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A Comparison of Meristics and Morphometrics between Two Strains of Pond Cultured Striped Bass (Morone saxatilis)

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A Comparison of Meristics and Morphometrics Between Two Strains of Pond Cultured Striped Bass (Morone saxatilis)

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by

Steven Gornak

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This thesis is submitted in partial fulfillment of

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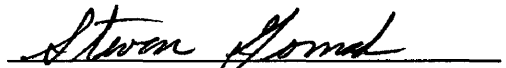

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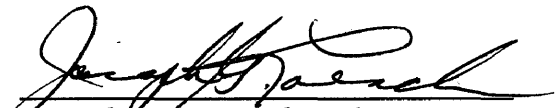

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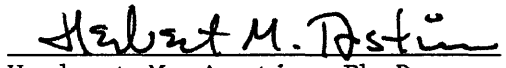

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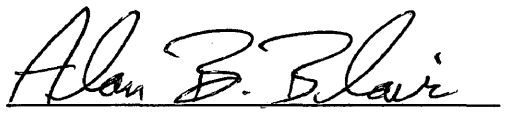

Alan B. Blair, B.S.

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ABSTRACT

The analysis of both morphometric and meristic characters of 619 juvenile pond cultured striped bass (Morone saxatilis) demonstrated the existence two separate stocks in the Northern Chesapeake Bay (Chesapeake and Delaware Canal and Patuxent River). The two measurements of depth, CPD and PC3, produced the best discrimination of stocks, while the length variables AI, PTO, PTI, and PC2 were also able to contribute to the delineation process. The principal components also proved to be better discriminators of stocks than the log-transformed variables. The analysis of meristic characters indicated that counts of the second dorsal fin rays produced the best separation of stocks. The anal fin rays appeared to be very sensitive to changes in temperature and; therefore, this variable is less stable and not considered to be a good discriminator.

LIFE HISTORY OVERVIEW OF THE STRIPED BASS STOCKS

The striped bass, Morone saxatilis, is an anadromous species that seasonally inhabits estuarine and coastal waters from the St. Lawrence River, Canada to the St. John's River, Florida (Merriman 1941; Vladykov and Wallace 1952; Nichols 1966). Spawning of coastal stocks range from the Hudson River, New York to Albemarle Sound, North Carolina. Throughout all of their range striped bass are fished commercially and recreationally. Previous studies of the striped bass population have provided useful information on the segregation of stocks; however, there is still disagreement as to whether discrete stocks exist on the Atlantic Coast (Raney 1957; Fabrizio 1987; and Chapman 1989). Declines in annual landings in the early 1980's pointed out the need for a greater understanding of the striped bass stock structure to provide increased management effectiveness for the fishery.

Historically, striped bass have shown large fluctuations in abundance that cannot be attributed to changes in fishing effort (Nicholson and Young 1979; and Kohlenstein 1981). Atlantic coast commercial landings went from just over 455 metric tons (1,000,000 pounds) in 1934 to almost 4,095 metric tons (9,000,000 pounds) in 1966, with the majority of the landings from the Chesapeake Bay (Raney 1952; Vladykov and Wallace 1952; Nichols 1966; Koo 1970). Virginia catch records show a declining trend in abundance from the late 1800's until the mid 1930's (Merriman 1937; Merriman 1941; Vladykov and Wallace

1952). In 1936 the fishery rebounded and displayed an upward trend, similar to the coastal landings, before again declining in 1974 (Figure 1). The current fishery remains at its lowest point with an annual average of 200,000 thousand pounds of fish landed in 1987 and 1988 (Hill and Loesch 1989). Striped Bass landings were severly depressed in 1987 and 1988 due to the closure of the striped bass fishery from December 1 through May 31 by the Virginia Marine Resource Commission (VMRC). In 1989 a total moratorium was imposed.

The cause of the historical fluctuations in striped bass is year-class strength. Declines in abundance of striped bass have been attributed to a number of causes including effects of pollution on juveniles and juvenile nursery grounds (Chittenden 1971), lower than normal water temperatures (Vladykov and Wallace 1952 and Kernehan et al. 1981), reduced inflow of organic carbon into the estuary that provides nutrients for the organisms of the food chain that are fed upon by the juvenile striped bass (Heinle et al. 1974), and overfishing of migrating spawning stocks. These are reviewed in the Atlantic States Marine Fishery Commision (ASMFC) Interstate Fisheries Management Plan for striped bass (Anonymous 1989).

Early spring spawning runs of anadromous striped bass compose the first part of a thousand mile northerly migration. Spawning takes place in the tidal freshwater from February to May with peak production in April (Hardy 1978). The Chesapeake Bay has been identified as a major spawning area of the Atlantic Coast (Pearson 1938; Vladykov and Wallace 1952; Nichols 1966; and Berggren and Lieberman 1978). After spawning the mature striped bass continue their northerly coastal migration and become part of the coastal fishery.

The northward spring migration of striped bass is age and sex dependent. The age of first migration is four or five years old for males and two or three years old for females (Koo 1970; Nicholson and Young 1979; Kohlenstein 1981). In times of high stock density two-year-old striped bass are known to move into coastal waters (Raney 1952; Austin and Hickey 1978; Loesch and Kriete 1983; Goodyear 1985). This early participation in migration may be due to overcrowding in the Bay and its tributaries by dominant year classes (Raney 1952). As water temperatures cool in the fall, fish that have entered coastal waters migrate south to over-winter in warmer waters off the Chesapeake Bay and Cape Hatteras.

Although most of the mature striped bass participate in this migration, there are some fish in the Chesapeake Bay and its tributaries that do not and these are thought to compose the resident stocks (Merriman 1937; Chapoton and Sykes 1961). The resident striped bass stocks in the Chesapeake Bay are composed mainly of two-year-olds (Vladykov and Wallace 1952) and studies indicate that these immature fish particpate in a migratory route that takes them to the southern end of the bay in the winter and to the northern end in the summer. Tagging studies indicate that the southward movement occurs along the western shore of the Bay but the route of the northward movement during the spring is unknown (Vladykov and Wallace 1938). Overall, the resident Chesapeake Bay stocks tend to have a net intra-bay movement northward until the fish reach the age of three and become part of the coastal migration.

Contributions to the coastal fishery from the various estuaries is related to year-class strength. Prior to 1975, 90% of the coastal

striped bass came from the Chesapeake Bay (Berggren and Lieberman 1978), but since 1980 approximately 40% of the striped bass in the coastal fishery comes from the Hudson River while a reduction in numbers has dropped the Chesapeake Bay contribution to 60% (Lassen 1983). In 1985, the coastal population was not influenced by a dominant year class (Boreman and Austin 1985).

The reduced landings since 1980 have stimulated interest in the stock structure of the Chesapeake Bay striped bass. However, stock assessment studies that were designed to provide insight into the structure of these stocks have produced inconsistent results. Meristic, morphometeric and tagging studies identified four stocks within the Bay: the Upper Bay, the James River, the Potomac River, and the York-Rappahannock complex (Vladykov and Wallace 1952; Lewis 1957; Lund 1957; Raney 1957; Murawski 1958; Massman and Pacheco 1961; Nichols and Miller 1967). Some of this early research indicated the possibility of other identifiable stocks existing within the Rappahannock, York and the Pamunkey rivers (Raney and deSylva 1953; Lund 1957; Massman and Pacheco 1961). Grove et al. (1976) used tags to identify discrete spawning stocks and found that he was only able to segregate stocks from the major estuaries. Fabrizio (1987) classified stocks to major tributaries using both morphometric and electrophoretic methods but made no attempt to assess stocks within the tributaries. Morgan (1971) and Morgan et al. (1973) utilized electrophoresis to identify the: Patuxent, Potomac, Choptank, Elk, and Nanticoke rivers as five separate stocks in the Upper Bay. In contrast, the work of Sidell et al. (1980), Chapman (1989), and Furman (1989), using the more

precise Mitochondrial DNA (MtDNA) methodology, have provided evidence for a single stock in the Upper and mid-Chesapeake Bay.

OBJECTIVES

The primary objective of this study was to determine if the morphometric and meristic characters of pond cultured striped bass could be used to delineate stock differences in the upper Chesapeake Bay, secondly, to try and quantify the variability of multiple measurements into a set of principal components that could be used for stock discrimination, and finally, to analize the data set for those characteristics which produced the greatest amount of discriminatory power so that effort is not wasted on the measurement or counts of variables which do not contribute to the overall discrimination of stocks.

MATERIALS AND METHODS

Collection of Adults:

During the spring of 1986 a total of 24 adult striped bass were collected from two different river systems in the northern Chesapeake Bay, 3 females and 15 males from the Chesapeake and Delaware (C&D) Canal and 1 female and 5 males from the Patuxent River (Figure 2). Each female was placed into a tank with three to five males and spawning was allowed to take place naturally. The striped bass eggs and larvae were held under identical conditions of temperature, pH and salinity until the age of five to twelve days. The fish were then transported to the U.S. Fish and Wildlife Service's Harrison Lake National Fish Hatchery (HLNFH) and approximately 75,000 fry were stocked to a pond (Figure 3). The culture period lasted a total of six months from May to October.

Collection of Juveniles:

Juveniles were sampled twice a week for the first three months, then once a week for the remaining culture period.

Due to growth over time, three different seine sizes were used to collect striped bass from the culture ponds. The first was 2 m long with a stretched mesh size of 3 mm, the second was 9 m long with a stretched mesh size of 9 mm, and the third was 15 m long with a stretched mesh size of 13 mm. Since striped bass tend to school in the

deepest part of the pond (called a kettle), the nets were towed through the vicinity of the kettle.

Samples were placed in 5% borax-buffered formalin and stored for seven months. They were then rinsed, soaked in tap water for one week and placed in 70% ethanol (EtOH).

Counts and Measurements:

Meristic and morphometric characters were taken from 619 juveniles using the methods described by Hubbs and Lagler (1958). Counts of the spines and soft rays of the first and second dorsal fins, pectoral fins, pelvic fins, and anal fins were taken from each specimen using a binocular dissecting microscope. Seventeen measurements were taken from each specimen using a binocular dissecting microscope with an ocular micrometer calibrated to the nearest 0.1 mm and a dial caliper (Figure 4).

Abbreviations for the meristic and morphometric characters used throughout this text are defined in Tables 1 and 2.

Hydrologic Data:

Temperature (^{o}C) and dissolved oxygen (mg/l) were measured to the nearest 0.1 units using a Yellow Springs Instrument Model 57. The acidity was measured to the nearest 0.1 pH unit with an Omega VHH-1 pH meter. These data were collected three times a week during the hours of 0700 and 0800. The dissolved oxygen concentration is lowest at this time and is a good indicator of the biological state of the ponds.

Food Levels:

The juvenile striped bass were fed artificial food three to five times a day throughout the duration of the phase II period. This period began when the fish attained a total length (TL) of 9 to 13 mm and terminated when they reached 88 to 154 mm TL (A. Blair, Hatchery Manager, HLNFH, personal communication). Injestion of the artificial food was validated by the analysis of gut contents and visual observations of feeding behavior. The amount of food introduced into each pond was determined by the equation:

$$F = p\ (wt)/100$$

where F is the amount of food the fish were fed, p is the percentage of food per total weight of fish in the pond (this was approximately 10-15%) and wt is the total weight of fish in the pond at the end of the phase I period (this is approximately 7 mm TL). This allowed for standardization of the amount of food introduced into each pond (A. Blair, personal communication).

Statistical Analysis:

A) Morphometrics

The problem of analyzing morphometric variables is a multivariate one and requires the use of multivariate techniques (Pimental 1979). The selection of multivariate analysis of variance and discriminant analysis was made because these techniques allow for the comparison of two or more groups using several variables simultaneuosly (Humphries 1990) and, it is widely accepted in fisheries (Pearson 1964; Messieh

1975; Wilk et al. 1980; Humphries et al. 1981; Winans 1984; Reist 1985; Henault and Fortin 1989; Schaefer 1989). The advantage of a multivariate approach is that distinction between groups based on a composite effect of variables rather than on the effect individual variables is revealed.

Various graphical techniques were used to examine the morphometric data. Each variable was regressed against fork length (FL) to determine the degree of linearity. Frequency histograms, residual plots and normal probability plots were also developed to give an indication of normality, homogeneity of variance, and visually assess the need for transformations.

Ihssen et al. (1981), Johnson and Loesch (1983), Misra and Ni (1983), Johnson and Loesch (1986), Bowering (1988), and Scoles (1990) have suggested that allometric growth of morphometric characters introduces additional variation into the data set. Therefore, all measurements were expressed as ratios of fork length to allow for the the comparison of individuals of various size classes (Marr 1955; Hill 1978; Dodson 1978; Casselman et al. 1981; Reist 1985). Fork length was chosen as the scaling variable (denominator) by the guidelines set by Atchley et al. (1976). The data in Table 3 shows that fork length has the largest standard deviation and is positively correlated to all other variables. Total length was omitted due to the addition of variation introduced by deteriorated or worn caudal fins. Ratio data were then regressed against fork length, and by doing so produced a slope of zero indicating that the variation due to allometry had effectively been removed (Table 4).

Equality of the variance-covariance matrices and multivariate normality are two basic assumptions that are required for multivariate analysis of variance and discriminant function analysis (Norusis 1986). To satisfy these assumptions the ratio data were transformed to common logarithms for the following reasons: 1) Multivariate normality is usually better approximated by logarithms than by the original data (Pimental 1979); 2) logarithmic transformations should satisfy tests of linearity, which is assumed for multivariate statistics (Mottley 1941; Misra and Ni 1983); 3) to increase the level of homogeneity of the variance-covariance matrices between samples; and 4) the convention is to use common logarithms when analyzing morphometric data (Pimental 1979; Misra and Ni 1983; Currens et al. 1989; McEachran et al. 1989). The Box's M test was used to test for equality of the variance-covariance matrices while residual and normal probability plots were used as checks of normality. Additional assumptions for the multivariate analysis and the discriminant function can be found in Klecka (1980), Snedecor and Cochran (1980), Reist (1985), and Davis (1986). Only those specimens with all 17 measurements were used in the analyses because unequal sample size created by missing observations virtually destroy morphometrics (Pimental 1979). The log transformed data were used for all subsequent statistical tests of morphometric characters unless otherwise specified.

Principal component analysis (PCA) was used to reduce the complexity of the data set from fourteen variables to a set of principal components, to explore the relationships of those variables which gave rise to each of the principal components (Bhattacharyya 1980), and to give insight as to which variables have the best

discriminating power. The principal components are eigenvectors which are produced from a variance-covariance matrix and are mutually orthogonal (Winans 1984). These eigenvectors give the orientation of the principal axis of the ellipsoid, and the eigenvalues represent the lengths of the principal axes (Bhattacharyya 1980; Davis 1986). The eigenvalues also represent the amount of variability described by a linear combination of variables and only those eigenvalues which account for the majority of the variability in the data set will be utilized in the following statistical analysis (Davis 1986; Norusis 1986).

Before the discriminant analysis is performed it must be preceded by a test of significance between population means (Pimental 1979; Misra and Ni 1983; Prager and Fabrizio 1990). Multivariate analysis of variance (MANOVA) was used to statistically test for stock differences using the combined effects of the principal components (PC1, PC2, PC3) and the log-transformed variables. Wilks' Lambda was the criterion used and represents the ratio of within-groups sum of squares to the total sum of squares (Norusis 1986). Values of Wilks' Lambda range from 0 to 1, where small values indicate high variability between groups and small variability within each group (Norusis 1986). Wilks' Lambda is then converted to a value which approximates the F distribution and it is this value which is used to test the hypothesis that there is no difference between group means (Norusis 1986).

The univariate analysis of variance (ANOVA) gives an indicaton of the relative contribution of the individual variables used in the multivariate procedure. Those variables which have larger values of F

have greater between-groups variability and are better discriminators of stocks.

Discriminant function analysis (DFA) was performed on the morphometric data, using the stepwise procedure for the selection of the important variables (Method = MAHAL), while those variables not contributing significantly to the total variability were omitted. This procedure maximizes the separation between reference sample means and minimizes the within-group variability by producing a linear equation of the morphometric variables (Norusis 1985; Davis 1986). The distance between sample means (centroids) has been termed "Mahalanobis' Distance" (Fisher 1936). The reference samples are those groups which are known to differ in morphometric characters and are assumed to be of pure stocks (Fabrizio 1987).

The discriminant function which is developed from the reference sample is then used to classify individuals from a mixed population. This is accomplished by determining the discriminant scores for the observations of the reference samples and the mixed population (unknowns). Group centroids for each reference sample are obtained and unknowns with discriminant scores which lie closest to a particular centroid are classified to that reference sample (Klecka 1980).

B) Meristics

The selection of meristic characters for stock discrimination was based on a previous recommendation in 1980 by the Scientific and Statistical Committee (Austin 1980).

Meristic counts were analyzed in a 2 by K contingency table where the columns and rows denote the dependent (counts) and independent

(rivers) variables, respectively. The chi-square statistic is the most commonly used procedure for analyzing contingency table data. However, it has been suggested by Cochran (1954), Sokal and Rohlf (1969), Zar (1984) and SAS (1985) that the chi-square value is biased when the expected frequencies are less than 1.0 and when 20% of the expected cell counts are less than 5.0. Williams (1976), recommends use of the G test (Log-likelihood ratio) in preference to the chi-square whenever the difference between the observed and expected values is less than the expected value. Since the G test uses log-ratios of the observed values and does not attempt to calculate the expected cell frequencies it will not have the associated bias and, therefore, is better suited for analyzing contingency tables.

RESULTS

Regression plots for all untransformed morphometric variables on fork length were highly significant ($P < 0.001$). The variables of HL, PTO, PTI, PO, PI, D_1O, and BD indicated slight deviations from normality and homogeneity of variance, but were not significantly different when examined with Kolmogorov-Smirnov and the Cochran's C tests ($P > 0.05$), respectively. Normal probability plots and frequency histograms indicated that the transformed data did not significantly deviate from the normal.

The regression plots also indicated a shift in the growth pattern from isometric to allometric growth (Appendix). The variables HL, PTO, PTI, PO, PI, and D_1O showed a reduction in growth rate at approximately 95 and 105 mm of FL for the Patuxent River and the C&D Canal, respectively. For the C&D Canal samples, the Variables D_1I, D_2O, D_2I, AO, AI, V, and BD, showed an increase in growth rate at 130 mm of FL while CPD showed a change in growth at 100 mm. This second growth stanza was not observed in the Patuxent River.

Principal component analysis reduced the dimensionality of the data set from 14 variables to three principal components. Of the 14 different principal components produced, the first three account for 70% of the total variance in the morphometric data set. Of these, the first principal component contributed 42%, the second 20%, and the third 8% (Figure 5). The remaining principal components represent only

30% of the total variance in the morphometric data and were eliminated from any further statistical analysis. The first principal component axis is heavily loaded on PTO, PO, PI, and HL, the second on V and AO, and the third on a single variable CPD (Table 5).

The principal components and the log-transformed data were used in the multivariate comparison of reference sample means. The results of Cochran's C test indicated that the assumption of homogeneity of variance was rejected ($P < 0.001$) by the variables: HL, D_1I, D_2O, D_2I, AI, V, BD, CPD, PC1, and PC2. The Kolmogorov-Smirnov tests also indicated that the assumption of normality was rejected by the variables: D_1I, D_2O, D_2I, AO, AI, V, BD, and PC2 (Tables 6A; 6B). The Box M test for the assumption of equal variance-covariance matrices was also violated ($P < 0.001$). Results of the MANOVA test demonstrated that the means between reference samples were not equal (Tables 7A; 7B).

The results of the univariate F test indicated that PC3, BD and CPD are the variables which are most capable of separating group means (Tables 8A; 8B). The differences between group means using PC3, BD and CPD are highly significant ($P < 0.001$). The variables PC2, HL, PTO, AO, and V also resulted in significant differences between group means but to a smaller degree than PC3, BD, and CPD. Statistical differences between group means were undetectable when analyzed with PC1 and the remaining log-transformed variables ($P > 0.05$).

All variables were used in the discriminant analysis except for D_2I, which was eliminated because it did not provide additional information to the analysis. All principal components were selected for the discriminant analysis of the principal components. A listing

of each variable, change in Mahalanobis' distance, values for Wilks' Lambda, and the order of selection by the stepwise linear discriminant analysis are reported (Tables 9A; 9B). The variables CPD and PC3 had the largest Wilks' Lambda and the smallest Mahalanobis' distance; thus, these variables provided the most information for the separation of groups and were the first to be entered into the analysis.

The results of the discriminant analysis classification are provided in Tables 10A and 10B. Of the 606 specimens used in the analysis, 70% were correctly reclassified to the actual group from which the specimen came when the log-transformed variables were used. The matrix indicated that 242 (69%) and 185 (71%) of the individuals were correctly reclassified to the C&D Canal and the Patuxent River, respectively. Reclassification of the principal components reached a level of 64%.

All meristic characters except PL and AN were highly significant ($P < 0.001$) when analyzed with the chi-square and log-likelihood statistics (Table 12). The significance of the log-likelihood ratios for the variables PL and AN were $P = 1.000$ and $P = 0.001$, respectively. Values of the likelihood test (G statistic) are present in Table 13. For the variables D_1, D_2, and AN, at least 25% of the cells contained expected counts less than five (Table 12). The largest percentage of cells with expected counts less than five were found in variables D_2 (50%) and AN (56%). However, as previously mentioned (statistical analysis section) the likelihood test avoids the associated bias encountered in the chi-square analysis by eliminating the estimation of expected counts.

Plots of temperature, pH, and dissolved oxygen concentrations are shown in Figures 6, 7, and 8, respectively. Although temperature fluctuations occurred from one sample period to the next, no variation between pond groups was observed within a single sampling period. The plots of dissolved oxygen and pH over time indicated that some variability existed between pond groups.

DISCUSSION

Morphometrics:

Although the log-transformed data were able to discriminate stocks, the principal component analysis better quantified the variation of the individual measurements as a set of principal components that represent body segments (Figure 9). The three principal components describe the general shape of the anterior (PC1), medial (PC2), and posterior (PC3) segments of the body for each river system. However, principal component analysis does not unequivocally indicate that morphologically discrete stocks exist between the C&D Canal and the Patuxent River.

As noted, most of the variables violated at least one of the assumptions required for multivariate testing (Tables 6A; 6B). Violations of the assumptions may produce erroneous results; however, Pimental (1979), Klecka (1980), and Neter et al. (1991) suggested that multivariate tests are robust, and that these violations do not necessarily nullify the results of the tests. The reliability of the results of the multivariate analysis are supported by the classification matrix of the discriminant analysis (Tables 10A; 10B). On average, correct reclassification of the specimens ranged from 63.8% to 70.5%. For the lowest correct reclassification group, the chi-square analysis of a 1:1 ratio indicated that there was strong statistical evidence for a difference between the observed and expected

correct placements. If the assumptions had been severely violated, the expected rate of correct reclassification would have been no greater than 50%. Because the present study makes use of the univariate F test with a fixed model (Model I), the lack of normality and homogeneity of variance found in some variables is not an important matter (Neter 1991) when using the F test to interpretion of the relative contribution of the individual variables to the overall analysis.

Examination of the variables by multivariate analysis of variance (MANOVA) identified significant morphological differences between reference samples of pond cultured juvenile striped bass. The univariate F statistics produced by the SPSS^{X} MANOVA program indicated that PC2, PC3, HL, PTO, AO, V, BD, and CPD are variables that have stock discriminating capabilities (Tables 8A; 8B). High levels of significance ($P < 0.001$) were found for the variables CPD, BD, and PC3. The remaining variables had smaller levels of significance ($P > 0.001$), and may not be warranted as stock discriminators. The significant morphological differences found by multivariate analysis of variance justified the use of discriminant function analysis.

