INHS
CAE
2001(11)

ANNUAL PROGRESS REPORT

QUALITY MANAGEMENT OF BLUEGILL: FACTORS AFFECTING POPULATION SIZE STRUCTURE

D.D. Aday, J.E. Claussen, J.H. Hoxmeier,
D.E. Shoup, D.H. Wahl, D.P. Philipp

Submitted to
Division of Fisheries
Illinois Department of Natural Resources
Federal Aid Project F-128-R

David H. Wahl
David H. Wahl
Principal Investigator

David P. Philipp
Co-Investigator

John Epifanio
Director, Center for Aquatic Ecology

November 2001

Aquatic Ecology Technical Report #01/11

Acknowledgments

The authors of this report would like to acknowledge the help and input from the staff of the Kaskaskia and Sam Parr Biological Stations, including , Matt Mangan, Rick Damsta, Aaron Larsen, Brian Vodvarka, Shari Fanta, Blake Davis, Kurt Ostrodka, Karen Schnake, Troy Jaecks, Ben Braetigam, and Holly Leonard. We would also like to thank Thomas Harper and all of the conservation police officers that collected compliance data on bluegill regulations.

A special note of thanks to the regional and district biologists that assisted in collections, participated in project discussions, and provided advice on various portions of this project.

Natural History

Table of Contents

Executive Summary

This study contains four jobs, 101.1 Categorization of bluegill populations in Illinois impoundments, 101.2 Evaluation of bluegill life-history variation in Illinois impoundments, 101.3 Pre- and post- regulation characterization of experimental study lakes, and 101.4, Analysis and reporting.

In Job 101.1 existing creel and standardized sampling databases from project F-69-R were used to make assignments of study populations from Illinois into three categories: quality (populations with many/most adults > 180mm), stunted (populations with many/most adults <150mm) and intermediate (populations with a mixture of adult sizes). The final list of potential study lakes proposed for in depth sampling included 60 lakes. These lakes were grouped by predicted size structure (stunted or quality), by regions (north, central, or south) and by lake size groups (small = < 100 acres, or large = > 100 acres). From these lakes, 32 were identified for use in an intensive management experiment (described in job 101.3). To assess baseline population data and harvest levels in all stunted and quality populations, creels were conducted on a number of these experimental lakes prior to the manipulations imposed as a management experiment. Harvest data have been summarized and analyses of the FAS data will continue as information becomes available.

We removed otoliths for aging and measured lengths, weights, and maturity status on the samples collected. Preliminary analysis suggests that the size structure and age-at-maturation of these populations in unchanged since initial samples were taken in 1996-1997. Low sample sizes in other populations will result in the need for continued monitoring of these populations.

We continued our monitoring and assessment of bluegill growth, reproductive characteristics, and age-at-maturation in response to management manipulations. These manipulations consist of four treatments across 32 lakes (8 lakes per treatment): control, restrictive harvest regulations, predator stocking, and a combination of restrictive harvest regulations and predator stocking. Treatments have equal representation from regional, lake size, and bluegill size structure classifications of lakes. We examined important biotic and abiotic characteristics of the experimental lakes, such as prey resources, predation pressure, and lake-habitat characteristics.

To examine the importance of prey resources to bluegill growth and maturation, we regressed a variety of bluegill size, density, and maturation variables with measures of resource availability. In general, we found no relationship between bluegill z-age and prey availability, although bluegill size-at-age2 was positively correlated with total zooplankton density. In addition, we found no overall differences in prey resources

Job 101.1 Categorization of bluegill populations in Illinois impoundments.

OBJECTIVE

To use existing creel and standardized sampling databases to categorize bluegill populations based on adult size structure.

INTRODUCTION

Bluegill are a key component in Illinois sport fisheries, serving as both an important prey species and providing anglers with harvestable size fish. In Illinois lakes where creels of harvest and release were conducted, bluegill were consistently caught and harvested in great numbers(Table 1-1). Bluegill are susceptible to high levels of exploitation, which can shift size structures toward populations dominated by small fish (Coble, 1988). Size structures of bluegill populations have deteriorated in many lakes within the Midwest over the past 40 years. Anglers harvest fewer large bluegill from many exploited lakes that support high populations of small bluegill and the number of trophy-sized bluegill have also declined across the region(Olsen and Cunningham, 1989).

Before effective management strategies for increasing the size structure of "stunted" bluegill populations can be developed, we need more information about the factors controlling growth and maturation of bluegill. Competition has been shown to occur among sunfishes when high numbers of small fish are forced into refuges to avoid predation (Mittelbach 1984, 1986). The extent of the effect of this phenomenon on growth likely varies among reservoirs depending upon prey availability and predator densities. Certainly, availability of food resources for bluegill will impact growth. It is unclear, however, whether or not density dependent juvenile (or post-maturation) growth rates affect the ultimate size structure of bluegill populations.

Bluegill have been shown to exhibit complex reproductive behaviors such as colonial nest construction, territorial defense, courtship of females, and defense against brood predators (Gross, 1980). Furthermore, male bluegill exhibit alternative reproductive strategies, whereby some individuals mature precociously and become cuckolders at a younger age and a smaller size than their brothers, who delay maturation to become parental males (Gross 1980). The process of maturation has significant impacts upon growth trajectories in bluegill and likely all other fish species as well, because the physiological changes and mating behaviors associated with reproduction require high energetic investment, making that energy unavailable for somatic growth (Claussen 1991, Fox and Keast 1991, Jennings 1991, Jennings and Philipp 1992). Although the impact of sexual maturation and spawning activities on the growth of *Lepomis* individuals is well established, little is known about the reverse, i.e., how the growth and size structure within a population affects age at maturation and the expression of reproductive behaviors. If we are to manage bluegill populations effectively, we need to understand how exploitation and/or various management activities alter these life-history characteristics. Only by understanding these complex interactions can the success of bluegill regulations and management strategies be predicted and realized effectively.

PROCEDURES

We used a variety of methods to choose an initial list of 60 potential study lakes (interviews/suggestions from district biologists, meetings to review data with district/regional biologists). We subsequently assessed data from past years' creels (part of project F-69-R) to assess predicted size structure based on verbal assessments. Because creel survey data do not distinguish the sex of the fish, we used the following descriptor to classify quality versus stunted populations, Proportion of Quality Creeled Fish (PCF.170). For this calculation, the total number of fish caught ≥170mm was divided by the total number of fish caught.

FINDINGS

Potential study lakes were tentatively identified by district biologists as having a predominantly stunted adult population (<150mm) or a quality adult population (>180mm) based on previous sampling experience. A meeting with regional and district biologists was held in March of 1996 to discuss final criteria for choosing initial study lakes. Further input was solicited through a questionnaire to all regional and district biologists for suggestions on additional lakes, as well as comments on our preliminary list of proposed study lakes. Following this discussion, a final list of 60 target lakes was produced (Table 1-2).

Further information on lake populations and angler activities was gathered from historical creel survey data that was available; additional data have been collected over recent years through creels directed at our study lakes. Angler success and harvest data, as well as overall angling pressure, the proportion of anglers that target bluegill, and size of bluegill caught and harvested was used to assess the bluegill fishery in lakes for which there were data. Preliminary analyses of those data are summarized in Table 1-3, and indicate that size structure

Job 101.2. Evaluation of bluegill life-history variation in Illinois impoundments.

OBJECTIVE

To determine the extent of variation in important bluegill life-history characteristics in selected impoundments throughout Illinois

INTRODUCTION

In Illinois, as in many other Midwestern states, inadequate size structure (few bluegills longer than 150mm) is considered a primary management concern. In addition, the demand has continued to grow for populations with quality-sized and even trophy-sized bluegill. To manage a bluegill population successfully for desired human goals (quality size), we need to understand the factors that are driving population size structure.

The most commonly cited causes for inadequate bluegill size structure are excessive exploitation (Goedde and Coble, 1981; Coble 1988), alteration of ecosystem components, such as predators (Swingle, 1950; Anderson and Schupp, 1986; Colby et al, 1987; Guy and Willis, 1990) and inadequate food supply (Gerking 1962). By focusing on the above factors, however, no cost-effective management strategies have been developed that have improved bluegill size structures consistently. Other less explored factors that could also contribute to stunted size structures are related to age at maturation (Z age), and alternative male reproductive strategies.

Growth trajectories for parental male bluegill (and most other fish as well) follow a pattern in which growth slows significantly following sexual maturation (Wootton 1985). Figure 2-1 illustrates this "typical" pattern of growth and maturation for a male bluegill. Four major factors, therefore, shape a population's size structure: pre-maturation growth rate, post-maturation growth rate, age at maturation, and longevity. As a result, alterations that affect any one of these four components can impact population size structure.

Based on these principles, "stunted" bluegill populations (defined as ones that consist of individuals that are on average smaller than "normal" populations) occur as a result of one (or a combination) of four main hypotheses (Jennings et al, 1997).

In the first of these, the Adult Overharvest Hypothesis (Figure 2-2), growth rates and sexual maturation schedules are typical of "normal" populations. Large individuals (typically, mature parental males) are not found in the population because of rapid and excessive overharvest; when individuals reach some smaller size threshold, they are rapidly being removed by anglers. Even in the face of this overharvest, growth rates and sexual maturation schedules remain unchanged. In support of this hypothesis Coble (1988) has shown that size-selective harvest can quickly reshape the size distribution of bluegill within a fished population.

In the second, the Cuckolder Overproduction Hypothesis (Figure 2-3), growth rates and sexual maturation schedules are typical of "normal" populations, but in these populations a much greater percentage of males enter the cuckoldry rather than parental life history pathway. In this scenario, some perturbation (e.g., acute overharvest, winterkill) causes fewer males to delay maturation to become parental males, most males maturing early as cuckolders. Although the quantitative partitioning of males into the two life histories has only been determined for the bluegill population in Lake Opinicon, Ontario (Gross 1982, Philipp and Gross 1994), and both life histories clearly exist among populations in Illinois.

In the third, the Density-Dependent Growth Limitation Hypothesis (Figure 2-4), sexual maturation schedules are typical of "normal" populations. In response to overly high bluegill densities (caused by any one of a number of factors, e.g., reduction in predation, changes in habitat or water quality, etc.), early growth rates are diminished because of increased competition for limited food resources. In this scenario, large individuals are not produced in the population because the entire growth trajectory is slowed from birth. In a comparative study of reservoir bluegill populations (Belk and Hales 1993), it was proposed that differences in the resources available among habitats, including both food resources and refuges from predators such as largemouth bass, influenced growth rate. Similarly, Callahan et al. (1996) found growth of small bluegill across 14 reservoirs in Illinois was related to percent littoral zone. They proposed that fish in lakes with extensive littoral zones were experiencing high bluegill densities and, as a result, reduced growth rates.

In the fourth, the Social Influence / Early Maturation Hypothesis (Figure 2-5), early growth rates are typical of "normal" populations, but in response to some perturbation in the population (most likely the previous harvest of large individuals), parental males (and likely females) mature and reproduce at younger ages and smaller sizes. Because sexual maturation occurs at an earlier age (and size), the associated number of largemouth bass shocked) as recorded. Electrofishing runs consisted of an initial run, in which all individuals of all sizes were collected. These preliminary runs usually were from 30 to 60 minutes in duration. Those bluegill were then measured quickly to determine the number of individuals in each of eight specified size classes (<50mm, 50-99mm, 100-149mm, 150-159mm, 160-169mm, 170-179mm, 180-189mm, >189mm). The goal was to obtain at least 50 individuals from each size class. An additional secondary run was then conducted in an attempt to supplement those size classes in which sample sizes were below 50. During summer of 1997 and 1998 district fisheries biologists and project personnel attempted to collect bluegill from lakes that had low numbers in specific size classes from the 1996 samples. All sampled fish were frozen awaiting further analysis.

To analyze the bluegill collected from each lake sampled, individuals were thawed and total length, weight, and sex determined. In addition, gonads were identified as to stage of development (assigned a score of 1-5) and weighed. Scales and otoliths were removed for age and growth analysis. All otoliths were read in whole view unless there was a disagreement between two readers, or if crowding of annuli occurred. If so, the otolith was then sectioned by one of two methods: by either cracking the otolith in half and reading transverse section with fiber optic light or by mounting the mid-section on a slide and reading it with transmitted light. We used these data to determine age-specific growth curves, age at maturation, and abundance of cuckolders.

To calculate a descriptor of the size structure for a given population that would distinguish quality from stunted populations, we calculated an index termed the Proportion of Quality Males (PQM.170). The PQM.170 for a given population is post-maturation decrease in growth rate also occurs earlier. As a result, the size of mature males (and likely females) in the population is reduced. Although this relationship between male size/age structure and the onset of sexual maturation has been predicted from a theoretical standpoint (Reznick 1983, Stearns and Koella 1986), it has been tested in bluegill only recently (Jennings et al 1997).

Because sexual maturation and the expression of reproductive behaviors are energetically expensive, fish have most likely evolved to respond facultatively to social cues in a ways that maximize lifetime reproductive success (Stearns and Koella 1986, Jennings and Philipp 1992). Even though social control of reproductive behaviors has been demonstrated across a wide range of fish taxa (Robertson 1972, Borowsky 1978, Silverman 1978, Chapman et al. 1991, Fox and Keast 1991, Jennings 1991), we still do not know how these socially mediated shifts in life history interact with density-dependent mechanisms to impact size structure of bluegill populations.

PROCEDURES

In the first phase of this project, boat electrofishing was used to sample 60 target populations (see Job 101.1, Table 1-1) between the months of May and July 1996 to determine bluegill abundance, size, age, sex, and maturation status for each population. Sampling was conducted after bluegill spawning activity had been initiated in each lake and before it ceased in mid-summer.

During sampling, type of habitat, weather conditions, secchi disk readings, water temperatures, and information on other species of fish found in the lake (e.g., number of sunfish hybrids and calculated by dividing the number of mature parental males $\geq$170mm by the total number of mature parental males collected. A PQM.170 of $\leq$ 0.05 was considered indicative of stunted status; a PQM.170 of $\geq$ 0.50 was considered indicative of quality status; and a PQM.170 in between was considered intermediate or transitional.

FINDINGS

Data from each of the 60 lakes were analyzed to describe for each bluegill population the following characteristics for each sex: Z age, PQM.170 and PQM.180, average size at age 2 and at age 5, number of immature males at age 2, total number of age 2 males, total number of 2 yr olds, number of parental males, number of cuckolders (Table 2-1). Because ten of the original study lakes had low sample sizes or other problems that rendered data unreliable, they were omitted in the analysis. The summary data were used to test predictive outcomes of population characteristics under for each of the four hypotheses independently, as described below.

Hypothesis 1: Adult Overharvest predicts that in stunted populations there would be a decrease in the relative abundance of mature males to immature fish. This was calculated as the number of mature males in the populations divided by the number of two year olds. In this hypothesis, comparing stunted to quality populations (a low PQM.170 to a high PQM.170) the relative abundance of mature males should increase (Figure 2-6). Figure 2-7 is a plot of the summary data for all 50 study lakes, showing that there is no significant relationship between relative abundance of mature males and PQM.170 values. Stunted populations are not simply a short-term result of overharvest.

Hypothesis 2: Cuckolder Overabundance predicts that in stunted populations there would be an increase in the number of immature males that choose the cuckolder life history pathway rather than the parental pathway. In this hypothesis, the ratio of cuckolders to parentals should increase as the PQM.170 decreases (Figure 2-8). Figure 2-9 is a plot of the summary data for all 50 study lakes, showing that the ratio of cuckolders to mature parental males is not significantly correlated to the PQM.170, indicating that overproduction of cuckolders does not cause stunted bluegill populations.

Hypothesis 3: Density-Dependent Growth limitation predicts that in stunted populations bluegill would be growing slower than in quality populations. In this hypothesis, the average size at age 2 should be lowest in stunted populations and highest in quality populations (Figure 2-10). Figure 2-11 is a plot of the summary data for all 50 study populations showing that the PQm.170 is not correlated with size at age 2. This comparison shows that initial growth rates have little impact on the ultimate size structure of a bluegill population. This result does not say that density dependence is not important for determining bluegill growth rates, but rather that growth rates do not determine if a population becomes stunted.

Hypothesis 4: Social Influence / Early Maturation predicts that stunting is caused by males maturing at a younger age and as a result decreasing their post-maturation growth rates at an earlier age, as well. In this hypothesis, comparing stunted to quality populations, the average age of maturation (the Z Age) smaller males are less competitive than larger ones.

In addition to the above analysis, age and growth graphs for each sex in each lake were constructed. A sample of these graphs are given in Appendix A.

RECOMMENDATIONS

Regular sampling of the bluegill populations for the study lakes should be continued to determine changes in the bluegill size and age structure, prey resources and predator populations. The sampling schedule should be throughout the next several years to assess the stability of these populations over time so that we can determine the impacts of the enacted management manipulations.

in stunted populations should be lower than in quality populations (Figure 2-12). Figure 2-13 is a plot of the summary data for all 50 study lakes showing that there is a strong positive relationship between PQM.170 and the Z-age of parental males. Stunted populations have an early age at maturation and as a result, their post-maturation growth decreases at an earlier age, thereby limiting size structure.

To summarize, the size structure of any bluegill population is determined by the combination of four factors: growth rate before maturation (when all excess energy is directed toward somatic growth), the age at maturation (which is highly plastic in *Lepomis* spp.), growth rate after maturation (when much of the excess energy is directed toward reproduction), and longevity. Because bluegill reproduction includes behaviors such as nest construction, territorial defense, courtship of females, fanning the eggs, and defense against brood predators, they must commit large energetic investments into reproduction. Furthermore, bluegill are sexually dimorphic; i.e., within a population, males and females differ in growth patterns, maturation schedules, ultimate size, and longevity.

In this segment, we used age, growth, and maturation data from 50 study populations to test each of the four main hypotheses that have been proposed to explain the cause of stunting in bluegill. Our results clearly indicated that Hypothesis 4: Social Influence / Early Maturation is the dominant causative factor explaining stunting. Stunted bluegill populations are caused by fish maturing at an early age, thereby slowing post-maturation growth rates at an early age, as well. This early maturation is caused by a lack of large parental males, whose presence normally delays the maturation of younger males because

Job 101.3 Pre- and post-regulation characterization of experimental study lakes.

OBJECTIVE

To gather detailed baseline data on bluegill life-history characteristics as well as the biotic and abiotic variables that may affect bluegill recruitment, growth, and maturation in the chosen experimental study lakes.

INTRODUCTION

An important goal of this study is to examine the impact of various management actions (i.e., harvest regulations and predator stocking) on bluegill growth rates and size- and age-at-maturation, and determine how each acts to improve size structure among stunted bluegill populations in Illinois. Four aspects of a species' life-history trajectory determine the ultimate size structure of the adult population in a given waterbody: pre-maturation (larval/juvenile) growth rate, age at maturation, post-maturation (adult) growth rate, and longevity. These four aspects can be affected by a variety of things within a waterbody. Age-at-maturation and longevity are directly affected by the social relationships among surviving adults and can be greatly impacted, therefore, by harvest. Both pre- and post-maturation growth rates are directly affected by density-dependent processes (i.e., slower growth rates when there is an overabundance of bluegill or underabundance of prey) at all bluegill life stages. Additionally, biotic (e.g., interspecific competition, predation) and abiotic (e.g., temperature, dissolved oxygen saturation) factors can also influence all four aspects of a life-history trajectory. This job is designed to elucidate how these processes may act and interact to alter bluegill population size structure under different management options.

Results from Job 101.2 indicate that factors controlling the age-at-maturation have the greatest influence in determining size structure of bluegill populations throughout the state. Quality populations were characterized by a later age- and larger size-at-maturity than stunted populations. Manipulative experiments associated with this project continue to suggest that the social structure of the population, specifically the presence or absence of large, mature males, has a direct impact on age-at-maturation of juvenile male bluegill in the population and, therefore, a direct impact on population size structure. Management actions designed to increase the size structure of wild bluegill populations (i.e., convert stunted populations to quality populations) need to increase PQM170. From an evolutionary standpoint, that requires reaching a new life history state in which age-at-maturation is increased; i.e., males delay to older ages and larger sizes prior to maturing and entering the slower post-maturation growth phase. Moving a population from a stunted to a quality life history state, however, might be accomplished by increasing pre-maturation growth rates, increasing post-maturation growth rates, extending longevity, or increasing age-at-maturation directly. Which route successful management actions will use is unclear. As a result, it is important that we continue to collect juvenile and mature bluegill from study lakes to monitor size, age, and maturity states over the next several years.

for current and continued monitoring: 1)bluegill population parameters (adult abundance, size structure, and age-at-maturation; larval and juvenile growth and abundance); 2) biotic variables (e.g., prey availability, predation); and 3) abiotic variables (e.g., temperature, lake productivity, lake-habitat characteristics). The sampling protocol that was established at the initiation of the management experiment (Aday et al. 1999) was followed during the summer of 2001: all 32 experimental lakes were sampled for bluegill (juvenile and adults) and largemouth bass (as a predator) abundance. In addition, prey resources (zooplankton and macroinvertebrates) were collected in 16 (7 stunted and 9 quality) of the 32 experimental lakes, and larval bluegill were collected in 8 of them. We will continue to monitor these and other biotic and abiotic variables in the experimental lakes throughout the management experiment.

Because we are interested in how each of the experimental management manipulations impact bluegill growth rates, maturation schedules, and longevity, we need to know how temporally stable these parameters are within populations in the absence of experimental manipulations. To assess that stability, we re-sampled all control lakes and compared bluegill size- and age-structure with the original samples. In this segment, analysis of data that we began to collect in the previous segment was continued.

Bluegill Population Parameters

In this segment we continued to monitor changes in bluegill populations by examining length-frequencies of bluegill collected

Both pre- and post-maturation growth rates may be increased by an underabundance of bluegill or an overabundance of prey. This density-dependent alteration in growth rate can occur at any or all life stages of the bluegill. Bluegill feed on both zooplankton and benthic invertebrates throughout their ontogeny. Competition for food resources (intra- and interspecific) can occur at each life stage (i.e., larval, juvenile, adult) and could affect growth. Identifying the importance of altering competition for limited resources relative to other potential mechanisms designed to alleviate stunting will be important for evaluating the success of any management regulation. Monitoring prey resources and bluegill densities in the study lakes is necessary to assess the role that density-dependent mechanisms may play in altering size structure at our test bluegill populations.

PROCEDURE

The primary activity in this job was continued monitoring of experimental populations to determine influences of the management manipulations on bluegill population size and age structure. The management experiment, which began in April, 1999, involves 32 lakes across the state of Illinois, divided into four treatments (8 lakes per treatment): restrictive harvest regulations (8-inch minimum size limit, 10 fish daily creel limit); predator stockings (largemouth bass added to increase predation on juvenile bluegill); restrictive harvest regulations and predator stockings in combination; control (for complete details of the management experiment see Claussen et al. 1999; Table 3-1). Three components of each study lake are important in fall electrofishing samples in populations from each experimental treatment group. We also continued to examine potential density-dependent mechanisms to understand the role that they may play in altering population size structure. We determined larval, juvenile, and adult bluegill abundance in the experimental study lakes. Larval fish were collected from each offshore site by pushing an icthyoplankton net (0.5m diameter, 500 mm mesh) for 5 minutes. Volume of water filtered was calculated with a calibrated flow meter mounted inside the mouth of the net. Inshore bluegill density (primarily juveniles) was assessed by shoreline seining (9.2 x 1.2 m bag seine, 3.2 mm mesh) at four fixed sites within each lake. Effort was calculated as the length of the haul (nearest m). All fish were counted and a minimum of 50 individuals of each species collected were measured (total length in mm). Density (#/m of seine haul) was calculated for bluegill throughout the study period. Adult bluegill were collected by shoreline seining (6.7 x 1.2 m bag seine, 3.2 mm mesh) and electrofishing. A final fall sample was collected in September or October from all 32 experimental lakes to examine population length frequencies.

