F4.2,1X,F4.2,1X,F4.2)
ISN       29                  PRINT 2001,(FERT(I),WSURV(I),WN(I),I=1,K)
ISN       30          2001     FORMAT (1H0, F12.1,1X,F9.2,1X,F9.0,2X,'FEC, SURV, FREQ')
                      C            READ IN DATA FOR HYBRIDS
                      C           READ IN DATA FOR HYBRID STOCKING (CONSTANT ANNUALL STOCKING)
ISN       31                READ (3,3)(HSURV(I), HN(I), HLEN(I), HG(I), HWT(I), HZ(I),
                            $     HFMORT(I), HNMORT(I), I=1,K)
ISN       32          3       FORMAT (F4.2,1X,F3.1,1X,F5.1,1X,F5.3,1X,F6.1,1X,F4.2,
                            $            1X,F4.2,1X,F4.2,1X,'HYBRID INPUT VALUES')
ISN       33                  PRINT 3001,(HSURV(I),HN(I),I=1,K)
ISN       34          3001     FORMAT (1H0, F9.2,1X,F9.0,2X,'SURV, FREQ')
                      C
                      CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
                      C                                                                C
                      C         THIS PROGRAM SEGMENT CALLS TWO SUBROUTINES FOR         C
                      C         COMPUTATION OF WHITE BASS FRY SURVIVAL RATE AND FOR    C
                      C         HYBRID FINGERLING SURVIVAL RATE                        C
                      C                                                                C
                      C                                                                C
                      C       CALL SUBROUTINE TO COMPUTE FRY SURVIVAL FOR WHITE BASS   C
                      C                                                                C
ISN       35                 CALL CHRYSO(WVIVE)
                      C                                                                C
                      C       CALL SUBROUTINE TO COMPUTE FRY SURVIVAL FOR HYBRID       C
                      C                                                                C
ISN       36                 CALL HYBRID(HVIVE)
                      C                                                                C
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LEVEL 1.4.1 (MAY 1985)            VS FORTRAN          DATE: FEB 23, 1987    TIME: 10:23.54        NAME: MAIN     PAGE      4