Those variables that can predict group membership with large values of Wilks' Lambda and small values of Mahalanobis' Distance are considered the best discriminators of stocks. In relation to all measured variables, discriminant analysis indicated that CPD and PC3 are the variables which best fit this criterion (Table 9A; 9B). It is not surprising that these two variables produce the best discriminatory results since the third principal component is composed of a single log-transformed variable, CPD. It is desirable to have small Wilks' Lambda values and large values of Mahalanobis' Distances, but most

biological field data show patterns such as that shown in Figure 10 (large amounts of within groups variability with respect to the variability between groups and group centroids which are only slightly separated). The amount of overlap between these data sets is very high and from Table 9A it is evident that the first five variables used in the discriminant analysis are capable of detecting differences between the data sets. Although the remaining variables in the table contribute to the overall discrimination, their contribution is slight and they are not considered good discriminators.

The results of the discriminant analysis of the log-transformed variables suggested that individual measurements could be used to separate stocks of pond cultured striped bass. The variables that best discriminated between stocks were measurements of depth (i.e., CPD and BD). The samples taken from the C&D Canal were found to have a greater average body depth and thicker caudal peduncle than those taken from the Patuxent River (Table 11). These results are consistent with those of Lund (1957). Although BD has been described as a variable with good discriminating power, the additional variation introduced into this variable due to stomach fullness should not be over looked. This variation can not be quantified by simple measurements of body depth; and therefore, the actual contribution of this variable to the overall discrimination of stocks is in question. In general, the overall size of the C&D Canal specimens are longer and deeper with respect to those of the Patuxent River (Table 11).

The ability to quantify the variability of multiple measurements into a set of principal components proved to be very useful in the discrimination of stocks. Discriminant analysis of the principal

components indicated that all components are good separators of stocks (Table 9B). As noted previously, the posterior segment (PC3) of the specimens is the best discriminator with respect to the anterior (PC1) and medial (PC2) segments. All of the principal components produced larger Wilks' Lambda values and smaller values for Mahalanobis' Distance than that produced by the variable CPD of the log-transformed variables (Tables 9A; 9B). Therefore, the principal components are better separators of groups with low between groups variability and small distances between group centroids than the individual log-transformed variables.

The allometric growth characters which were observed in the regression plots also indicated the presence of separate stocks. Juveniles from the C&D Canal have longer and deeper posterior portions of the body than those from the Patuxent River. This further confirms the results of the discriminant analysis. Regressions of the anterior portions of the juveniles did not indicate differences between the Patuxent River and the C&D Canal. However, the different lengths at which allometry occurred in the anterior part of the body did suggest that discrete stocks exist.

Meristics:

Raney (1957) reported that counts of the fin rays and spines contain very little plasticity especially in geographical regions which are not separated by large nautical distances. However, results of the meristic analysis shown in Table 12 indicate that the C&D Canal differs significantly from the Patuxent River with respect to all variables except the pelvic fin. Based on the G statistic (Table 13), counts of

the second dorsal rays produced the best statistical separation of groups, while counts of the pelvic rays appear to be the most stable character. Anal fin ray counts also produced some separation of groups, but the level of significance was not as large as that found in the first three variables.

Examination of the frequency distributions indicates that the modal value of each character is the same between groups except for that of the second dorsal fin (Table 13). The frequency distribution of the second dorsal fin ray counts clearly indicate that two different modal values exist between the groups. The shape of the distribution was also capable of separating stocks. Counts of the first and second dorsal fin spines and rays both indicated a negatively and positively skewed distribution for the C&D Canal and the Patuxent River, respectively, while the remaining variables contained distributions that are skewed in the same direction for both river systems. The second dorsal fin produced the strongest separation based on skewness.

Within the upper Chesapeake Bay, the north-south cline of meristic characters found in this study agreed with the results of earlier studies by Raney (1957) and Lewis (1957). Except for the second dorsal and pectoral fins, the average number of rays and spines was higher in the samples drawn from the Patuxent River group than those drawn from the C&D Canal (Table 13). A comparison of the results of the present study to those of Raney (1957) indicate that the average number of rays of the second dorsal and anal fins has increased while the number of first dorsal spines has remained relatively constant.

In comparison with the study of Raney (1957), the average number of fin rays has increased by three rays in the second dorsal fin and

In comparison with the study of Raney (1957), the average number of fin rays has increased by three rays in the second dorsal fin and one ray in the anal fin. These differences can be attributed to differing environmental conditions during the the early stages of larval development. It is quite possible that the specimens used in this study were held under environmental conditions which were different from those of the natal river systems and thus produced the different fin ray counts that were observed between the two studies. Taning (1952) and Lindsey (1988) showed that temperature is the major factor influencing ray and spine development, and that small changes in temperature (flucuations as small as 0.5 C) can cause fluctuations in ray counts of up to four fin rays.

The range of the frequency distribution of the anal fin ray counts is much larger than that found in the study done by Raney (1957). This large range also appears to be related to temperature and the time at which larval development is reaching the critical age for the setting of meristic characters. The majority of the specimens may have reached this critical age when the temperature was at some point for the production of 10-12 rays (Table 13). The remaining specimens may have reached this age when the temperature was cooler or warmer which caused the production of more or less rays, respectively (Taning 1952 and Lindsey 1988). It appears that the anal fin rays are more sensitive to changes in the temperature than the remaining variables and; therefore, this variable is less stable and not considered to be a good discriminator.

Adult sample size:

The adult sample size of females is a limiting factor in this study. It is highly possible that the differences produced here are caused by an incomplete sampling of the genetic structure of the adult population. The genetic variability found in the C&D Canal reflects the variation of only three females while the genetic variability in the Patuxent River reflects that from a single specimen.

Future research should not only consist of utilizing more adult specimens but also examine the variability between years and between pond cultured and wild specimens. It should also be noted that correct classification with a discriminant function should use independent samples, not the ones used to construct the model. It would be most interesting to explore the relationship of the wild specimens to those of pond cultured stocks.

CONCLUSION

The analysis of morphometric characters with multivariate procedures proved to be a useful tool for the delineation of pond cultured stocks. Discriminant analysis of both the principal components and the log-transformed variables produced evidence that specimens from the C&D Canal have longer and deeper bodies in relation to those from the Patuxent River. The two measurements of depth, CPD and PC3, produced the best discrimination of stocks, while the length variables AI, PTO, PTI, and PC2 were also able to contribute to the delineation process. Although both of the data sets were capable of stock discrimination, principal components proved to be better discriminators of stocks than the log-transformed variables.

The meristic analysis indicated that counts of the spines and rays were also useful for the discrimination of stocks. Counts of the second dorsal fin produced the best separation of stocks while the first dorsal and pectoral fins also proved to be significant. Although the anal fin showed some discriminating power, it may not be warranted as a stock discriminator because of its instability to temperature at the time of fin ray formation.

Table 1. Abbreviations of meristic counts used throughout text, tables and figures.

D_1	First Dorsal Fin
D_2	Second Dorsal Fin
PC	Pectoral Fin
PL	Pelvic Fin
AN	Anal Fin

Table 2. Abbreviations of morphometric measurements used throughout the text, tables and figures.

HL	Head Length
PTO	Pectoral Fin Origin
PTI	Pectoral Fin Insertion
PO	Pelvic Fin Origin
PI	Pelvic Fin Insertion
D_1O	First Dorsal Origin
D_1I	First Dorsal Insertion
D_2O	Second Dorsal Origin
D_2I	Second Dorsal Insertion
AO	Anal Fin Origin
AI	Anal Fin Insertion
V	Vent Position
SL	Standard Length
FL	Fork Length
TL	Total Legnth
BD	Body Depth
CPD	Caudal Peduncle Depth

Table 3. Results of the condiscriptive procedure for the determination of the scaling variable for the Cheasapeake and Delaware (C&D) Canal and the Patuxent River. Values for the standard deviation (SD) and correlation coefficients (CC) for total length (TL), fork length (FL), and standard length (SL) are given.

C&D Canal			Patuxent River		
Variable	SD	CC	Variable	SD	CC
SL	27.489	0.99	SL	26.068	0.99
FL	33.375	0.99	FL	31.786	0.99
TL	35.535	0.99	TL	33.620	0.99

Table 4. Results of the regression plots of the ratio variables against fork length for the Chesapeake and Delaware (C&D) Canal and the Patuxent River. A slope (b) equal to zero indicates that size has been removed.

C&D Canal		Patuxent River	
Variable	b	Variable	b
HL	-.00006	HL	.00014
PTO	-.00016	PTO	.00006
PTI	.00017	PTI	.00030
PO	-.00014	PO	-.00008
PI	.00004	PI	.00001
D_1O	-.00014	D_1O	-.00007
D_1I	.00034	D_1I	.00041
D_2O	.00023	D_2O	.00039
D_2I	.00023	D_2I	.00026
AO	.00059	AO	.00068
AI	.00034	AI	.00025
BD	.00041	BD	.00057
CPD	-.00002	CPD	-.00012

Table 5. Matrix showing the breakdown of variables which describe most of the variability found each of the corresponding principal components.

VARIABLE	PC1	PC2	PC3
PTO	.88319	.09115	-.07697
PO	.87307	.06639	.15122
PI	.86468	.24472	.02917
HL	.85315	.23237	-.05110
D_1O	.79346	.00190	.00768
PTI	.72208	.36798	-.21486
V	.10619	.84643	-.09533
AO	.13215	.83987	-.16157
BD	.02809	.79384	-.00519
D_2O	.29940	.73017	-.15049
D_2I	.06249	.69500	.22684
AI	.12091	.68975	.24843
D_1I	.31316	.65475	-.19664
CPD	-.01425	-.02634	.91789

Table 6. Test of assumptions of homogeneity of variance (Cochrans' C) and normality (Kolmogorov-Smirnov) for the A) Log-transformed variables and B) Principal components in MANOVA.

A. Results of the Cochrans' C and K-S for the log-transformed variables.

Variable	Cochrans' C	K-S
HL	P = 0.002*	P = 0.378
PTO	P = 0.071	P = 0.504
PTI	P = 0.574	P = 0.129
PO	P = 0.437	P = 0.418
PI	P = 0.053	P = 0.672
D_1O	P = 0.415	P = 0.068
D_1I	P < 0.001*	P < 0.001*
D_2O	P = 0.008*	P < 0.001*
D_21	P < 0.001*	P < 0.001*
AO	P = 0.244	P < 0.001*
AI	P < 0.001*	P < 0.001*
V	P < 0.001*	P < 0.001*
BD	P < 0.001*	P < 0.001*
CPD	P = 0.014*	P = 0.677

Test of equality of variance-covariance matrices:

Box's M = 1153.56595
Chi-Square with 105 df = 1125.16546
P < 0.001

B. Results of the Cochrans' C and K-S for the Principal components.

Variable	Cochrans C	K-S
PC1	P = 0.023*	P = 0.050
PC2	P = 0.521	P < 0.001*
PC3	P = 0.001*	P = 0.930

Test of equality of variance-covariance matrices:

Box's M = 96.20023
Chi-Square with 6 df = 95.66692
P < 0.001

Note: * indicates significant differences at the 0.05 alpha level.

Table 7. Results of the multivariate analysis of variance test between the Chesapeake and Delaware Canal and the Patuxent River for A) Log-transformed variables and B) Principal components.

A. Log-transformed varaibles.

Test Name	Value	Approx. F	Sig. of F
Pillais	.16968	8.62655	.000*
Hotellings	.20435	8.62655	.000*
Wilks	.83032	8.62655	.000*

B. Principal components.

Test Name	Value	Approx. F	Sig. of F
Pillais	.03468	7.20946	.000*
Hotellings	.03593	7.20946	.000*
Wilks	.96532	7.20946	.000*

Note: * indicates significant differences at the 0.05 alpha level.

Table 8. Results of the MANOVA univariate F test between the Chesapeake and Delaware Canal and the Patuxent River for A) Log-transformed variables and B) Principal components.

A. Log-transformed variables

Variable	F	Sig. of F
HL	6.07022	P = 0.014*
PTO	11.63233	P = 0.001*
PTI	0.05761	P = 0.810
PO	1.64717	P = 0.200
PI	2.91457	P = 0.088
D_1O	0.02114	P = 0.884
D_1I	2.78677	P = 0.096
D_2O	0.71043	P = 0.400
D_2I	1.60533	P = 0.206
AO	6.19447	P = 0.013*
AI	2.11956	P = 0.146
V	8.01674	P = 0.005*
BD	19.26159	P < 0.001*
CPD	28.24070	P < 0.001*

B. Principal components

Variable	F	Sig. of F
PC1	1.87117	P = 0.172
PC2	4.90490	P = 0.027*
PC3	14.55955	P < 0.001*

Note: * indicates significant differences at the 0.05 alpha level.

Table 9. Variable selection for the discriminant analysis of A) Log-transformed variables and B) Principal components: Mahalanobis' distance, Wilks' Lambda, and the step by which the variables were added by stepwise linear discriminant analysis is shown.

A. Results of the selection criterion of discriminant analysis on the log-transformed variables.

Step	Variable	Wilks' Lambda	Mahalanobis' Distance
1	CPD	0.95533	0.19061
2	BD	0.92706	0.32076
3	AI	0.90542	0.42585
4	PTO	0.88382	0.53587
5	PTI	0.85820	0.67362
6	V	0.85079	0.71491
7	HL	0.84667	0.73830
8	PI	0.84369	0.75530
9	PO	0.83961	0.77878
10	D_2O	0.83719	0.79282
11	D_1I	0.83406	0.81108
12	AO	0.83247	0.82042
13	D_1O	0.83090	0.82970

B. Results of the selection criterion of discriminant analysis on the principal components.

Step	Variable	Wilks' Lambda	Mahalanobis' Distance
1	PC3	0.97646	0.09827
2	PC2	0.96841	0.13300
3	PC1	0.96532	0.14647

Table 10. Classification matrices developed from the discriminant analyses between the Chesapeake and Delaware (C&D) Canal and the Patuxent River of A) Log-transformed variables and B) Principal components.

A. Results of discriminant analysis on the log-transformed variables. Only variable D2I was not included in the analysis.

Reference Group	No. of Cases	Classified Samples C&D Canal	Patuxent R.
C&D Canal	348	242	106
% Reclass.		69.5%	30.5%
Patuxent R.	258	73	185
% Reclass.		28.3%	71.7%

Note: Percent of "Grouped" cases correctly classified: 70.46%.

B. Results of discriminant analysis on the principal components. All variables were included in the analysis

Reference Group	No. of Cases	Classified Samples C&D Canal	Patuxent R.
C&D Canal	348	216	132
% Reclass.		62.1%	37.9%
Patuxent R.	258	89	169
% Reclass.		34.5%	65.5%

Note: Percent of "Grouped" cases correctly classified: 63.8%.

Table 11. Values of the means ($\bar{X}$) and ranges for the morphometric characters of the Chesapeake and Delaware (C&D) Canal and the Patuxent River.

	C&D Canal			Patuxent River		
Variable	$\bar{X}$	Range		Variable	$\bar{X}$	Range
HL	17.64	2.8 -	44.7	HL	17.30	4.6 - 41.3
PTO	16.59	2.8 -	42.2	PTO	16.19	4.3 - 39.3
PTI	25.26	3.9 -	63.4	PTI	25.00	6.1 - 58.6
PO	19.39	3.1 -	45.5	PO	19.00	5.0 - 48.0
PI	21.54	3.4 -	49.7	PI	20.94	5.4 - 48.9
D_1O	20.25	3.4 -	49.7	D_1O	20.02	5.8 - 48.3
D_1I	30.94	5.1 -	82.5	D_1I	30.23	8.0 - 73.8
D_2O	32.73	5.6 -	86.3	D_2O	32.23	8.6 - 80.5
D_2I	42.54	6.9 -	115.1	D_2I	41.71	11.6 - 103.7
AO	36.39	5.9 -	100.2	AO	35.49	9.2 - 89.6
AI	43.68	7.1 -	118.4	AI	43.02	12.0 - 108.3
V	34.78	5.4 -	94.6	V	33.90	5.9 - 84.6
BD	14.33	1.9 -	41.6	BD	13.77	2.8 - 36.7
CPD	5.92	0.9 -	15.3	CPD	5.54	1.7 - 13.5

Table 12. Results of the chi-square and log-likelihood ratio tests between the Chesapeake and Delaware Canal and the Patuxent River. The % is the percentage of the cells which have expected counts less than 5.

Variable	df	Probabilities of Significance		%
		Chi-square	Likelihood ratio	
D_1	3	P < 0.001*	P < 0.001*	25
D_2	4	P < 0.001*	P < 0.001*	50
PC	4	P < 0.001*	P < 0.001*	0
PL	0	P = 1.000	P = 1.000	0
AN	7	P = 0.012	P = 0.001	56

Note: * indicates large significant differences.

Table 13. Frequency of the number of spines and rays in the fins of young striped bass from the Chesapeake and Delaware (C&D) Canal group and the Patuxent River group.

		First Dorsal Spines				
Group	n	7	8	9	10	$\bar{X}$
C&D Canal	358	2	56	293	7	8.85
Patuxent River	259	1	8	238	12	9.01

G statistic = 31.921*

		Second Dorsal Rays					
Group	n	12	13	14	15	16	$\bar{X}$
C&D Canal	358	2	42	313	1	--	13.87
Patuxent River	259	4	126	119	8	2	13.53

G statistic = 127.963*

		Pectoral Fin Rays					
Group	n	15	16	17	18	19	$\bar{X}$
C&D Canal	358	44	156	99	54	5	16.50
Patuxent River	259	7	135	103	10	4	16.49

G statistic = 48.908*

		Pelvic Fin Rays	
Group	n	5	$\bar{X}$
C&D Canal	358	358	5.00
Patuxent River	259	259	5.00

G statistic = 0.000

		Anal Fin Rays								
Group	n	7	8	9	10	11	12	13	14	$\bar{X}$
C&D Canal	358	3	--	4	16	69	262	4	--	11.65
Patuxent River	259	--	1	--	1	56	195	5	1	11.79

G statistic = 23.807

Note: * denotes large significant difference between groups.

Figure 1. Annual landings of striped bass in Virginia, 1962 - 1988.

Fig. 1. Annual Landings of Striped Bass In Virginia, 1962 - 1988

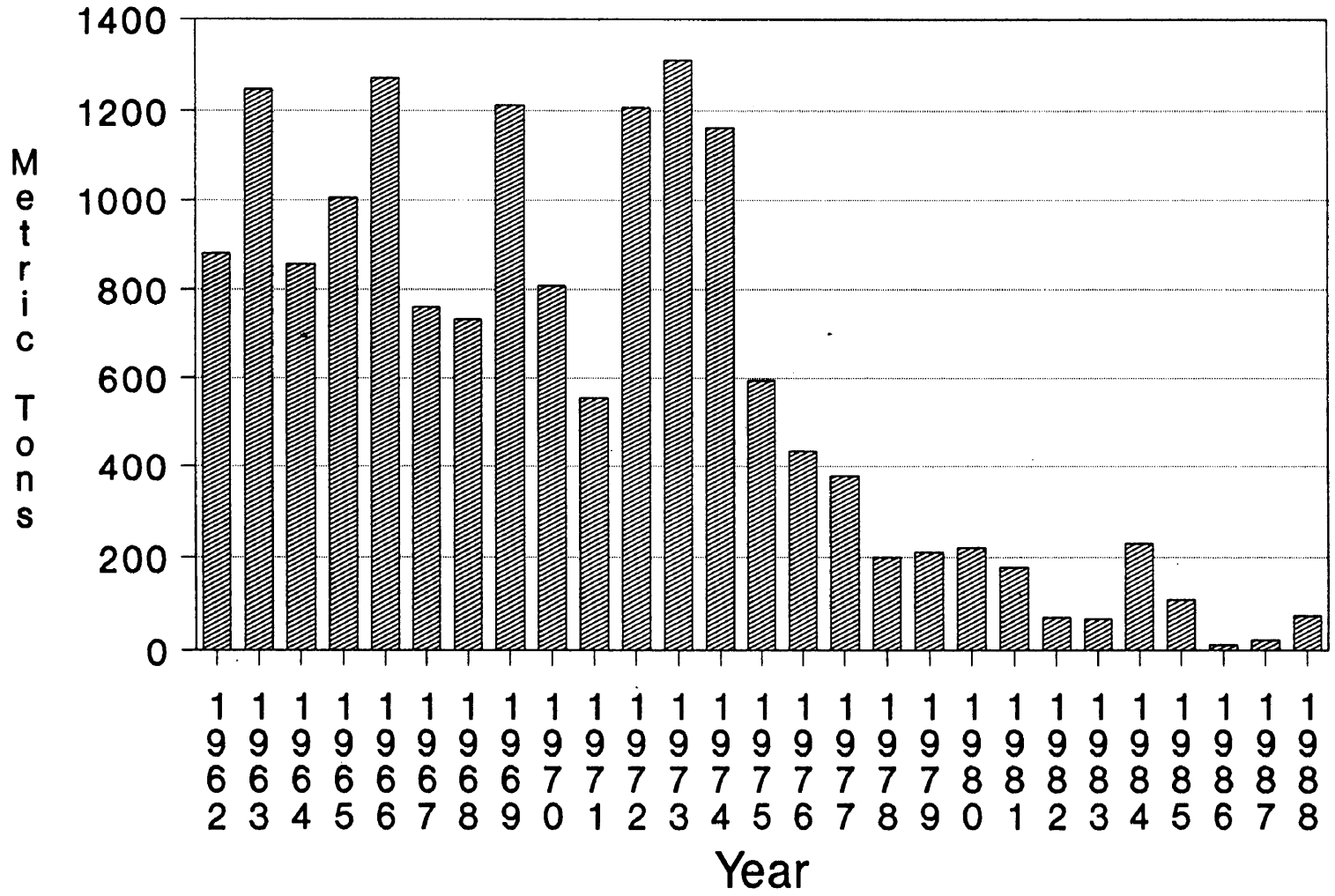


Figure 2. Chart of the Chesapeake Bay showing the locations of the Chesapeake and Delaware Canal and the Patuxent River.