In previous segments we examined correlations between juvenile bluegill growth rates and prey resources (total zooplankton and benthic invertebrate densities). In this segment we more closely examine the relationship between food resources and bluegill growth and maturity. We correlated total zooplankton and total benthos densities in each study lake with bluegill size-at-age 2 (pre-maturation), CPUE, and z-age (maturation). To directly assess the influence of prey availability on bluegill population size structure, we correlated total zooplankton and total benthos densities with PQM180,one variable that is used to define stunted and quality populations. Across lakes, we determined differences in prey availability between stunted and quality populations. In each of these analyses we control more variation than in past segments through the incorporation of data from multiple years in each study lake.

Prey Availability

Prey availability may interact with relative abundance of bluegill to affect growth at all life stages. Macroinvertebrates and zooplankton are important food items to larval, juvenile, and adult bluegill. We determined the abundance of these food resources in 16 of the experimental lakes. To quantify zooplankton abundance, collections were taken using vertical tows with a 0.5 m diameter, 64 mm mesh zooplankton net at four inshore and four offshore sites (one tow per site). Zooplankton were preserved in a Lugols solution (4%) for later processing. Inshore macroinvertebrates were collected using a stovepipe sampler (20 cm diameter) at 6 sites (one sample per site) within each lake. Depth of each sample collection was measured. Samples were cleaned in a 250 mm mesh benthos bucket and preserved in an ethanol/rose bengal solution (70%) for processing.

Predator Abundance

Predator abundance may also influence bluegill size structure and may be important at each life stage. Largemouth bass, the primary predator in these centrarchid-dominated experimental lakes, can consume large numbers of larval and juvenile bluegill.

stunted population, and Lincoln Trail Lake, a quality population)and placed them in experimental ponds in Champaign, Illinois. Experimental bluegill were all pre-reproductive size and were immature at the initiation of the experiment. Bluegill were given a distinctive fin clip to identify the source population from which they were collected. We also stocked 5 large, mature male bluegill in half of the ponds. The experiment was run for 12 weeks, after which time the ponds were drained and juvenile bluegill were weighed, measured, and frozen. In the laboratory, each bluegill was dissected, and gonads were weighed (to determine a gonadosomatic index, GSI) and given a score (1-5, with 1 being completely immature and 5 being completely mature). Growth rates and maturation were then compared in bluegill from both source populations and social treatments.

To determine the effects of gizzard shad on bluegill growth and population size structure, we selected ten reservoirs with and ten reservoirs without gizzard shad. In each population we examined bluegill growth rates and size structure. We also quantified important biotic and abiotic variables such as prey resources and water quality parameters.

In past segments, bluegill population data were collected on two quality and one stunted population to determine their suitability for a large-male addition experiment. Continued sampling of these populations has revealed that instability of water levels makes them unsuitable for this experiment. Instead, we conducted a pond experiment to determine the influence of genetics and social structure (presence or absence of large males) that will provide

In addition, bass may compete with bluegill for available resources at the larval and juvenile stages. To quantify largemouth bass abundance, fall electrofishing surveys were conducted on all experimental lakes.

As part of the management experiment, 16 lakes were stocked with advanced fingerling largemouth bass to increase predator numbers. Fingerlings were stocked in mid-August 2000 (Table 3-2), and each bass was given a distinct clip for future identification. We monitored growth and survival of stocked bass during the first fall and spring after they were stocked. Largemouth bass were collected by day AC electrofishing in the fall by INHS and Division of Fisheries personnel. All largemouth bass were examined for marks, measured, and weighed.

Other biotic and abiotic factors

Abiotic variables may also influence bluegill population parameters. We measured water transparency, dissolved oxygen, temperature, total dissolved phosphorous, and chlorophyll *a* on 16 lakes. Water transparency was measured with a secchi disc. Temperature and dissolved oxygen profiles were measured at one meter intervals. Water samples were collected monthly with an integrated water sampler for analysis of total phosphorous and chlorophyll *a*.

To assess the relative importance of genetic and environmental impacts on the plasticity of life history decisions controlling age-at-maturation among parental male bluegill, we collected bluegill from two distinctly separated populations (Paris Lake, a insight into the importance of social interactions in bluegill populations.

Compliance

To assess compliance of anglers to the experimental regulations, compliance cards were given to conservation officers at all lakes with experimental regulations. These cards were then completed by conservation officers each time they performed a bluegill regulation check on an experimental lake.

FINDINGS

Bluegill population parameters:

Examination of length-frequency histograms of fall electrofishing samples as a surrogate for actual analysis of size-specific population size structure from experimental lakes revealed differences in certain treatment lakes. Because only two years have passed since inception of the management experiment, however, it is not surprising that differences were minor. Comparing length histograms from 1998 (last year prior to initiation of management experiment) through 2000 shows that some lakes in each treatment group contain larger fish (e.g., Woods Lake,LMB treatment, Figure 3-1; Lake of the Woods, regulation treatment, Figure 3-2; Pierce Lake, regulation + LMB treatment; Figure 3-3). In each of the examples, more bluegill are appearing in the 151-200mm size class in 1999 and 2000 than in 1998. Because of high variability in larval bluegill production, percentages in each size class are based on only bluegill greater than 50mm.

Density-dependent growth and survival in bluegill could occur at all life stages, and may influence adult population size structure. We have CPUE data for each study lake over the last several years. We analyzed these data with repeated measures analysis of variance (ANOVA) to determine whether or not there are differences in bluegill density between stunted and quality lakes. Repeated measures ANOVA controls within-lake variation among years and helps deal with high variability often inherent in bluegill CPUE samples. There was no difference (F=0.98, P=0.35) in mean CPUE between stunted (mean ± 1 S.E.; 392 ± 17.9 bluegill/hr.) and quality (539 ± 16) lakes.

Resampling of the experimental control lakes demonstrated some temporal stability in growth and maturation of these populations. (e.g., Sterling figure 3-5). In other populations we found some differences in growth rates, size structure, and timing of maturation. In these cases, low sample sizes often prevented reliable comparisons between initial and re-sampled populations. Continued collections in these populations should help deal with issues of sample size.

Effects of prey availability on bluegill growth and maturity
Overall, prey availability explained very little variation in growth, size structure, or maturation rates of bluegill in the experimental study lakes. Similar to the bluegill density analyses, we were able to incorporate multiple years of data from each population to examine differences in prey resources and correlations between prey availability and bluegill population

Predators

Contribution of stocked largemouth bass was again variable the first fall after stocking in 2000. Pierce and Mcleansboro had the highest CPUE of stocked bass (18.0 and 15.0 per hour) while no stocked bass were collected in either Sam Parr or Jacksonville. Catch-per-unit-effort of stocked largemouth bass remained variable in the following spring, but results were consistent within lakes (e.g., Pierce and Mcleansboro again had the highest CPUE of stocked bass; Table 3-3).

Compliance

Angler compliance with regulations was assessed on eight lakes during 1999-2001. Across all three years, compliance by anglers was relatively high, ranging from 85-100% (Table 3-4). Compliance was lowest during the first two years of the study when anglers were most likely unaware of the new regulation. During 2001, compliance was 100% on all the lakes on which compliance was assessed. We will need to continue to work with the conservation officers to assess compliance in future years on lakes that were not monitored during 2001.

Additional experiments

The experiment on genetic versus environmental (social structure) effects on bluegill maturation indicated that, while genetic effects were minor, the presence of large, mature males had a strong effect on maturation schedules of juvenile males (Figure 3-7). Gonad scores and GSI's of juvenile males in treatments with large males were significantly lower ($F>10.0$; $P<0.01$)than in treatments with large males.

parameters, which helped control high variation among study lakes. A repeated measures ANOVA on prey resources across years in each study lake revealed no difference in total zooplankton density(F=0.01; P=0.91), macrozooplankton density(F=2.77; P=0.19) or total benthos density (F=4.01; P=0.09) between stunted and quality populations (Figure 3-6). To determine whether there was any relationship between prey availability and bluegill growth, density, and age-at-maturity, we regressed total zooplankton density and total benthos density with bluegill size-at-age 2, z-age, and CPUE. There were no significant correlations between z-age, bluegill size-at-age 2, or bluegill CPUE and prey resources, with the exception of a significant correlation between benthos density and bluegill z-age (Table 3-2). We also regressed PQM180, one characteristic used to define stunted and quality lakes, with both measures of prey. We again found no correlation between PQM180 and total zooplankton density(F=0.94; P=0.09; r^2=0.24)or total benthos density (F=6.23;P=0.09;r^2=0.03). These analyses suggest that, in general, prey resources are abundant enough that no one prey type is limiting bluegill growth at each life stage. More importantly, however, variation in prey resources does not appear to explain why bluegill populations are stunted. Analyses across lakes including several years of data reveal no differences in prey resources between lake types and no correlations between size structure and prey resources. Continued analyses with additional years of data collection will be necessary to validate these conclusions. In addition, bluegill diet data will help us continue to assess the importance of prey resources to growth and maturation rates of bluegill within and among populations.

The presence of gizzard shad also appears to influence bluegill population size structure; we found that adult male and female bluegill were smaller (F>5.0; P<0.05) in lakes with gizzard shad than in lakes without them (Figure 3-8). One likely mechanism is increased turbidity in the gizzard shad lakes, which reduces bluegill foraging. While we did not assess the influence of gizzard shad on other important bluegill life-history parameters such as timing of maturation, these results suggest that fish community variables will also be important considerations when implementing these management strategies.

RECOMMENDATIONS

We need to continue to examine bluegill population parameters, prey and predator abundances, and fish community variables in the study populations to determine mechanisms responsible for alteration in bluegill population size structure expected to result from the experimental management actions. These assessments will be critically important to determine the mechanisms by which each management action alters growth and maturity schedules, and, hence, size structure of the population.

We need to continue to monitor population size structure in each of the experimental study lakes. Our ability to detect changes in population size structure should increase each year as the effects of each management action influences new and existing cohorts. We also need to continue to measure important biotic and abiotic variables and their relationship to bluegill abundances at each life stage. Additional data will help control for high variability in the analyses. We need to continue to evaluate the importance of prey resources relative to the initial findings in this segment and verify relationships between prey availability and bluegill growth and maturation. Because fall bluegill collections are particularly variable, we need to continue to collect bluegill population data in spring (a procedure that began during this segment) and use these data to evaluate length-frequency histograms and to determine sex-specific size structures. Preliminary results of the gizzard shad investigation provide evidence that fish community variables should be considered as we assess the impacts of the experimental regulations. Lakes with and without gizzard shad are distributed fairly equally across experimental treatment lakes, so this variable should be easily accounted for in our analyses.

To examine the effects of prey availability on growth at each life stage, we need to continue to monitor prey resources in selected study lakes. More intensive analyses should focus on community analyses of both zooplankton and benthic invertebrates to determine whether individual prey taxa may be disproportionately important to bluegill growth or maturity. We need to continue to correlate prey abundance with bluegill densities and size-at-age data to determine the importance of density-dependent growth on age-at-maturation and population size structure. Diet data should be processed and analyzed during the next segments to determine differences in prey selection by bluegill at each life stage. In addition, differences in prey selection and prey availability within populations should be determined to provide insight into optimal food resources for bluegill in these eutrophic and hypereutrophic populations.

In addition to these lakes, several other lakes with compliance checks in 1999-2000 were not checked in 2001 (Forbes, Pana, Red Hills) and should be assessed in future years. Also, three state lakes (Kakusha, Jacksonville, Walton Park) have never been assessed for angler compliance and five lakes (Busse South, Mermet, Tampier, Dolan, Bullfrog) in Forest Preserve Districts need to be assessed. We will work with the conservation officers responsible for each of these lakes to monitor angler compliance.

Results of our prey analyses suggest that variation in prey availability is not driving differences in bluegill population size structure. This is an interesting result, and one that reiterates our earlier conclusion (job 101.2) that the stunted bluegill populations are not the result of density-dependent slow growth, but rather that bluegill size structure is driven more by the presence or absence of large males controlling age-at-maturation. In addition, predator abundances should continue to be monitored to determine the effects of predation on bluegill abundance and growth. By monitoring these variables before and after implementation of the experimental management actions, we will be able to assess the cause of changes in age-at-maturation and growth rates that may result. Understanding the conditions under which changes in bluegill population size structure occur will be important in determining the future utility of these management options across a range of lakes.

We will continue to stock fingerling largemouth bass in manipulation treatment lakes. Stocking bass in 2000 had varied success across the 16 study lakes, as was the case with the 1999 stockings. Continued stocking efforts in subsequent segments will focus on increasing the success of stocked bass to increase the numbers of largemouth bass in these systems.

Based on data collected from conservation officers, compliance was high across all of the regulation lakes. However, creel data indicate that a few of the lakes (Pierce and Homer) need more conservation officer presence and education of the public on the importance of the management regulation to increase compliance.

REFERENCES

Anderson, D.W. and D.H. Schupp. 1986. Fish community response to northern pike stocking in Horseshoe Lake, Minnesota. Minnesota Dept. of Natural Resources, Section of Fisheries Investigational Report 387.

Bayley P.B., S.T. Sobaski, D.J. Austen (1993). The fisheries analysis system (FAS): creel survey and lake analysis. Aquatic Ecology Technical Report 93/7, Illinois Natural History Survey, Champaign, IL.

Belk, M.C. and L.S. Hales, Jr. (1993). Predation-induced differences in growth and reproduction of bluegills (Lepomis macrochirus). Copeia 1993: 1034-1044.

Borowsky, R.L. (1978). Social inhibition of maturation in natural populations of Xiphophoris variatus (Pisces: Poeciliidae). Science 201:933-935.

Callahan, S.P., D.H. Wahl, D. E. Shoup, and C.L. Pierce. 1996. Growth of bluegill, largemouth bass, and channel catfish in relation to fish abundances, food availability, and other limnological variables. (in prep).

Chapman, L.J., D.L. Kramer, and C.A. Chapman. (1991). Population dynamics of the fish Poecilia gillii (Poeciliidae) in pools of an intermittent tropical stream. J. of An. Ecol. 60:441-453.

Claussen, J.C. (1991). Annual variation in the reproductive activity of a bluegill population: effect of clutch size and temperature. M.S. Thesis, U. Toronto.

Coble, D.W. (1988). Effects of angling on bluegill populations: management implications. North American Journal of Fisheries Management 8:277-283.

Colby, P.J., P.A. Ryan, D. H. Schupp, and S.L. Serns. 1987. Interactions in north-temperate lake fish communities. Canadian Journal of Fisheries and Aquatic Sciences 44 (supplement 2):104-128.

Fox, M.G. and A. Keast. (1991). Effect of overwinter mortality on reproductive life history characteristics of pumpkinseed (Lepomis gibbosus) populations. Can. J. Fish. Aqu. Sci. 48:1792-1799.

Reznick, D. (1983). The structure of guppy life histories: the tradeoff between growth and reproduction. Ecology 64:862-873.

Robertson, D.R. 1972. Social control of sex reversal in a coral-reef fish. Science 177:1007-1009.

Silverman, H.I. (1978). The effects of visual stimulation upon age at first spawning in the mouth-brooding cichlid fish _Sarotherodaon_ (Tilapia) _mossambicus_ (Peters). An. Beh. 26:1120-1125.

Stearns, S.C. and J.A. Koella. (1986). The evolution of phenotypic plasticity in life-history traits: predictions of reaction norms for age and size of maturity. Evolution 40:893-913.

Swingle, H.S. 1950. Relationships and dynamics of balanced and unbalanced fish populations. Alabama Polytechnic Institute, Agricultural Experimental Station Bulletin 274, Auburn.

Wootton, R.J. (1985). Energetics of reproduction. pp. 231-254 in P. Tyler and P. Callow (eds) Fish Energetics: New Perspectives. Johns Hopkins University Press, Baltimore, MD.

Gerking, S.D. 1962. Production and food utilization in a population of bluegill sunfish. Ecological Mongraphs 32:31-78.

Goedde, L. E. and D.W. Coble. 1981. Effects of angling on a previously fished and unfished warmwater community in two Wisconsin lakes. Transactions of the Am Fish Soc 110:594-605.

Gross, M.R. (1982). Sneakers, satellites and parentals: polymorphic mating strategies in North American sunfishes. Z. Tierpsychol 60: 1-26.

Gross, M.R. and E.L. Charnov (1980). Alternative male life histories in bluegill sunfish. Proc. Natl. Acad. Sci. 77: 6937-6940.

Guy, C. S., and D. W. Willis. 1990. Structural relationships of largemouth bass and bluegill populations in South Dakota ponds. North American Journal of Fisheries Management 10:338-343.

Jennings, M.J. (1991). Sexual selection, reproductive strategies and genetic variation in the longear sunfish (Lepomis megalotis). Ph.D. dissertation, University of Illinois, Urbana.

Jennings, M.J. and D.P. Philipp. (1992). Reproductive investment and somatic growth in longear sunfish. Envir. Biol. of Fish 35:257-271.

Jennings, M.J., J.E. Claussen and D.P. Philipp. (1997). Effect of population size structure on reproductive investment among male bluegill. North American Journal of Fisheries Management 17: 516-524.

Mittelbach, G.G. (1984). Predation and resource partitioning in two sunfishes (Centrarchidae). Ecology 65:499-513.

Mittelbach, G.G. (1986). Predator-mediated habitat use: some consequences for species interactions. Env. Bio. Fish. 16:159-169.

Olsen, D.E. and P.K. Cunningham. 1989. Sport fisheries trends shown by an annual Minnesota fishing contest over a 58-year period. North American Journal of Fisheries Management 9:287-297.

Philipp, D.P. and M.R. Gross. (1994). Genetic evidence for cuckoldry in bluegill Lepomis macrochirus. Molecular Ecology 3:563-569.

TABLE 1-1. Summary of the total number of sportfish harvested and released from creeled lakes for three sample years. Bluegill rank among the highest in both harvest and release.

	1990			1998			1999		
SPECIES	RELEASED	HARVESTED	TOTAL	RELEASED	HARVESTED	TOTAL	RELEASED	HARVESTED	TOTAL
BLACK CRAPPIE	423	2307	2730	1374	884	2258	451	903	1354
BLUEGILL	**2517**	**10088**	**12605**	**6944**	**4032**	**10976**	**2942**	**7038**	**9980**
CHANNEL CATFISH	1357	11094	12451	3319	3313	6632	2569	4242	6811
GREEN SUNFISH	234	749	983	642	570	1212	307	292	599
LARGEMOUTH BASS	11405	3980	15385	29123	2095	31218	17555	1323	18878
WALLEYE	357	317	674	482	148	630	179	151	330
WHITE BASS	468	2476	2944	1583	635	2218	243	20	263
WHITE CRAPPIE	2204	7635	9839	10753	4162	14915	1070	2207	3277

Table 1-3. Creel data for the 32 experimental bluegill populations. Data includes, the lake classification, the percentage of anglers targeting bluegill, the number of angler hours per acre, the number of bluegill caught and harvested per hour, the average weight of bluegill caught and harvested per hour, the proportion of creeled fish (PCF).

Class	Lake Name	Year of Creel	% BLG Intrvws	Angler Hrs/Acre	#/Hr Caught (Harvest)	Ave Wt (g) Caught (Harvest)	PCF.180
Q N L	Bloomington	1996	2.0%	63	.312 (.140)	85.7 (112.1)	0.38
St N S	Bullfrog	1998	10.2%	111	.355 (.068)	32.1 (51.5)	0.01
Q N L	Busse	1989	0.6%	451	.262 (.167)	46.1 (49.9)	0.01
St S S	Dolan Lake	1998	5.2%	274	.399 (.242)	47.5 (65.6)	0.05
Q S L	Forbes	1999	7.7%	84	.470 (.047)	118.9 (137.3)	0.13
Q S S	Glendale Lake	1999	3.7%	95	.828 (.308)	83.2 (84.3)	0.29
St S S	Hillsboro	1999	5.1%	78	.158 (.057)	52.6 (60.1)	0.11
Q S S	Homer Lake	1999	4.6%	330	.300 (.017)	66.8 (86.2)	0.18
St S L	Jacksonville	1999	0.5%	48	.304 (.008)	37.9 (43.5)	0.02
Q N S	Kakusha	1998	17.6%	124	.135 (.095)	91.8 (105.8)	0.37
St N S	Lake of the Woods	1998	5.0%	837	.732 (.136)	32.6 (39.8)	0.02
St N S	Le-Aqua-Na	1994	6.5%	742	.412 (.213)	73.2 (99.0)	0.27
Q S L	Lincoln Trail	1996	9.5%	112	.188 (.166)	111.5 (118.5)	0.60
St S S	McLeansboro	1999	9.7%	60	.094 (.055)	133.4 (157.4)	0.38
Q S L	Mermet	1997	11.9%	81	.488 (.351)	108.4 (142.2)	0.48
St S L	Mingo	1988	3.9%	173	.202 (.114)	42.1 (46.7)	0.01
Q S L	Murphysboro	1987	23.2%	198	.362 (.165)	70.2 (111.9)	0.25
St S L	Pana Lake	1999	0.1%	68	.226 (.011)	35.9 (NO DATA)	0.06
St S L	Paris	1999	14.7%	87	.435 (.088)	49.3 (59.9)	0.14
St N L	Pierce Lake	1999	4.7%	407	.207 (.016)	35.6 (39.7)	0.05
Q S S	Red Hills Lake	1994	18.1%	473	.612 (.278)	79.7 (104.3)	0.21
St N L	Round Lake	1999	3.8%	28	227 (.042)	61.2 (81.5)	0.26
Q S S	Sam Parr	1997	16.6%	217	1.671 (1.020)	66.7 (94.4)	0.31
Q N S	Siloam Springs	1997	6.6%	416	.279 (.076)	55.0 (99.8)	0.15
St N L	Spring Lake North	1999	23.2%	64	2.00 (.624)	82.1 (83.4)	0.07
Q N L	Spring Lake South	1996	31.8%	150	1.380 (.675)	61.1 (92.4)	0.19
St N S	Sterling	1989	0.8%	125	.006 (.002)	38.2 (61.0)	0.00
St N L	Tampier	1998	3.2%	951	.118 (.022)	25.7 (46.9)	0.02
Q N S	Walnut Point	1997	37.9%	199	.302 (.197)	62.9 (95.6)	0.23
St S S	Walton Park	1999	4.3%	107	.108 (.000)	47.4 (107.5)	0.03

Table 1-2. Potential bluegill study lakes (n=60). The list of lakes is organized by region (north, central, and south) and then split into categories based both on population size structure (quality populations = adults >180mm or stunted populations = adults <150mm) and lake size (large lakes are ≥ 100 acres and small lakes are < 100 acres). Names of counties follow each lake name.