                         *....*...1.........2.........3.........4.........5.........6.........7.*.......8

                         CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
                         C      THIS PROGRAM SEGMENT COMPUTES TOTAL POPULATION SIZE FOR   C
                         C      BOTH SPECIES AS WELL AS AGE-SPECIFIC MEAN LENGTH, MEAN    C
                         C      WEIGHT, AND MEAN ANNUAL BIOMASS. IT ALSO COMPUTES TOTAL   C
                         C      POPULATION SIZE FOR EACH SPECIES AS WELL AS FOR THE       C
                         C      ENTIRE FISHERY. TOTAL BIOMASS FOR EACH SPECIES AS WELL AS C
                         C      FOR THE ENTIRE FISHERY IS ALSO COMPUTED                   C
                         C                                                                C
                         C      THE VARIABLE NAMES ARE:                                   C
                         C                                                                C
                         C      VARIABLE NAME          USAGE                              C
                         C        WTOT          TOTAL ANNUAL WHITE BASS POPULATION SIZE   C
                         C        HTOT          TOTAL ANNUAL HYBRID POPULATION SIZE       C
                         C        TOT           TOTAL ANNUAL POPULATION SIZE OF FISHERY   C
                         C        WAVLEN(I)     MEAN ANNUAL LENGTH OF WHITE BASS OF AGE   C
                         C                      I+1 AT TIME AT TIME T+1                   C
                         C        HAVLEN(I)     MEAN ANNUAL LENGTH OF HYBRID OF AGE       C
                         C                      I+1 AT TIME AT TIME T+1                   C
                         C        WBIOMS(I)     MEAN ANNUAL BIOMASS OF WHITE BASS OF      C
                         C                      AGE GROUP I                               C
                         C        WAVWT(I)      MEAN ANNUAL WEIGHT OF WHITE BASS OF AGE   C
                         C                      I+1 AT TIME T+1                           C
                         C        HBIOMS(I)     MEAN ANNUAL BIOMASS HYBRID OF AGE GROUP I C
                         C        HAVWT(I)      MEAN ANNUAL WEIGHT OF HYBRID OF AGE       C
                         C                      I+1 AT TIME T+1                           C
                         C        SUMBIO        ANNUAL TOTAL WHITE BASS AND HYBRID BIOMASSC
                         C        WTOTBI        ANNUAL TOTAL WHITE BASS BIOMASS           C
                         C        HTOTBI        ANNUAL TOTAL HYBRID BIOMASS               C
                         C        BIOMAS(I)     AGE-SPECIFIC TOTAL ANNUAL BIOMASS FOR     C
                         C                      BOTH SPECIES                              C
                         C                                                                C
                         CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
                         C       COMPUTE TOTAL POPULATION SIZE FOR BOTH SPECIES
ISN        37            172         TOT=0.0
ISN        38                        WTOT=0.0
ISN        39                        HTOT=0.0
ISN        40                        DO 5 I=1,K
ISN        41                              WTOT=WTOT+WN(I)
ISN        42                              HTOT=HTOT+HN(I)
ISN        43                              TOT=HTOT+WTOT
ISN        44            5           CONTINUE
                         C
                         C
                         C           COMPUTE MEAN WEIGHT AT AGE FOR WHITE BASS
                         C
ISN        45                          DO 6 I=1,K
ISN        46                                WWF(I)=XNEG*WZ(I)
ISN        47                                WREXP(I)=EXP(WWF(I))
ISN        48                                WBG(I)=WBWT*WG(I)*PG
ISN        49                                WEEXP(I)=EXP(WBG(I))
ISN        50                                WEXPG(I)=EXP(WG(I)*PG)
ISN        51                                WAVLEN(I)=WLEN(I)*WEXPG(I)
ISN        52                                WAVWT(I)=WWT(I)*WEEXP(I)
ISN        53                                WBIOMS(I)=WN(I)*WWT(I)*0.001
ISN        54            6             CONTINUE
                         C
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LEVEL 1.4.1 (MAY 1985)          VS FORTRAN          DATE: FEB 23, 1987    TIME: 10:23:54       NAME: MAIN     PAGE:     5
              *....*...1.........2.........3.........4.........5.........6.........7.*...... 8
              C             COMPUTE MEAN WEIGHT AT AGE FOR HYBRID
              C
ISN        55             DO 7 I=1,K
ISN        56                  HHF(I)=XNEG*HZ(I)
ISN        57                  HREXP(I)=EXP(HHF(I))
ISN        58                  HBG(I)=HBWT*HG(I)*PG
ISN        59                  HEEXP(I)=EXP(HBG(I))
ISN        60                  HEXPG(I)=EXP(HG(I)*PG)
ISN        61                  HAVLEN(I)=HLEN(I)*HEXPG(I)
ISN        62                  HAVWT(I)=HWT(I)*HEEXP(I)
ISN        63                  HBIOMS(I)=HN(I)*HWT(I)*0.001
ISN        64 7           CONTINUE
              C
              C       COMPUTE MEAN BIOMASS AT AGE FOR WHITE BASS
              C
ISN        65                    HTOTBI=0.0
ISN        66                    WTOTBI=0.0
ISN        67                    SUMBIO=0.0
ISN        68                DO 8 I=1,K
ISN        69                    IF (WBG(I) .LT. WZ(I)) THEN
ISN        70                       WZEXP(I)=-(WZ(I)-WBG(I))
ISN        71                       WZZEXP(I)=EXP(WZEXP(I))
ISN        72                       WZUPER(I)=1-WZZEXP(I)
ISN        73                       WZDENM(I)=WZ(I)-WBG(I)
ISN        74                    ELSEIF (WBG(I) .GT. WZ(I)) THEN
ISN        75                       WZEXP(I)=(WBG(I)-WZ(I))