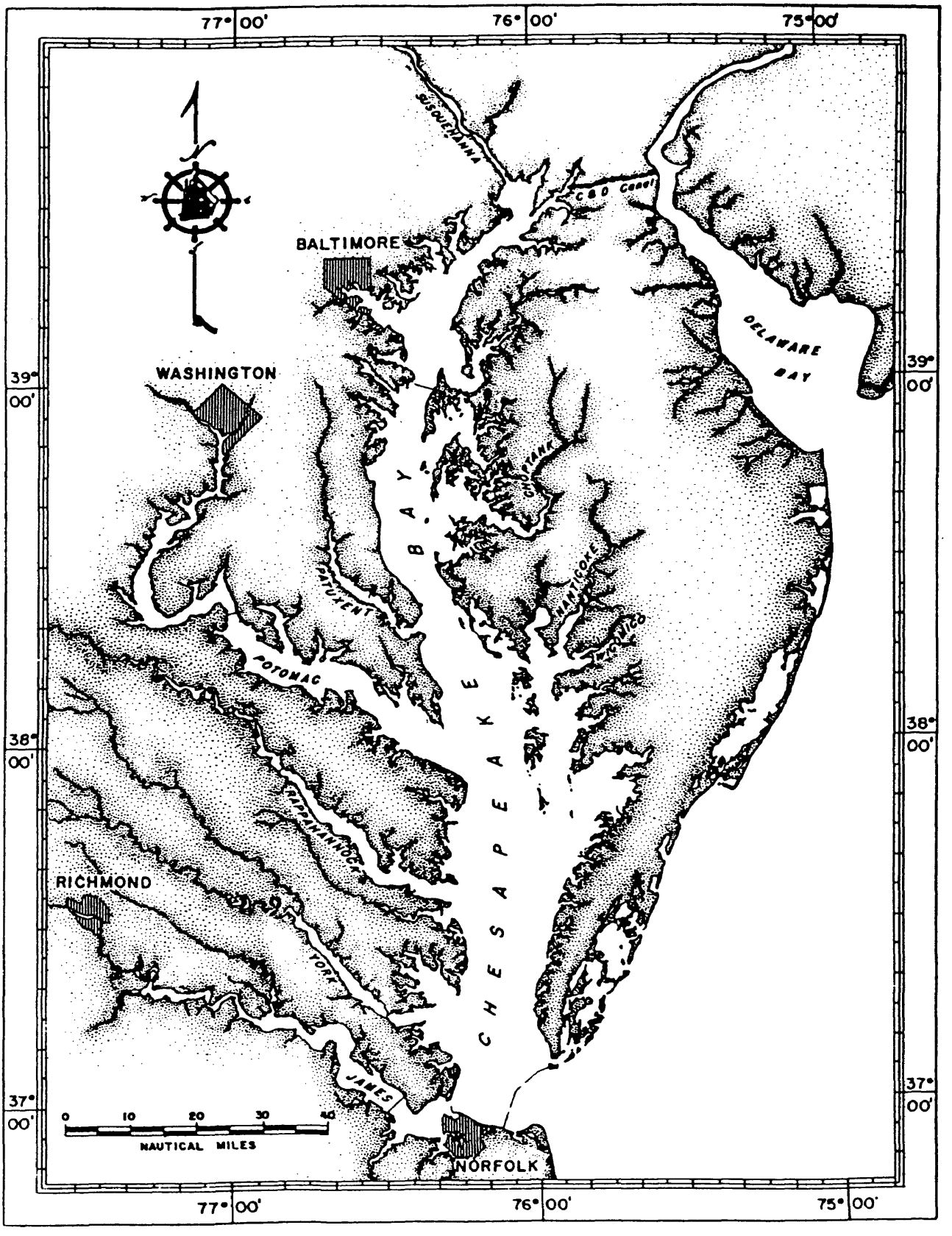

77° 00'
76° 00'
75° 00'
SUSQUEHANNA
C & D CANAL
BALTIMORE
DELAWARE BAY
39° 00'
WASHINGTON
CHOPTANK
PATUXENT
POTOMAC
CHESAPEAKE BAY
NANTICOKE
WICOMICO
38° 00'
RAPPAHANNOCK
RICHMOND
YORK
JAMES
37° 00'
0 10 20 30 40
NAUTICAL MILES
NORFOLK

Figure 3. Schematic of the pond layout at Harrison Lake National Fish Hatchery.

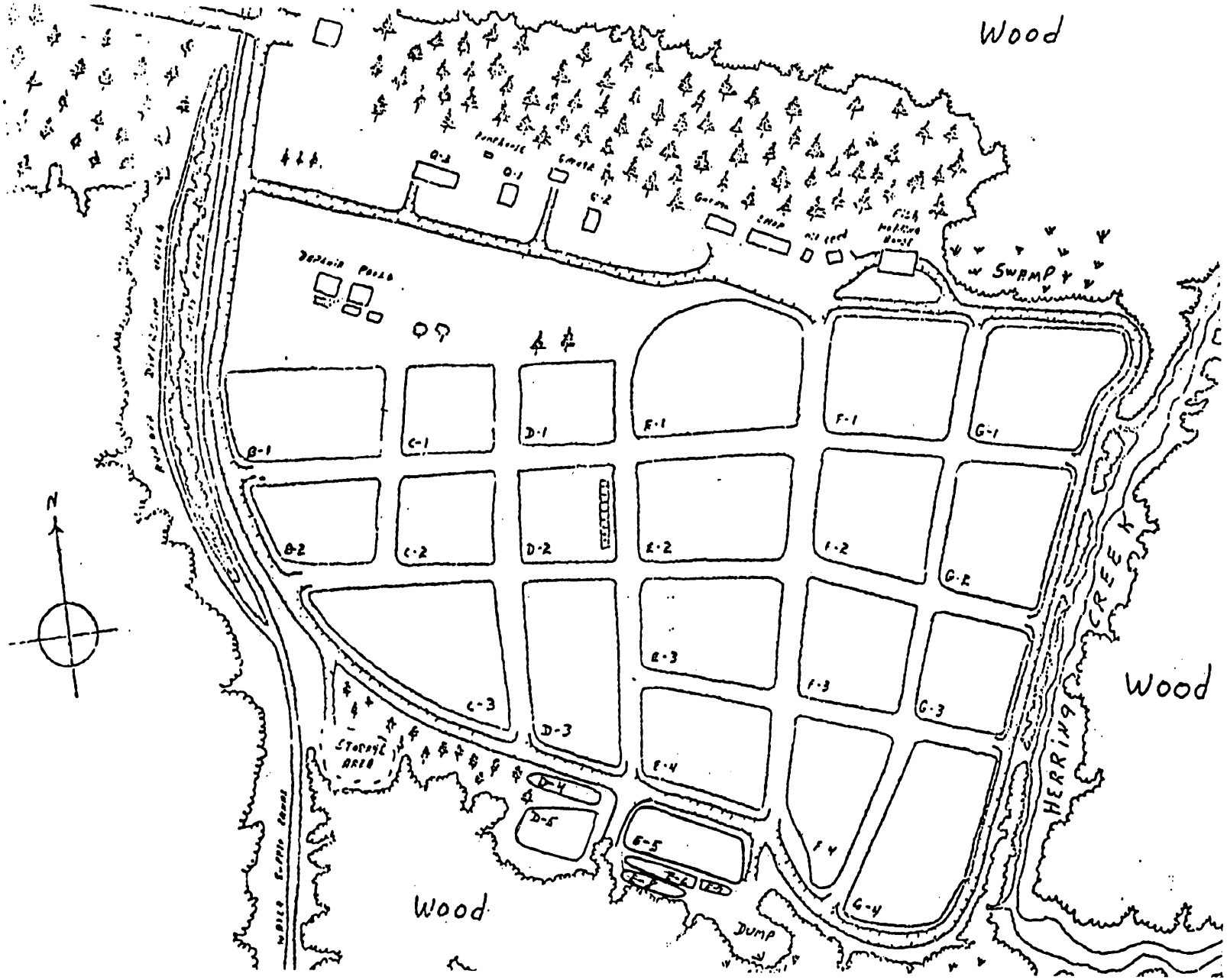

Wood
SWAMP
B-1
B-2
C-1
C-2
C-3
D-1
D-2
D-3
D-4
D-5
E-1
E-2
E-3
E-4
F-1
F-2
F-3
F-4
G-1
G-2
G-3
G-4
G-5
HERRING CREEK
Wood
Wood
DUMP
STORAGE AREA
N

Figure 4. Illustration of striped bass, Morone saxatilis, with morphometric characters diagrammed.

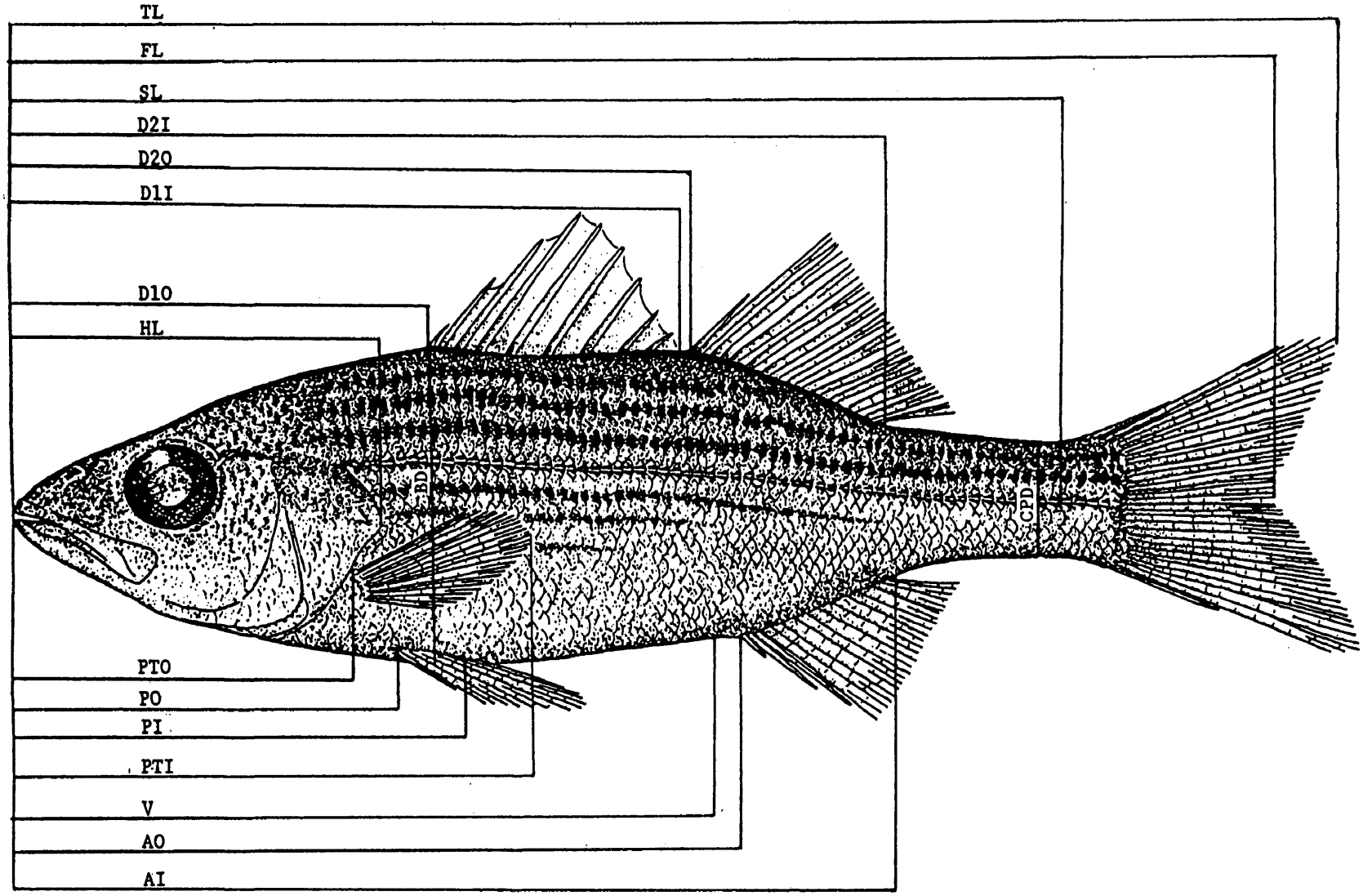

TL
FL
SL
D2I
D2O
D1I
D1O
HL
BD
CPD
PTO
PO
PI
PTI
V
AO
AI

Figure 5. Plot of the cumulative percent variation of the eigenvalues extracted by principal component analysis.

CUMULATIVE PERCENT VARIATION OF THE EIGENVALUES EXTRACTED BY PCA

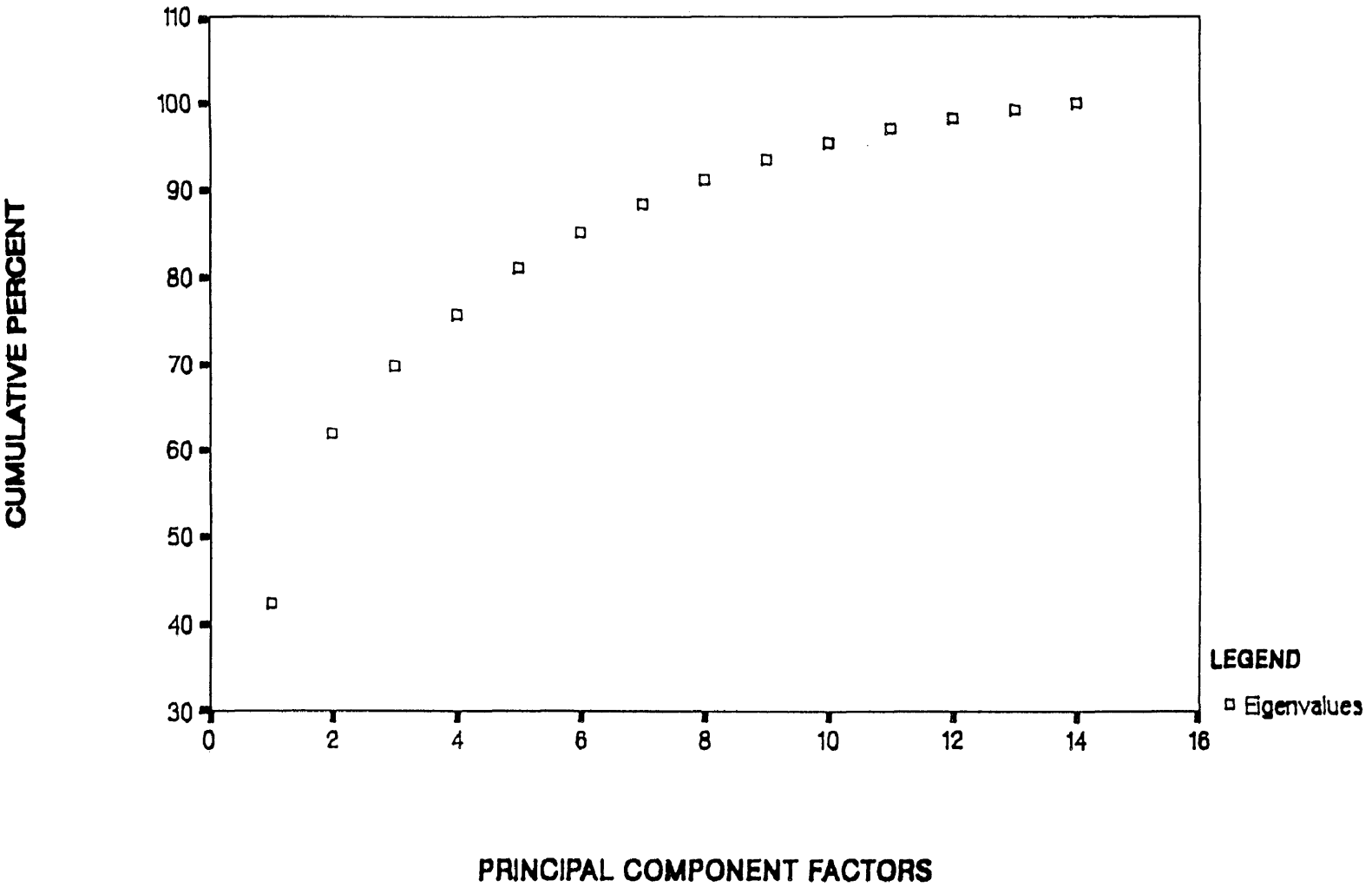


Figure 6. Plot of the temperature fluctuations for pond groups A and B.

TEMPERATURE FLUCTUATIONS FOR POND GROUPS A & B

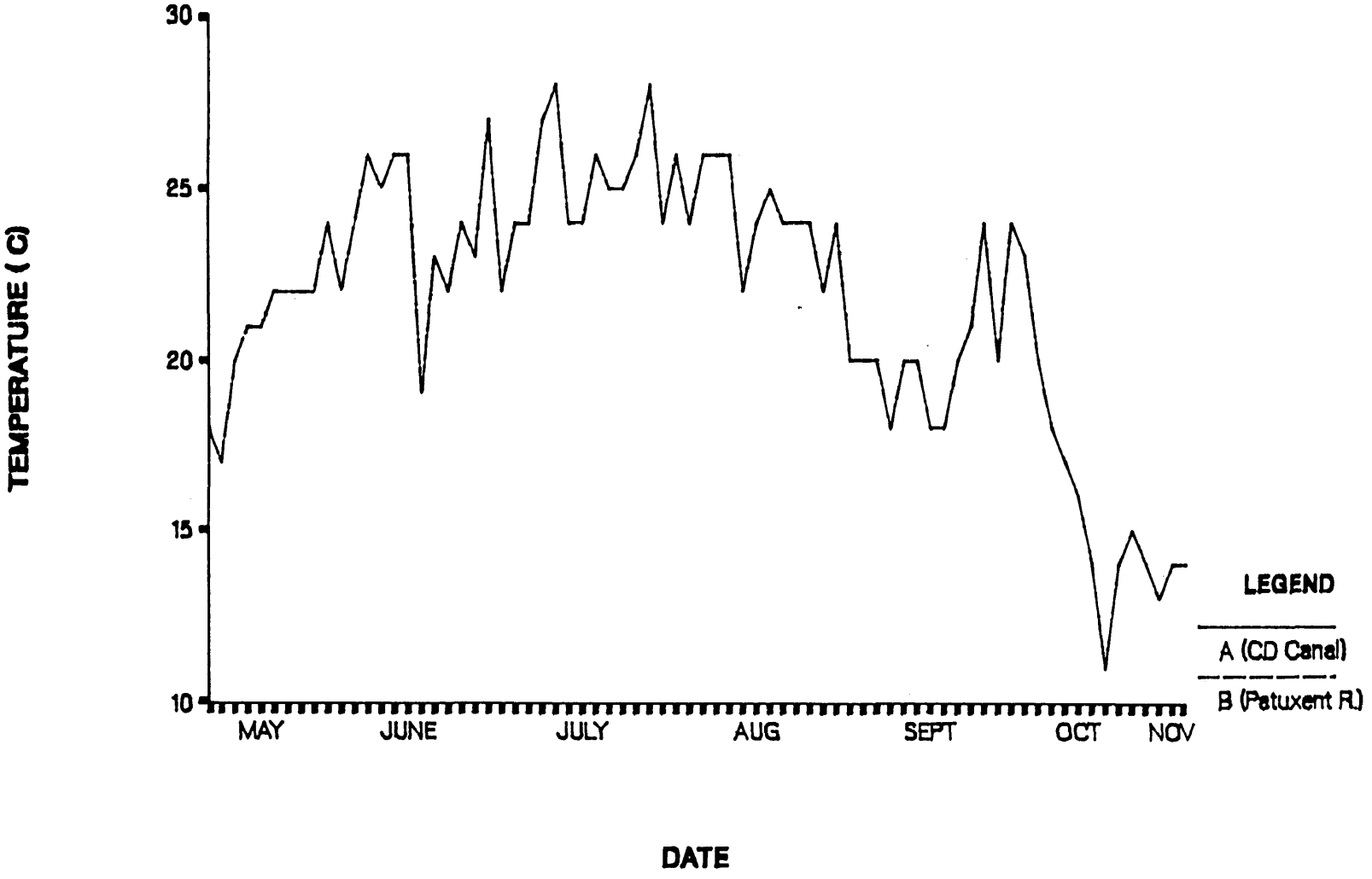


Figure 7. Plot of the pH fluctuations for pond groups A and B.

MEAN pH FLUCTUATIONS FOR POND GROUPS A & B

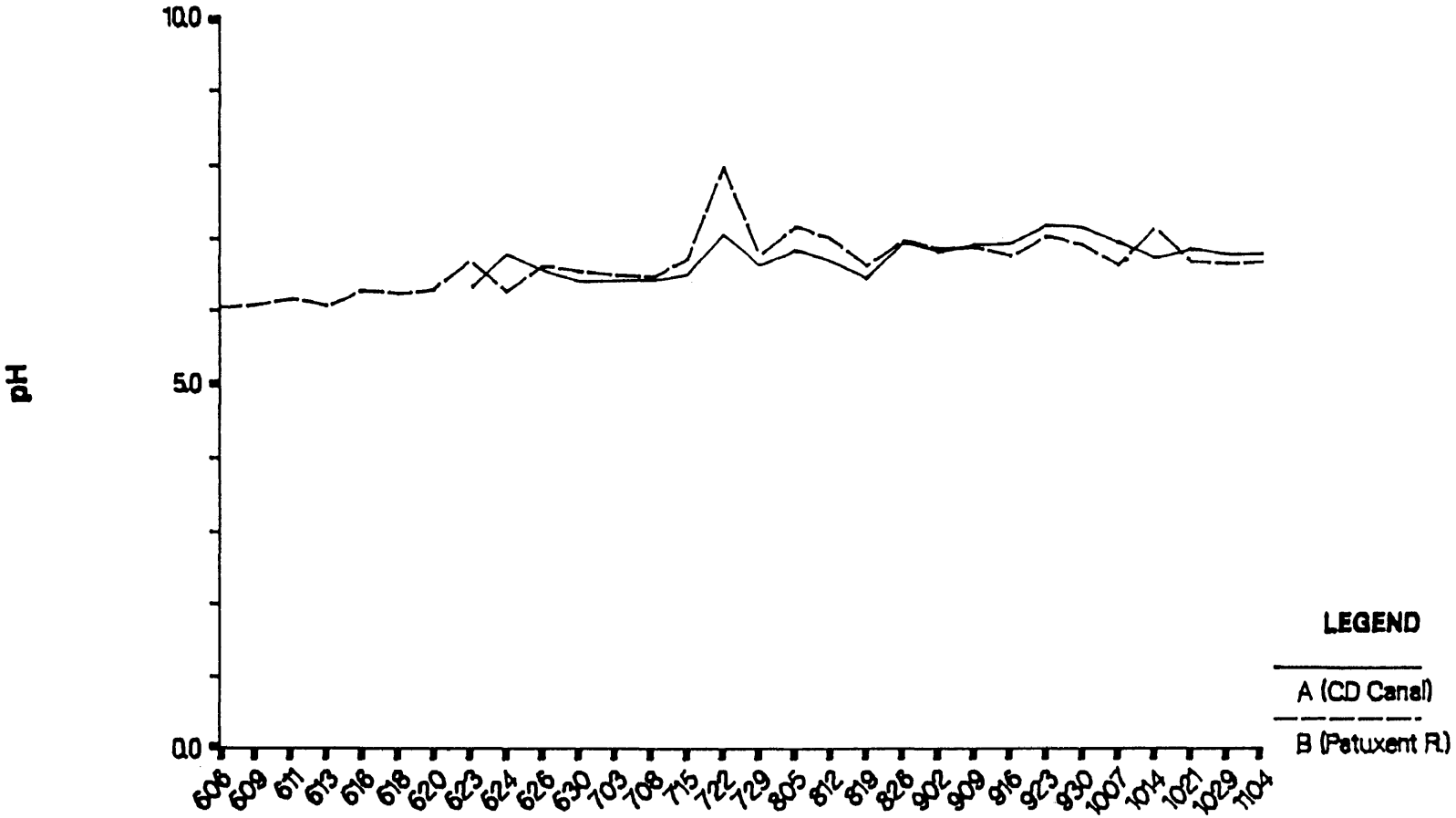


Figure 8. Plot of the mean dissolved oxygen concentrations for pond groups A and B.