NORTHERN LAKES

Quality/Large

Tampier (Cook)
Shabbona (Dekalb)
Apple Canyon (Jo Davies)
Busse - Main (Cook)
Busse - South Pool (Cook)
Holiday (Lasalle)

Quality/Small

Botanical Garden (Cook)
Johnson Sauk Trail (Henry)
Kakushka (Lasalle)
Baumann Park Lake (Winnebago)

Stunted/Large

Pierce (Winnebago)
George (Rock Island)
Round (Lake)
Long (Lake)

Stunted/Small

Carleton (Whiteside)
Sterling (Lake)
Bullfrog (Cook)
Wampum (Cook)
Busse North (Cook)
Le-Aqua-Na (Stephenson)
Turner (Lake)
Levings (Winnebago)

CENTRAL LAKES

Quality/Large

Lincoln Trail (Clark)
Mill Creek (Clark)
Spring Lake South (Tazewell)
Paradise (Coles)
Bloomington (Mclean)

Quality/Small

Woods Lake (Moultrie)
Homer Lake (Champaign)
Coles Co. Airport Lake (Coles)
Beaver Dam Lake (Macoupin)
Siloam Springs (Adams)
Walnut Point (Douglas)

Stunted/Large

Spring Lake North (Tazewell)
Paris East (Edgar)
Pana (Shelby)
Mingo (Vermilion)
Jacksonville (Morgan)
Charleston (Coles)

Stunted/Small

Lake of the Woods (Champaign)
Oakland City Lake (Coles)
Weldon Springs (Dewitt)
Walton Park (Montgomery)
Hillsboro Old City (Montgomery)

SOUTHERN LAKES

Quality/Large

Mermet (Massac)
Murphysboro (Jackson)
Sam Parr (Jasper)
East Fork (Richland)
Dutchman (Johnson)

Quality/Small

Red Hills (Lawrence)
St. Elmo/South Lake (Fayette)
Glendale (Pope)

Stunted/Large

Jones (Saline)
Forbes (Marion)
Harrisburg (Saline)
Sam Dale (Wayne)

Stunted/Small

Dolan (Hamilton)
One Horse Gap (Pope)
Mcleansboro (Hamilton)
Nellie (Fayette)

Table 3-3. Contribution of largemouth bass fingerlings stocked into 14 bluegill study lakes. Predator addition lakes were those stocked with advanced fingerling largemouth bass, whereas predator addition plus regulation lakes were those with stocked largemouth bass, and had an 8-inch minimum size limit, and a 10 fish daily creel. Catch per unit effort (CPUE) is based on the number of fish collected per hour of AC electrofishing. Total length (TL) is the average length of stocked bass collected in the fall and spring. Dash marks indicate no collection data available.

	Stock		Stocking	CPUE		TL	
Lake	Date	#/acre	Size (TL)	Fall	Spring	Fall	Spring
Predator Addition Lakes							
Leaquana	08/23/00	25.8	98	5.6	1.3	126	153
Mcleansboro	08/09/00	24.3	135	18.0	4.7	145	144
Mingo	08/15/00	24.3	102	6.3	4.0	118	129
Murphysboro	08/09/00	24.3	135	4.0	2.0	146	154
Sam Parr	08/09/00	24.3	135	0.0	2.0	NA	168
Spring Lake North	08/11/00	24.3	98	3.0	-	110	NA
Woods	08/14/00	24.3	101	2.0	2.0	117	108
Regulation Plus Predator Addition Lakes							
Bloomington	08/10/00	24.3	98	4.0	2.0	116	133
Forbes	07/18/00	12.1	135	6.8	2.8	146	159
Homer	08/10/00	24.3	102	7.8	2.0	171	179
Jacksonville	08/09/00	19.0	126	0.0	0.0	NA	NA
Kakusha	08/24/00	24.3	104	5.4	0.0	116	NA
Pierce	08/17/00	24.3	98	15.0	10.7	123	145
Walton Park	08/11/00	43.3	118	2.0	-	149	NA

Table 3-1. Experimental management lakes, controlling for region (north, south), lake size (large, small), and population size structure (quality, stunted). Treatments include control, restrictive regulation (8 inch minimum size limit, 10 fish creel limit), predator stocking, and combination of restrictive regulation and predator stocking

Type	Region	Lake Size	Control	Regulation	Pred. Stocking	Regulation/ Pred. Stocking
Quality	North	Large	Apple Canyon	Busse South	Spring L. S.	Bloomington
	North	Small	Siloam Springs	Walnut Pt.	Woods	Kakusha
	South	Large	Lincoln Trail	Mermet	Murphysboro	Forbes
	South	Small	Glendale	Red Hills	Sam Parr	Homer
Stunted	North	Large	Round	Tampier	Spring L. N.	Pierce
	North	Small	Sterling	L. of the Woods	Le-Aqua-Na	Bullfrog
	South	Large	Paris	Pana	Mingo	Jacksonville
	South	Small	Hillsboro	Dolan	Mcleansboro	Walton Park

Table 3-2. Results of linear regressions between food resource measurements and bluegill size and density measurements.

Variables in Regression	*t*	*P*	R^2
Zooplankton density vs bluegill size at age-2	0.31	0.76	0.08
Zooplankton density vs bluegill PQM 180	0.05	0.96	0.00
Zooplankton density vs bluegill z-age	-0.78	0.45	0.05
Zooplankton density vs bluegill CPUE	0.70	0.50	0.06
Benthos density vs bluegill size at age-2	-0.46	0.66	0.01
Benthos density vs bluegill PQM 180	-0.45	0.66	0.01
Benthos density vs bluegill z-age	-3.08	0.01	0.40
Benthos density vs bluegill CPUE	-0.30	0.77	0.01

Figure 2-1. "Typical" pattern of fish growth. The relationship between age and body size changes before and after sexual maturation. The slope of line A shows the rate of growth before maturation and the slope of line B shows the decreased rate of growth after maturation. The flex point indicated the time of maturaiton. The length of the line represents the average longevity of fish in the population.

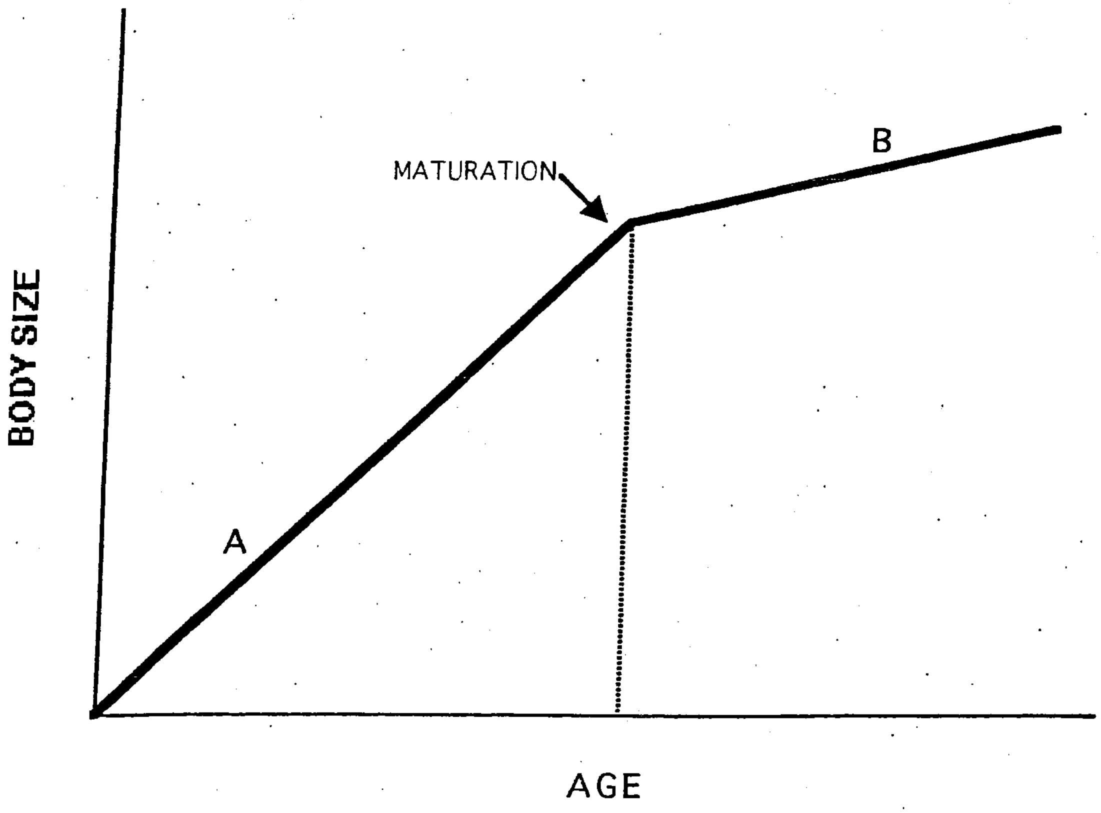


Figure 2-3. Hypothesis 2: Cuckolder Overproduction. Growth rates are shown for both the parental (P) and cuckolder (C) male life histories. Age of sexual maturation for these two strategies are shown by the two dashed lines. In this hypothesis growth rates and age at maturation do not change for either male type. The thickness of the lines in this graph indicates that significantly more immature males enter the cuckolder life history pathway than the parental pathway.

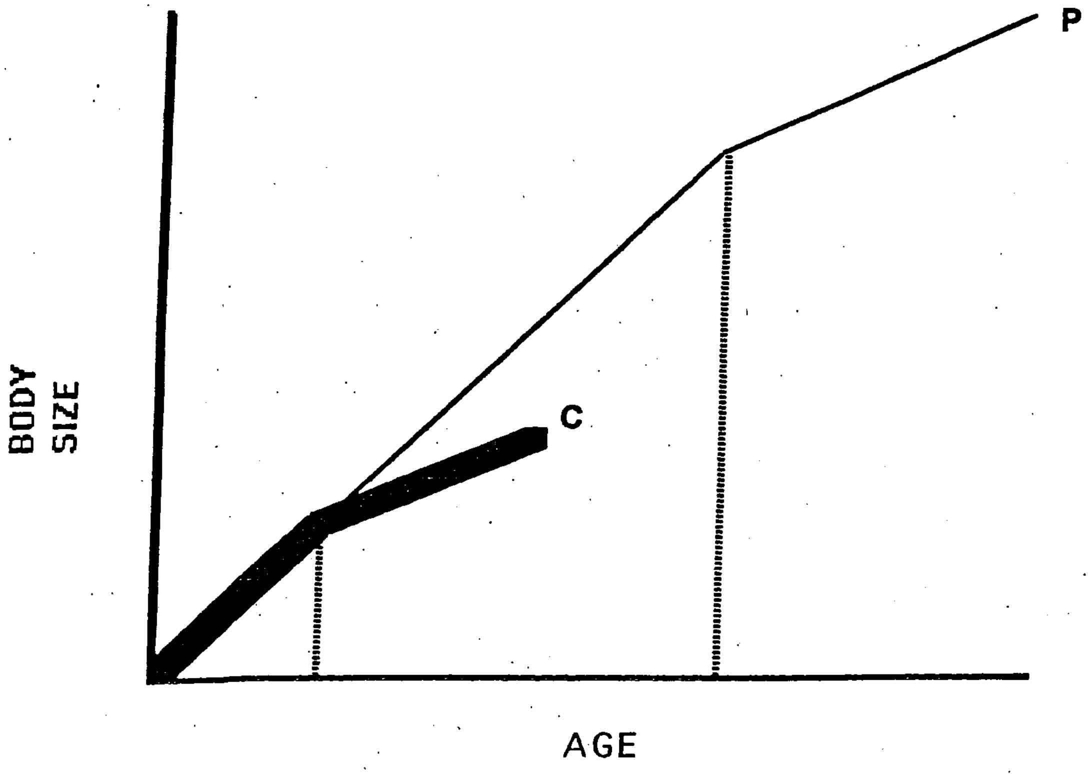


Figure 2-2. Hypothesis 1: Adult Overharvest. Growth rates are shown for both the parental (P) and cuckolder (C) male life histories. Age of sexual maturation for these two different strategies are shown by the two dashed lines. In this hypothesis growth rates and age at maturation do not change for either male strategy. The change in the thicknes of the line depicts the effects of fishing pressure and overharvest, i.e., large sized individuals being removed from the population. In this hypothesis, large individuals are not found in the population because as soon as males reach some size threshold, they are removed through angling.

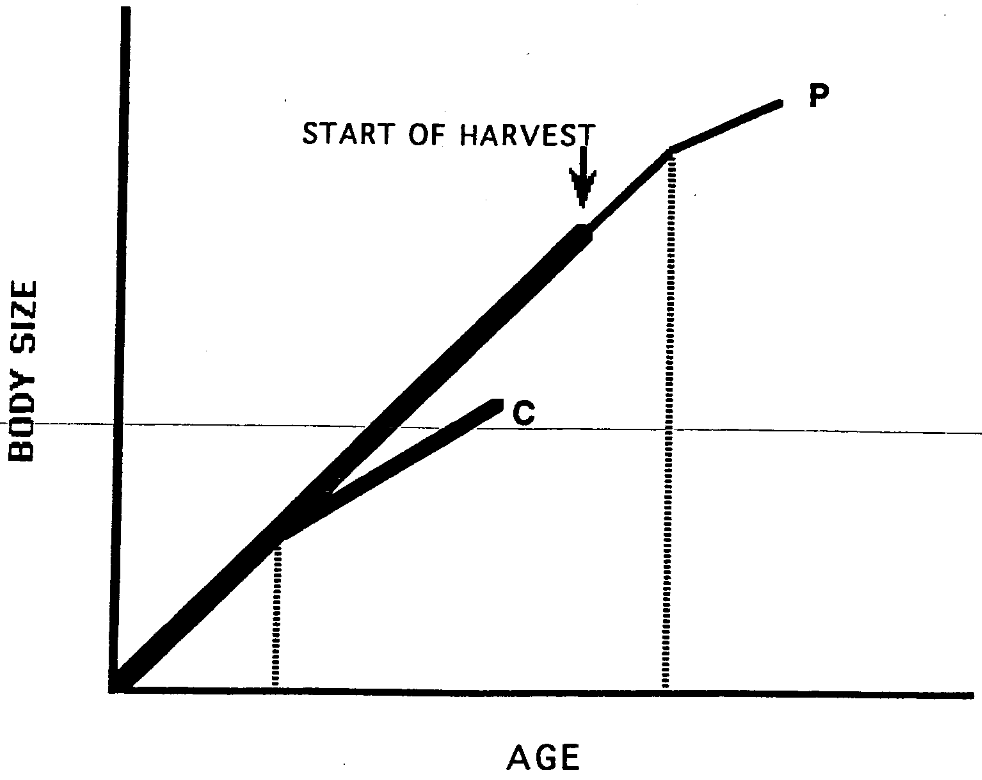


Figure 2-4. Hypothesis 3: Density-Dependence Growth Limitation. Growth rates are shown for both the parental (P) and cuckolder (C) male life histories. Age of sexual maturation for these two stratagies are shown by the two dashed lines. In this hypothesis, the sexual maturation schedules for both parental and cuckolder male life history pathways stay the same as in the typical bluegill population. However, growth rates for both life histories both decrease, shown by the grey arrows. In this hypothesis, large individuals are not produced in the population because the entire growth trajectory is slowed from birth, because of reduced food resources.

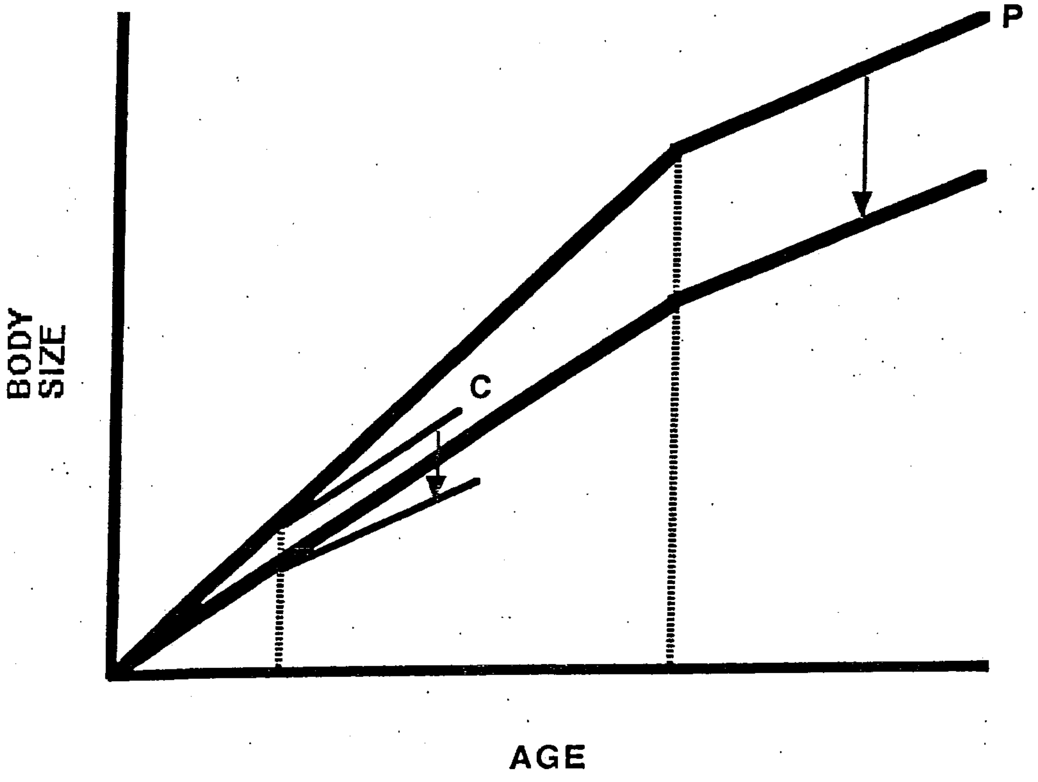


Figure 2-6. Prediction from Hypothesis 1: Adult Overharvest. In this hypothesis, stunted populations would have very few mature parental males (of any size), and great numbers of two year olds. Quality populations, on the other hand, would have many more mature males per two year old.

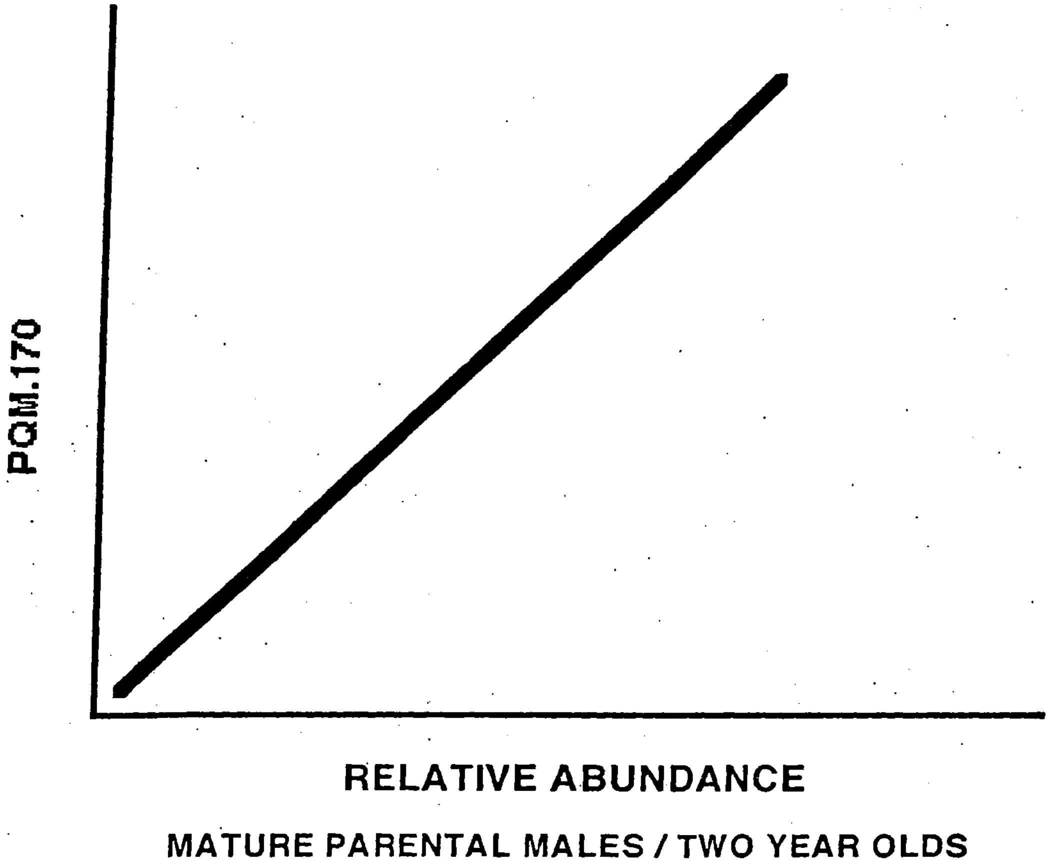


Figure 2-5. Hypothesis 4: Social Influence / Early Maturation. Growth rates are shown for both the parental (P) and cuckolder (C) male life histories. Age of sexual maturation for these two strategies are shown by the two dashed lines. In this hypothesis, early growth rates are typical of "normal" populations, but sexual maturation occurs at a younger age, depicted by the grey arrow. As a result, growth rates which change after maturation slow earlier in life than is "typical", as shown by the grey line. In this scenario, large individuals are not produced in the population because the post-maturation reduction in growth rate occurs at an earlier age.

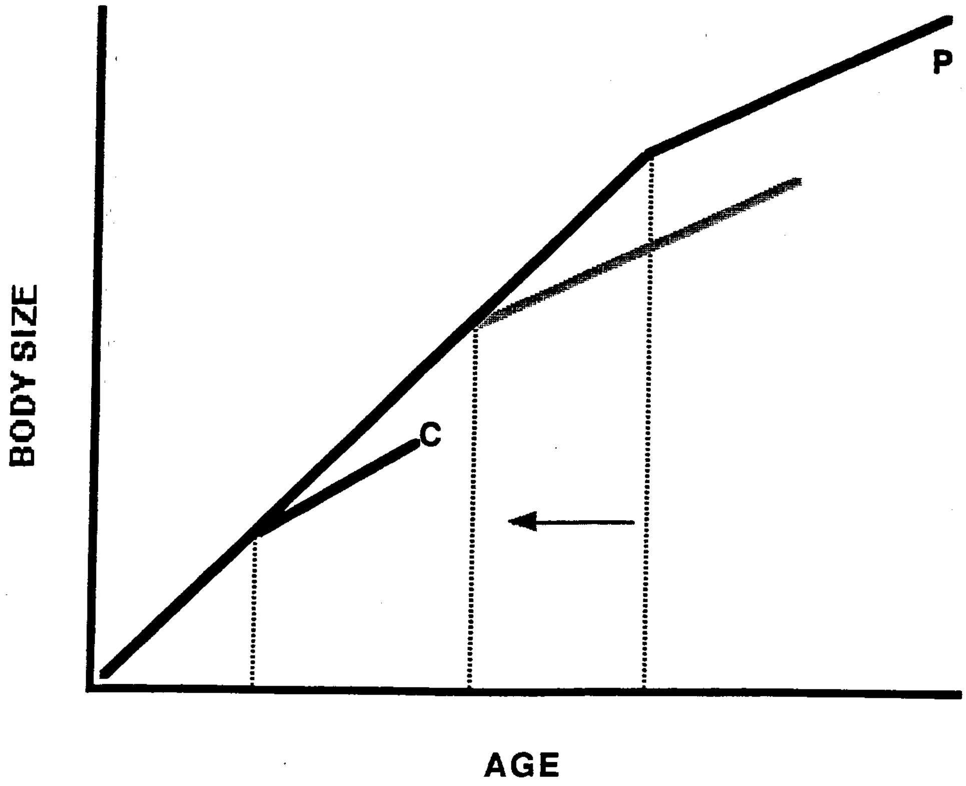


Figure 2-7. Test of Hypothesis 1: Adult Overharvest. Linear regression of PQM.170 versus ratio of mature parental males to total number of age 2 fish using data from all 50 study populations. There is no positive significant relationship (r^2 = .002; p= .778).