ISN        76                       WZZEXP(I)=EXP(WZEXP(I))
ISN        77                       WZUPER(I)=(WZZEXP(I)-1)
ISN        78                       WZDENM(I)=WBG(I)-WZ(I)
ISN        79                    ENDIF
ISN        80                       WAVBIO(I)=WBIOMS(I)*WZUPER(I)/WZDENM(I)
              C
              C           COMPUTE MEAN BIOMASS AT AGE AND TOTAL BIOMASS FOR HYBRID
              C
ISN        81                    IF (HBG(I) .LT. HZ(I)) THEN
ISN        82                       HZEXP(I)=-(HZ(I)-HBG(I))
ISN        83                       HZZEXP(I)=EXP(HZEXP(I))
ISN        84                       HZUPER(I)=1-HZZEXP(I)
ISN        85                       HZDENM(I)=HZ(I)-HBG(I)
ISN        86                    ELSEIF (HBG(I) .GT. HZ(I)) THEN
ISN        87                       HZEXP(I)=(HBG(I)-HZ(I))
ISN        88                       HZZEXP(I)=EXP(HZEXP(I))
ISN        89                       HZUPER(I)=(HZZEXP(I)-1)
ISN        90                       HZDENM(I)=HBG(I)-HZ(I)
ISN        91                    ENDIF
ISN        92                       HAVBIO(I)=HBIOMS(I)*HZUPER(I)/HZDENM(I)
ISN        93                       HTOTBI=HTOTBI+HAVBIO(I)
ISN        94                       WTOTBI=WTOTBI+WAVBIO(I)
              C                   COMPUTE TOTAL ANNUAL MEAN BIOMASS FOR BOTH SPECIES
ISN        95                       BIOMAS(I)=HAVBIO(I)+WAVBIO(I)
ISN        96                       SUMBIO=SUMBIO+BIOMAS(I)
ISN        97 8                     CONTINUE
              C
              CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
              C                                                                    C
              C    THIS PROGRAM SEGMENT COMPUTE DENSITY-DEPENDENT EFFECTS ON       C
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LEVEL 1.4.1 (MAY 1985)           VS FORTRAN          DATE: FEB 23, 1987    TIME: 10:23:54       NAME: MAIN    PAGE:     6
               *....*...1.........2.........3.........4.........5.........6.........7.*.......8
               C               (I) SURVIVAL OF STOCKED HYBRID FINGERLING           C
               C               (II) WHITE BASS FECUNDITY                           C
               C               (III) PROPORTION OF GROWTH ACHIEVED BY ADULTS OF    C
               C                     BOTH SPECIES                                  C
               C                                                                   C
               C          VARIABLE NAME              USAGE                         C
               C                                                                   C
               C            STKSUV           SURVIVAL RATE OF STOCKED HYBRID       C
               C                             FINGERLING DUE TO DENSITY-DEPENDENCE  C
               C                                                                   C
               C            EGGDEN           PROPORTION OF THEORETICAL FECUNDITY   C
               C                             REALIZED BY FEMALE WHITE BASS DUE     C
               C                             TO DENSITY-DEPENDENCE                 C
               C                                                                   C
               C            PG               PROPORTION OF GROWTH IN LENGTH        C
               C                             ACHIEVED BY ADULTS OF BOTH SPECIES    C
               C                             AS A RESULT OF DENSITY-DEPENDENCE     C
               CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
               C      INSERT DENSITY DEPENDENT EFFECTS ON BOTH POPULATIONS HERE
ISN        98                  IF (SUMBIO .GE. 700.0) THEN
ISN        99                         STKSUV=A2*EXP(B2*SUMBIO)
ISN       100                         EGGDEN=A1*EXP(B1*SUMBIO)
ISN       101                         PG=0.90*EXP(B1*SUMBIO)
ISN       102               ELSEIF (SUMBIO .LT. 700.0) THEN
ISN       103                         EGGDEN=1.0*A11*EXP(B1*SUMBIO)
ISN       104                         STKSUV=A3*EXP(B2*SUMBIO)
ISN       105                         PG=1.05*EXP(B1*SUMBIO)
ISN       106                      ENDIF
               C
               C     COMPUTE CATCH, YIELD, GROSS AND NET PRODUCTION FOR WHITE BASS
               C
ISN       107                  WGP=0.0
ISN       108                  WNP=0.0
ISN       109                  DO 37 I=1,K
ISN       110                     WJEXP(I)=1-WREXP(I)
ISN       111                     WYRCL(I)=(WN(I)*WJEXP(I))/WZ(I)
ISN       112                     WCATCH(I)=WFMORT(I)*WYRCL(I)
ISN       113                     WYIELD(I)=WFMORT(I)*WAVBIO(I)
ISN       114                     WGPROD(I)=WB*WG(I)*WAVBIO(I)*PG
ISN       115                     WNEPRO(I)=(WB*WG(I)*WAVBIO(I)*PG-WB*WZ(I)*WAVBIO(I))
ISN       116                     WNP=WNP+WNEPRO(I)
ISN       117                     WGP=WGP+WGPROD(I)
ISN       118  37                 CONTINUE
               C
               C      PRINT OUTPUT FOR MEAN WEIGHT AT AGE, TOTAL ANNUAL BIOMASS
               C      AND AVERAGE ANNUAL BIOMASS FOR WHITE BASS
               C
ISN       119        PRINT 55, (WAVWT(I),WBIOMS(I),WAVBIO(I),WTOTBI,WAVLEN(I),I=1,K)
ISN       120  55     FORMAT(1HO,F8.O,1X,F8.O,1X,F8.O,1X,F8.O,1X,F8.O,1X,'SBBIOMASS')
               C
               C       PRINT OUTPUT FOR WHITE BASS
               C     CATCH, YEAR CLASS STRENGTH, YIELD, GROSS AND NET PRODUCTION
               C
ISN       121          PRINT 59, (WCATCH(I), WYIELD(I), WGPROD(I), WNEPRO(I), I=1,K)
ISN       122  59      FORMAT (1HO,F8.O,1X,F8.O,1X,F8.O,1X,F8.O,1X,'WBASS HARVEST')
               C
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LEVEL 1.4.1 (MAY 1985)          VS FORTRAN          DATE: FEB 23, 1987    TIME: 10:23:54      NAME: MAIN     PAGE:      7
                •....•...1.........2.........3.........4.........5.........6.........7.•.......8