MEAN DISSOLVED OXYGEN CONCENTRATIONS FOR POND GROUPS A & B

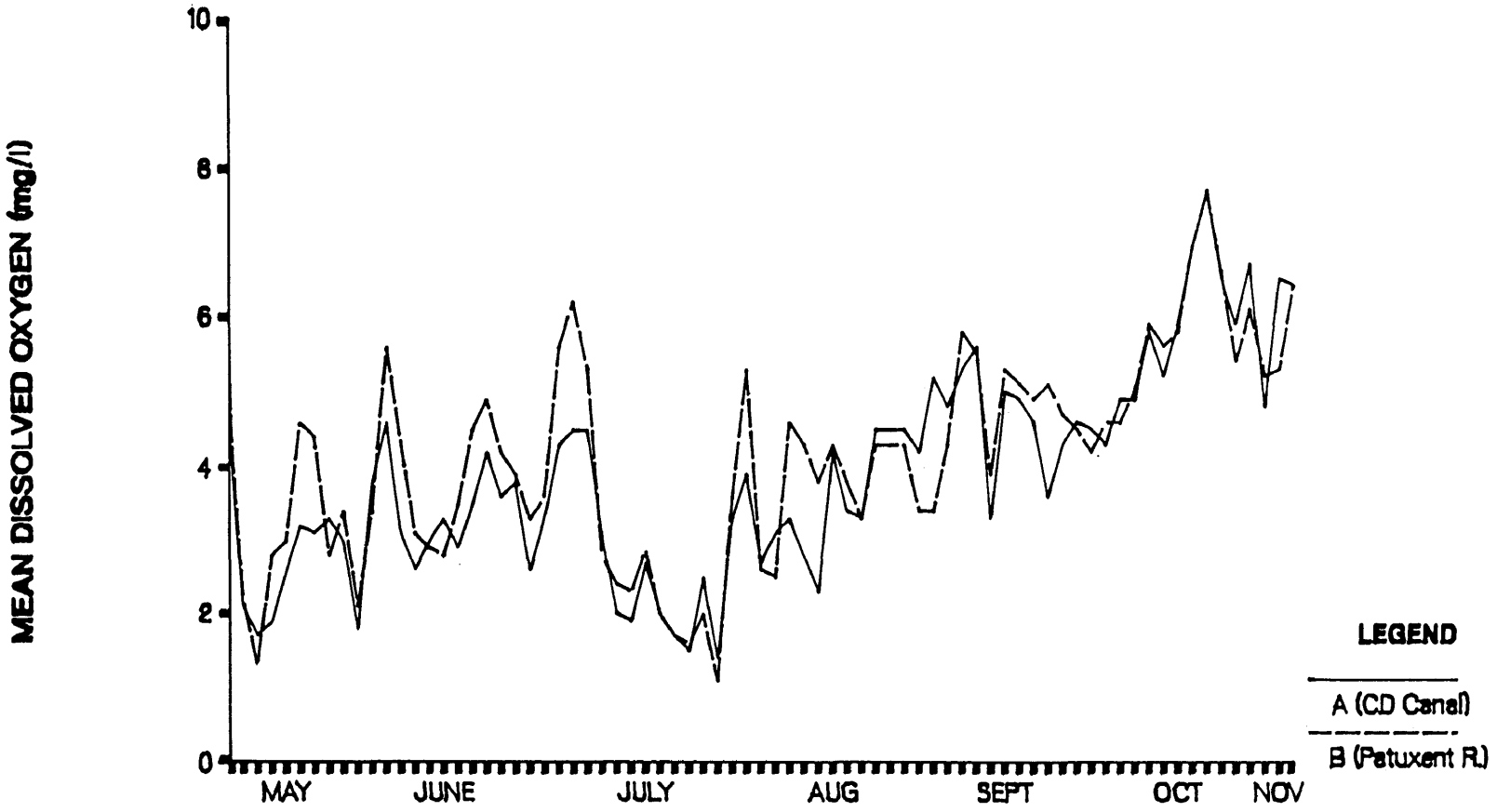


Figure 9. Illustration of striped bass, Morone saxatilis, with the principal components diagrammed.

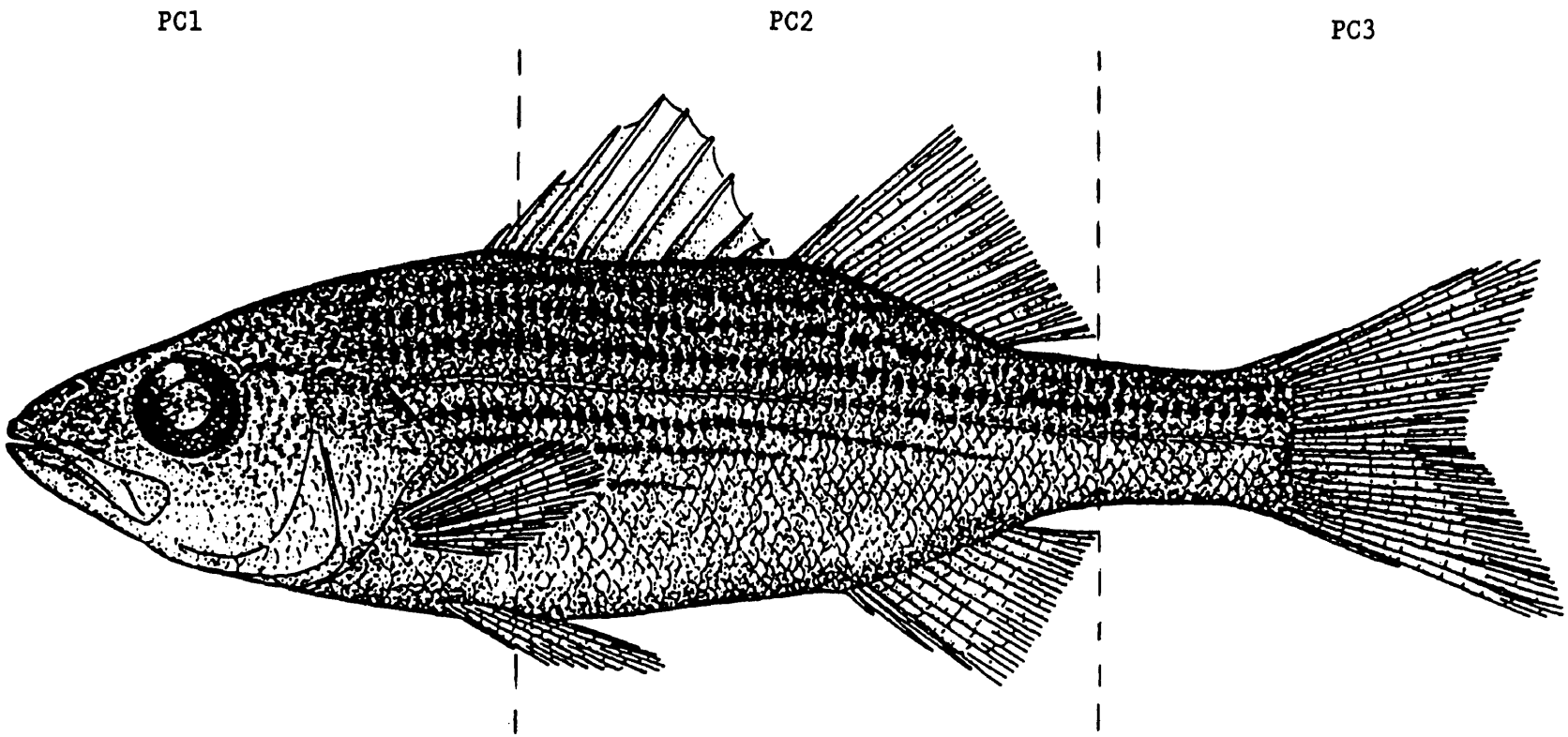
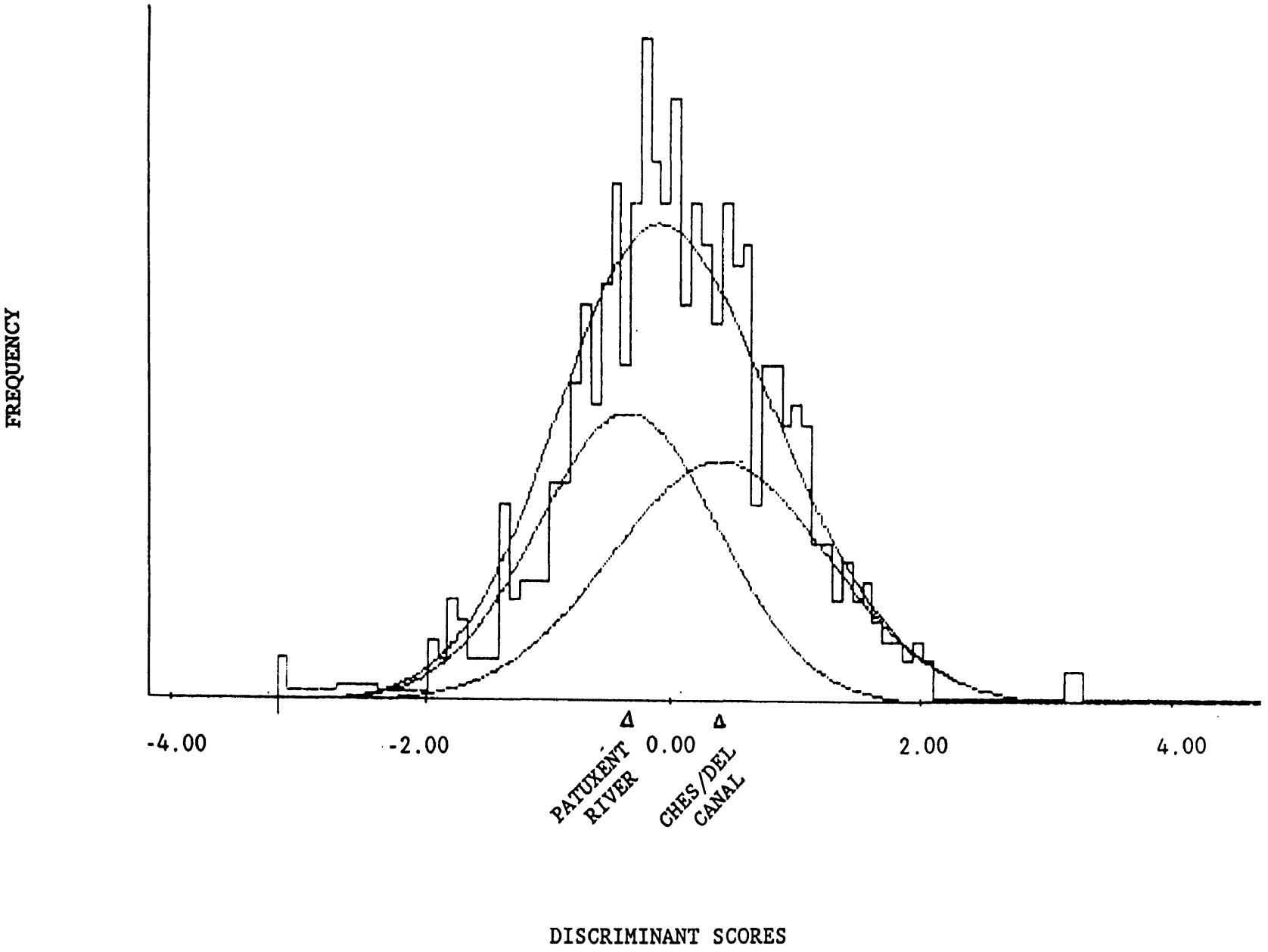

PC1
PC2
PC3

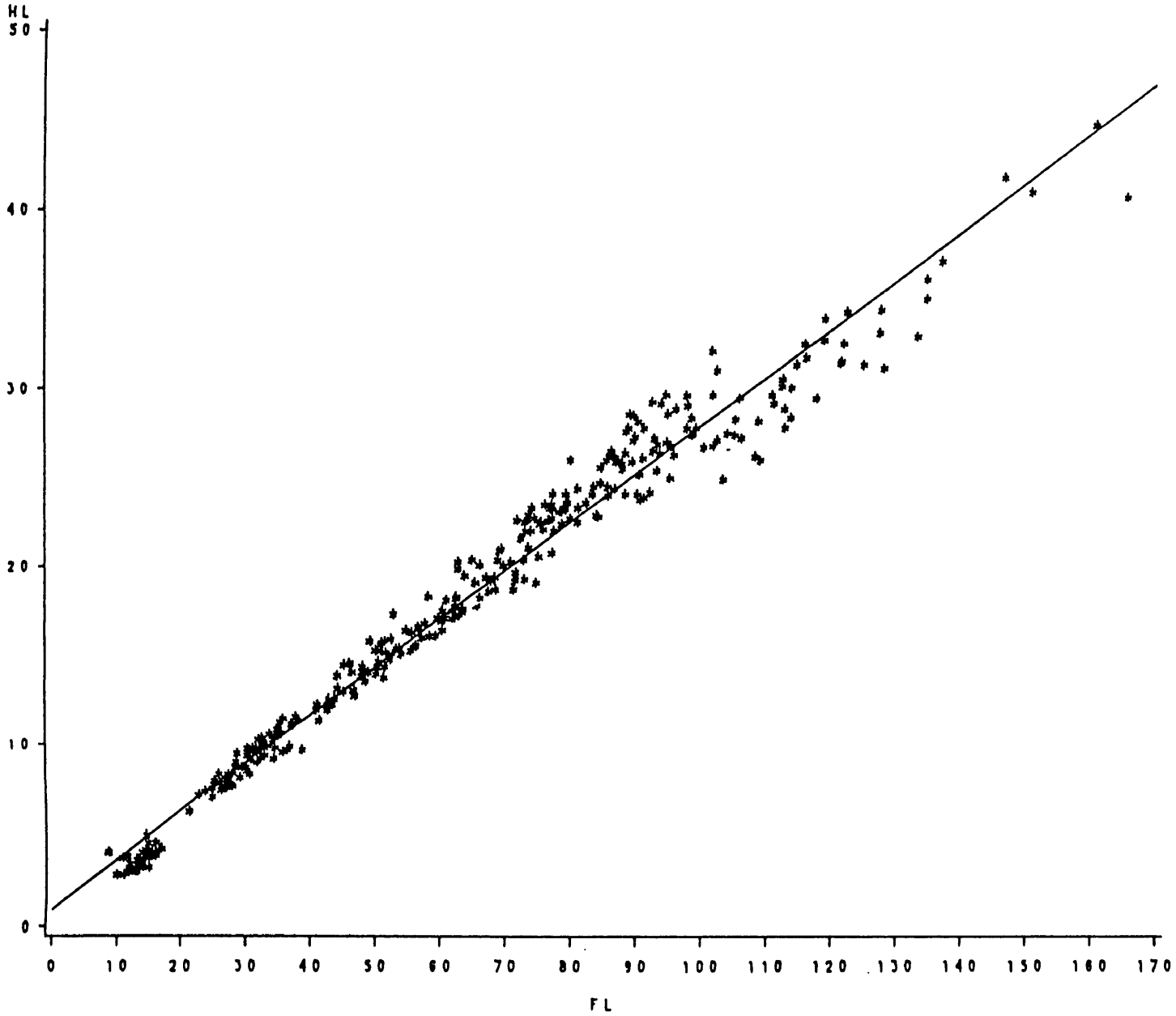
Figure 10. Histogram of discriminant scores of the log-transformed variables for the Chesapeake and Delaware Canal and the Patuxent River.


FREQUENCY
-4.00
-2.00
0.00
2.00
4.00
PATUXENT RIVER
CHES/DEL CANAL
DISCRIMINANT SCORES

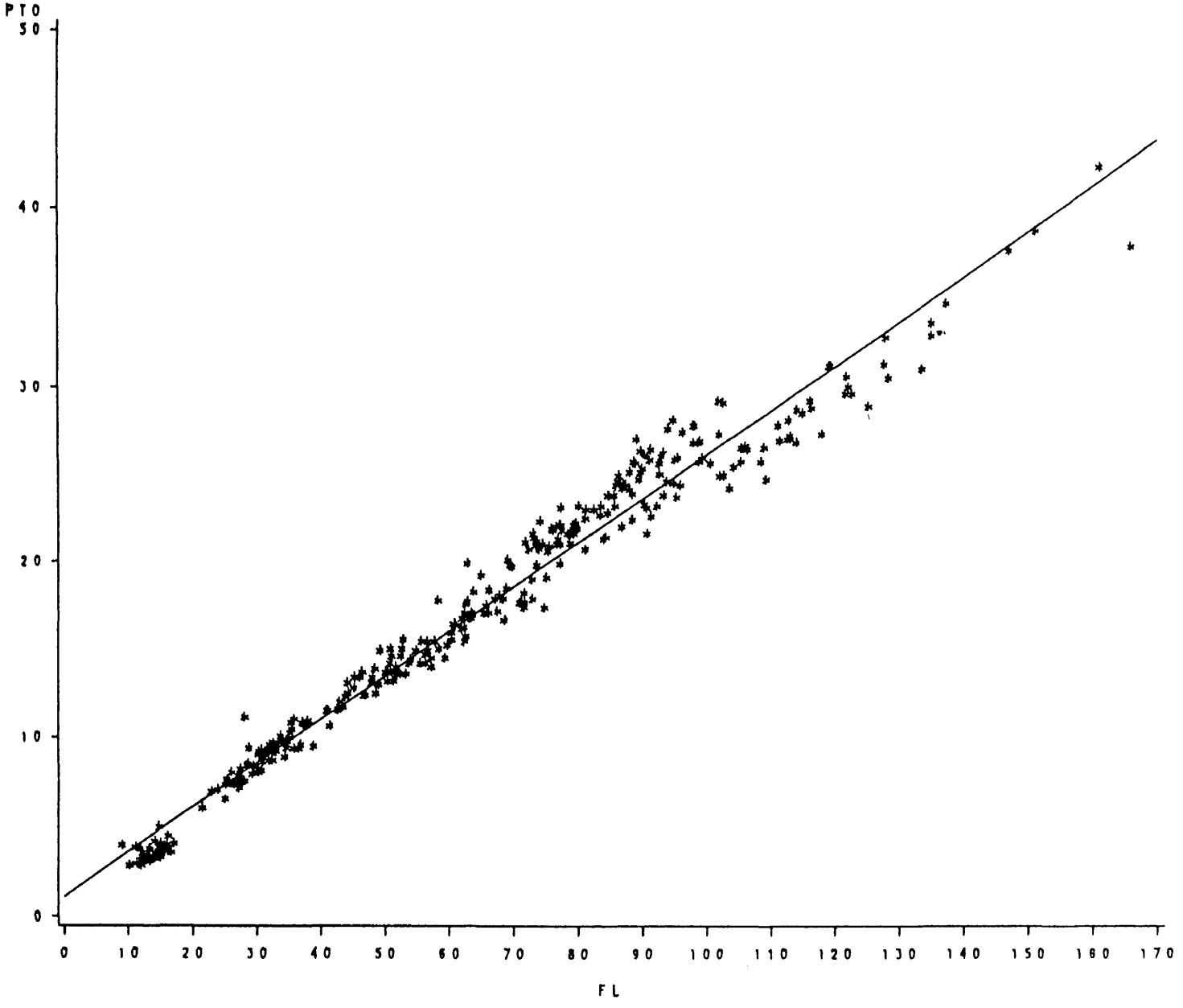
APPENDIX

Regression plots of the dependent variables (HL, PTO, PTI, PO, PI, D_1O, D_1I, D_2O, D_2I, AO, AI, V, BD, CPD) on FL to illustrate isometric and allometric growth patterns.

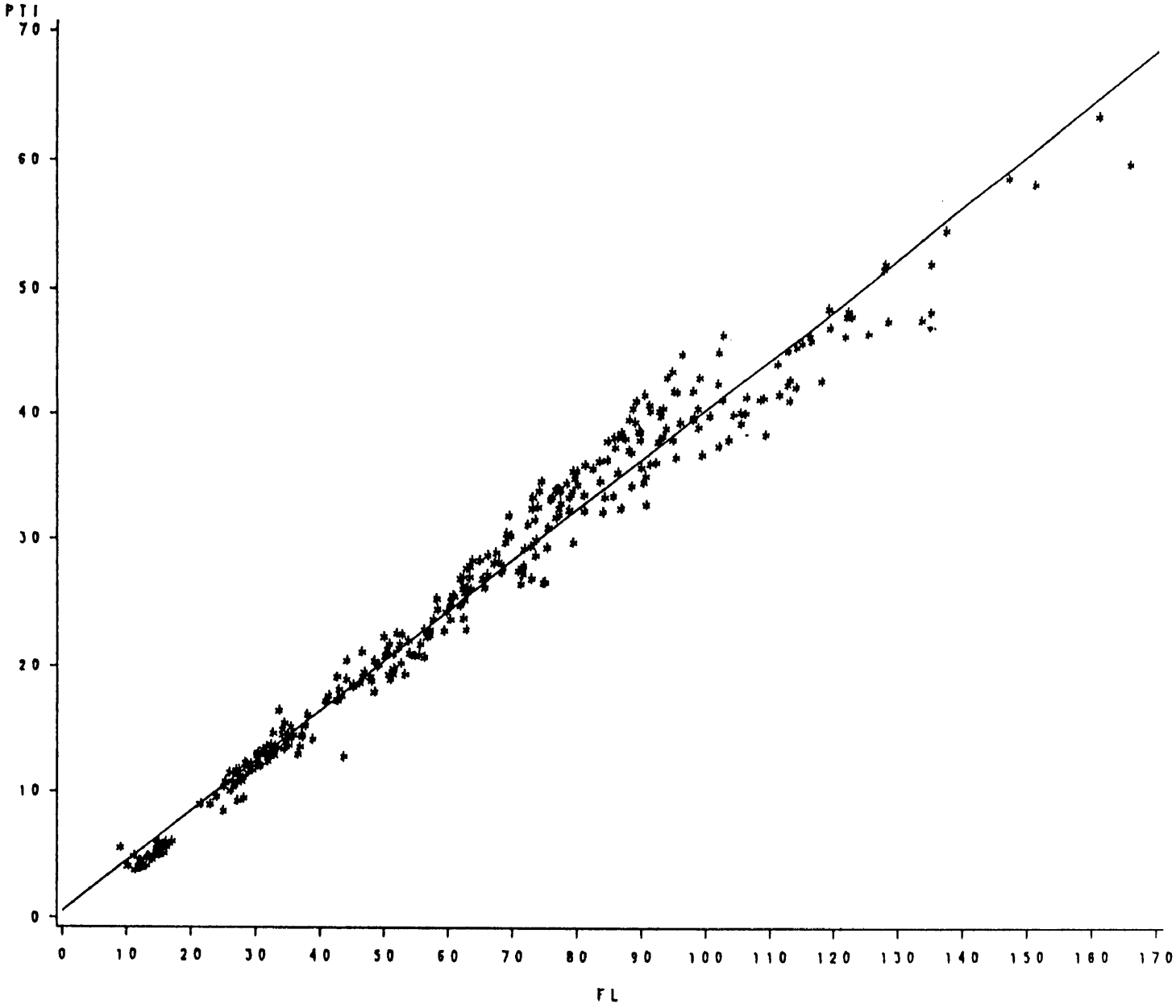
HEAD LENGTH VS FORK LENGTH (C D Canal)