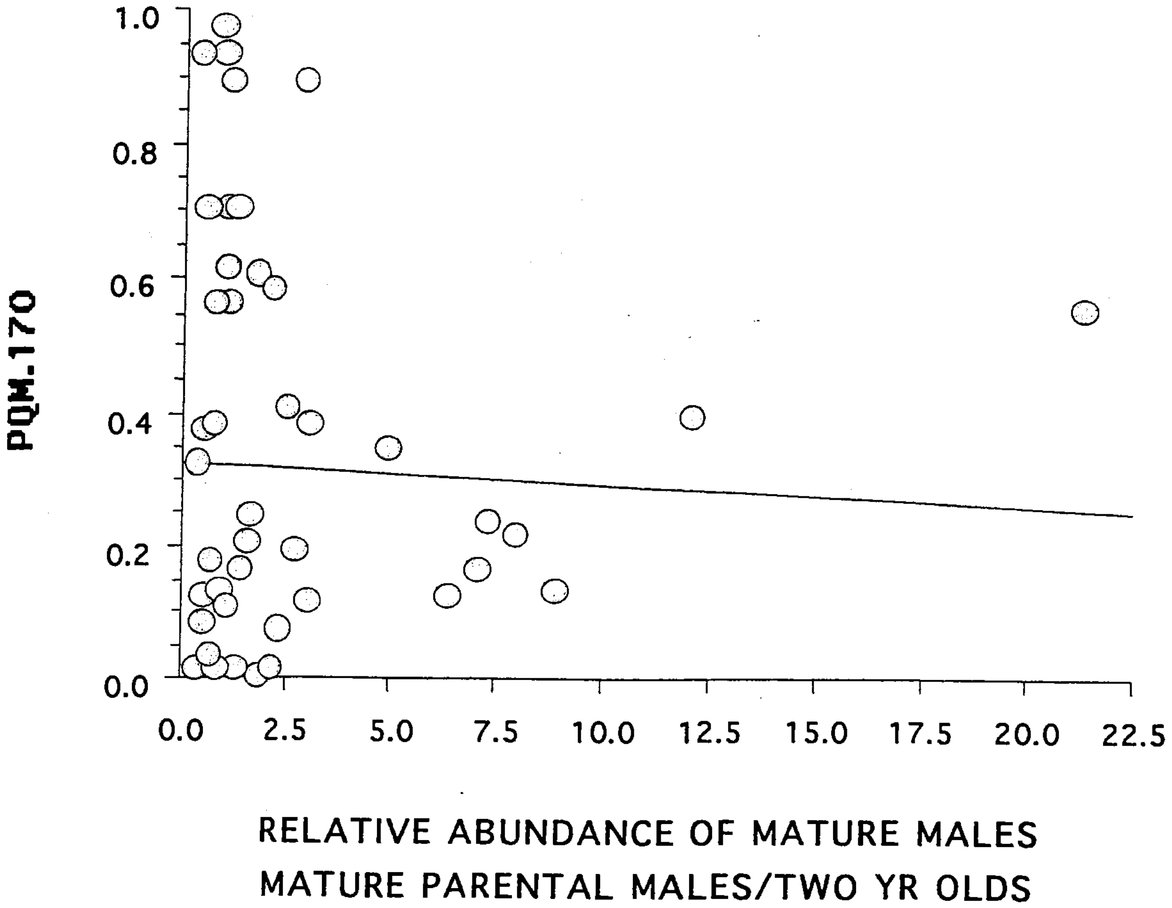


Figure 2-8. Prediction from Hypothesis 2: Cuckolder Overabundance. In this hypothesis stunted populations would have a high ratio of cuckolders to parental males. Quality populations, on the other hand, would have a low ratio.

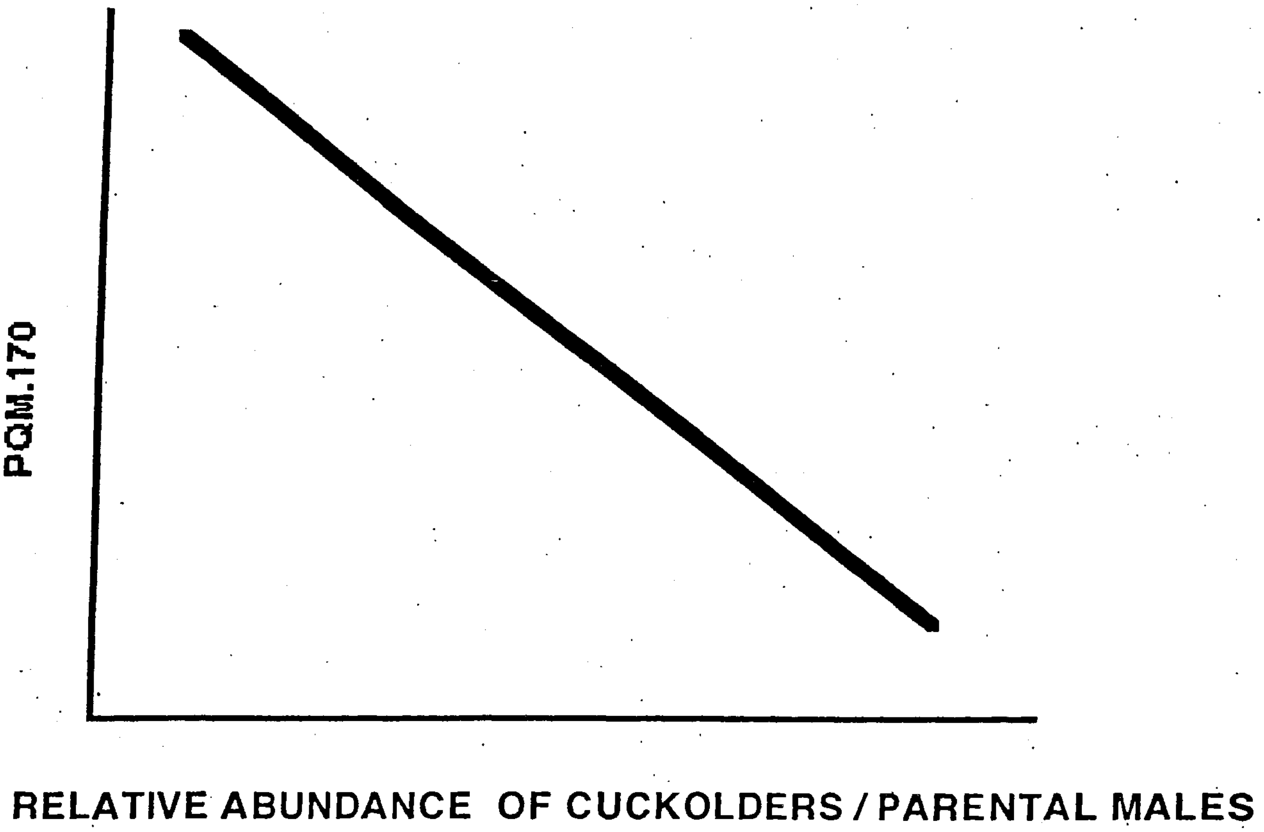


Figure 2-10. Prediction of Hypothesis 3: Density-Dependent Growth Limitations. In this hypothesis, stunted populations would have slower initial growth rates than quality populations.

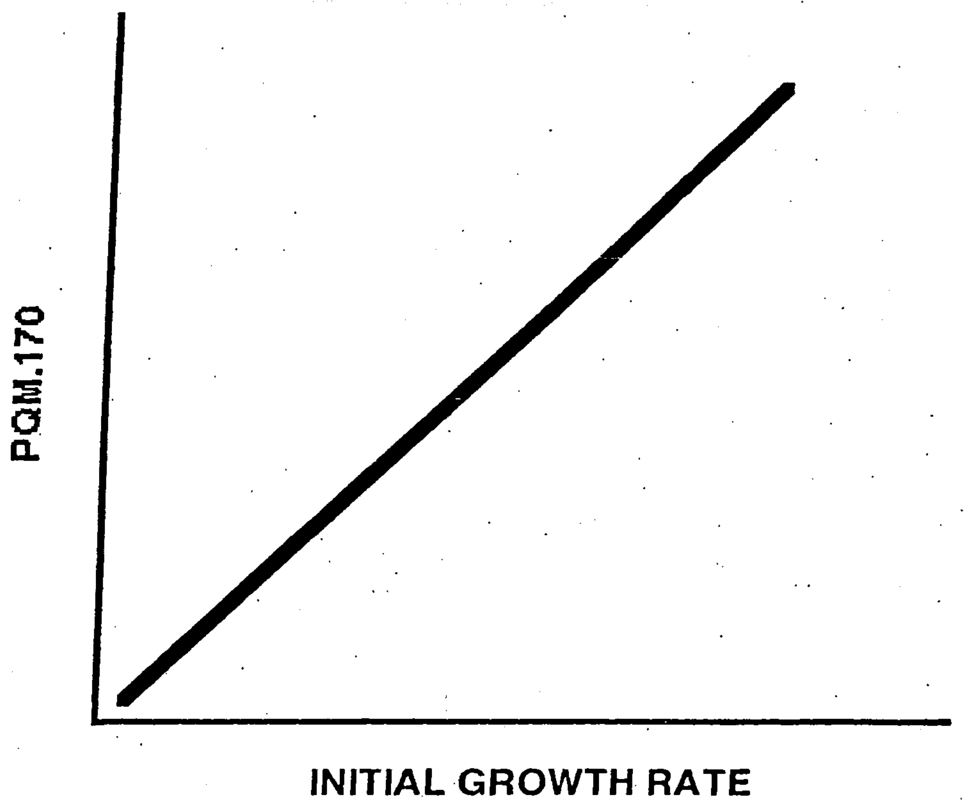


Figure 2-9. Test of Hypothesis 2: Cuckolder Overproduction: Linear regression of PQM.170 versus ratio of cuckolder males to parental male bluegill using data from all 50 study populations. Although the fit of the line is slightly negative, there is not a significant relationship ($r^2 = .019$; p=.338).

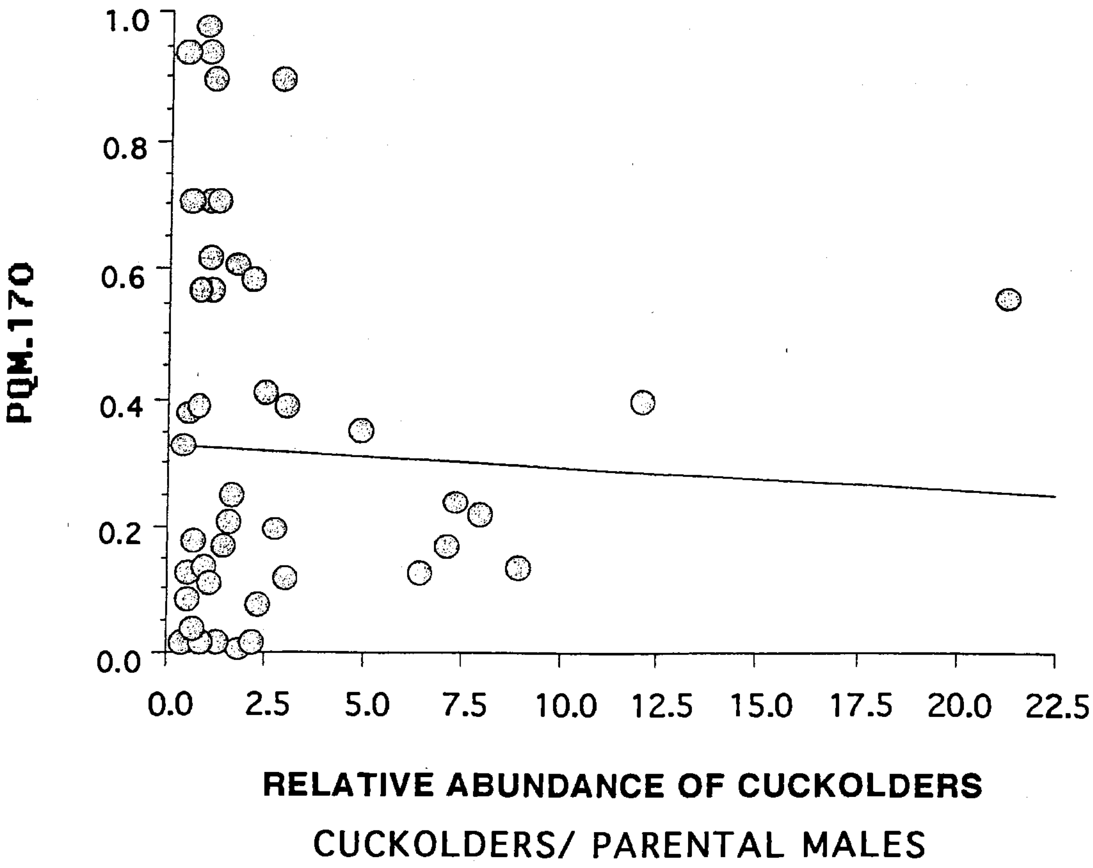


Figure 2-11. Test of Hypothesis 3: Density-Dependent Growth Limitation. Linear regression of PQM.170 versus size at age 2 using data from all 50 study populations. Although the fit of the line is slightly negative, there is not a significant relationship using data from the 50 study populations. There is no significant relationship (r^2 = .001; p=.916).

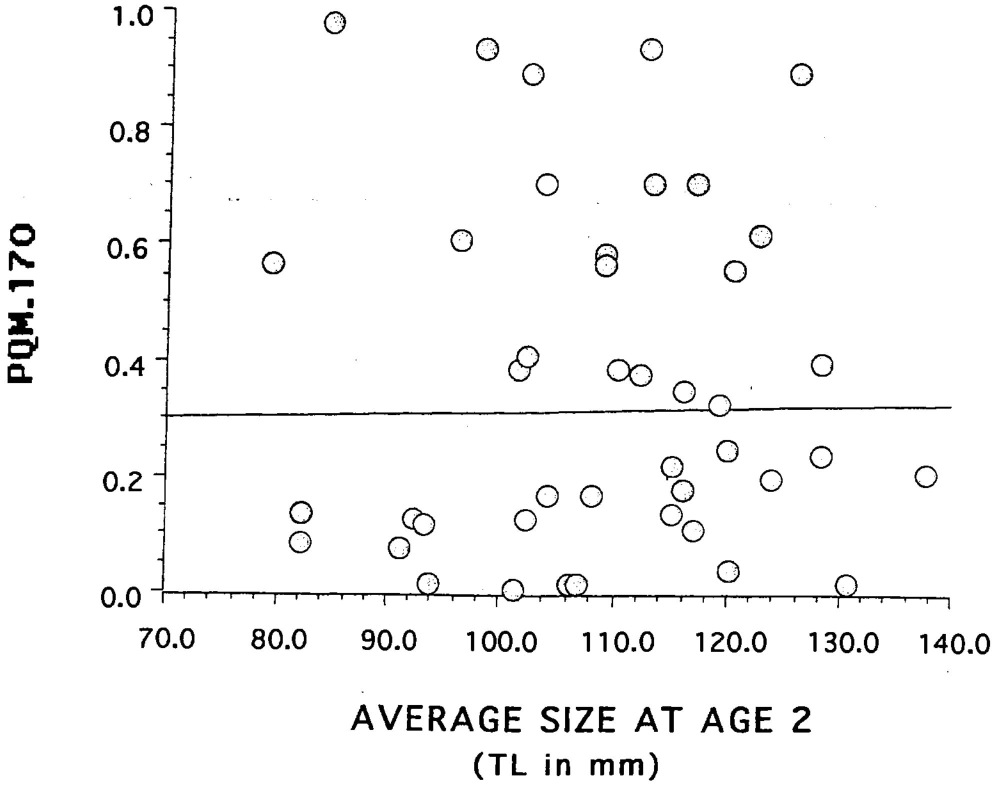


FIGURE 2-12. Prediction of Hypothesis 4: Social Influence / Early Maturation. In this hypothesis stunted populations wouls mature earlier (have lower Z-Ages) than those quality populations.

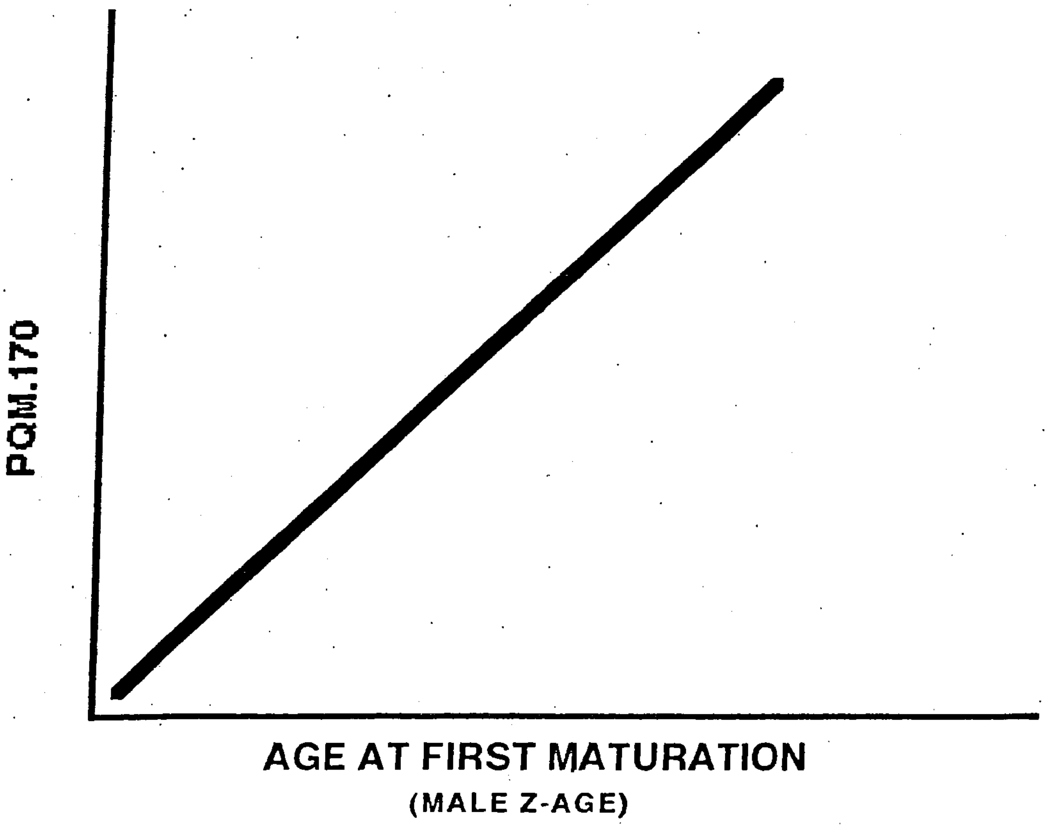


Figure 3-1. Length-frequency histogram for Woods Lake (LMB treatment) before (19
and after (1999,2000) implementation of the management experiment. Bluegill were collected by electrofishing during fall of each year. Only bluegill greater than 50mm were included in the analysis.

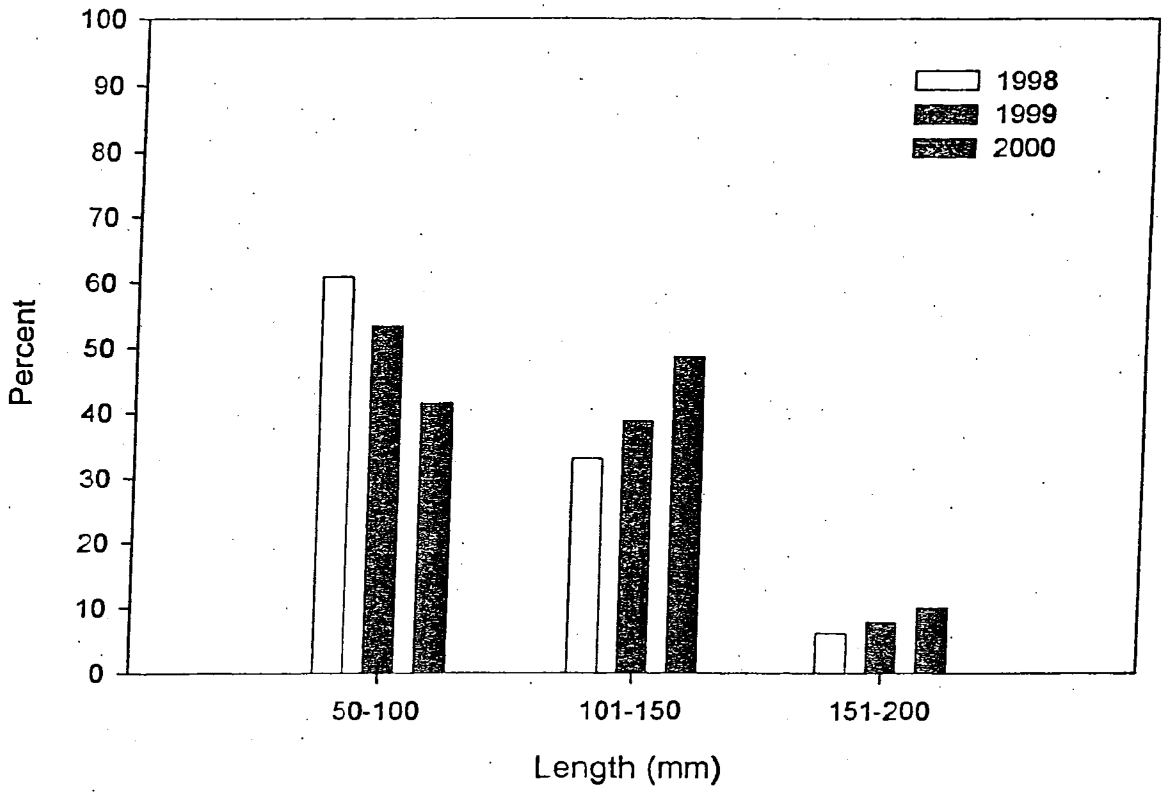


Figure 3-2. Length-frequency histogram for Lake of the Woods (Regulation treatment) before (1998) and after (1999,2000) implementation of the management experiment. Bluegill were collected by electrofishing during fall of each year. Only bluegill greater than 50mm were included in the analysis.