                C
                C
                C     COMPUTE CATCH, YIELD, GROSS AND NET PRODUCTION FOR HYBRID BASS
                C
ISN       123                   HNE=0.0
ISN       124                   HGP=0.0
ISN       125                   DO 307 I=1,K
ISN       126                      HJEXP(I)=1-HREXP(I)
ISN       127                      HYRCL(I)=(HN(I)*HJEXP(I))/HZ(I)
ISN       128                      HCATCH(I)=HFMORT(I)*HYRCL(I)
ISN       129                      HYIELD(I)=HFMORT(I)*HAVBIO(I)
ISN       130                      HGPROD(I)=HB*HG(I)*HAVBIO(I)*PG
ISN       131                      HNEPRO(I)=(HB*HG(I)*HAVBIO(I)*PG-HB*HZ(I)*HAVBIO(I))
ISN       132                      HNP=HNP+HNEPRO(I)
ISN       133                      HGP=HGP+HGPROD(I)
ISN       134   307            CONTINUE
                C
                CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
                C                                                                   C
                C         THIS PROGRAM SEGMENT COMPUTES PROPORTIONAL STOCK DENSITY C
                C         FOR BOTH SPECIES. QUALITY AND STOCK LENGTHS USED IN       C
                C         COMPUTATIONS ARE FROM GABELHOUSE (1984)                   C
                C                                                                   C
                C        VARIABLE NAME          USAGE                               C
                C                                                                   C
                C         WSTK          ANNUAL NUMBER OF WHITE BASS OF AT LEAST     C
                C                       STOCK LENGTH                                C
                C         HSTK          ANNUAL NUMBER OF HYBRID OF AT LEAST         C
                C                       STOCK LENGTH                                C
                C         WQUAL         ANNUAL NUMBER OF WHITE BASS OF AT LEAST     C
                C                       QUALITY LENGTH                              C
                C         HQUAL         ANNUAL NUMBER OF HYBRID OF AT LEAST         C
                C                       QUALITY LENGTH                              C
                C         HPSD          HYBRID ANNUAL PROPORTIONAL STOCK DENSITY    C
                C                                                                   C
                C         WPSD          WHITE BASS ANNUAL PROPORTIONAL STOCK        C
                C                       DENSITY                                     C
                C                                                                   C
                CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
                C      COMPUTE PROPORTIONAL STOCK DENSITY FOR BOTH SPECIES
                C
                C      INITIALIZE NUMBER OF FISH OF QUALITY AND STOCK SIZES TO ZERO
ISN       135                       WSTK=0.0
ISN       136                       HSTK=0.0
ISN       137                       WQUAL=0.0
ISN       138                       HQUAL=0.0
ISN       139                    DO 880 I=1,K
ISN       140                      IF(WAVLEN(I) .GE. 150.0) THEN
ISN       141                          WSTK=WSTK+WN(I)
ISN       142                      ENDIF
ISN       143                      IF(HAVLEN(I) .GE. 200.0) THEN
ISN       144                          HSTK=HSTK+HN(I)
ISN       145                      ENDIF
ISN       146                      IF(WAVLEN(I) .GE. 230.0) THEN
ISN       147                          WQUAL=WQUAL+WN(I)
ISN       148                      ENDIF
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LEVEL 1.4.1 (MAY 1985)            VS FORTRAN          DATE: FEB 23, 1987     TIME: 10:23:54       NAME: MAIN     PAGE:     8
                 *....*...1.........2.........3.........4.........5.........6.........7.*.......8
                   IF(HAVLEN(I) .GT. 300.0) THEN
                          HQUAL=HQUAL+HN(I)
                   ENDIF
880              CONTINUE
C
C                  COMPUTE PSD'S HERE
C
C          WPSD IS WHITE BASS PSD
C       PSD IS CALCULATED ONLY IF NUMBER OF STOCK SIZE FISH EXCEEDS 0
C
           IF (WSTK .GT. 0.0) THEN
              WPSD=WQUAL*100.0/WSTK
           ENDIF
C          HPSD IS HYBRID PSD
           IF (HSTK .GT. 0.0) THEN
              HPSD=HQUAL*100.0/HSTK
           ENDIF
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                           C
C     THIS PROGRAM SEGMENT COMPUTES TOTLA YIELD AND HARVEST C
C     FOR BOTH SPECIES                                      C
C                                                           C
C      VARIABLE             USAGE                           C
C      WYLD         TOTAL ANNUAL WHITE BASS YIELD(KG)       C
C      HYLD         TOTAL ANNUAL HYBRID YIELD (KG)          C
C      WHAVST       TOTAL ANNUAL WHITE BASS HARVEST         C
C      HHAVST       TOTAL ANNUAL HYBRID HARVEST             C
C                                                           C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C          COMPUTE TOTAL YIELD AND HARVEST FOR BOTH SPECIES
C          INITIALIZE TOTAL YIELD AND HARVEST TO ZERO
                    WYLD=0.0
                    HYLD=0.0
                    WHAVST=0.0
                    HHAVST=0.0
                       DO 440 I=1,K
                        WYLD=WYLD+WYIELD(I)
                        HYLD=HYLD+HYIELD(I)
                        WHAVST=WHAVST+WCATCH(I)