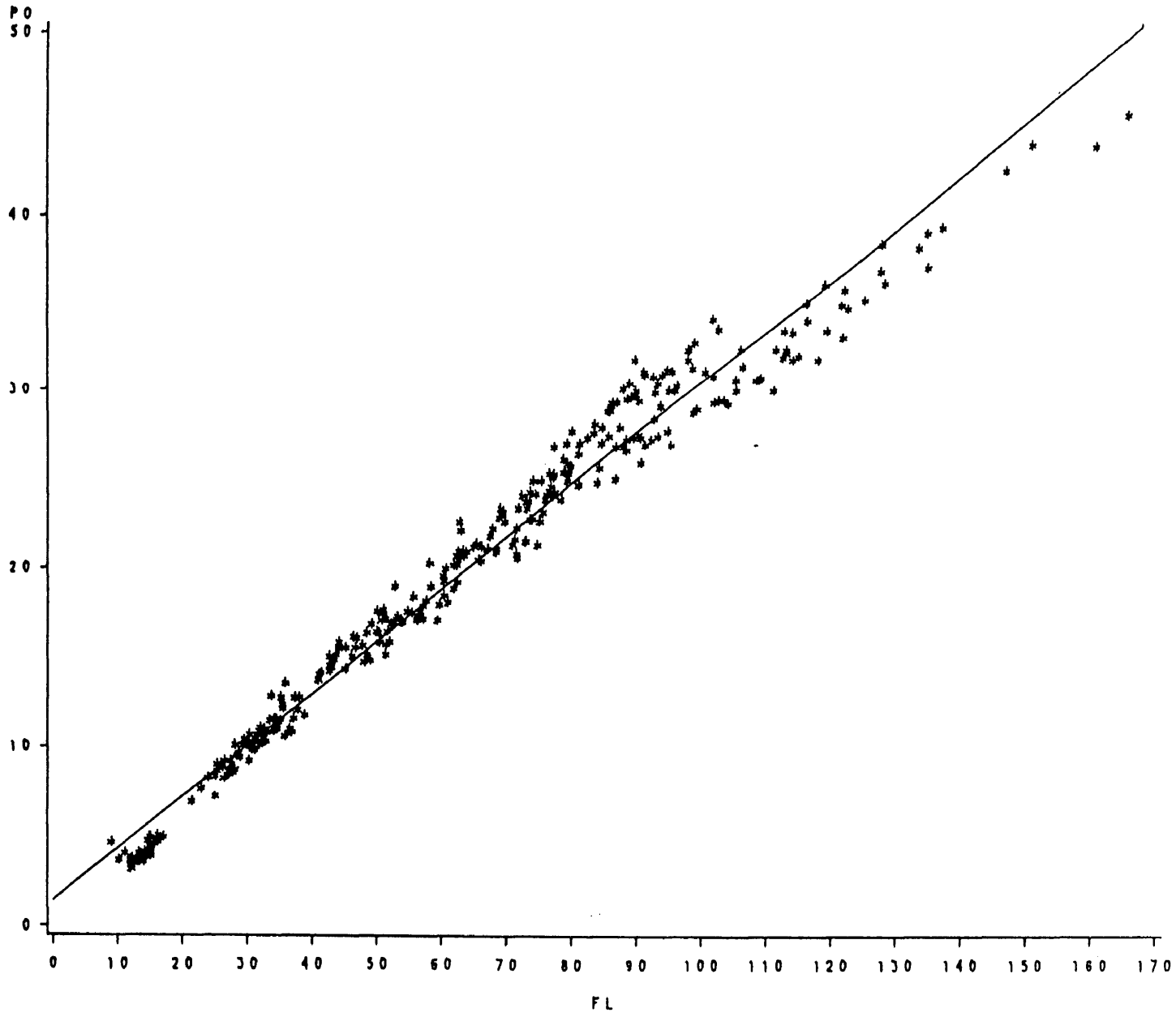
PECTORAL ORIGIN VS FORK LENGTH (C D Canal)



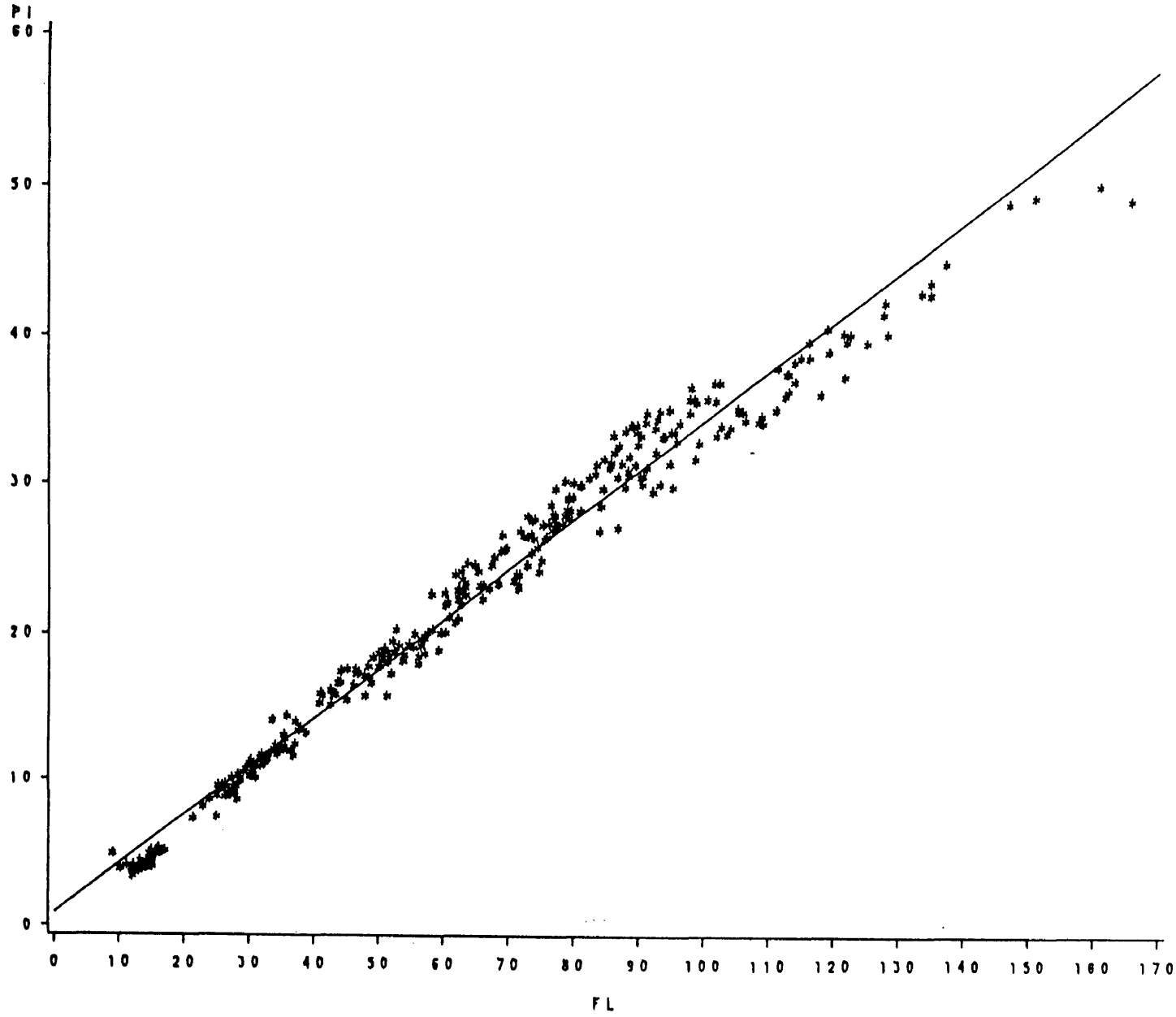
PECTORAL INSERTION VS FORK LENGTH (C D Canal)



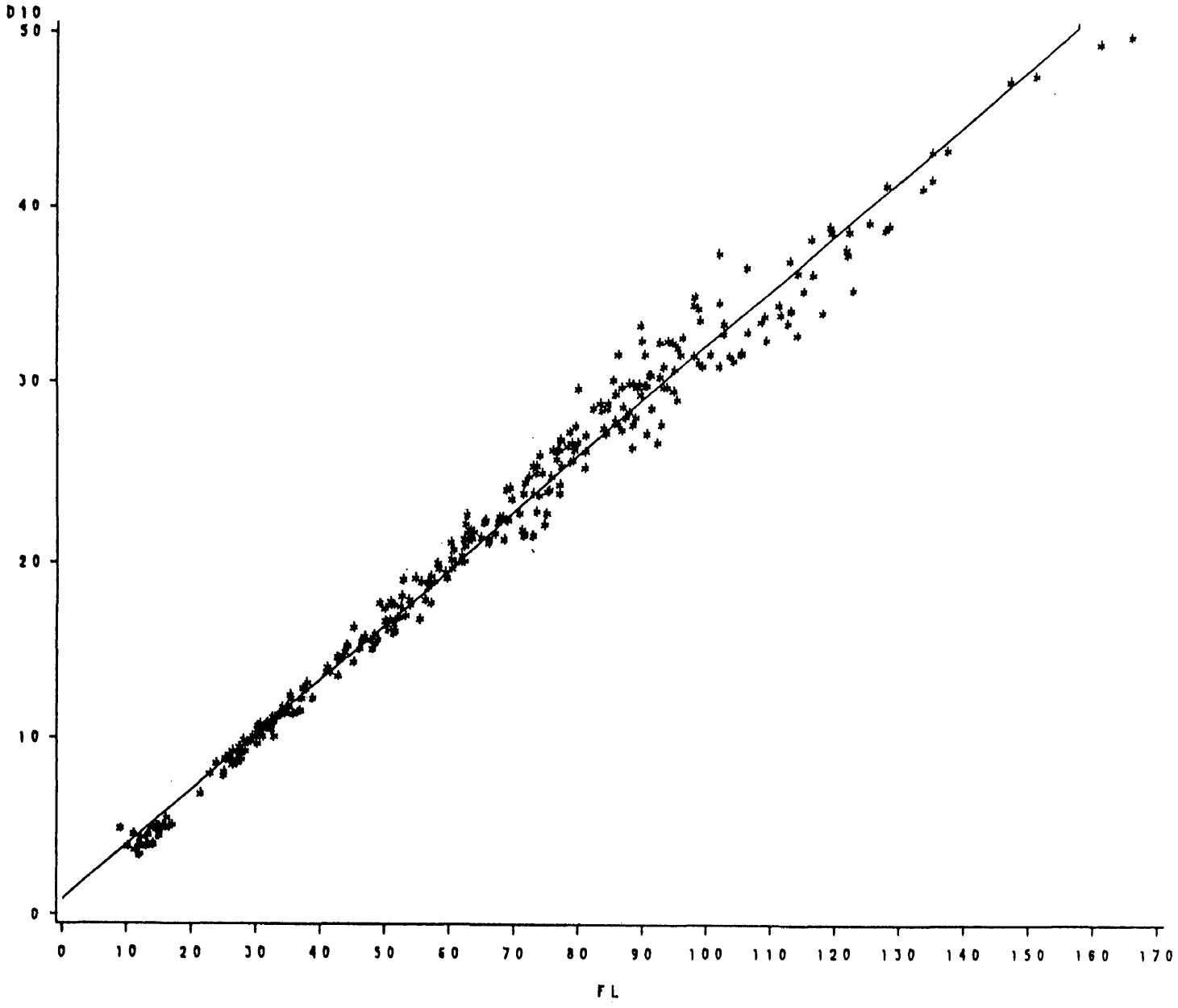
PELVIC ORIGIN VS FORK LENGTH (C D Canal)



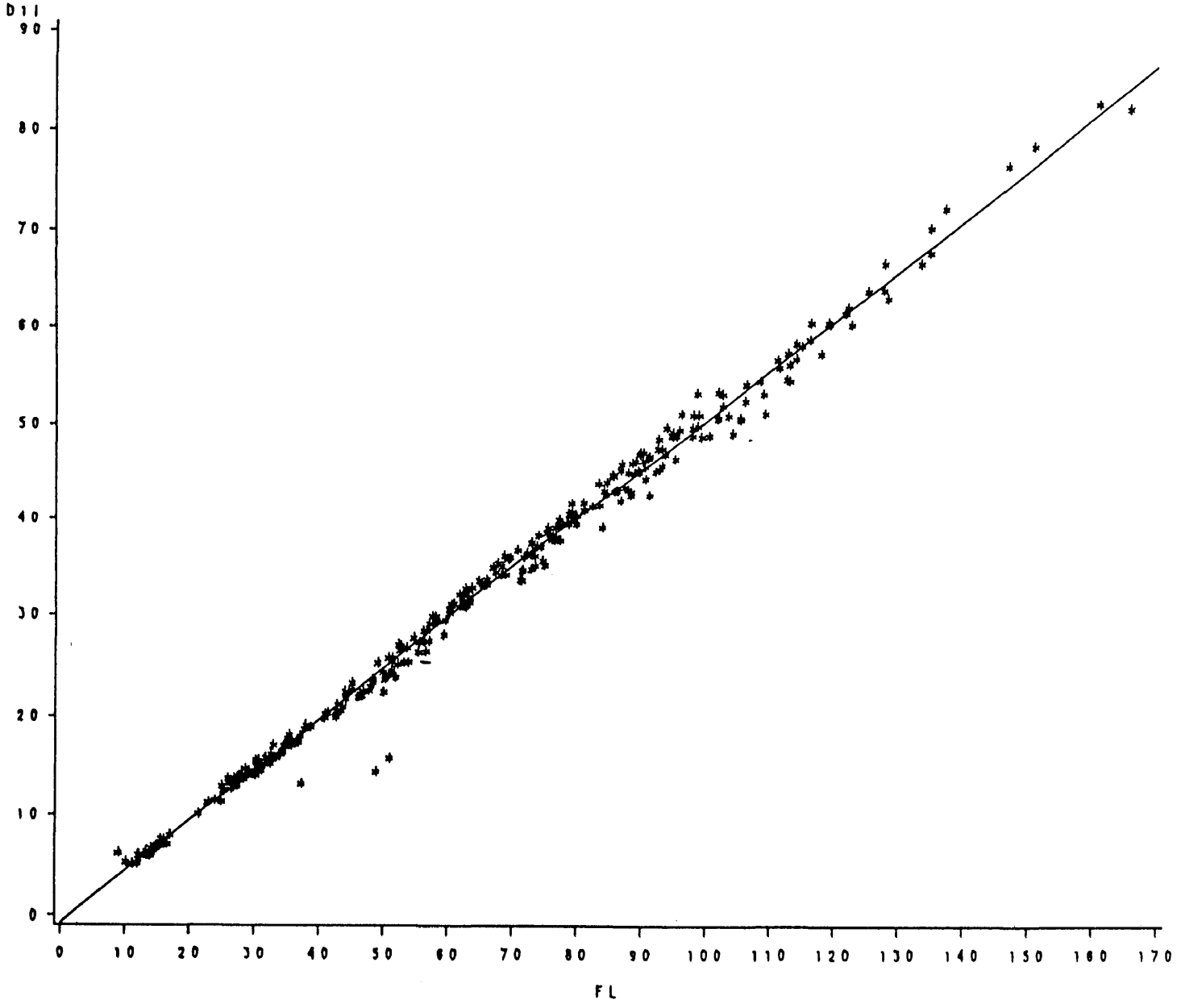
PELVIC INSERTION VS FORK LENGTH (C D Canal)



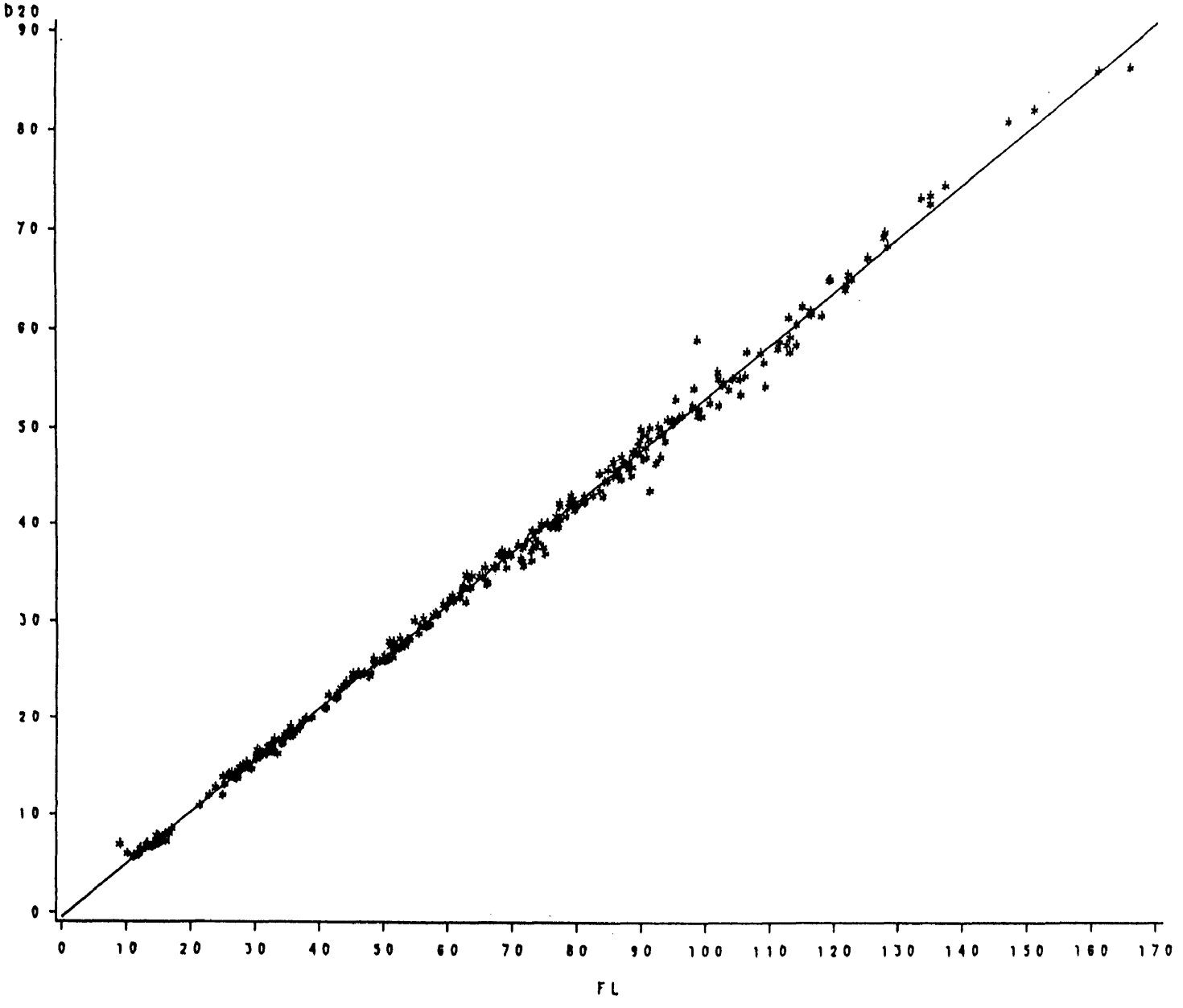
FIRST DORSAL ORIGIN VS FORK LENGTH (C D Canal)



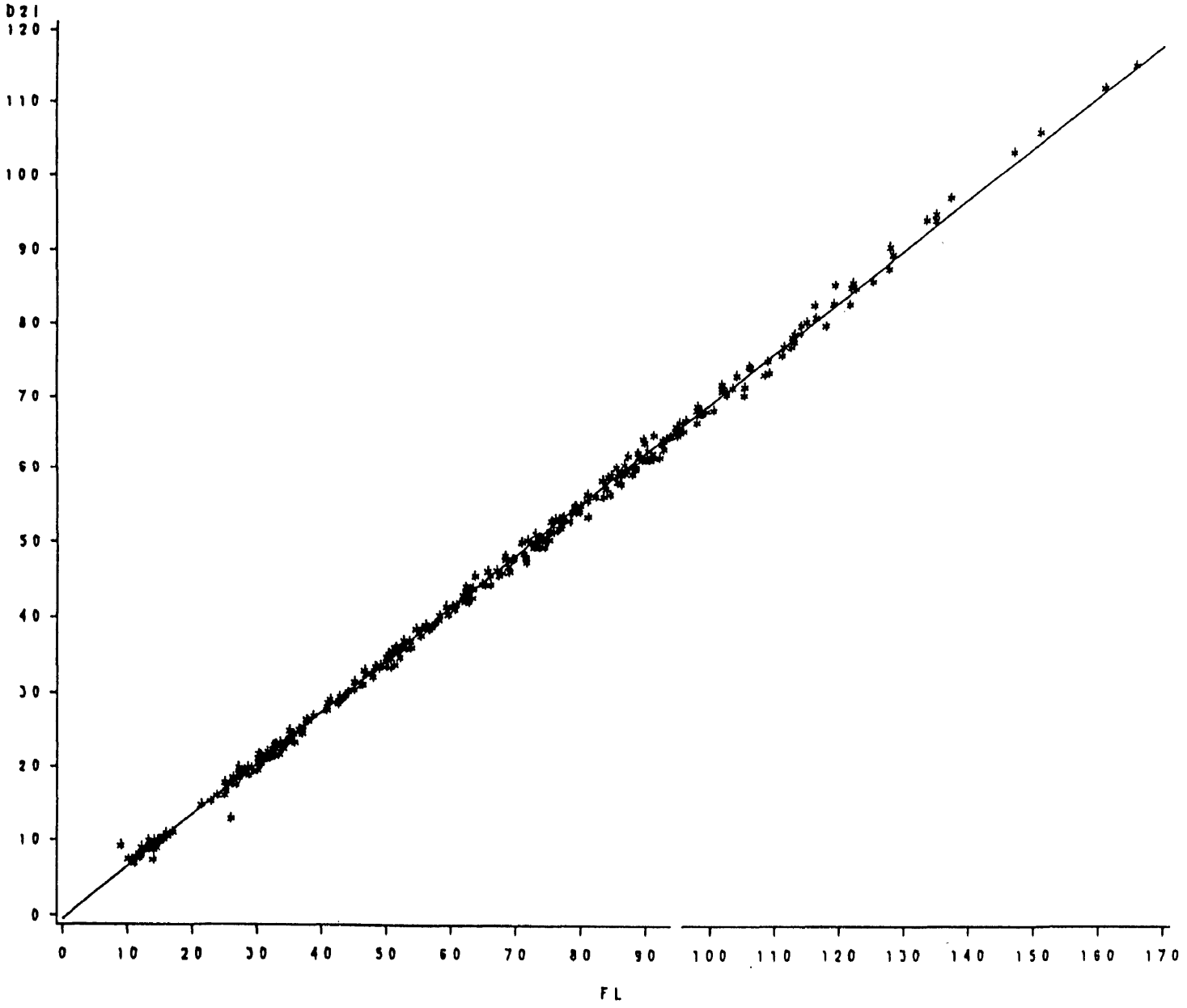
FIRST DORSAL INSERTION VS FORK LENGTH (C D Canal)



SECOND DORSAL ORIGIN VS FORK LENGTH (C D Canal)



SECOND DORSAL INSERTION VS FORK LENGTH (C D Canal)