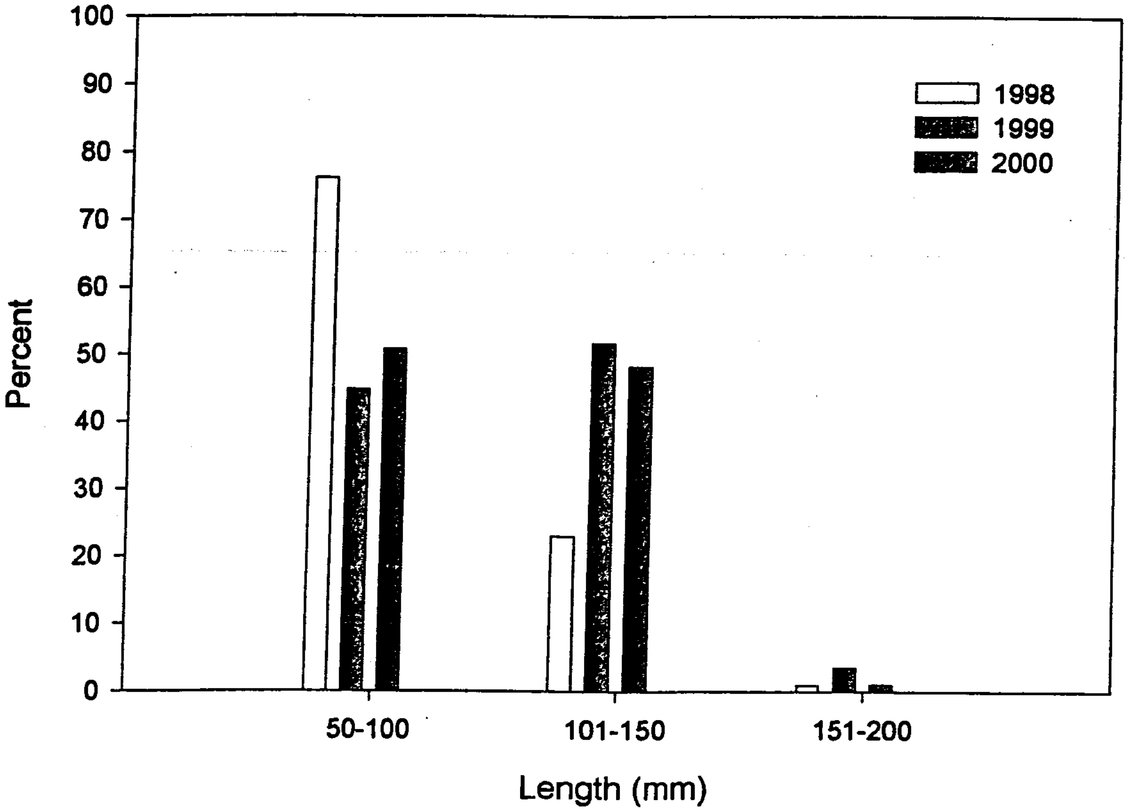


Figure 3-3. Length-frequency histogram for Pierce Lake (Regulation + LMB treatment) before (1998) and after (1999,2000) implementation of the management experiment. Bluegill were collected by electrofishing during fall of each year. Only bluegill greater than 50mm were included in the analysis.

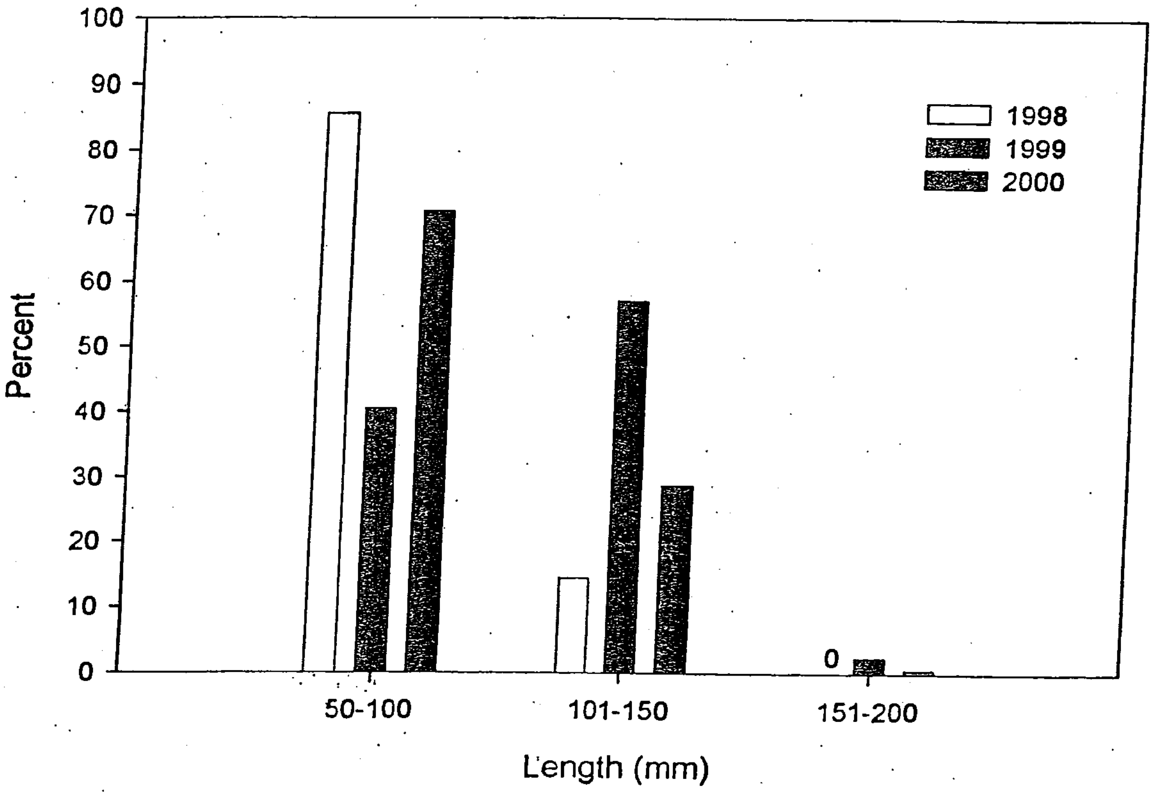
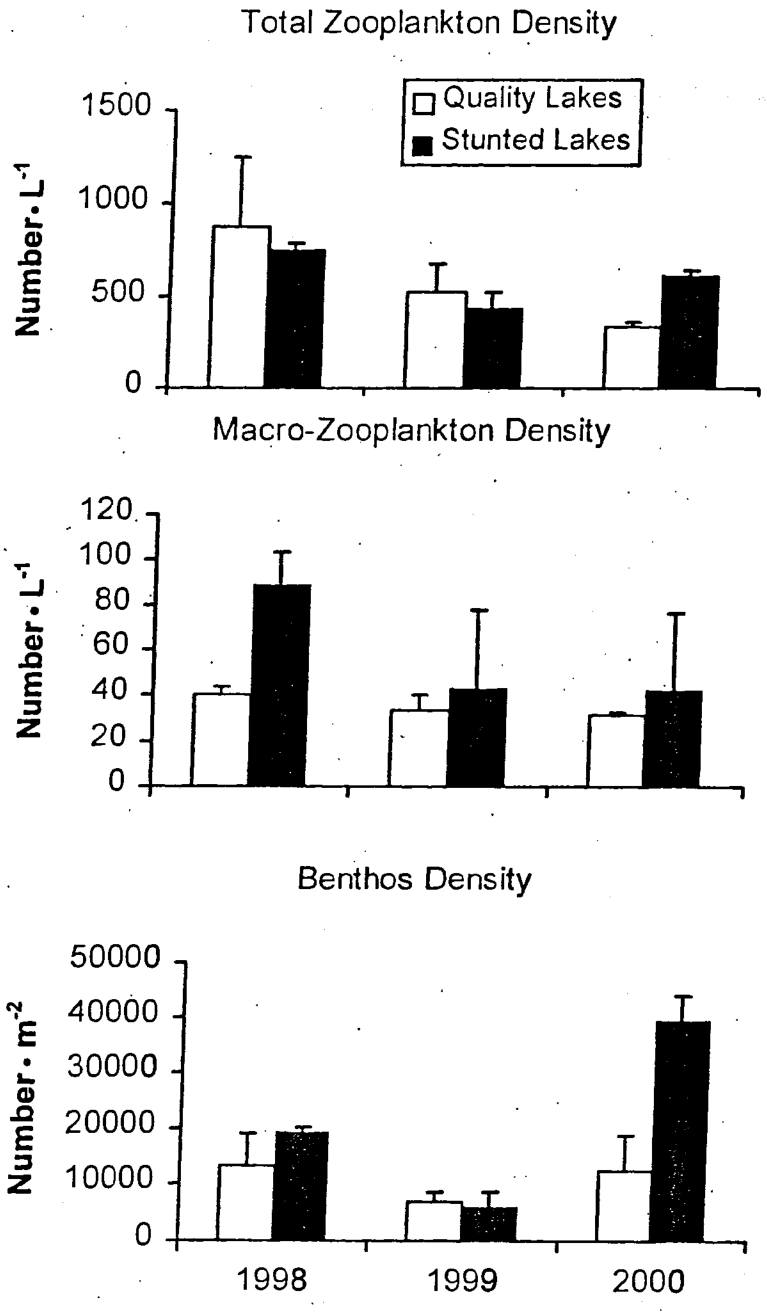


Figure 3-6. Mean zooplankton, macrozooplankton and benthos density by year in quality and stunted bluegill lakes. Bars indicate 1 SE.



Total Zooplankton Density

Macro-Zooplankton Density

Benthos Density

Figure 3-5. Comparison of length-at-age data for male bluegill collected in the initial sample (1996-1997; square symbols) and in the re-sample period (2000-2001; diamond symbols) from **Lake Sterling**, a stunted lake.

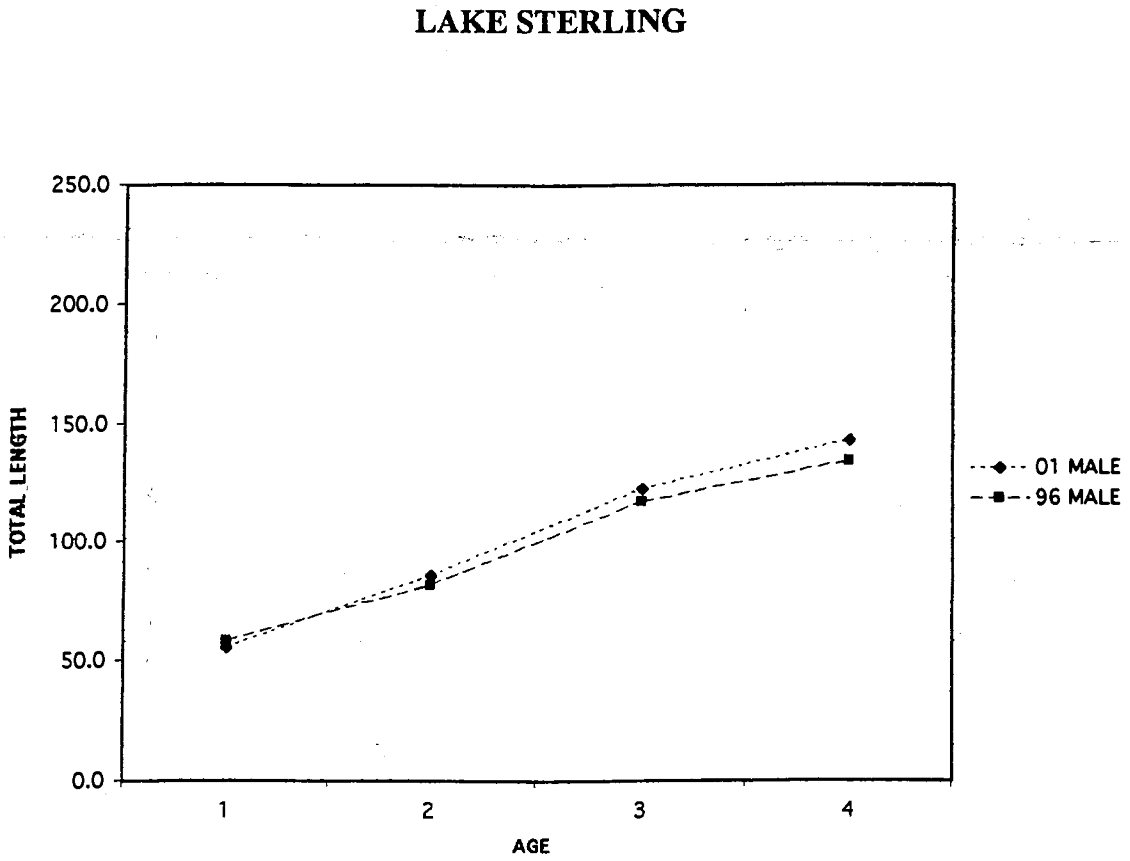


Figure 3-7. Results of the genetic vs. environment experiment showing the strong influence of the presence of large males on maturation of juvenile male bluegill. Gonadosomatic indices of juvenile males are significantly lower in treatment ponds with large, mature males present than in treatment ponds without them.

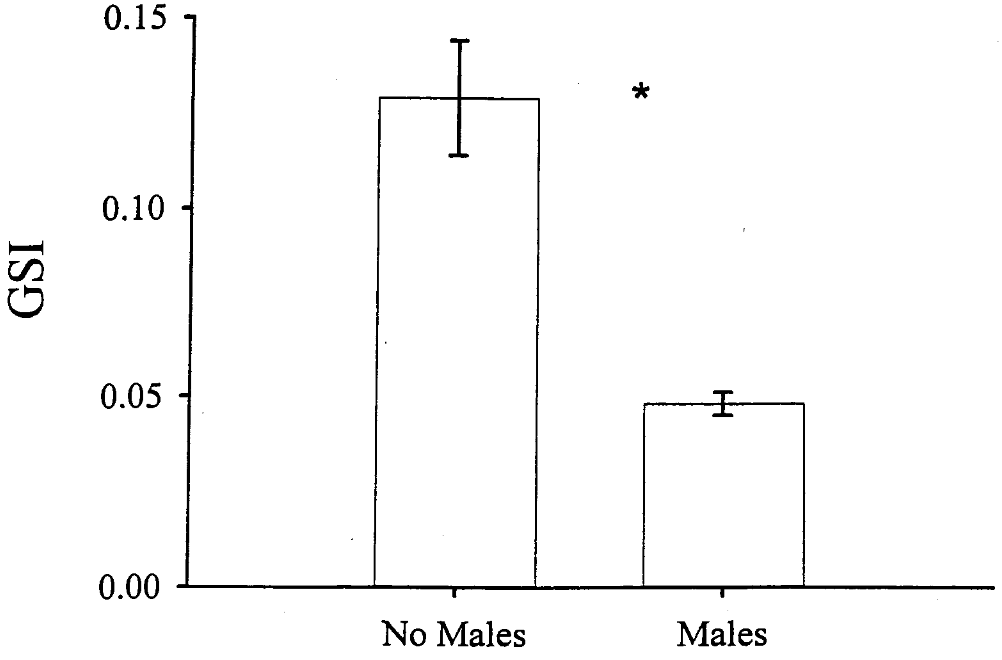
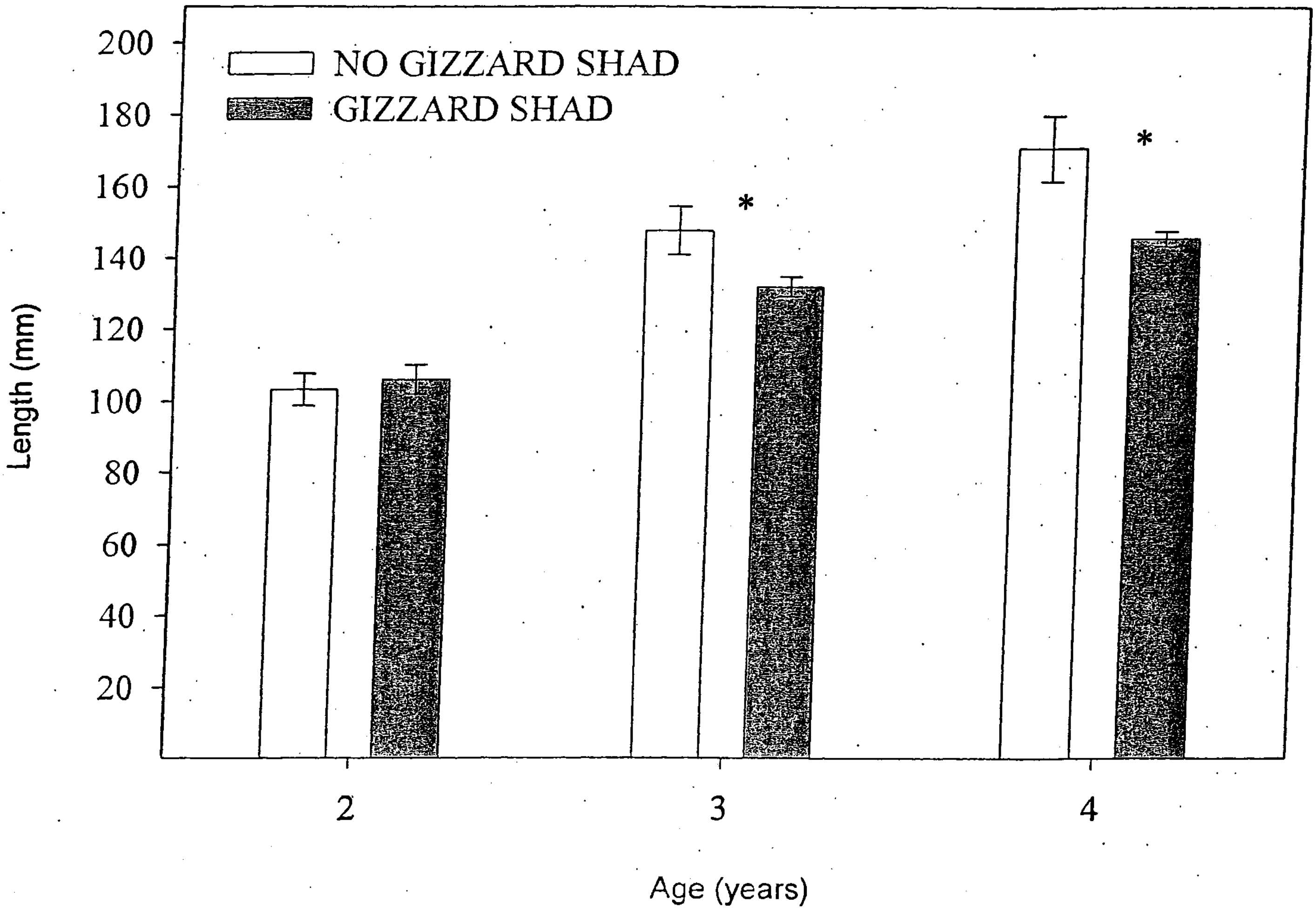
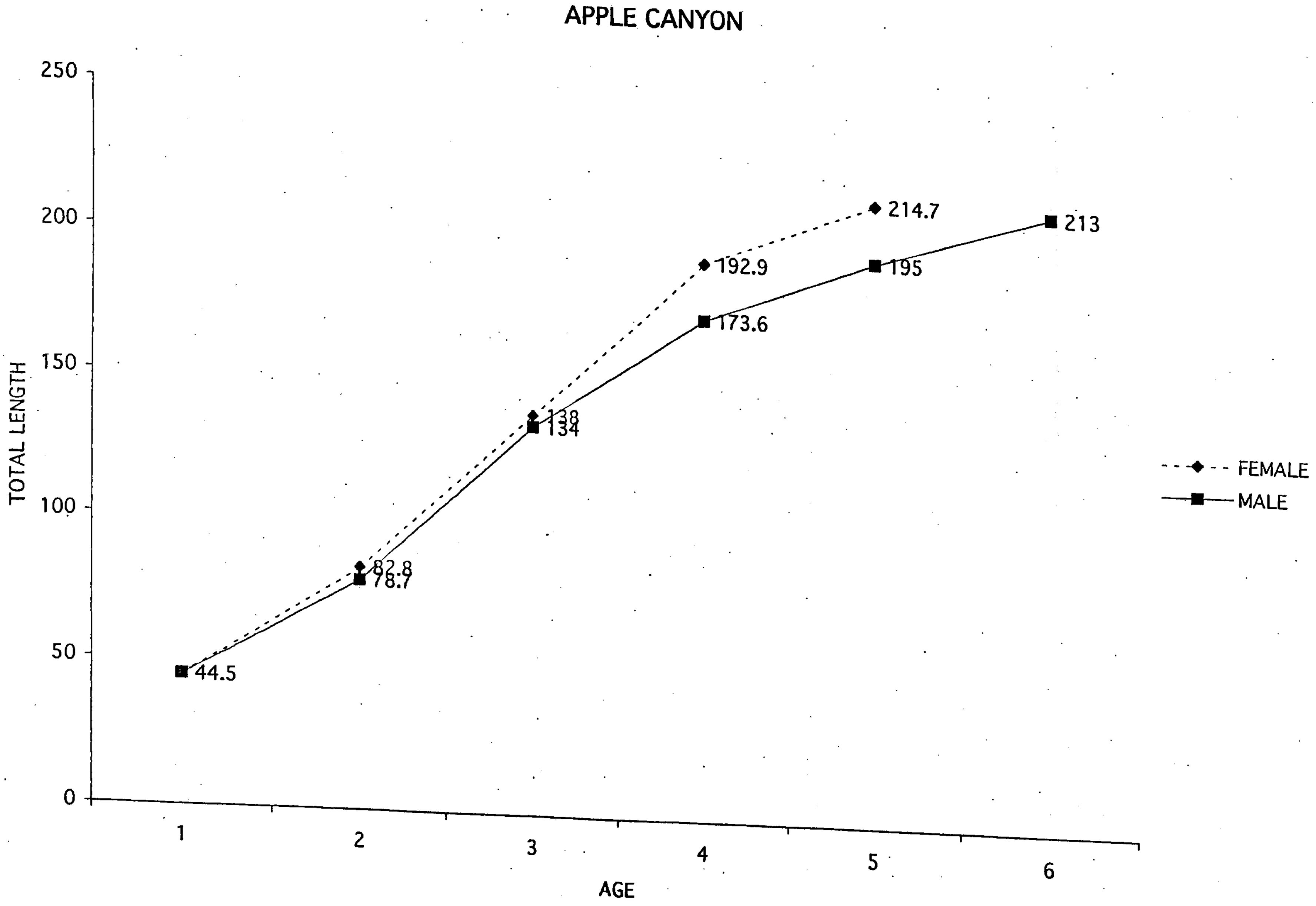


Figure 3-8. Influence of gizzard shad on adult bluegill population size structure. Populations containing gizzard shad (dark bars) contained significantly smaller bluegill than populations without gizzard shad (light bars). Asterisks indicate significant differences.