                        HHAVST=HHAVST+HCATCH(I)
440                    CONTINUE
C
C      PRINT OUTPUT FOR HARVEST, YIELD, AND PSD
C
         PRINT 950, WHAVST, HHAVST, WYLD, HYLD, WPSD, HPSD
950    FORMAT(1H0,F6.0,1X,F6.0,1X,F6.0,1X,F6.0,1X,F6.0,1X,F6.0,'PSD')
C
C      PRINT OUTPUT FOR MEAN WEIGHT AT AGE, TOTAL ANNUAL BIOMASS
C      AND AVERAGE ANNUAL BIOMASS FOR HYBRID BASS
C
C
      PRINT 505, (HAVWT(I),HBIOMS(I),HAVBIO(I),HTOTBI,HAVLEN(I),I=1,K)
505   FORMAT(1H0,F8.0,1X,F8.0,1X,F8.0,1X,F8.0,1X,F8.0,1X,'HBBIOMASS')
```

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LEVEL 1.4.1 (MAY 1985)          VS FORTRAN          DATE: FEB 23, 1987    TIME: 10:23:54       NAME: MAIN     PAGE:     9

               *....*...1.........2.........3.........4.........5.........6.........7.*.......8

               C
               C       PRINT OUTPUT FOR HYBRID
               C     CATCH, YEAR CLASS STRENGTH, YIELD, GROSS AND NET PRODUCTION
               C
ISN     173            PRINT 509, (HCATCH(I), HYIELD(I), HGPROD(I), HNEPRO(I), I=1,K)
ISN     174    509    FORMAT(1HO,F8.O,1X,F8.O,1X,F8.O,1X,F8.O,1X,'HYBRID HARVEST')
               C
               C         PRINT TOTAL, WHITE BASS, AND HYBRID BIOMASS
               C
ISN     175            PRINT 19, SUMBIO, WTOTBI, HTOTBI
ISN     176    19     FORMAT (1HO,F7.O,1X,F7.O,1X,F7.O,2X,'TOTAL SANDBASS HYBRID')
               C
               C
               C
               CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
               C                                                      C
               C   THIS PROGRAM SEGMENT CALLS THE SUBROUTINES FOR WHITE C
               C   BASS SPAWNING AND FOR GENERATION ON RANDOM NORMAL    C
               C                                                      C
               C      VARIABLE NAME        USAGE                      C
               C                                                      C
               C       SPAWN          SUBROUTINE FOR WHITE BASS FECUNDITY C
               C       NORMAL         SUBROUTINE FOR GENERATION OF RANDOM C
               C                      NORMAL VARIATE                  C
               C                                                      C
               C                                                      C
               CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
               C          CALL SUBROUTINE FOR WHITE BASS SPAWNING
ISN     177                    CALL SPAWN
               C          CALL SUBROUTINE FOR RANDOM NORMAL VARIATE
ISN     178                  CALL NORMAL (ISEED,AVERAG, STDDEV, RANDEV)
               C
               CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
               C                                                           C
               C     THIS PROGRAM SEGMENT COMPUTES STOCHASTIC EFFECTS ON   C
               C     SURVIVAL OF HYBRID FINGERLING AND WHITE BASS EGGS TO  C
               C     AGE 1. IT ALSO COMPUTES WHITE BASS FECUNDITY AS A     C
               C     RESULT OF DENSITY-DEPENDENCE, RATIO OF THEORETICAL    C
               C     VERSUS ACHIEVED FECUNDITY, PERCENT OF ADULT WHITE BASS C
               C     IN THE POPULATION, AND THE DENSITY-DEPENDENT EFFECTS  C
               C     ON STOCKED HYBRID FINGERLING                          C
               C                                                           C
               C     VARIABLE NAME               USAGE                     C
               C     YOYCF            STOCHASTIC EFFECT ON WHITE BASS      C
               C                      SURVIVAL TO AGE 1                    C
               C     RANDEV           NORMALLY DISTRIBUTED RANDOM VARIATE  C
               C                      OF MEAN 1 AND STANARD DEVIATION      C
               C                      PROVIDED BY USER                     C
               C     HATCH            NUMBER OF WHITE BASS EGGS THAT ARE   C
               C                      PRODUCED AS A RESULT OF DENSITY-     C
               C                      DEPENDENT MECHANISMS                 C
               C     GENDER           WHITE BASS SEX RATIO (ASSUME 50%)    C
               C     SUMEGG           THEORETICAL WHITE BASS FECUNDITY     C
               C     PERCEN           RATIO OF WHITE BASS IN POPULATION    C
               C     WRATIO           RATIO OF THEORETICAL VERSUS ACHIEVED C
               C                      WHITE BASS FECUNDITY                 C
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LEVEL 1.4.1 (MAY 1985)           VS FORTRAN          DATE: FEB 23, 1987    TIME: 10:23:54      NAME: MAIN     PAGE:    10

               *....*...1.........2.........3.........4.........5.........6.........7.*.......8
               C     HYBFRY           NUMBER OF STOCKED HYBRID FINGERLING    C
               C                      THAT SURVIVE AS A RESULT OF DENSITY-   C
               C                      DEPENDENCE                             C
               C     HRATIO           DENSITY-DEPENDENT SURVIVAL RATIO OF    C
               C                      HYBRID FINGERLING                      C
               C                                                             C
               CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
ISN       179                         YOYCF*EXP(RANDEV)
               C
               C                PRINT Y-O-Y CORRECTION FACTOR
               C
ISN       180                    PRINT 1018, YOYCF