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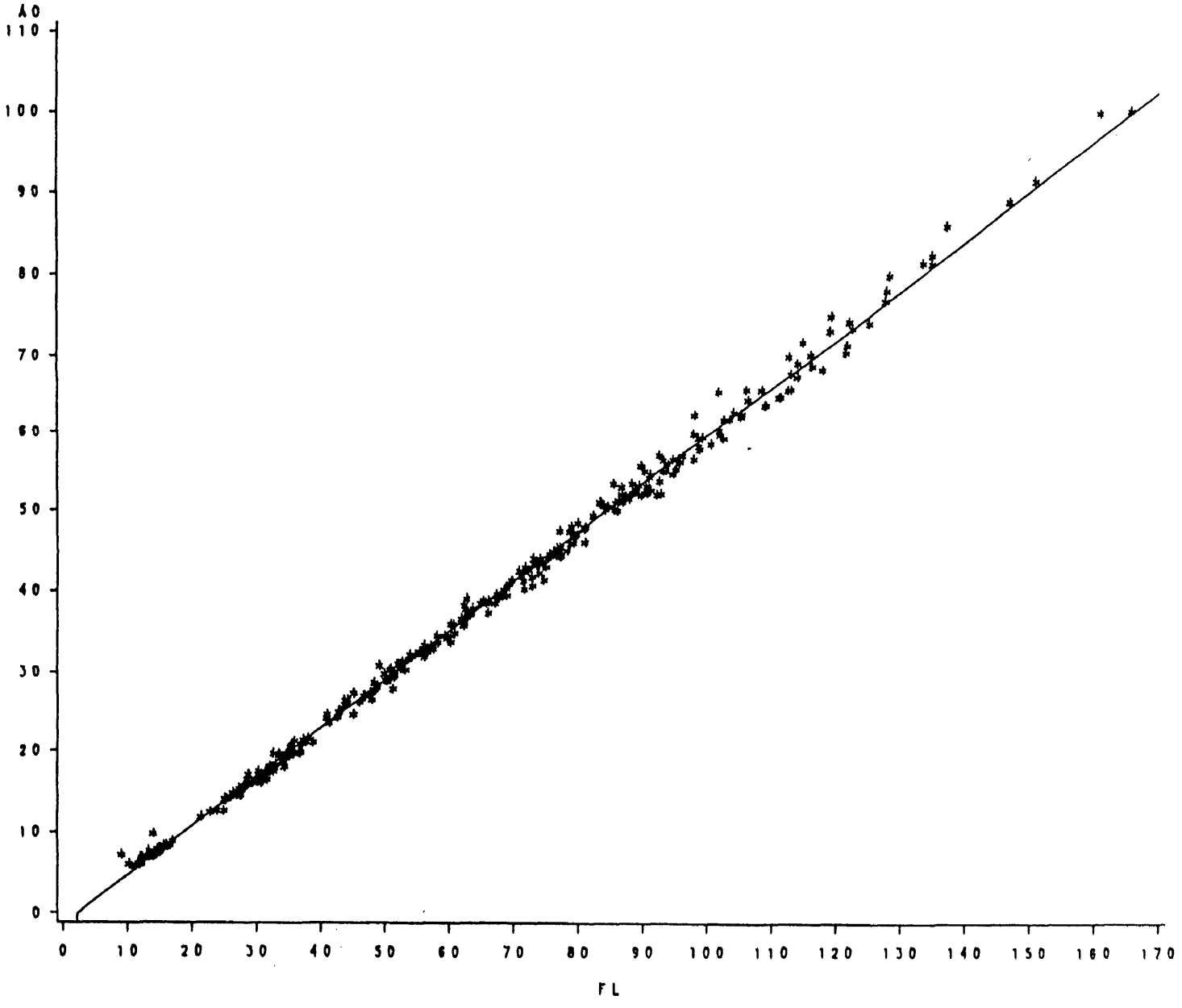

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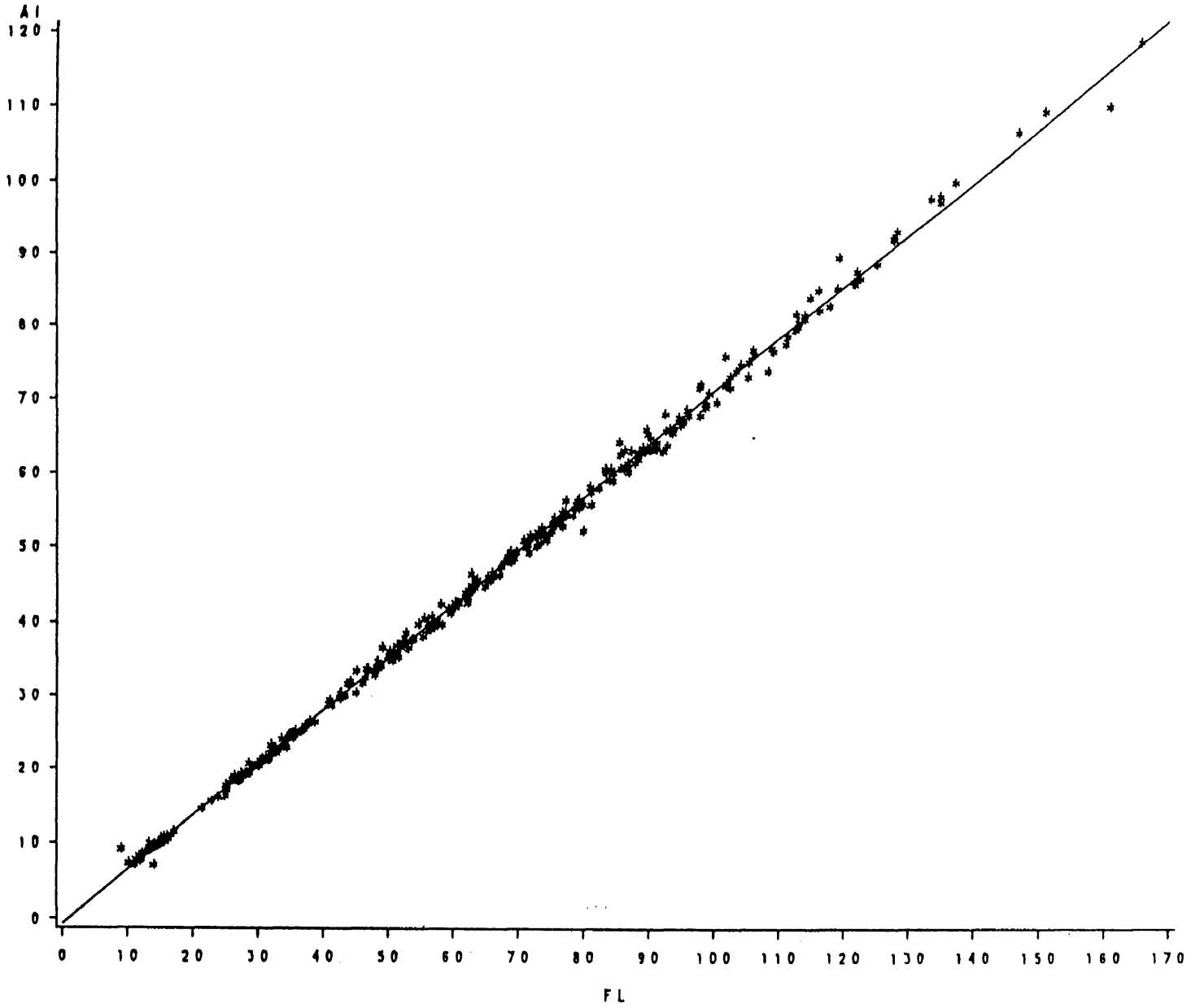

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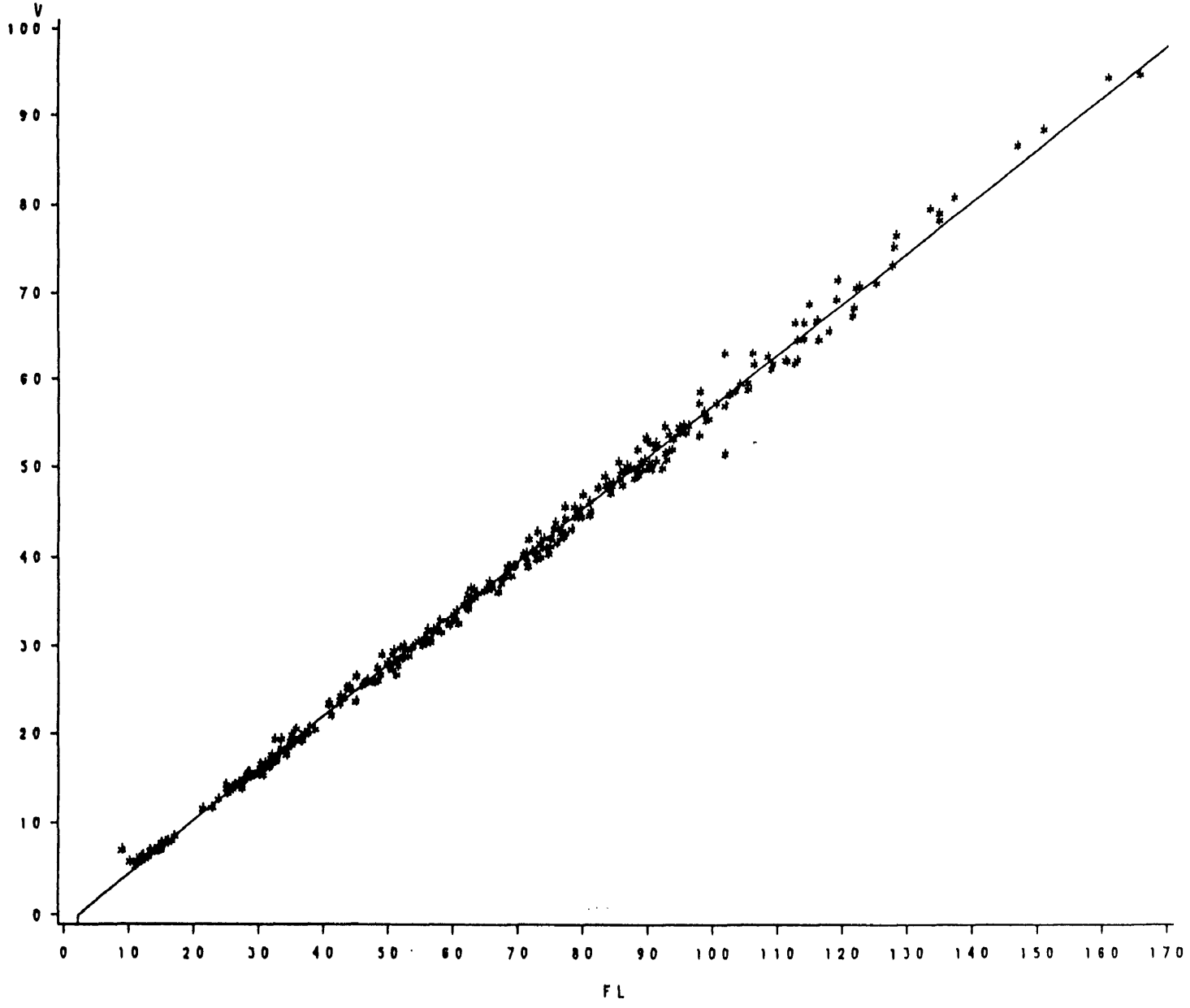

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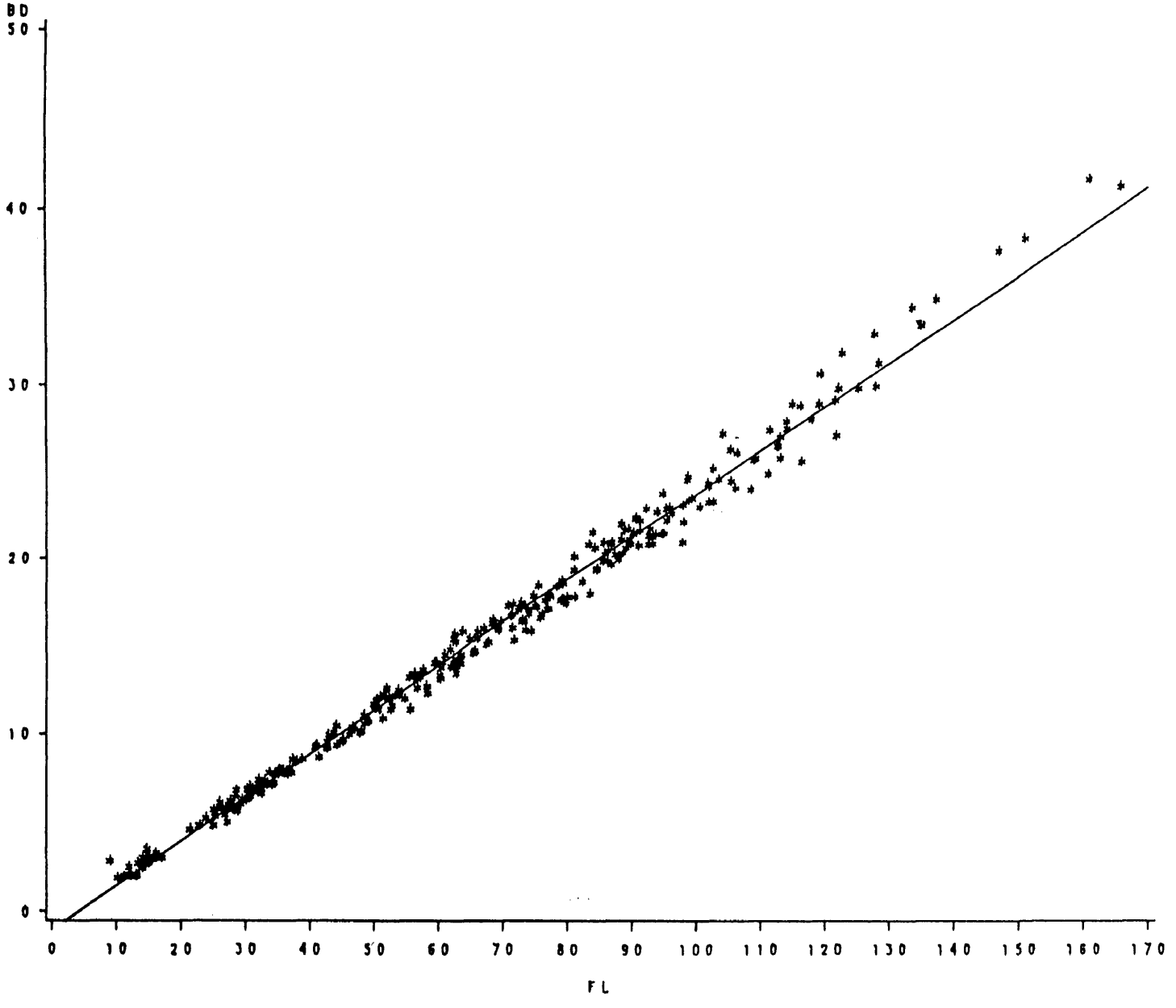
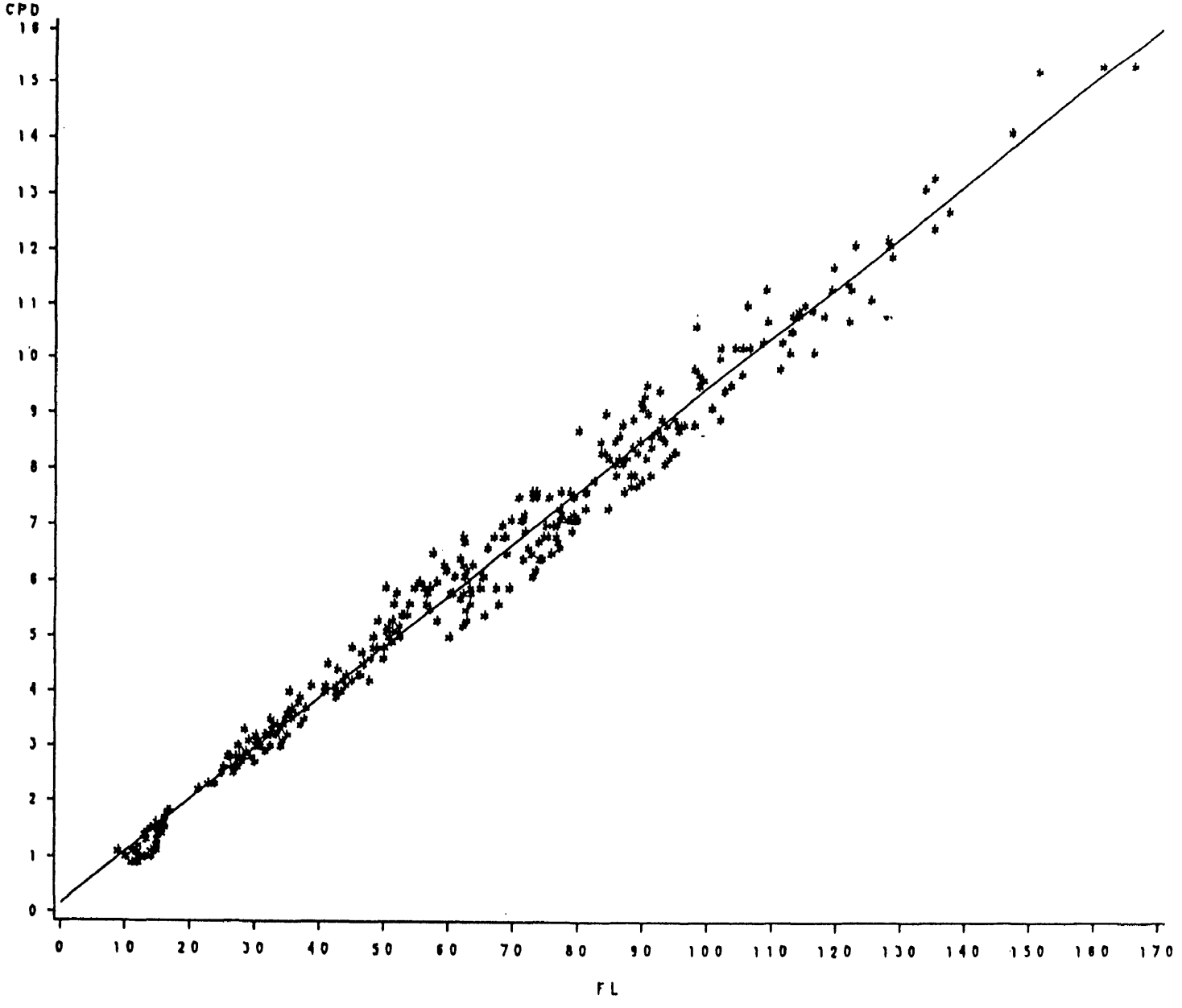
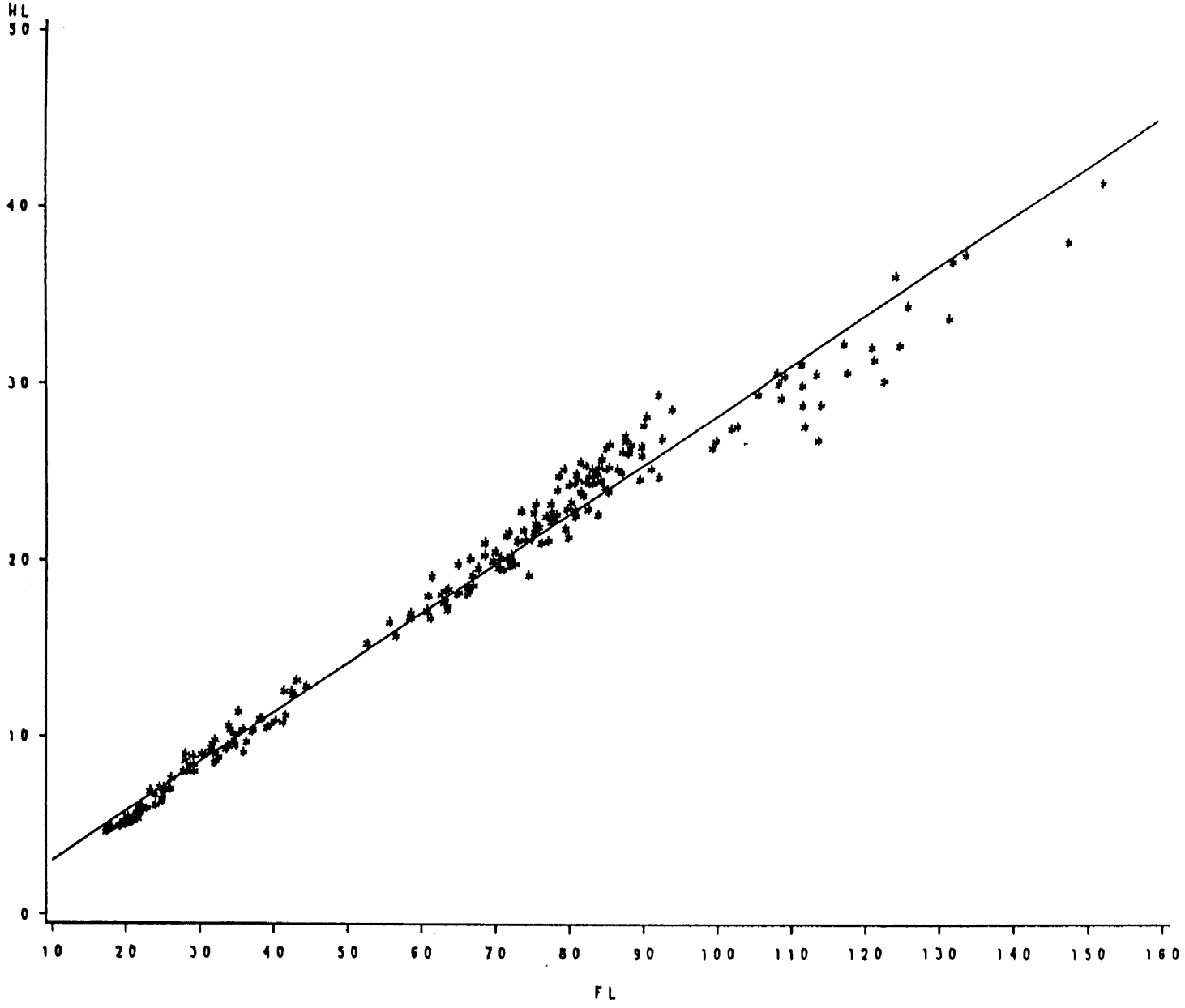


CAUDAL PEDUNCLE DEPTH VS FORK LENGTH (C D Canal)



HEAD LENGTH VS FORK LENGTH (Patuxent River)



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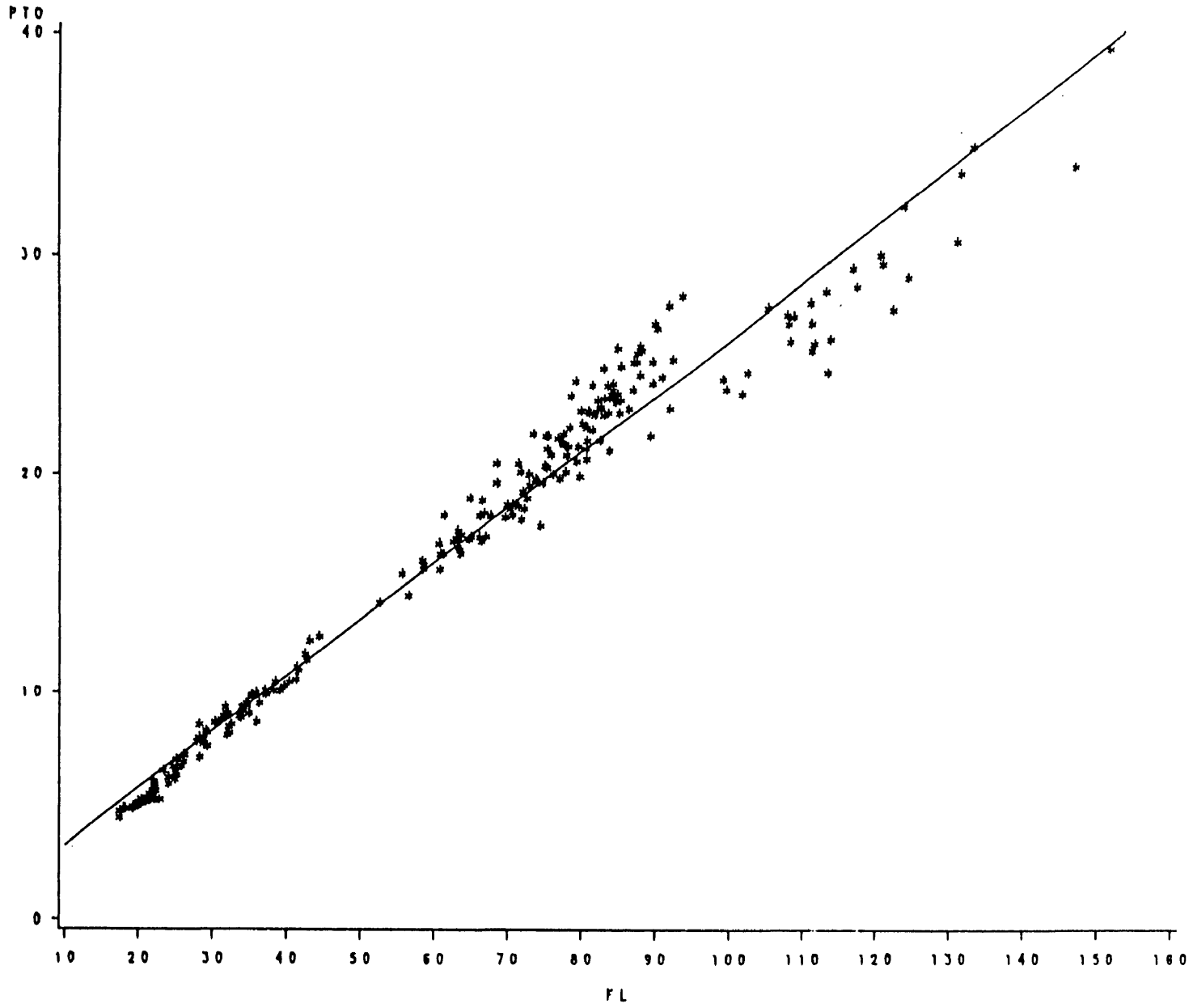