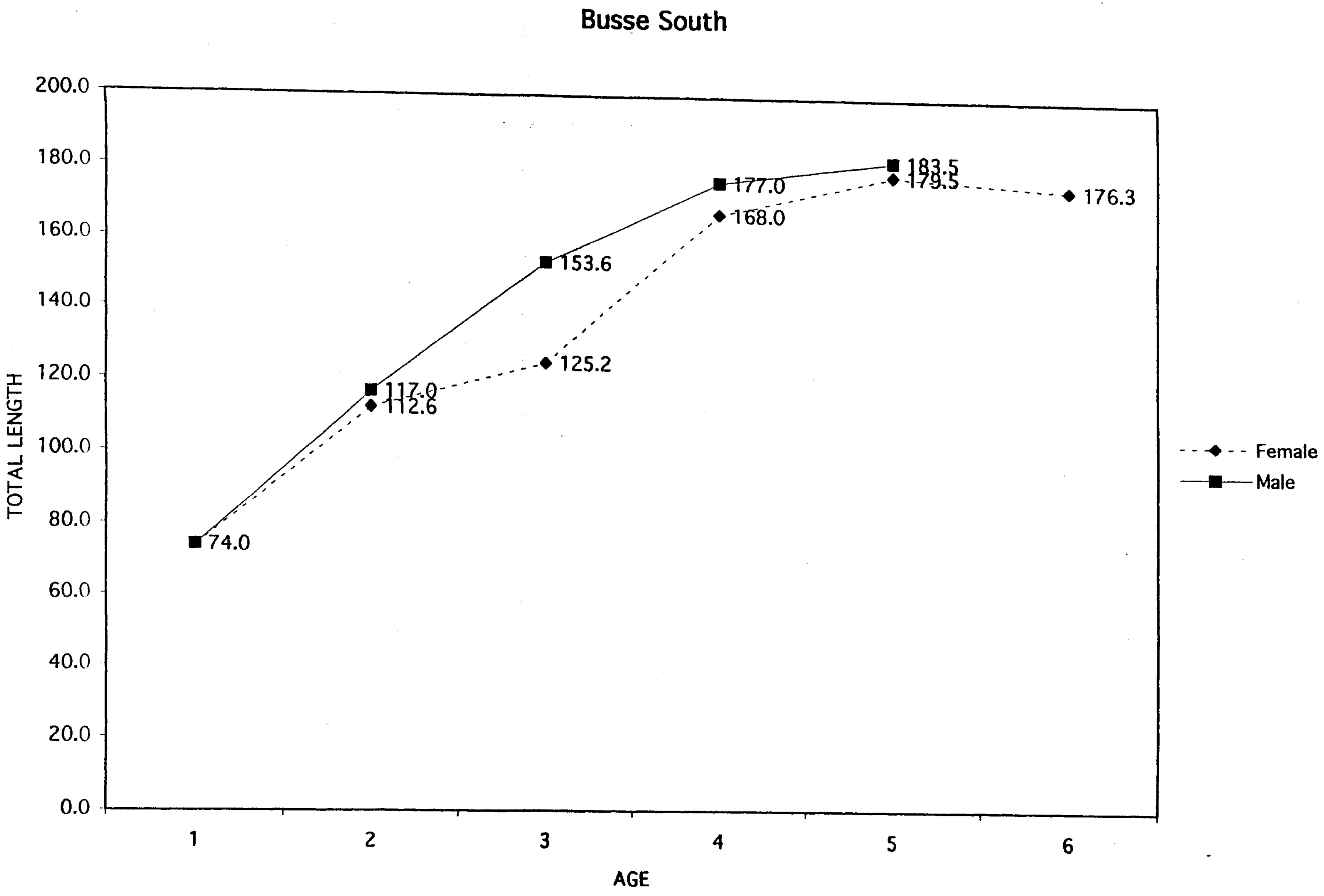


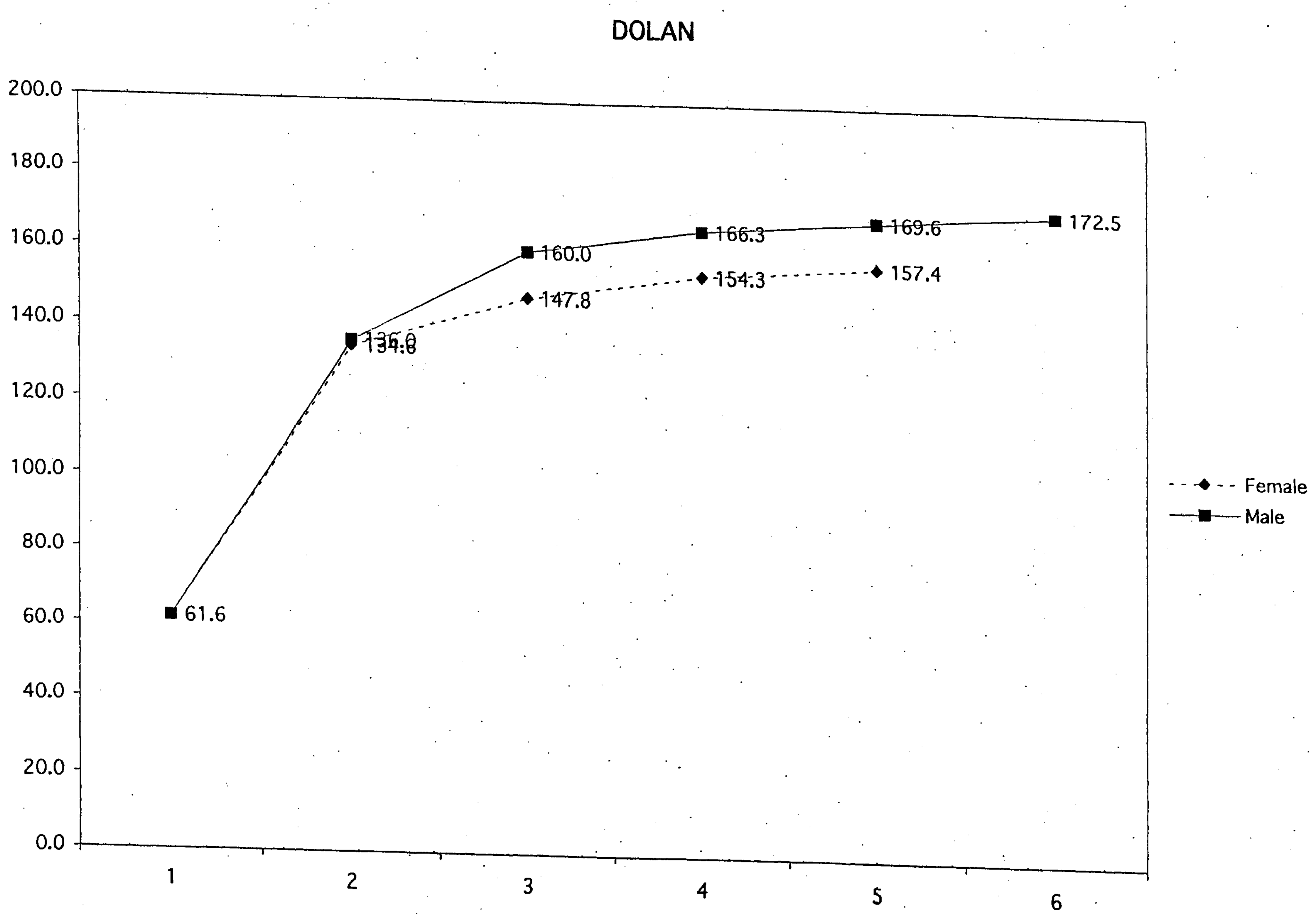

APPLE CANYON
TOTAL LENGTH
250
200
150
100
50
0
AGE
1
2
3
4
5
6
44.5
82.8
78.7
138
134
192.9
173.6
214.7
195
213
FEMALE
MALE

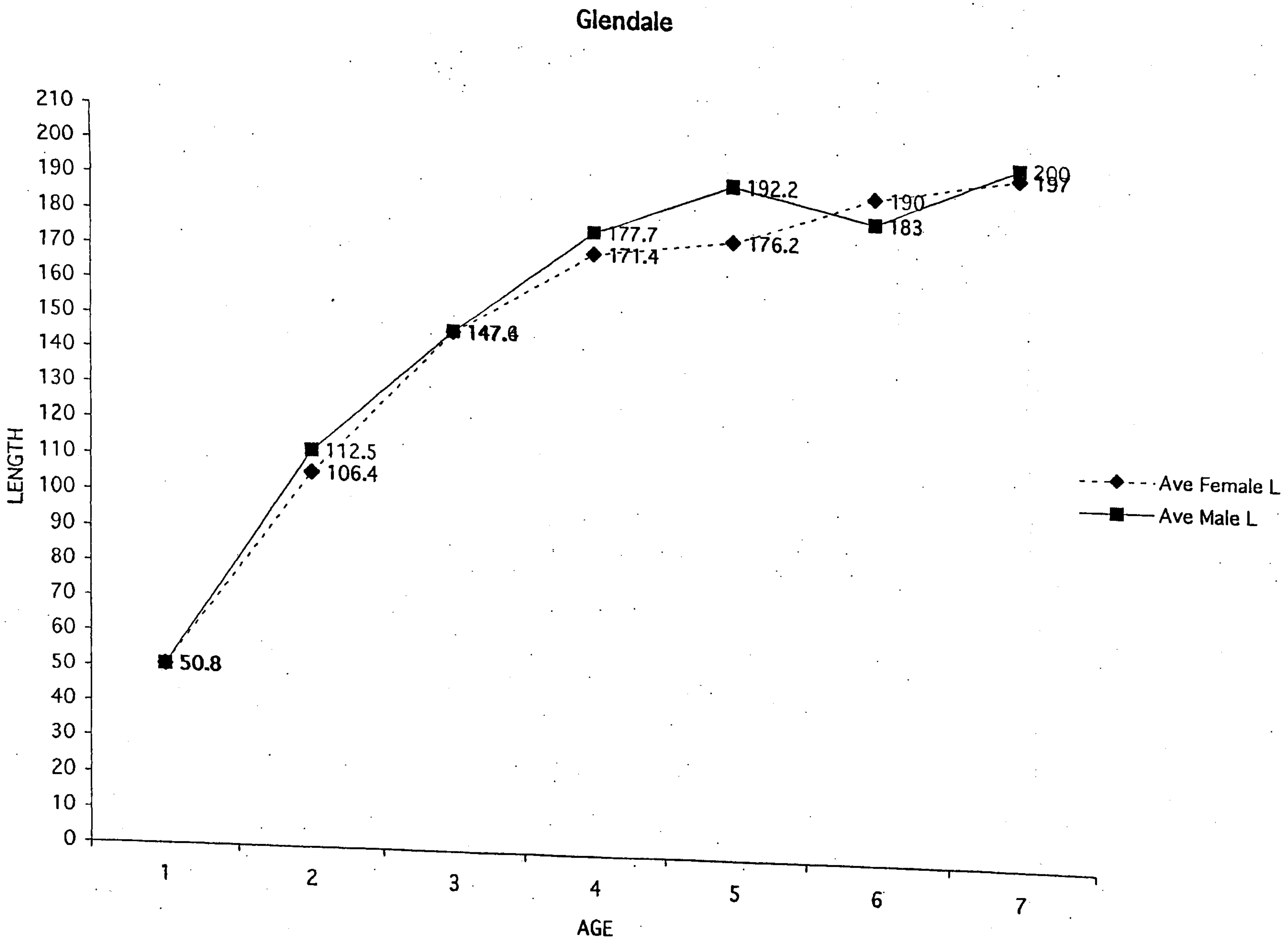
Appendix A.

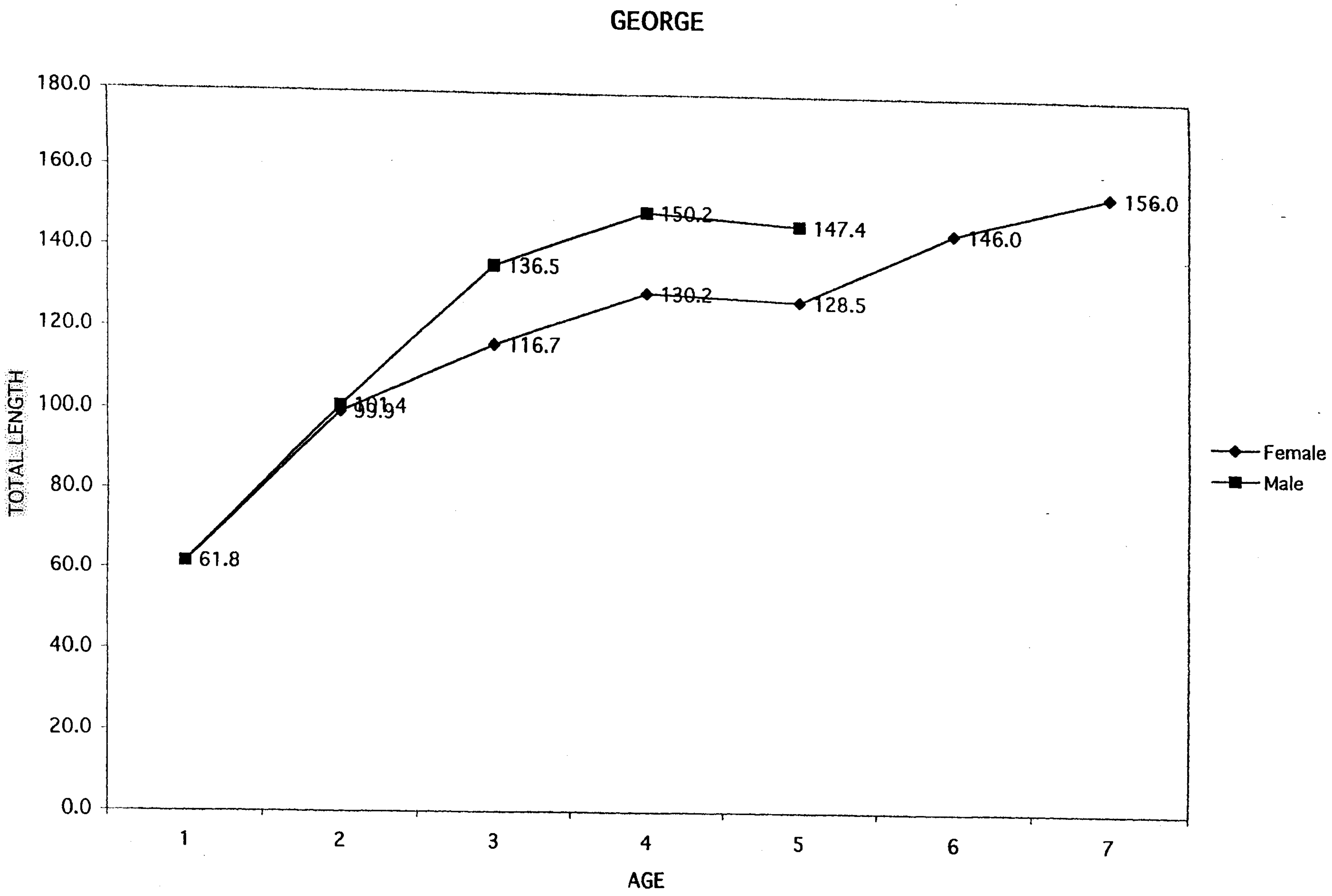
Examples of age and growth graphs that have been completed for each of the study lakes. Average size is given in each graph for each age for both males and females.

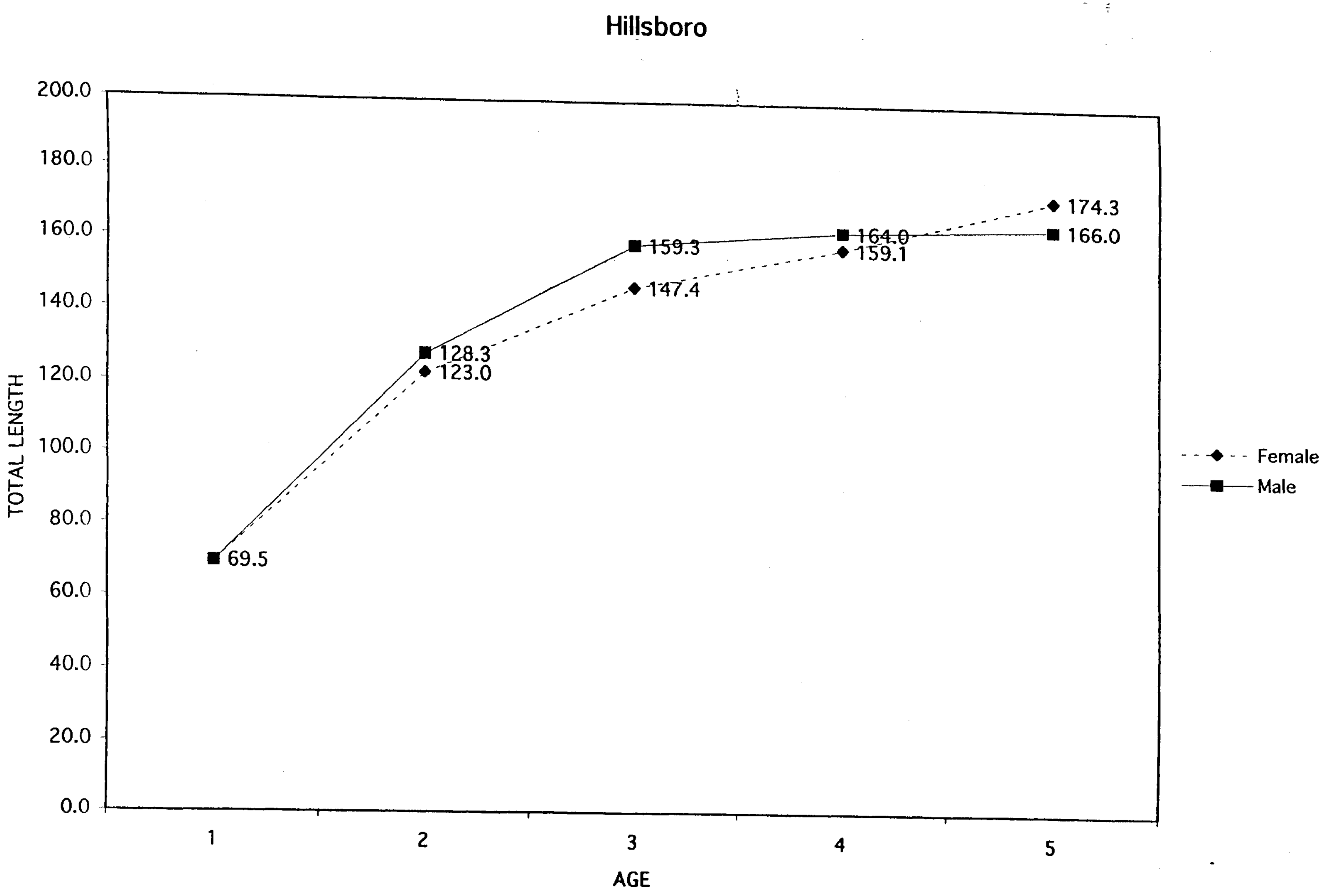
LAKE NAME
Apple Canyon
Busse South
Dolan
George
Glendale
Hillsboro
Jacksonville
Le Aqua Na
Lincoln Trail
Mermet
North Spring Lake
Pana
Paris
Round
Sam Parr
Shabbona
Sterling
Walnut Point
Walton Prk
Woods


Busse South
TOTAL LENGTH
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1
2
3
4
5
6
AGE
74.0
117.0
112.6
153.6
125.2
177.0
168.0
183.5
179.5
176.3
Female
Male

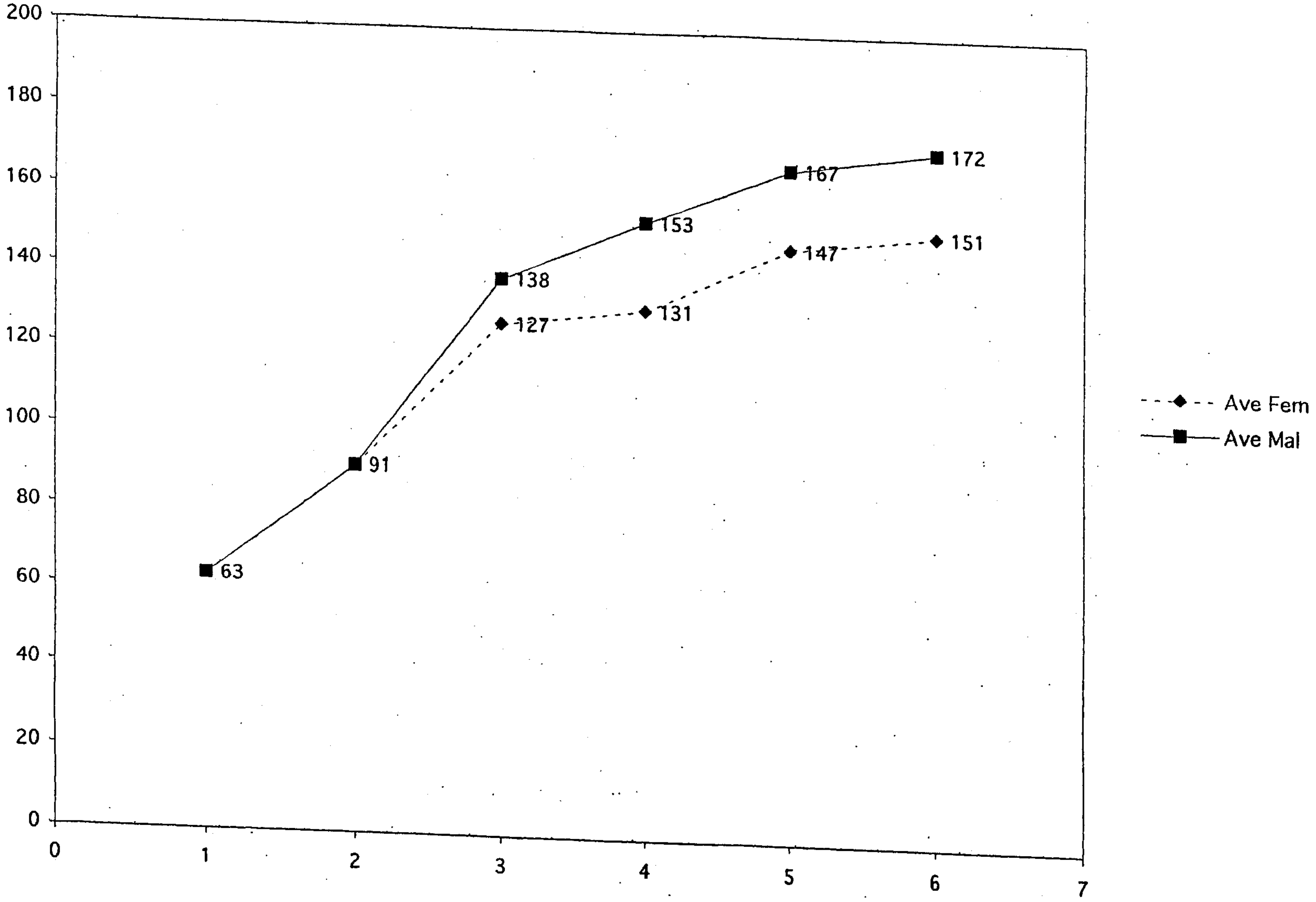
DOLAN
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1
2
3
4
5
6
61.6
136.0
134.8
160.0
147.8
166.3
154.3
169.6
157.4
172.5
Female
Male


Glendale
LENGTH
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
AGE
1
2
3
4
5
6
7
50.8
112.5
106.4
147.6
177.7
171.4
192.2
176.2
190
183
200
197
Ave Female L
Ave Male L