ISN       181  1018             FORMAT( 1H0,F14.8,7X,'Y-O-Y CORRECTION FACTOR')
               C
               C      PRINT YOUNG OF THE YEAR SURVIVAL RATES FOR WHITE BASS & HYBRID
ISN       182            PRINT 4, WVIVE,HVIVE
ISN       183  4         FORMAT( 1H0,F20.6,1X,F20.6,1X,'Y-O-Y SURVIVAL RATES')
               C       PRINT TOTAL NUMBER OF WHITE BASS EGGS
ISN       184                  PRINT 81, SUMEGG, PG
ISN       185  81     FORMAT ( 1H0, F28.0,1X,F8.4,1X,'EGG POTENTIAL & PROP GROWTH')
               C
               C             MANIPULATE EGG PRODUCTION USING DENSITY DEPENDENCE
               C
ISN       186                HATCH=SUMEGG*EGGDEN*RANDEV*GENDER/RANDEV
               C
               C      COMPUTE HATCH RATE DUE TO DENSITY-DEPENDET EFFECTS
               C
               C             COMPUTE RATIO ONLY IF SUMEGG IS GREATER THAN ZERO
               C
ISN       187                IF (SUMEGG .GT. 0.0) THEN
ISN       188                WRATIO=HATCH*100.0/SUMEGG
ISN       189                ENDIF
               C            COMPUTE PROPORTION OF WHITE BASS IN THE POPULATION
ISN       190                  IF (TOT .GT. 0.0) THEN
ISN       191                    PERCEN=WTOT/TOT*100.0
ISN       192                  ENDIF
               C
               C      COMPUTE DENSITY-DEPENDENT HYBRID FINGERLING SURVIVAL RATE
               C
ISN       193                  IF (HSTOCK .GT. 0.0) THEN
ISN       194                     HYBFRY=STKSUV*HSTOCK
ISN       195                     HRATIO=HYBFRY*100.0/HSTOCK
ISN       196                  ENDIF
               C             PRINT SUMEGG, EGGDEN, RANDEV, GENDER, HATCH, WRATIO
               C
ISN       197         PRINT 91, SUMEGG,EGGDEN,RANDEV,GENDER,HATCH,WRATIO,PERCEN,HRATIO
ISN       198  91         FORMAT ( 1H0,F15.0,1X,F9.7,1X,F7.5,1X,F3.1,1X,
                    $  F15.0,1X,F10.6,1X,F8.4,1X,F10.6,3X,'S E R G H  W-&-HRATIO')
               C
               C          INSERT DENSITY DEPENDENT MANIPULATIONS ON EGG PRODUCTION
               C
ISN       199                         FAMILY=0.0
ISN       200                      DO 10 I=1,K
ISN       201          CLUTCH(I)=FERT(I)*WN(I)*EGGDEN*RANDEV*GENDER/RANDEV
ISN       202                         FAMILY=FAMILY+CLUTCH(I)
ISN       203                     PRINT 11, FAMILY, CLUTCH(I)
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LEVEL 1.4.1 (MAY 1985)          VS FORTRAN          DATE: FEB 23, 1987     TIME: 10:23:54       NAME: MAIN     PAGE:    11

                •....•...1.........2.........3.........4.........5.........6.........7.•.......8

ISN      204    11            FORMAT (1H0,F18.0,1X,F12.0,2X,'EGGS',2X,'EGGS/AGE')
ISN      205    10                CONTINUE
                C
                C       PRINT EGG DENSITY DEPENDENT FACTOR AND RANDOM VARIATE
                C
ISN      206           PRINT 12, EGGDEN, RANDEV, HSTOCK, STKSUV
ISN      207    12     FORMAT (1H0, F19.6, 1X, F19.6, 1X, F8.0, 1X, F10.6,1X,'STKSURV')
                C
                C         PRINT OUTPUT FOR START OF NEXT YEAR (WHITE BASS AND HYBRID)
                C
ISN      208                   PRINT 13, JYEAR, TOT, WTOT, HTOT, SUMEGG, HATCH
ISN      209    13     FORMAT (1H0,I4,2X,F10.0,2X,F10.0,2X,F10.0,2X,F15.0,1X,F12.0)
                C           PRINT AGE SPECIFIC SAMPLE SIZES IN POPULATION
ISN      210                   PRINT 14, (WN(I), HN(I), I=1,K)
ISN      211    14          FORMAT (1H0, F8.0, 2X,'SAND BASS',1X, F8.0,2X,'HYBRID')
                C
                C               CREATE OUTFILE  FOR GRAPHICS
                C
ISN      212                  WRITE(10,66) JYEAR,TOT,WTOT,HTOT,SUMBIO,WTOTBI,HTOTBI
ISN      213    66     FORMAT(1X,I4,1X,F6.0,1X,F6.0,1X,F6.0,1X,F6.0,1X,F6.0,1X,F6.0)
                C
ISN      214           WRITE(11,616)JYEAR,TOT,WTOT,HTOT,SUMEGG,HATCH,WRATIO,PERCEN,
                     $ HRATIO
ISN      215    616    FORMAT(1X,I4,1X,F6.0,1X,F6.0,1X,F6.0,1X,F12.0,1X,
                     $ F10.0,1X,F6.3,1X,F6.3,1X,F6.3)
                C
                C
                C
                C     CREATE ANOTHER OUTFILE FOR HARVEST, YIELD, AND PSD
                C
ISN      216            WRITE(13,95) JYEAR, WHAVST, HHAVST, WYLD, HYLD, WPSD, HPSD
ISN      217    95      FORMAT(1X,I4,1X,F6.0,1X,F6.0,1X,F6.0,1X,F6.0,1X,F6.0,1X,F6.0)
                C
                C     CREATE ANOTHER OUTFILE FOR NET AND GROSS PRODUCTION
                C
ISN      218           WRITE(12,2914) JYEAR,WNP,WGP,HNP,HGP
ISN      219    2914   FORMAT(1X,I4,2X,F5.0,2X,F5.0,2X,F5.0,2X,F5.0)
                C
                C
                C     CREATE ANOTHER OUTFILE FOR LENGTHS- AND WEIGHTS-AT-AGE
                C
ISN      220                 DO 555 I=1,K
ISN      221           WRITE(14,2994) JYEAR,I,WAVLEN(I),WAVWT(I),HAVLEN(I),HAVWT(I)
ISN      222    2994   FORMAT(1X,I4,2X,I2,2X,F5.0,2X,F5.0,2X,F5.0,2X,F5.0)
ISN      223    555          CONTINUE
ISN      224                      IF (JYEAR .GT. LAST) GO TO 1888
                C
                C            GENERATE NEW AGE DISTRIBUTION FOR NEXT YEAR
                C
ISN      225                         DO 15 I=1,K
ISN      226                           IWLSTY(I)=WN(I)
ISN      227                           IHLSTY(I)=HN(I)
ISN      228    15                   CONTINUE
                C
                C                    INCLUDE SURVIVAL FACTOR
                C
```