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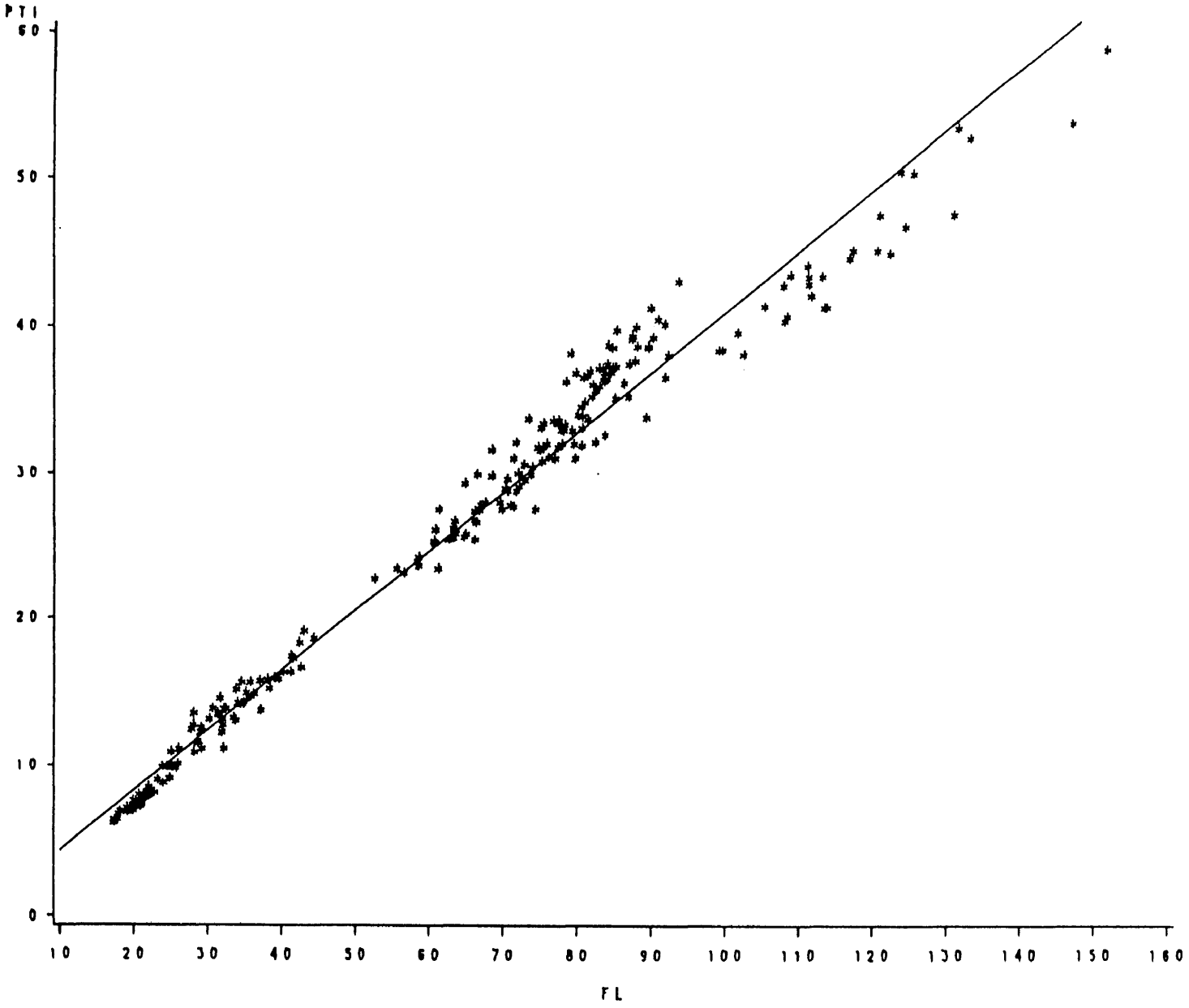

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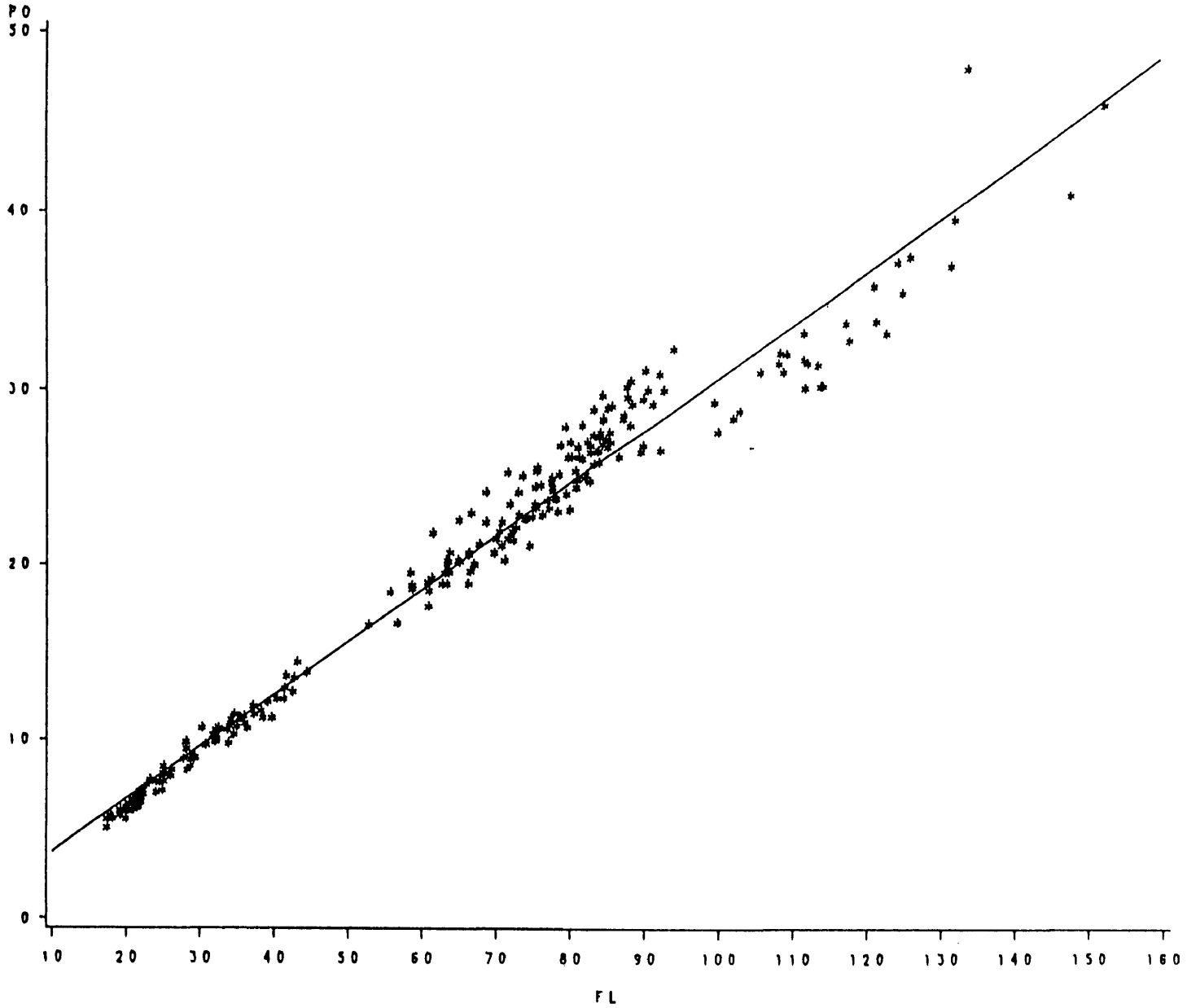
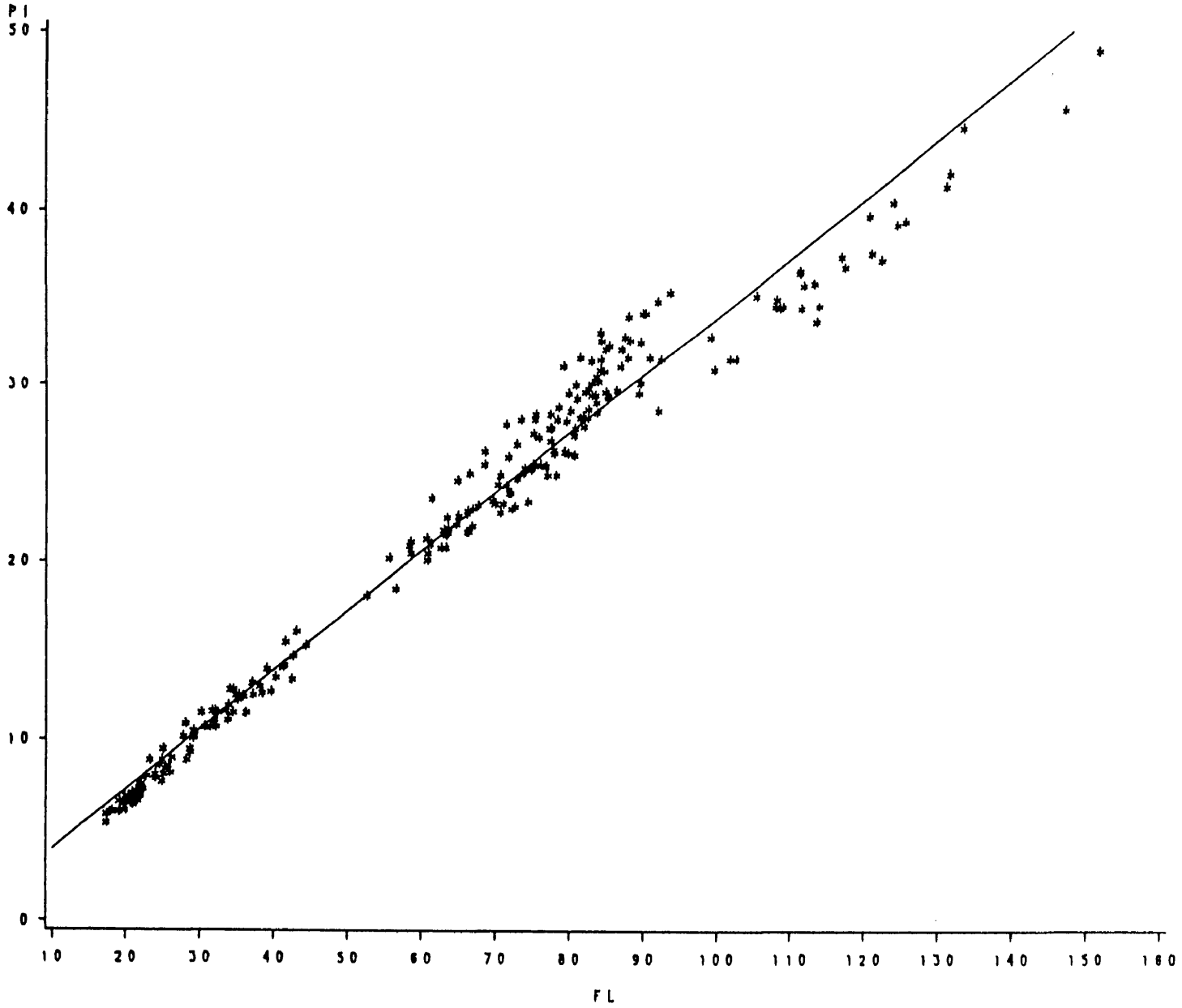


PELVIC INSERTION VS FORK LENGTH (Patuxent River)



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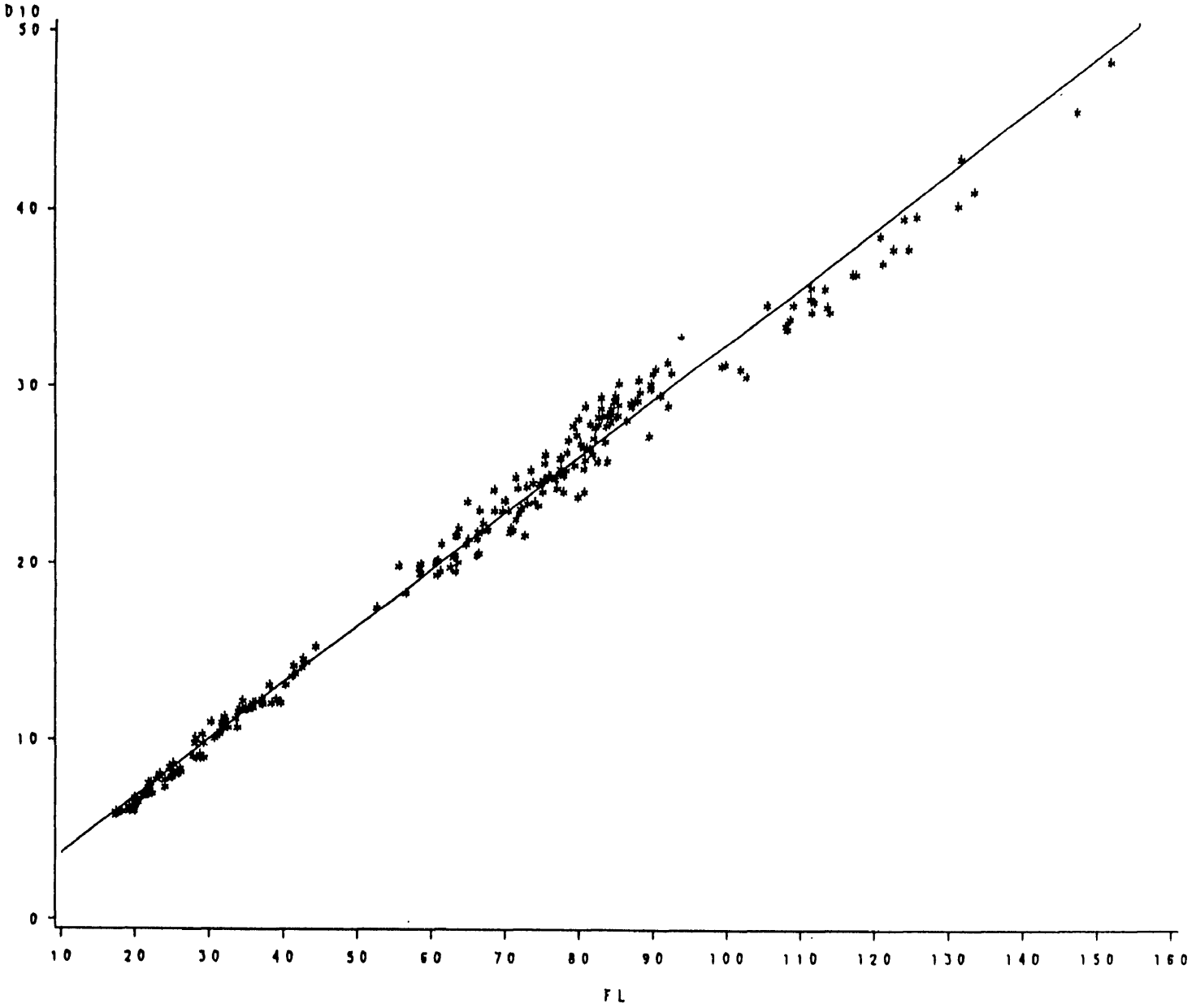

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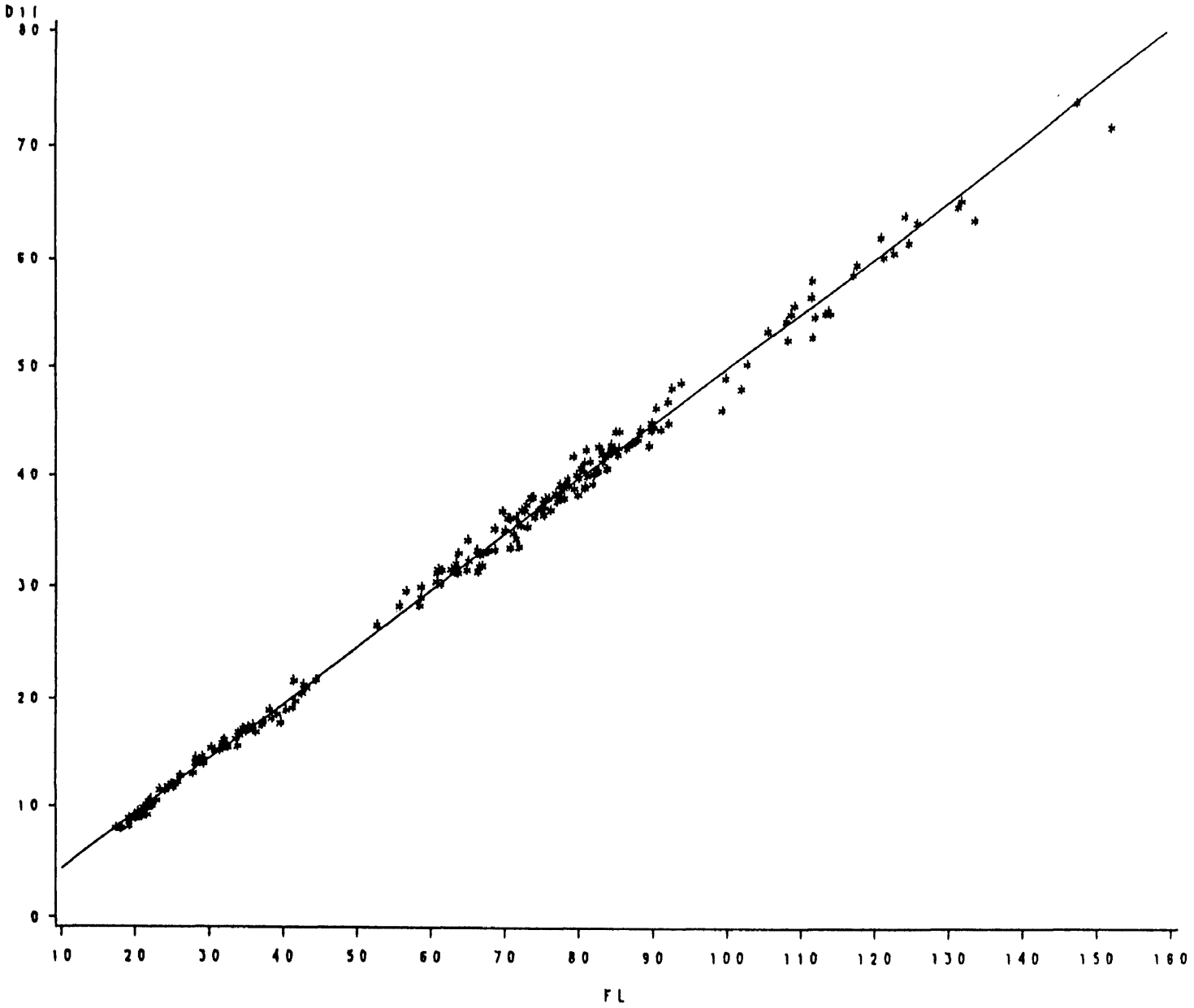

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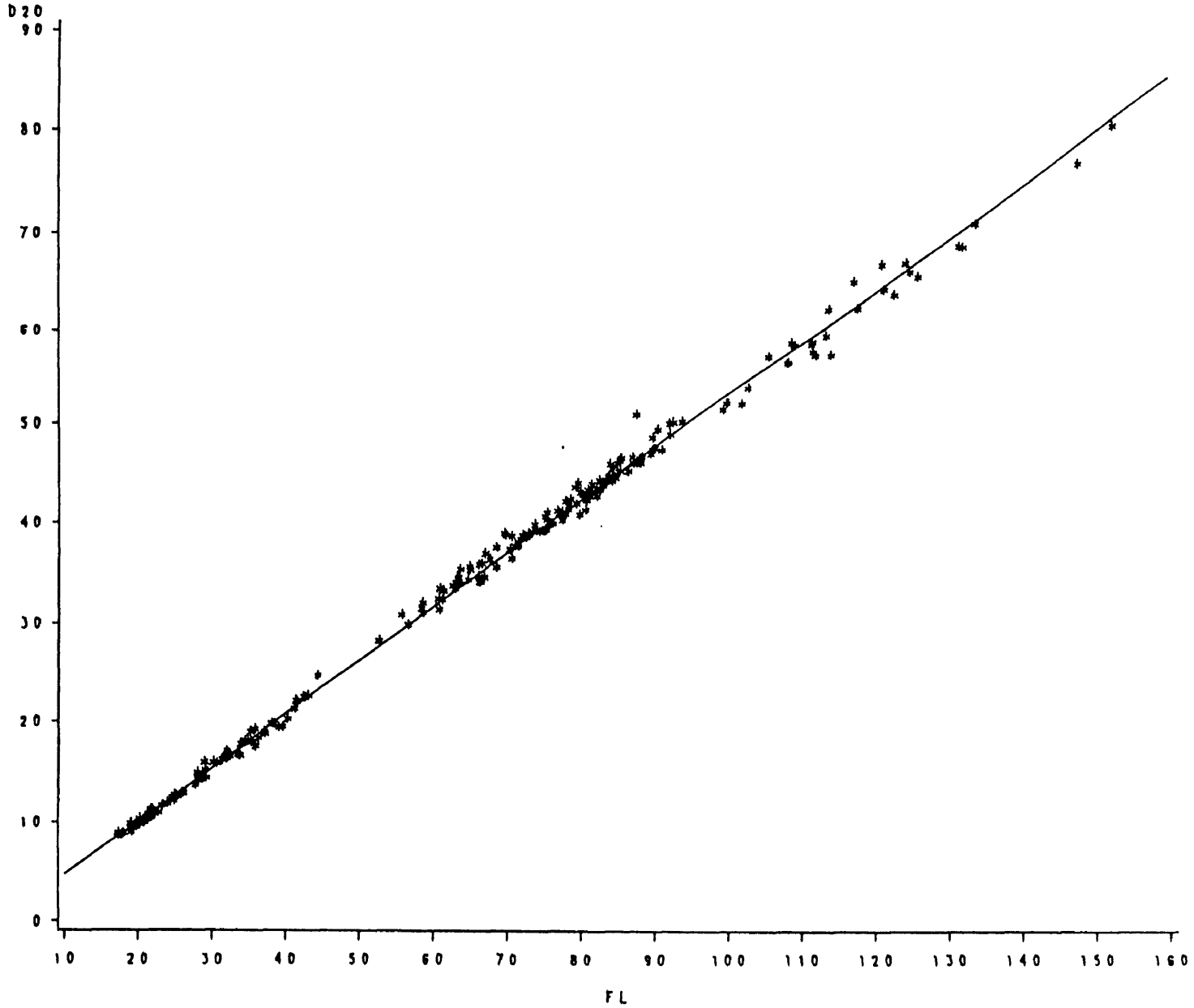