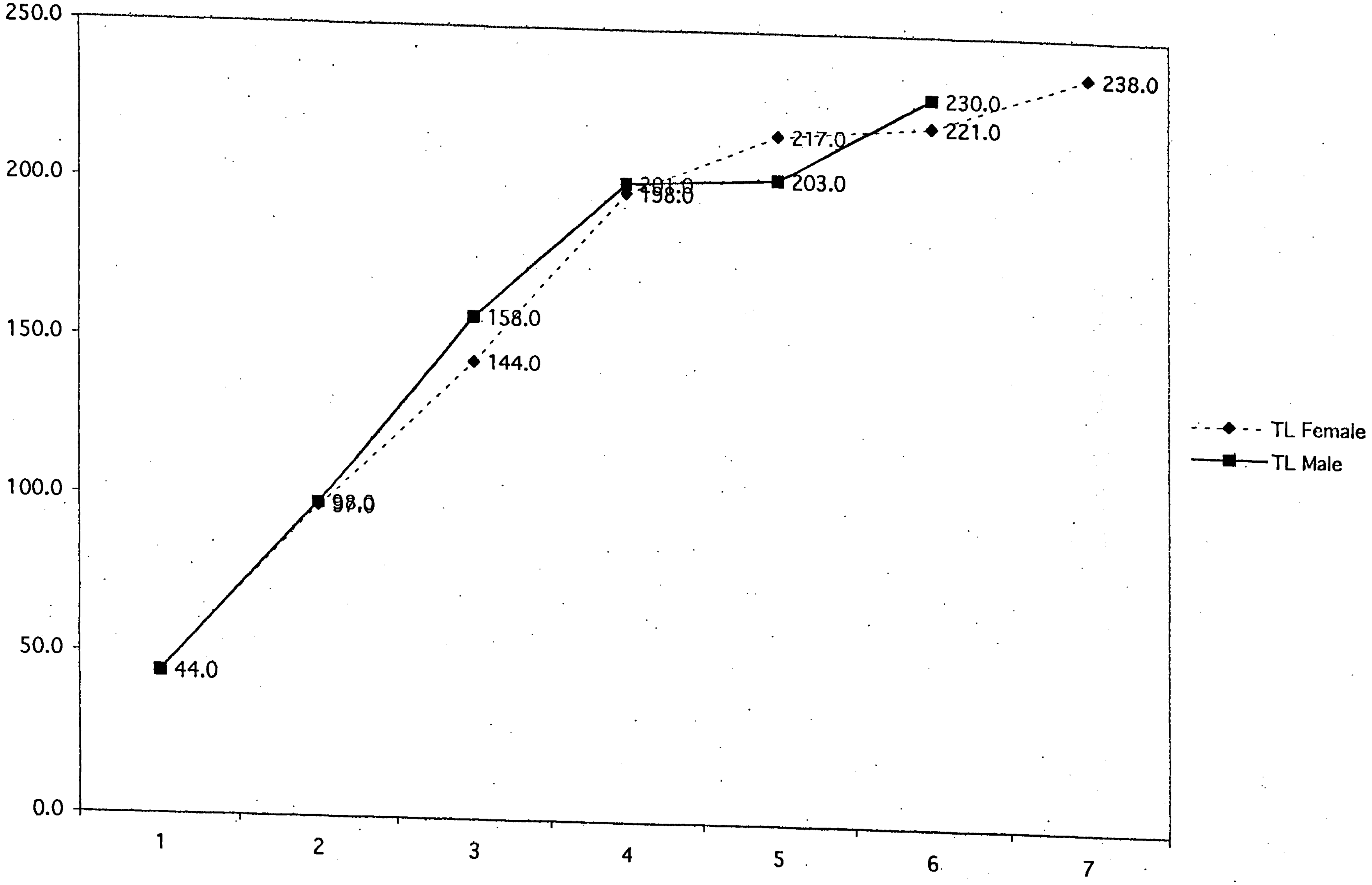

GEORGE
TOTAL LENGTH
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
AGE
1
2
3
4
5
6
7
61.8
101.4
99.9
136.5
116.7
150.2
130.2
147.4
128.5
146.0
156.0
Female
Male

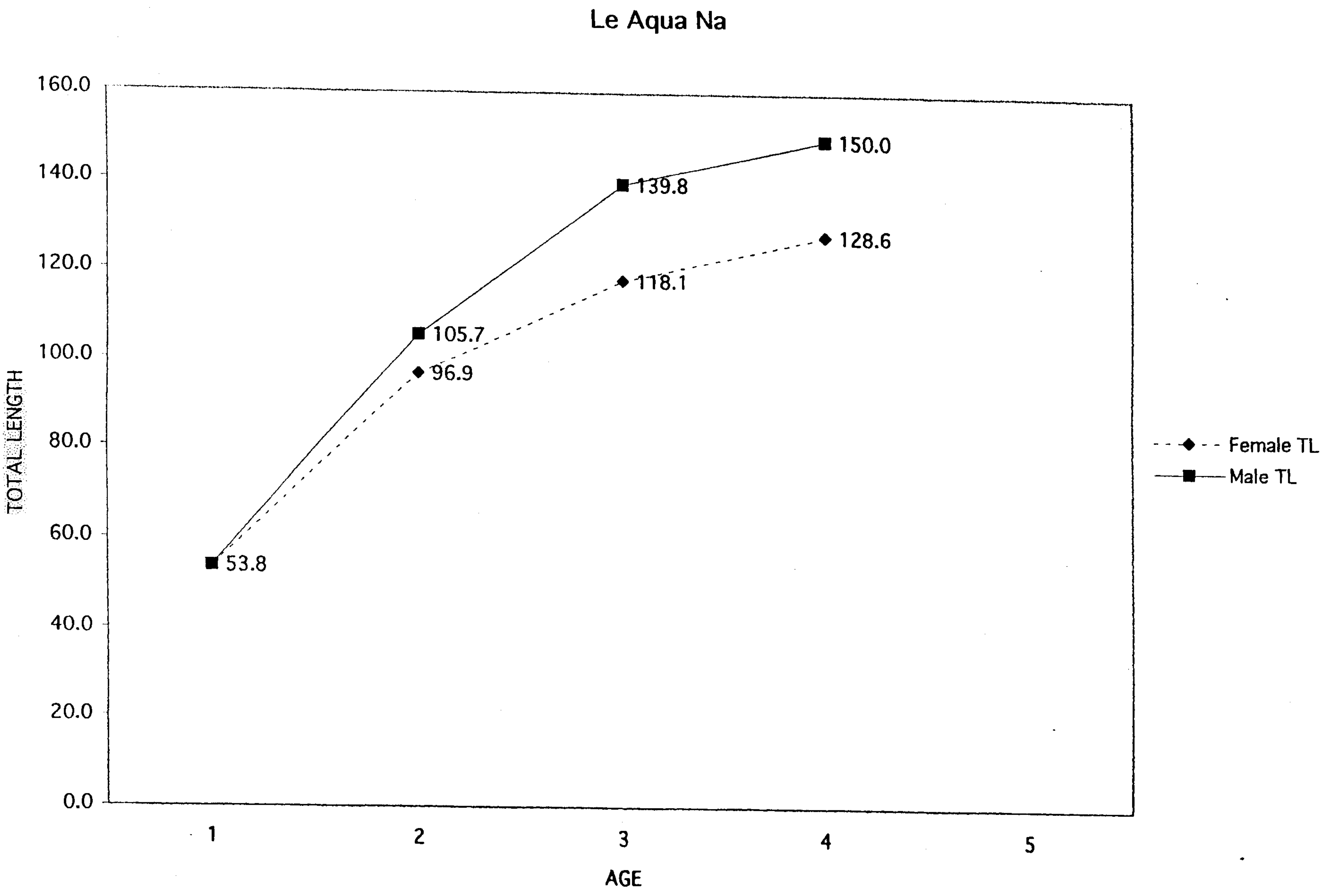

Hillsboro
TOTAL LENGTH
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
AGE
1
2
3
4
5
69.5
128.3
123.0
159.3
147.4
164.0
159.1
174.3
166.0
Female
Male

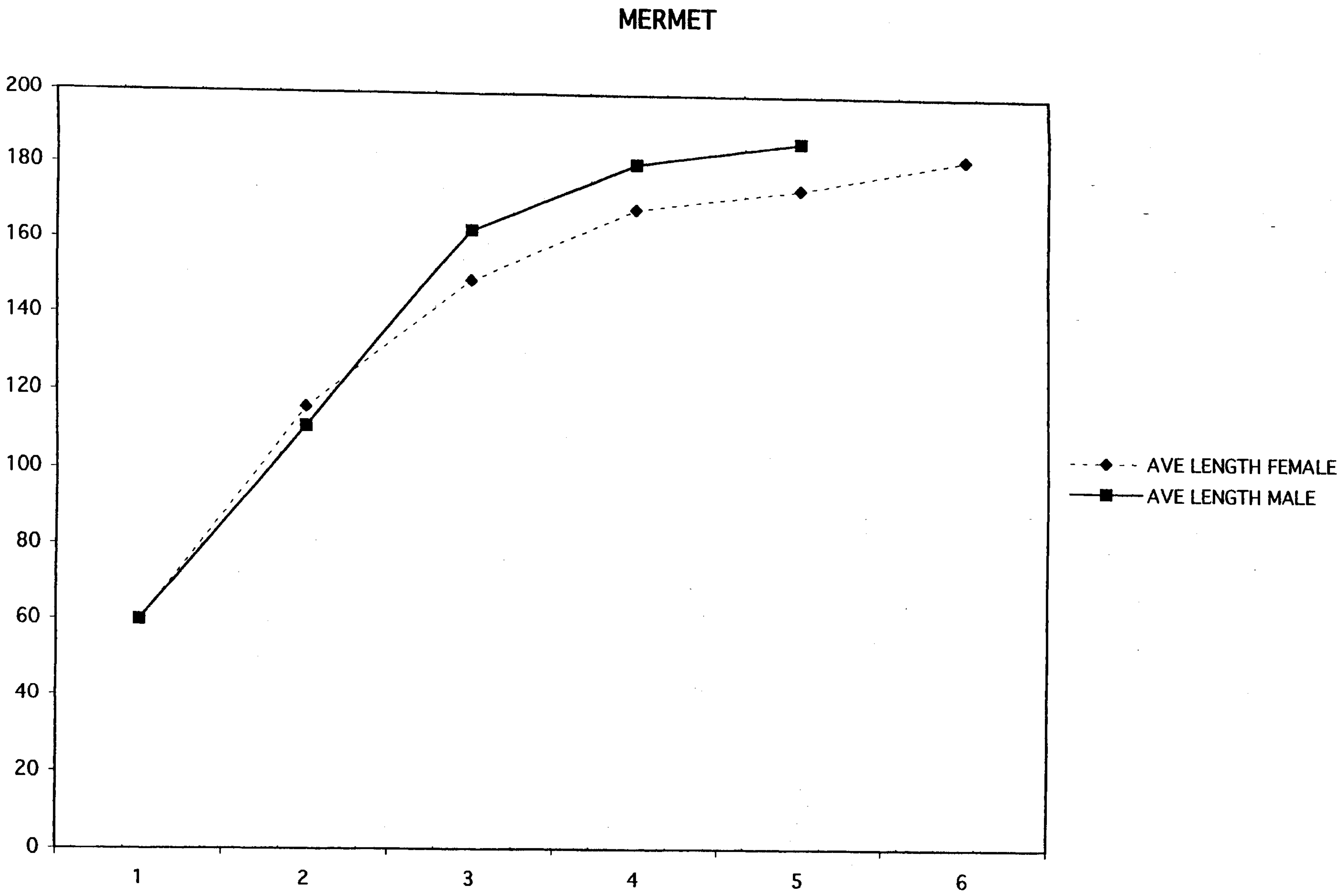
JACKSONVILLE



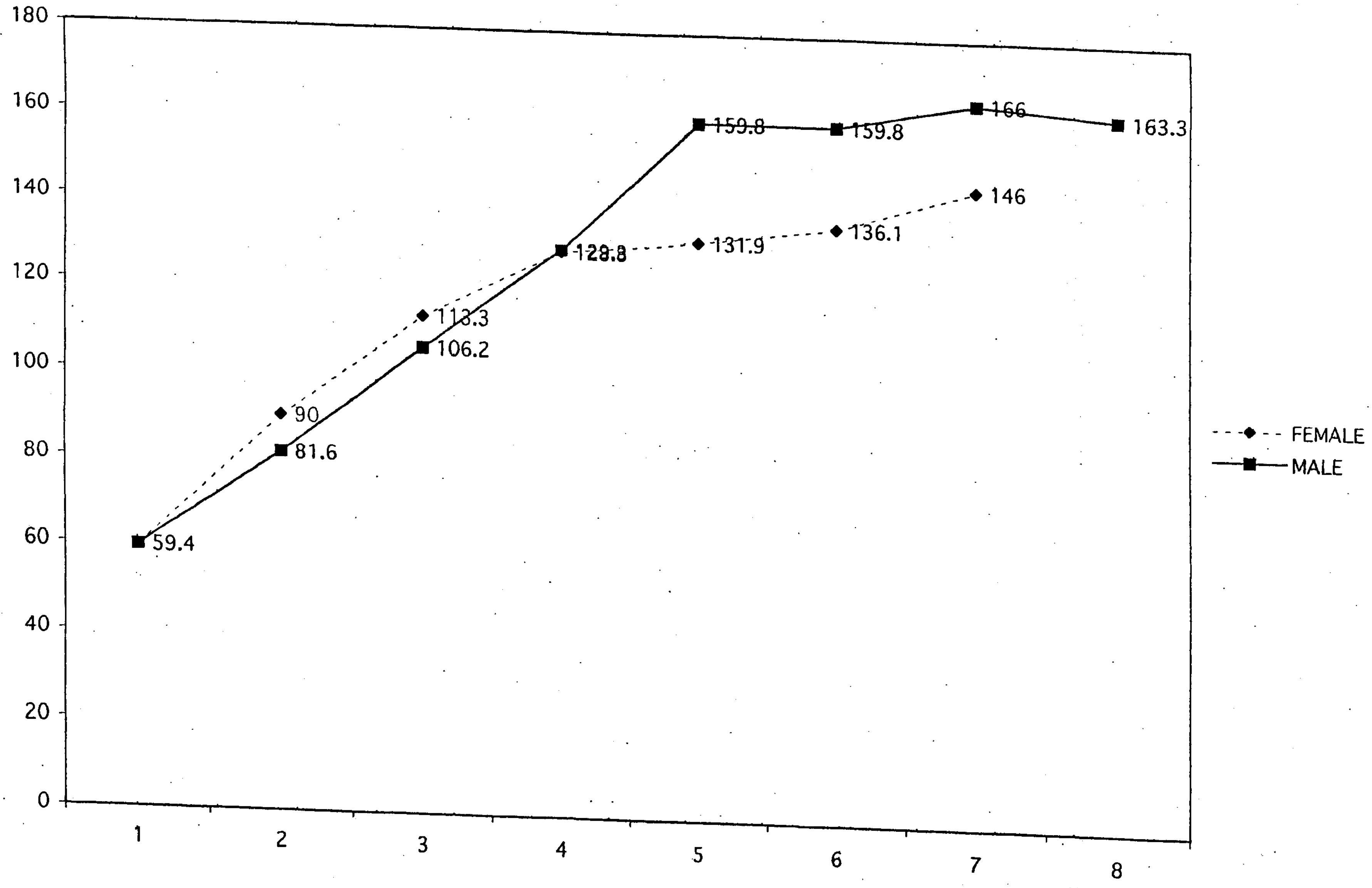
LINCOLN TRAIL



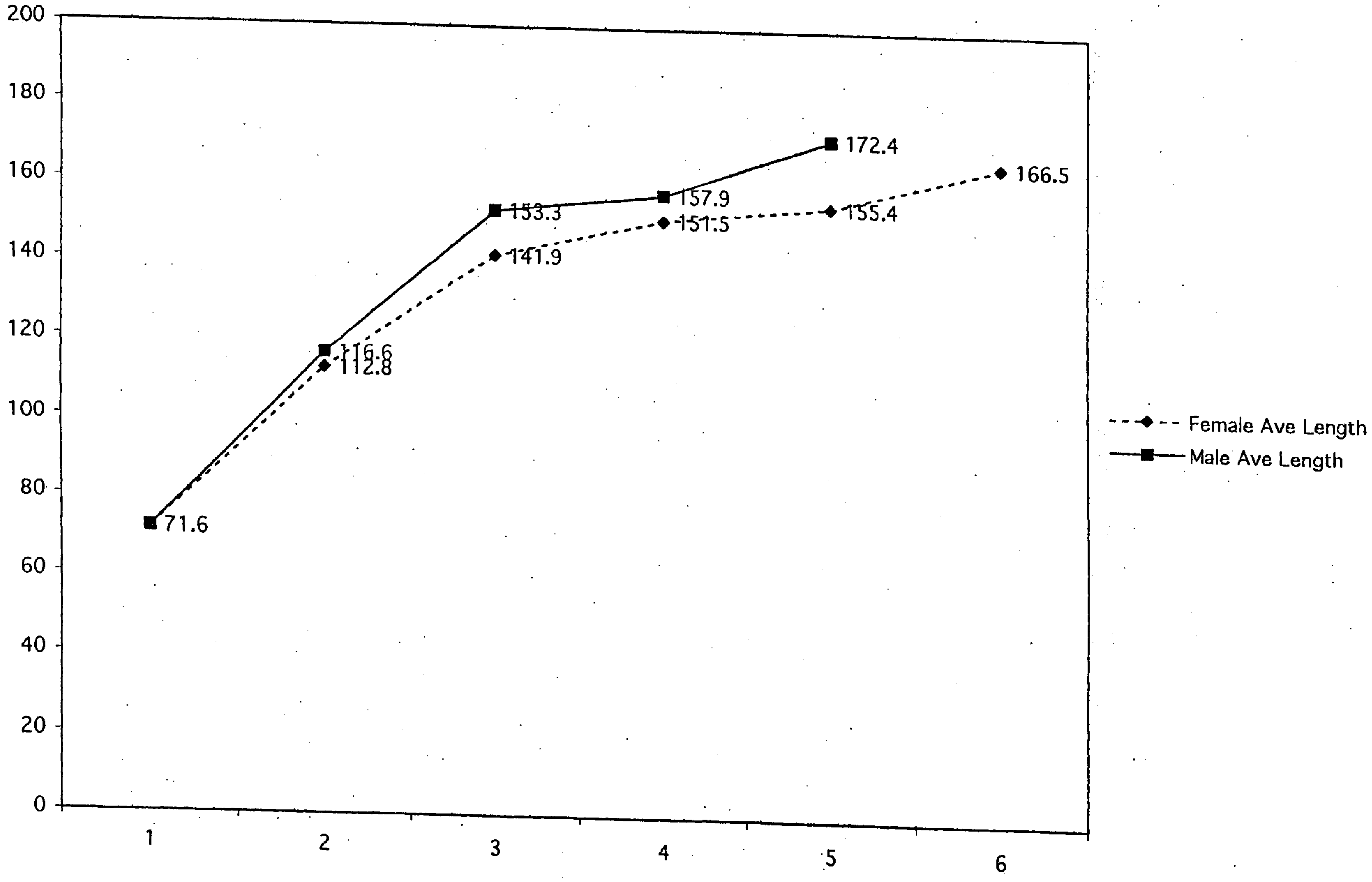

Le Aqua Na
TOTAL LENGTH
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1
2
3
4
5
AGE
53.8
105.7
96.9
139.8
118.1
150.0
128.6
Female TL
Male TL


MERMET
200
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
AVE LENGTH FEMALE
AVE LENGTH MALE