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LEVEL 1.4.1 (MAY 1985)          VS FORTRAN          DATE: FEB 23, 1987    TIME: 10:23:54       NAME: MAIN    PAGE:    12

               *....*...1.........2.........3.........4.........5.........6.........7.*.......8

ISN      229                         DO 16 I=1,K
ISN      230                           WN(I+1)=IWLSTY(I)*WSURV(I)
ISN      231                           HN(I+1)=IHLSTY(I)*HSURV(I)
ISN      232   16                    CONTINUE
               C
               CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
               C                                                             C
               C      THIS PROGRAM SEGMENT COMPUTES ANNUAL POPULATION SIZE   C
               C      OF AGE I FISH. FOR THE WHITE BASS, IT USES INFORMATION C
               C      ON ACHIEVED FECUNDITY DUE TO DENSITY-DEPENDENCE AS WELLC
               C      AS RANDOM FLUCTUATION. FOR THE HYBRID, IT USES RANDOM  C
               C      VARIATION AS WELL AS THE DENSITY DEPENDENT SURVIVAL    C
               C      RATE OF STOCKED FINGERLINGS                            C
               C                                                             C
               C        VARIABLE NAME          USAGE                         C
               C                                                             C
               C         WVIVE           SURVIVAL RATE OF WHITE BASS FROM    C
               C                         EGGS TO AGE I                       C
               C         HVIVE           SURVIVAL RATE OF HYBRID FINGERLINGS C
               C                         TO AGE I                            C
               CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
               C                    COMPUTE AGE 1 YEAR CLASS STRENGTH
               C        COMPUTE Y-O-Y SURVIVAL CORRECTION FACTOR (YOYCF)
               C
               C
ISN      233                       WN(1)=HATCH*WVIVE*YOYCF
ISN      234                       HN(1)=HSTOCK*HVIVE/HVIVE*STKSUV*YOYCF
ISN      235                       JYEAR=JYEAR+1
ISN      236                       GO TO 172
               C
               C                PRINT END OF DATA PROCESSING
               C
ISN      237   1888             PRINT 17
ISN      238   17              FORMAT (1H0,44X,'SIMULATION TERMINATED NORMALLY')
ISN      239   781                       STOP
ISN      240                             END

*STATISTICS*   SOURCE STATEMENTS = 240, PROGRAM SIZE = 10716 BYTES, PROGRAM NAME = MAIN       PAGE:     1.

*STATISTICS*    NO DIAGNOSTICS GENERATED.

**MAIN** END OF COMPILATION 1 ******
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LEVEL 1.4.1 (MAY 1985)          VS FORTRAN          DATE: FEB 23, 1987    TIME: 10:23:55                   PAGE:    13

OPTIONS IN EFFECT:  NOLIST NOMAP NOXREF NOGOSTMT NODECK   SOURCE NOTERM   OBJECT FIXED  NOTEST NOTRMFLG   SRCFLG
                    NOSYM NORENT   SDUMP AUTODBL(NONE)   NOSXM   IL
                      OPT(3) LANGLVL(77) NOFIPS   FLAG(I)  NAME(MAIN  )  LINECOUNT(60)      CHARLEN(500)

               *....*...1.........2.........3.........4.........5.........6.........7.*.......8

               C
               CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
               C                                                                  C
               C      THIS SUBROUTINE COMPUTES TOTAL ANNUAL WHITE BASS FECUNDITY  C
               CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
               C     SUBROUTINE SPAWN COMPUTES THE TOTAL WHITE BASS EGG PRODUCTION
               C
ISN        1                SUBROUTINE SPAWN
               C
ISN        2         COMMON/YOA/K,WN(5),HN(5),TOT,WTOT,HTOT,WSURV(5),HSURV(5),JYEAR
ISN        3         COMMON/YOB/FERT(5),SUMEGG,WCATCH(5),HCATCH(5),WBG(5),HBG(5)
ISN        4                  SUMEGG=0.0
ISN        5                    DO 88 I=1,K
ISN        6                      SUMEGG=SUMEGG+(FERT(I)*WN(I))
ISN        7   88               CONTINUE
ISN        8                    RETURN
ISN        9                    END

*STATISTICS*   SOURCE STATEMENTS = 9, PROGRAM SIZE = 904 BYTES, PROGRAM NAME = SPAWN      PAGE:    13.

*STATISTICS*    NO DIAGNOSTICS GENERATED.

**SPAWN** END OF COMPILATION 2 ******
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LEVEL 1.4.1 (MAY 1985)          VS FORTRAN          DATE: FEB 23, 1987    TIME: 10:23:55                    PAGE:    14

OPTIONS IN EFFECT:  NOLIST NOMAP NOXREF NOGOSTMT NODECK   SOURCE NOTERM   OBJECT FIXED  NOTEST NOTRMFLG   SRCFLG
                    NOSYM NORENT   SDUMP AUTODBL(NONE)   NOSXM   IL
                      OPT(3) LANGLVL(77) NOFIPS   FLAG(I)  NAME(MAIN  )  LINECOUNT(60)      CHARLEN(500)