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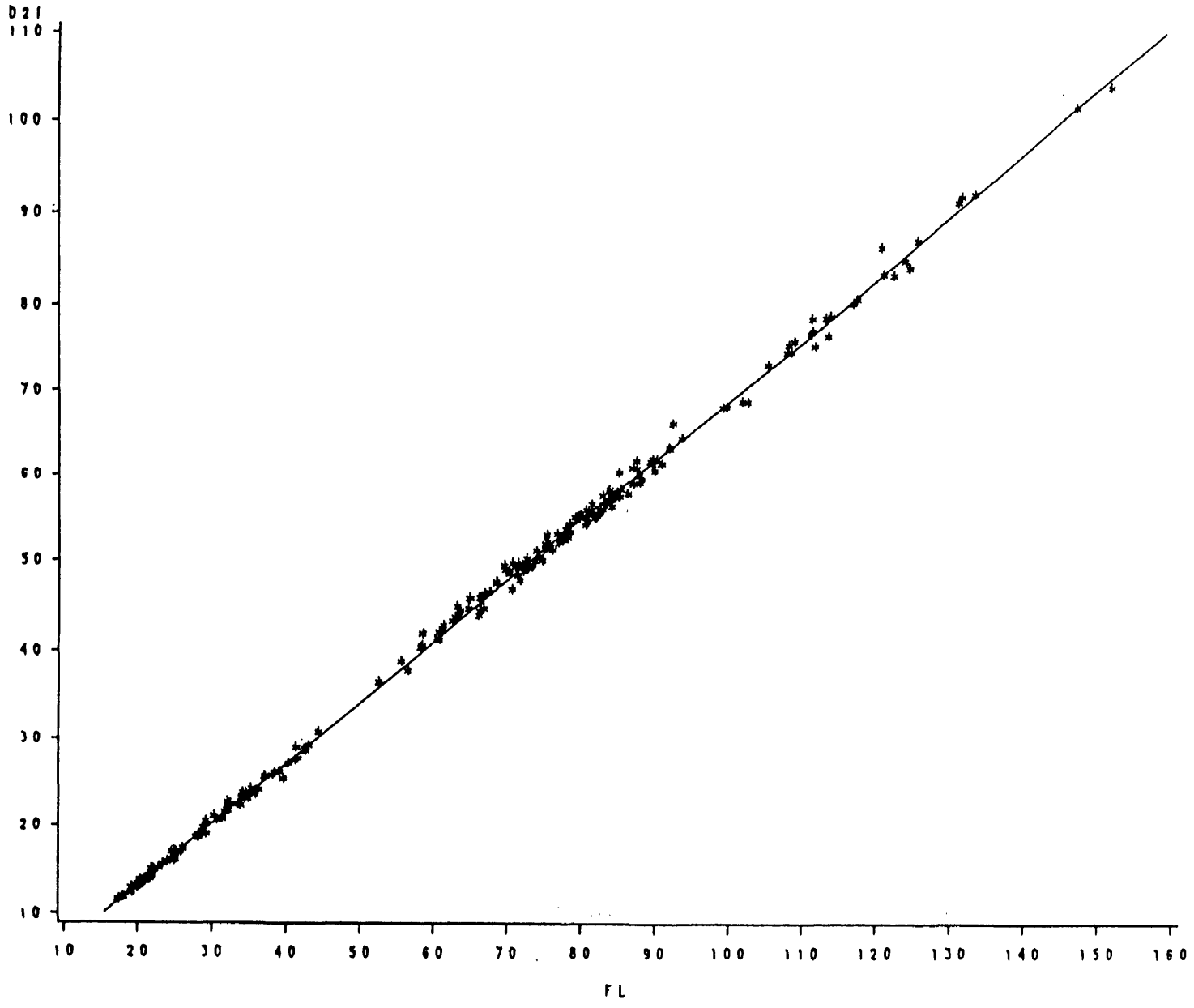
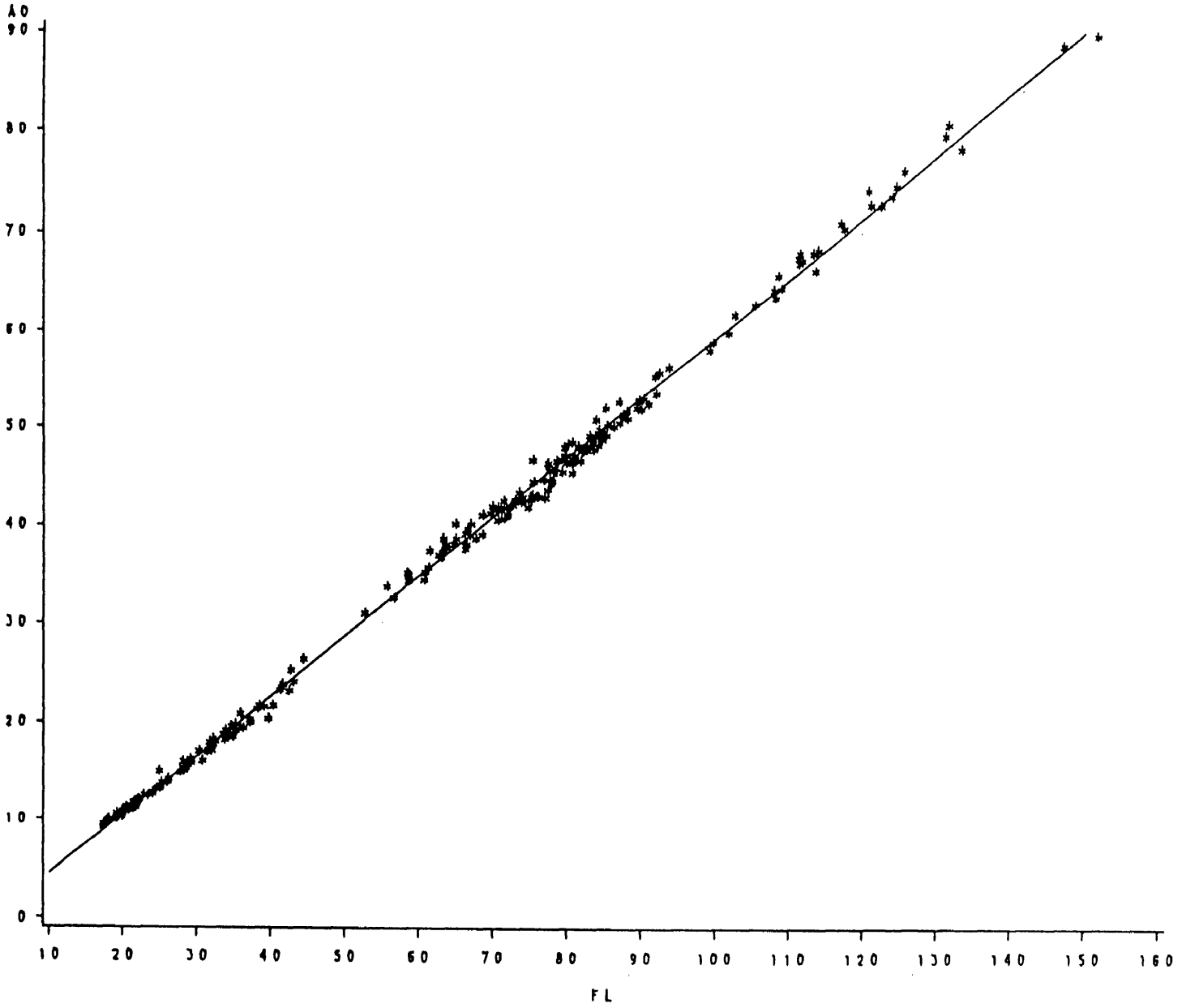
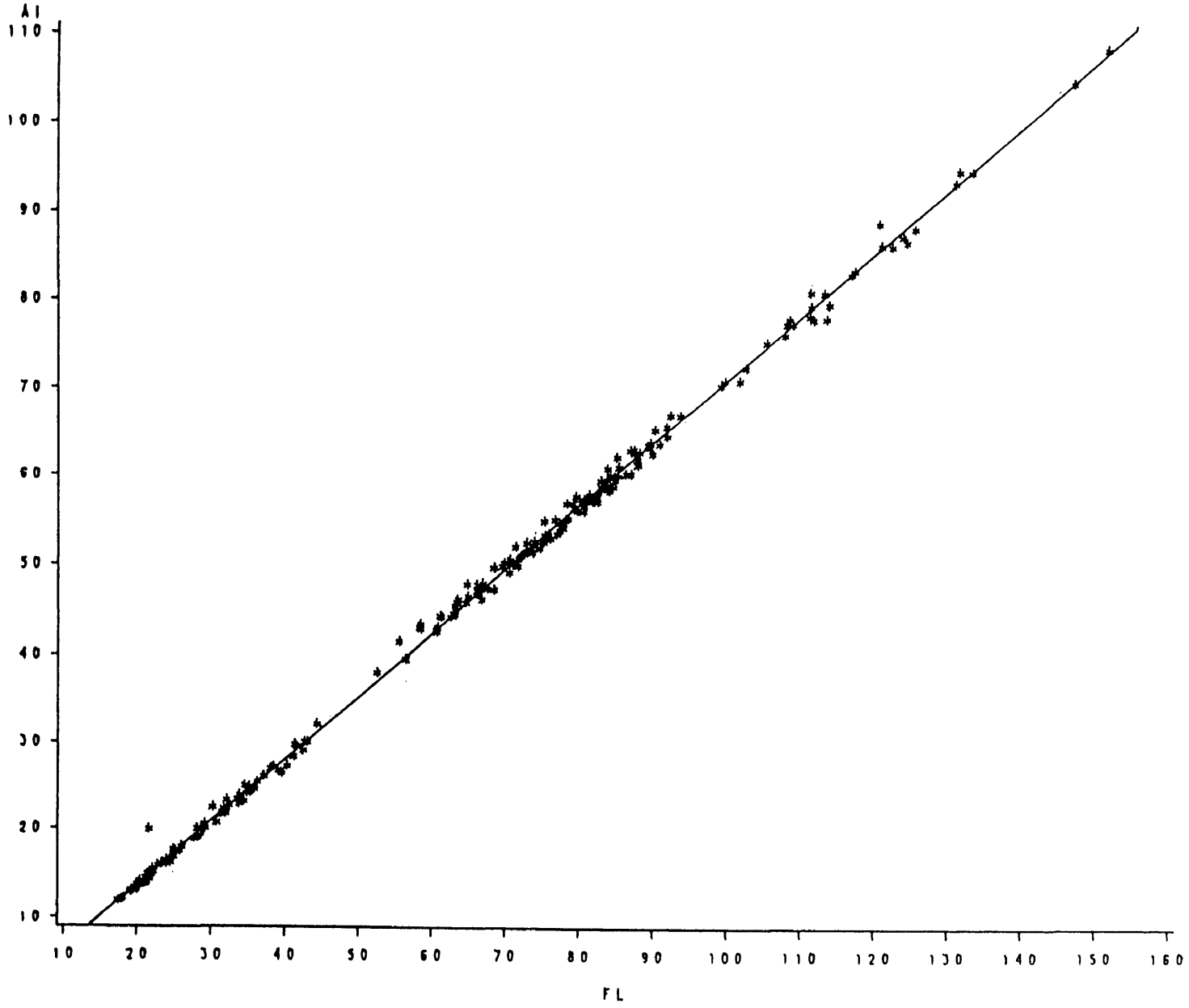


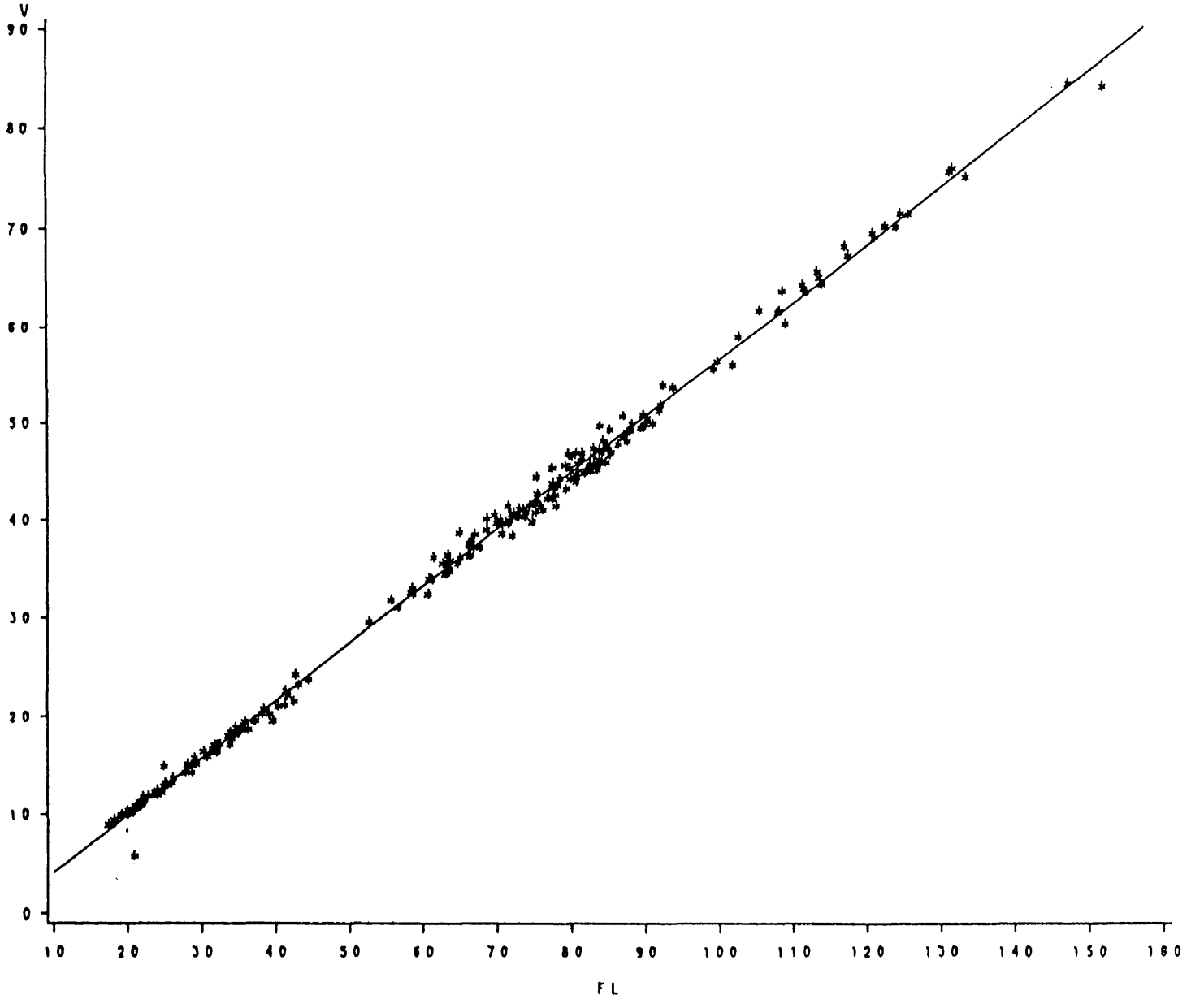
ANAL FIN ORIGIN VS FORK LENGTH (Patuxent River)



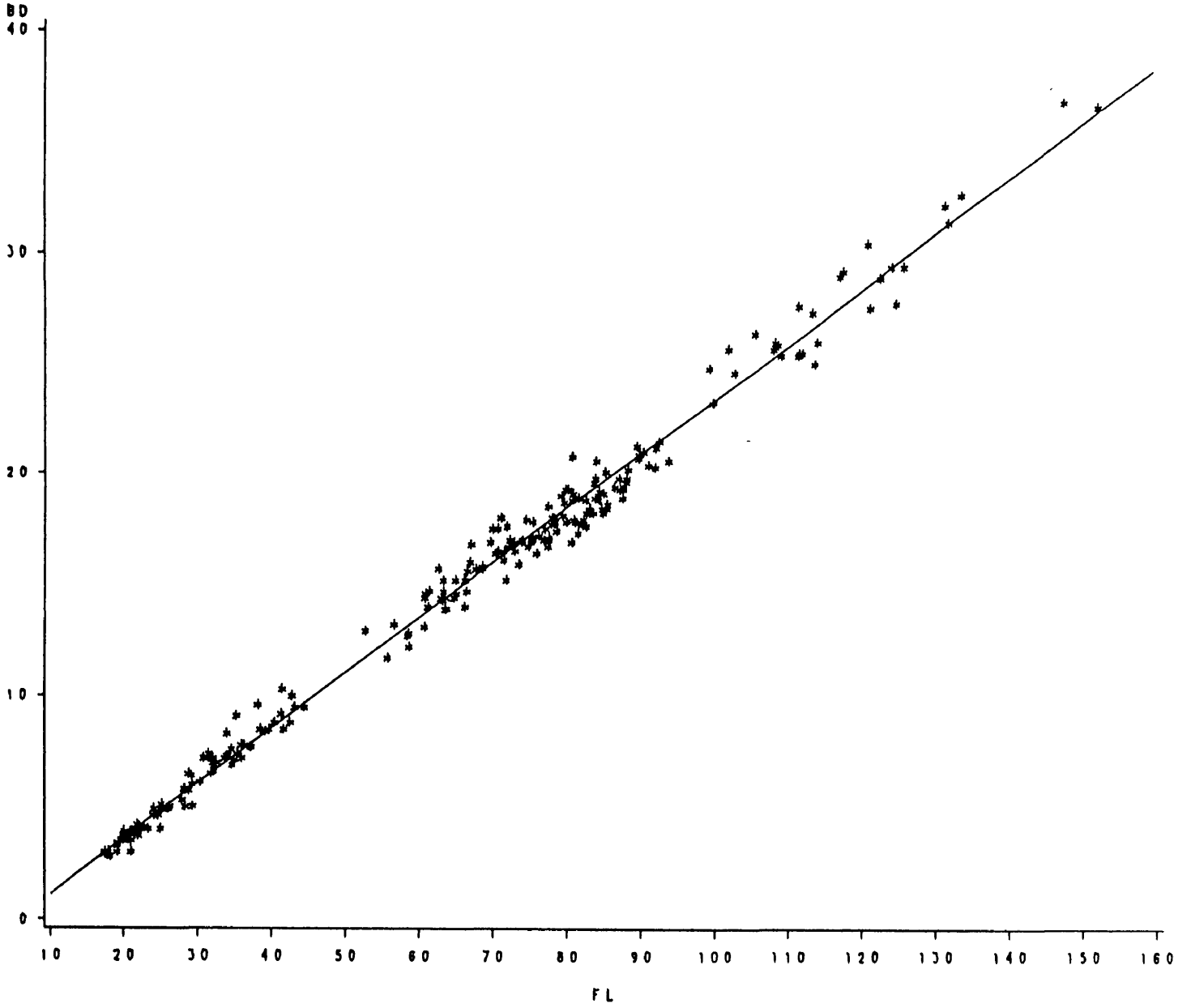
ANAL FIN INSERTION VS FORK LENGTH (Patuxent River)



VENT VS FORK LENGTH (Patuxent River)



BODY DEPTH VS FORK LENGTH (Patuxent River)



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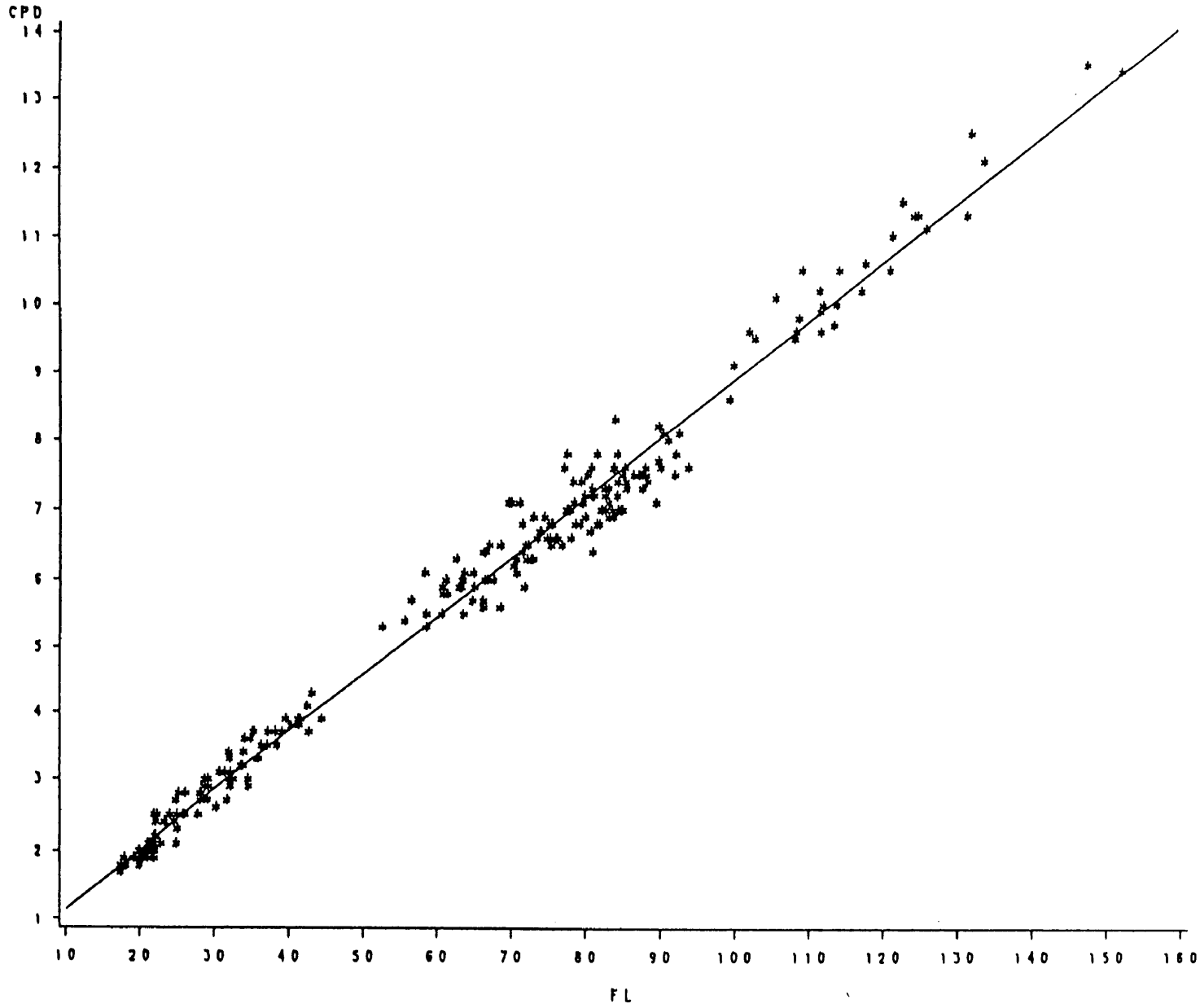

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