                 *....*...1.........2.........3.........4.........5.........6.........7.*.......8

                 C
                 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
                 C                                                                  C
                 C      THIS SUBROUTINE COMPUTES ANNUAL WHITE BASS SURVIVAL RATE    C
                 C      FROM EGG STAGE TO AGE I USING THE METHOD OF VAUGHAN AND     C
                 C      SAILA (1976)                                                C
                 C                                                                  C
                 C      VARIABLE NAME             USAGE                             C
                 C                                                                  C
                 C         WVIVE           SURVIVAL RATE OF WHITE BASS FROM         C
                 C                         EGGS TO AGE I                            C
                 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
                 C           SUBROUTINE TO COMPUTE WHITE BASS Y-O-Y & FRY SURVIVAL
                 C
ISN           1                     SUBROUTINE CHRYSO(WVIVE)
ISN           2        COMMON/YOA/K,WN(5),HN(5),TOT,WTOT,HTOT,WSURV(5),HSURV(5),JYEAR
ISN           3        COMMON/YOB/FERT(5),SUMEGG,WCATCH(5),HCATCH(5),WBG(5),HBG(5)
ISN           4              WADD=0.0
ISN           5              WPROD=1.0
ISN           6              L=K-1
                 C           COMPUTE FECUNDITY & SURVIVAL (CUMMULATIVE) HERE
ISN           7                        DO 89 I=1,L
ISN           8                           WPROD=WPROD*WSURV(I)
ISN           9                           WADD=WADD+FERT(I+1)*WPROD
ISN          10   89                   CONTINUE
ISN          11                        WVIVE=1.0/WADD
ISN          12                        RETURN
ISN          13                        END

*STATISTICS*   SOURCE STATEMENTS = 13, PROGRAM SIZE = 1028 BYTES, PROGRAM NAME = CHRYSO     PAGE:    14.

*STATISTICS*    NO DIAGNOSTICS GENERATED.

**CHRYSO** END OF COMPILATION 3 ******
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LEVEL 1.4.1 (MAY 1985)           VS FORTRAN         DATE: FEB 23, 1987    TIME: 10:23:55                   PAGE:   15

OPTIONS IN EFFECT:  NOLIST NOMAP NOXREF NOGOSTMT NODECK  SOURCE NOTERM   OBJECT FIXED  NOTEST NOTRMFLG   SRCFLG
                    NOSYM NORENT   SDUMP AUTODBL(NONE)  NOSXM   IL
                      OPT(3) LANGLVL(77) NOFIPS  FLAG(I)  NAME(MAIN  )  LINECOUNT(60)      CHARLEN(500)

               *....*...1.........2.........3.........4.........5.........6.........7.*.......8

               C
               CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
               C                                                                  C
               C      THIS SUBROUTINE COMPUTES ANNUAL HYBRID SURVIVAL RATE         C
               C      FROM FINGERLING TO AGE I USING THE METHOD OF VAUGHAN AND    C
               C      SAILA (1976)                                                C
               C                                                                  C
               C      VARIABLE NAME             USAGE                             C
               C                                                                  C
               C         HVIVE           SURVIVAL RATE OF HYBRID FINGERLINGS      C
               C                         TO AGE I                                 C
               CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
               C           SUBROUTINE TO COMPUTE HYBRID Y-O-Y & FINGERLING SURVIVAL
               C
ISN        1                       SUBROUTINE HYBRID(HVIVE)
ISN        2         COMMON/YOA/K,WN(5),HN(5),TOT,WTOT,HTOT,WSURV(5),HSURV(5),JYEAR
ISN        3         COMMON/YOH/WLEN(5),HLEN(5),WJEXP(5),HJEXP(5),WGPROD(5),HSTOCK
ISN        4               HADD=0.0
ISN        5               HPROD=1.0
ISN        6               L=K-1
               C           COMPUTE FECUNDITY & SURVIVAL (CUMMULATIVE) HERE
               C
               C
ISN        7                         DO 899 I=1,L
ISN        8                            HPROD=HPROD*HSURV(I)
ISN        9                            HADD=HADD+HSTOCK*HPROD
ISN       10   899                   CONTINUE
ISN       11                         HVIVE=1.0/HADD
ISN       12                         RETURN
ISN       13                         END

*STATISTICS*   SOURCE STATEMENTS = 13, PROGRAM SIZE = 1032 BYTES, PROGRAM NAME = HYBRID     PAGE:   15.

*STATISTICS*    NO DIAGNOSTICS GENERATED.

**HYBRID** END OF COMPILATION 4 ******
```

VITA 2

Maurice Ibechema Muoneke

Candidate for Degree of

Doctor of Philosophy

Thesis: POPULATION DYNAMICS OF WHITE BASS AND STRIPED BASS X WHITE BASS HYBRIDS IN LAKE CARL BLACKWELL, OKLAHOMA

Major Field: Zoology

Biographical:

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Education: Graduated from Comprehensive High School, Orlu, Imo State, Nigeria, June 1973; graduated from Federal Government College, Kaduna, Kaduna State, Nigeria, June 1975; received Bachelor of Science degree in Marine Biology from Nicholls State University, Thibodaux, Louisiana, May 1979; received Master of Science degree in Fisheries from Louisiana State University, Baton Rouge, December 1982; completed requirements for the Doctor of Philosophy degree at Oklahoma State University, May 1987.

Professional Experience: Graduate research assistant, Louisiana Cooperative Fish and Wildlife Research Unit, Louisiana State University, Baton Rouge, Louisiana, August 1979 to December 1982; Graduate research Assistant, Oklahoma Cooperative Fish and Wildlife research Unit, Oklahoma State University, Stillwater, Oklahoma, January 1983 to June 1986; Graduate Teaching Assistant, Department of Zoology, Oklahoma State University, Stillwater, Oklahoma, August 1986 to present. Research biologist, Texas Parks and Wildlife Department, January 1987 to present.

Professional Organizations: American Fisheries Society-Early life History Section. Gamma Sigma Delta (honor Society for Agriculture).