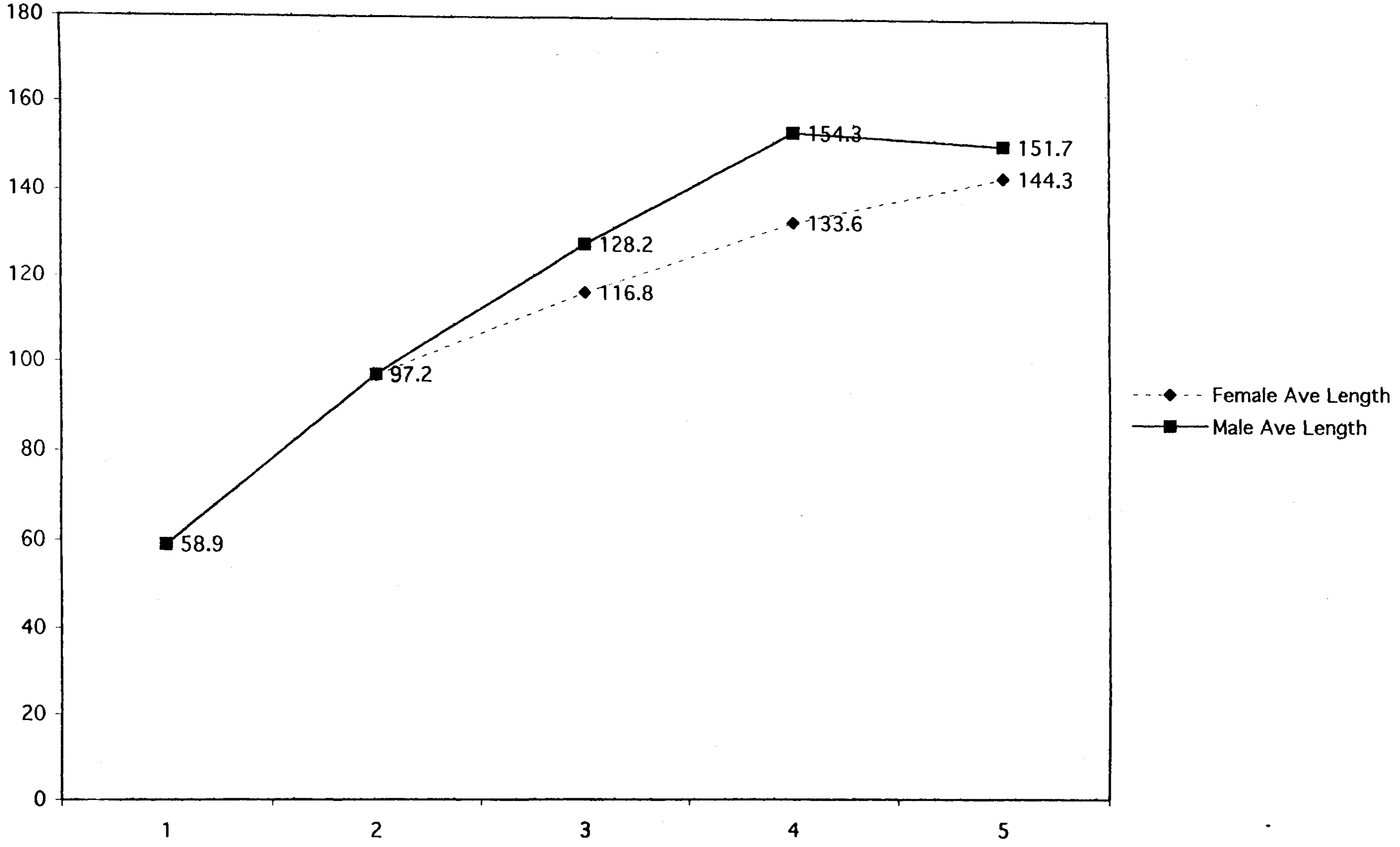
NORTH SPRING LAKE



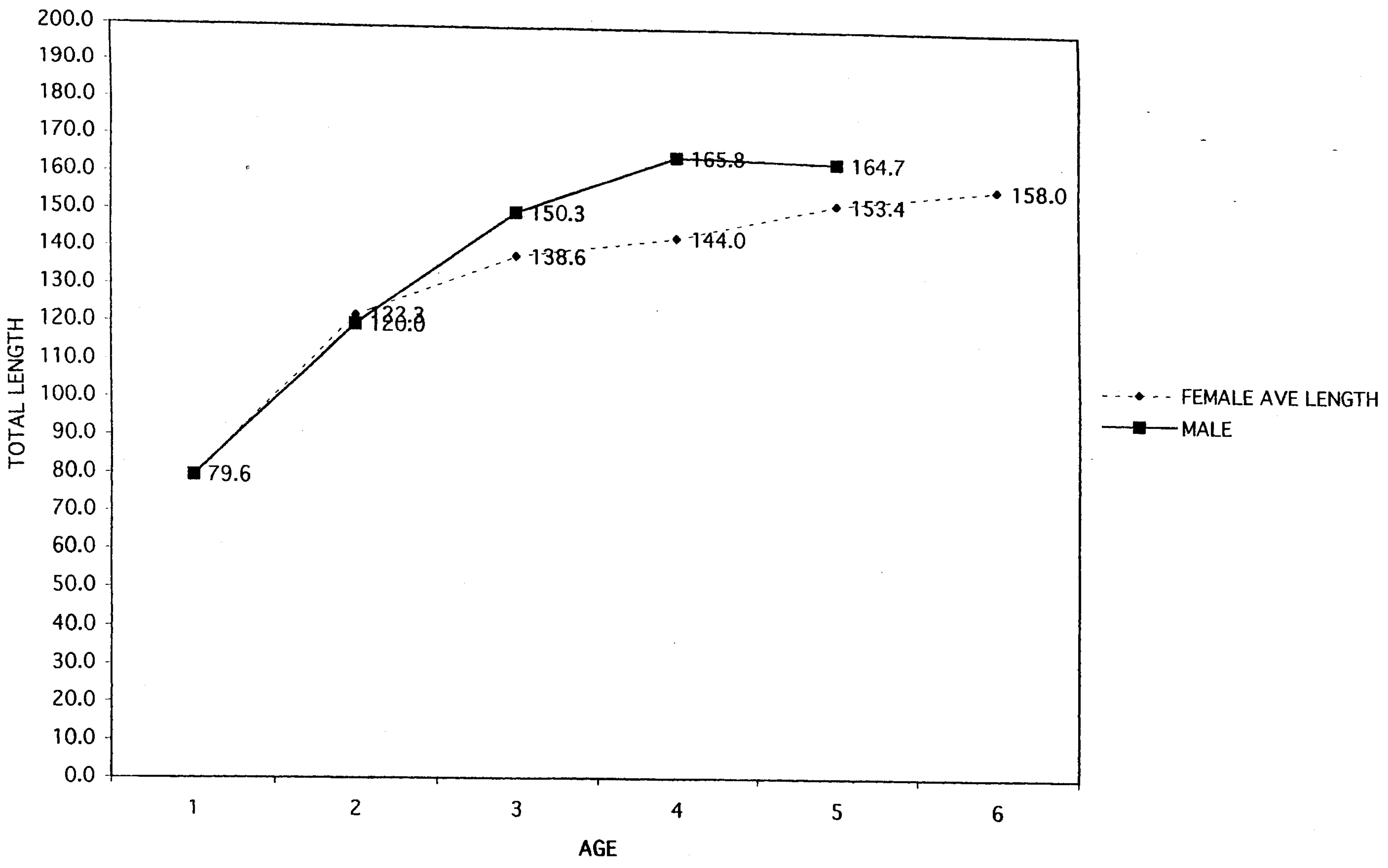
PARIS


200
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
71.6
116.6
112.8
153.3
141.9
157.9
151.5
172.4
155.4
166.5
Female Ave Length
Male Ave Length

PANA

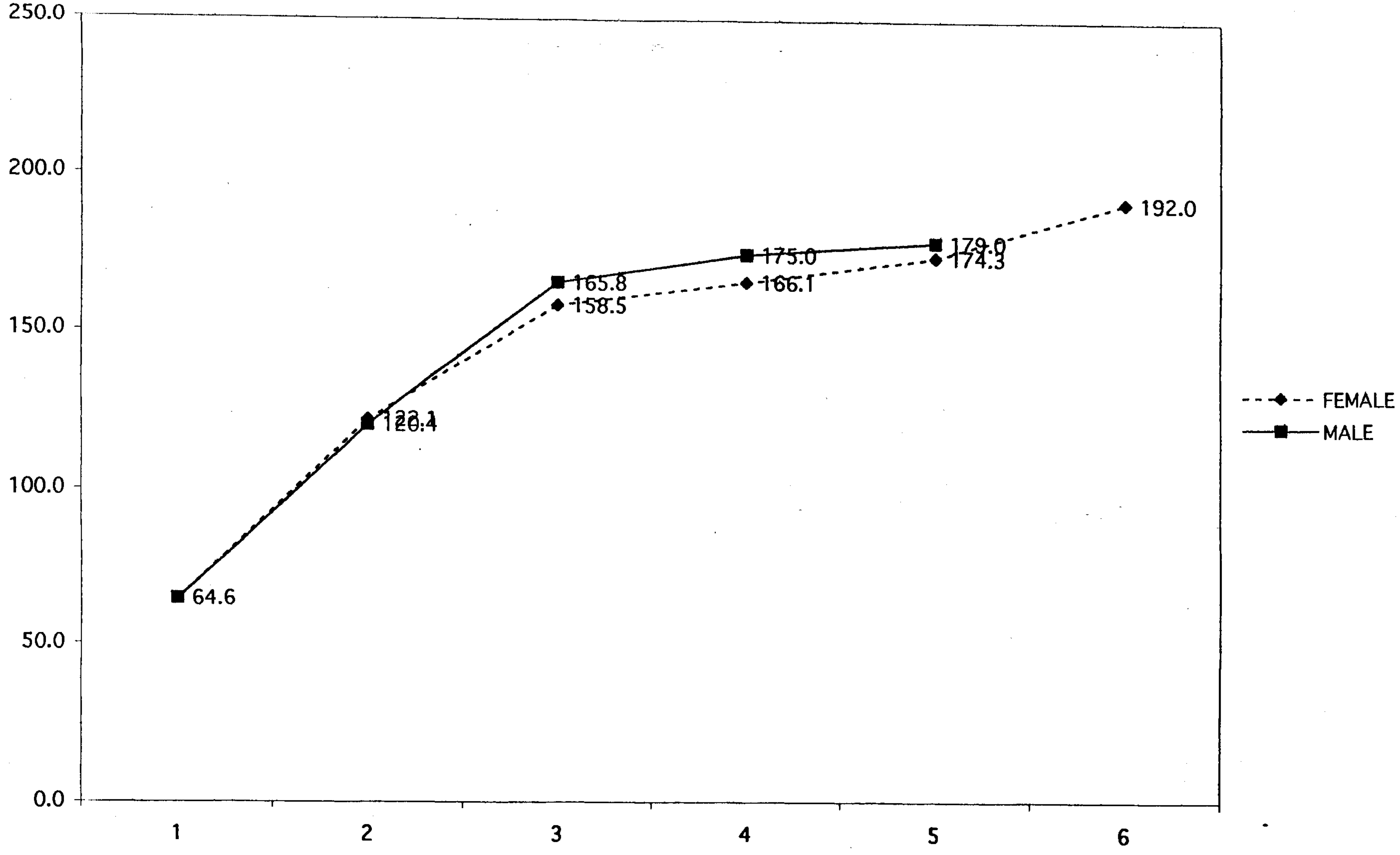

180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
58.9
97.2
128.2
116.8
154.3
133.6
151.7
144.3
Female Ave Length
Male Ave Length

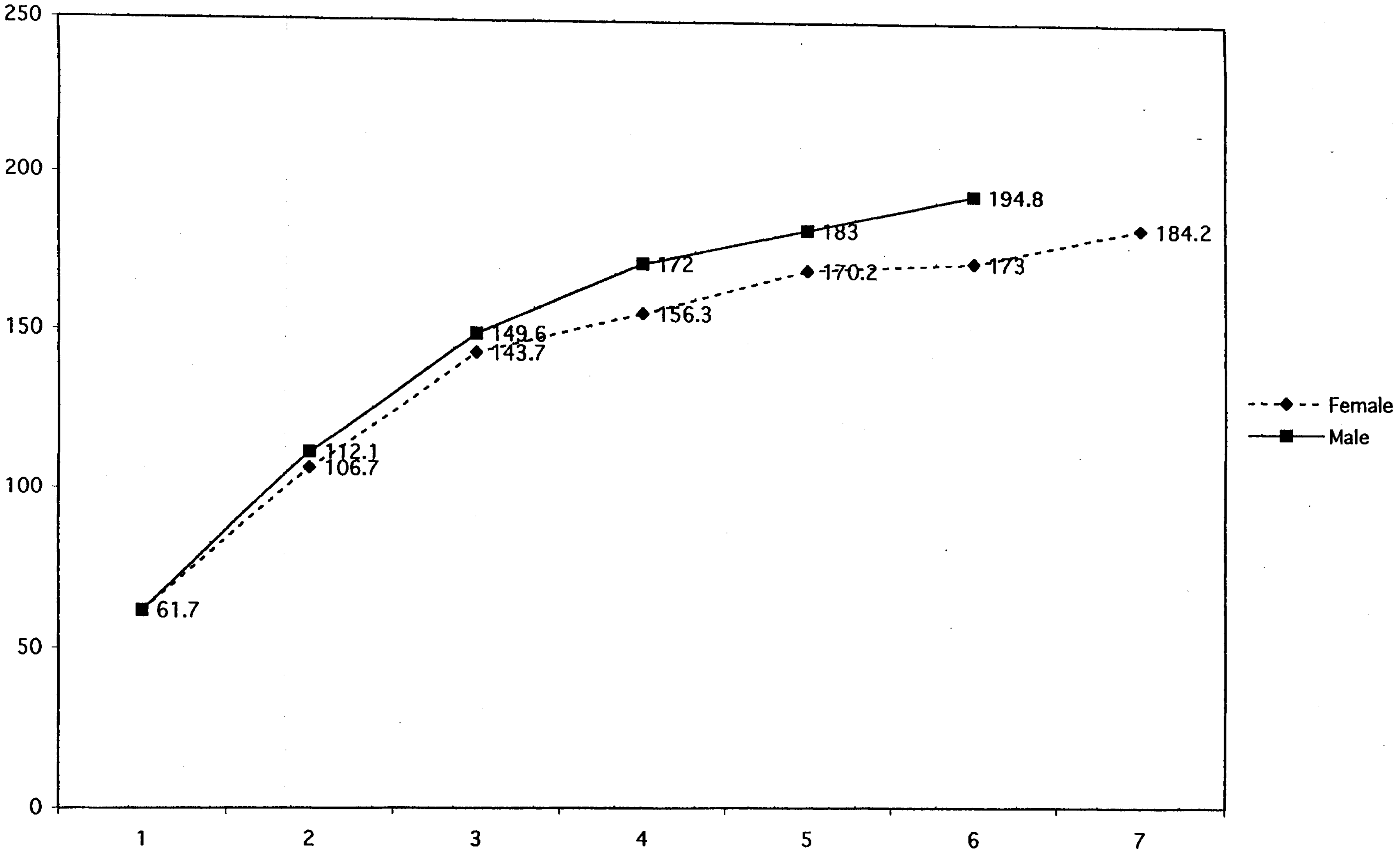
Round



TOTAL LENGTH
200.0
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1
2
3
4
5
6
AGE
79.6
122.3
120.0
138.6
150.3
144.0
165.8
153.4
164.7
158.0
FEMALE AVE LENGTH
MALE

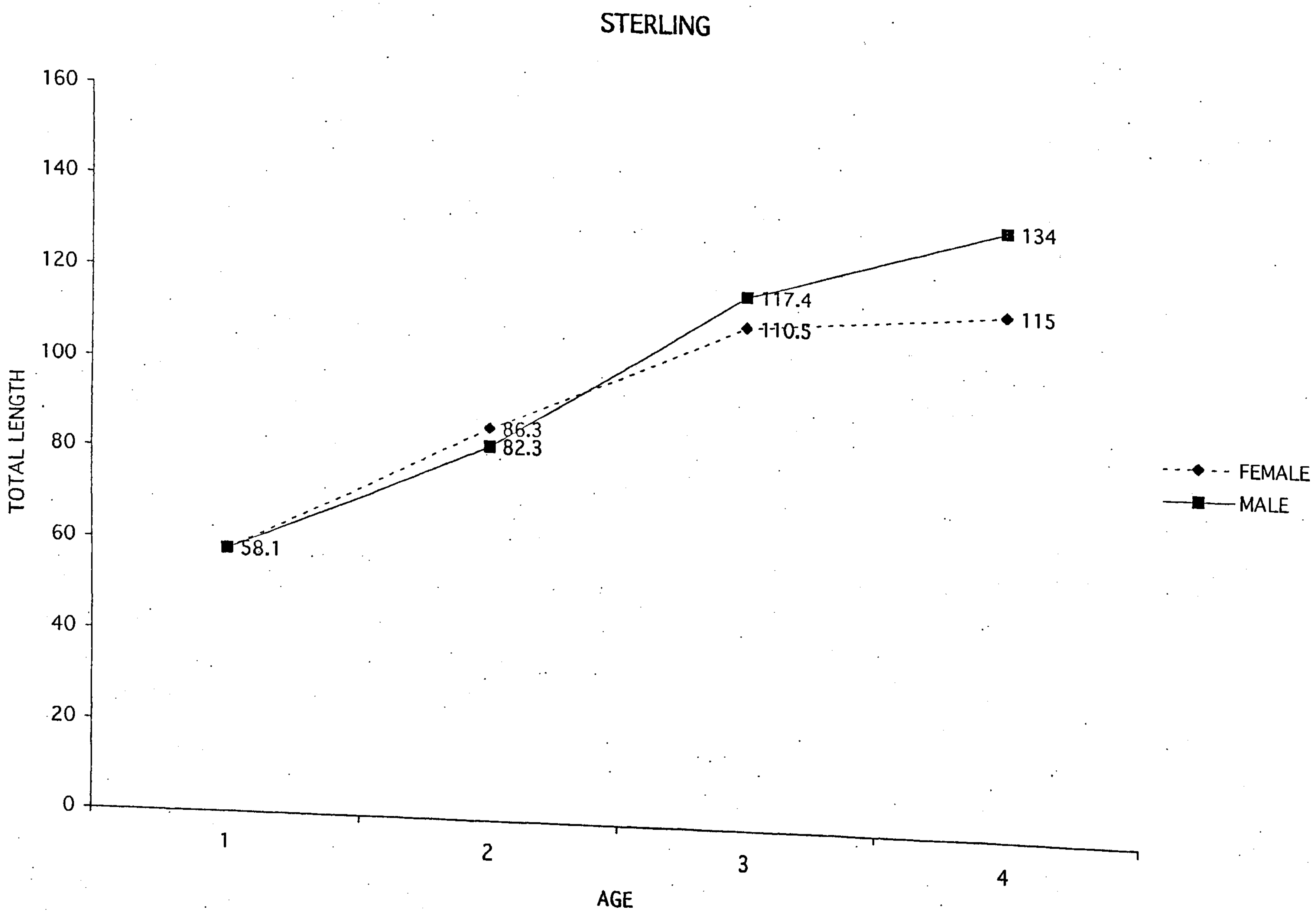
SAM PARR

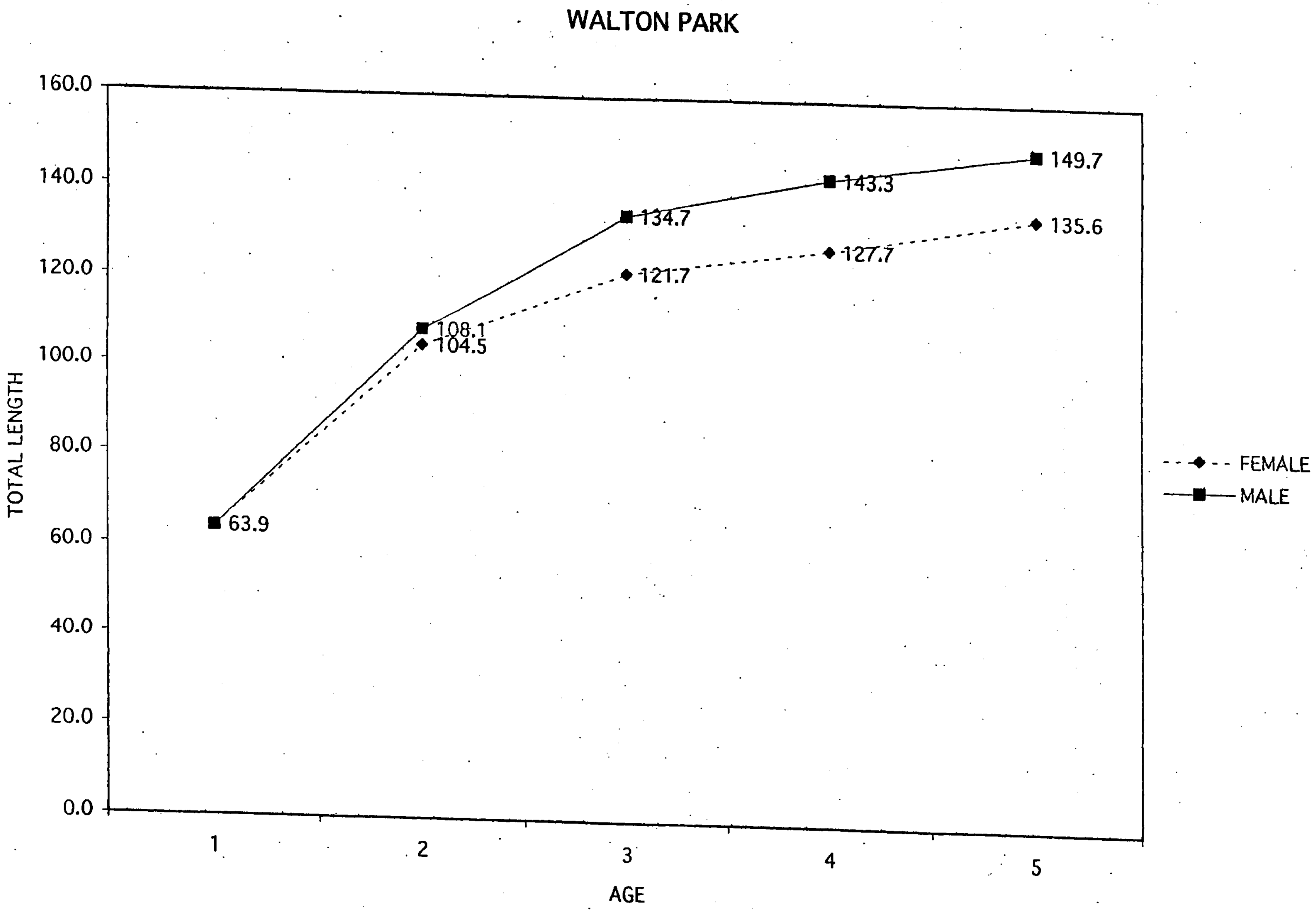

250.0
200.0
150.0
100.0
50.0
0.0
1
2
3
4
5
6
64.6
122.1
120.4
165.8
158.5
175.0
166.1
179.0
174.3
192.0
FEMALE
MALE



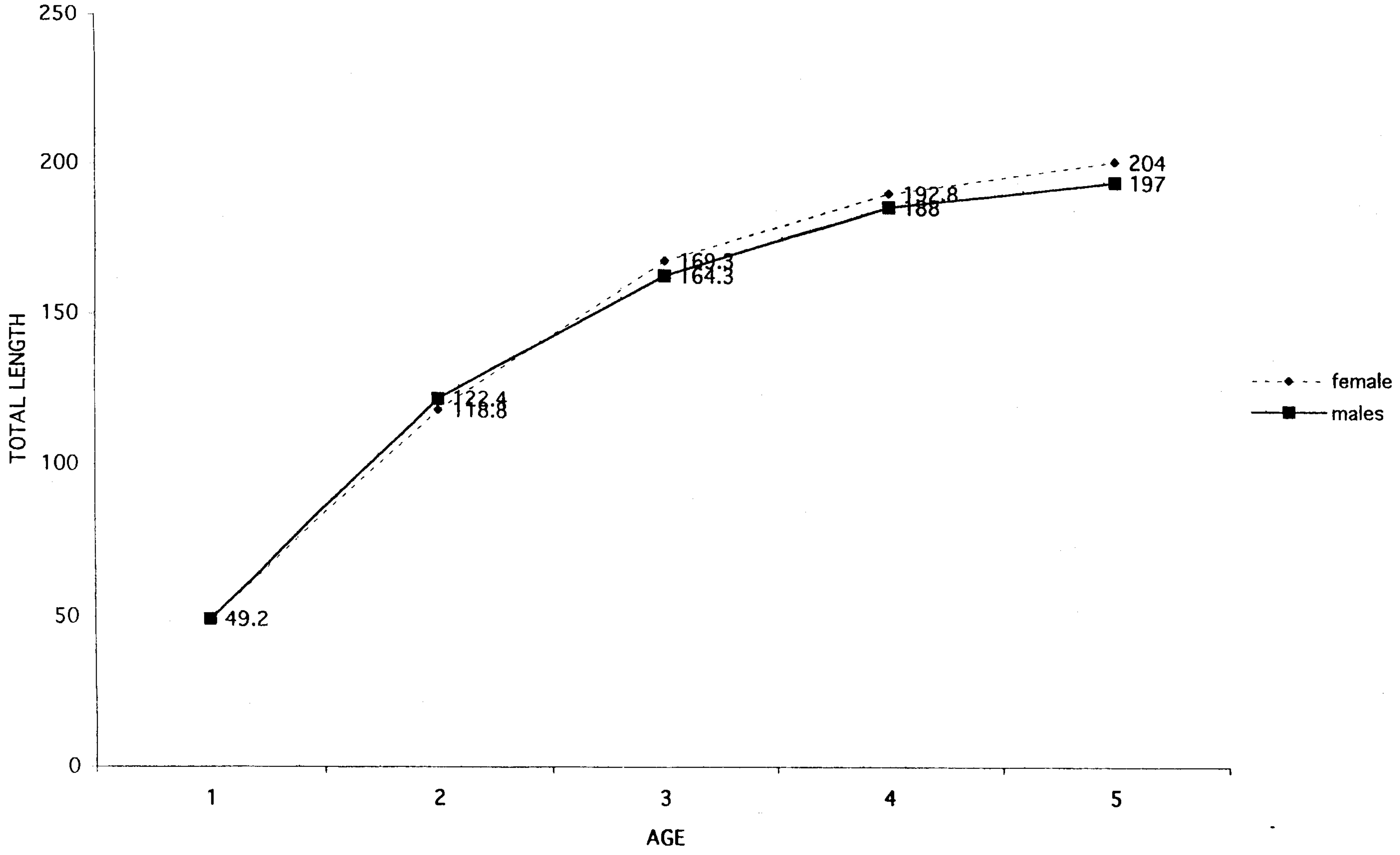
SHABBONA

250
200
150
100
50
0
1
2
3
4
5
6
7
61.7
112.1
106.7
149.6
143.7
172
156.3
183
170.2
194.8
173
184.2
Female
Male

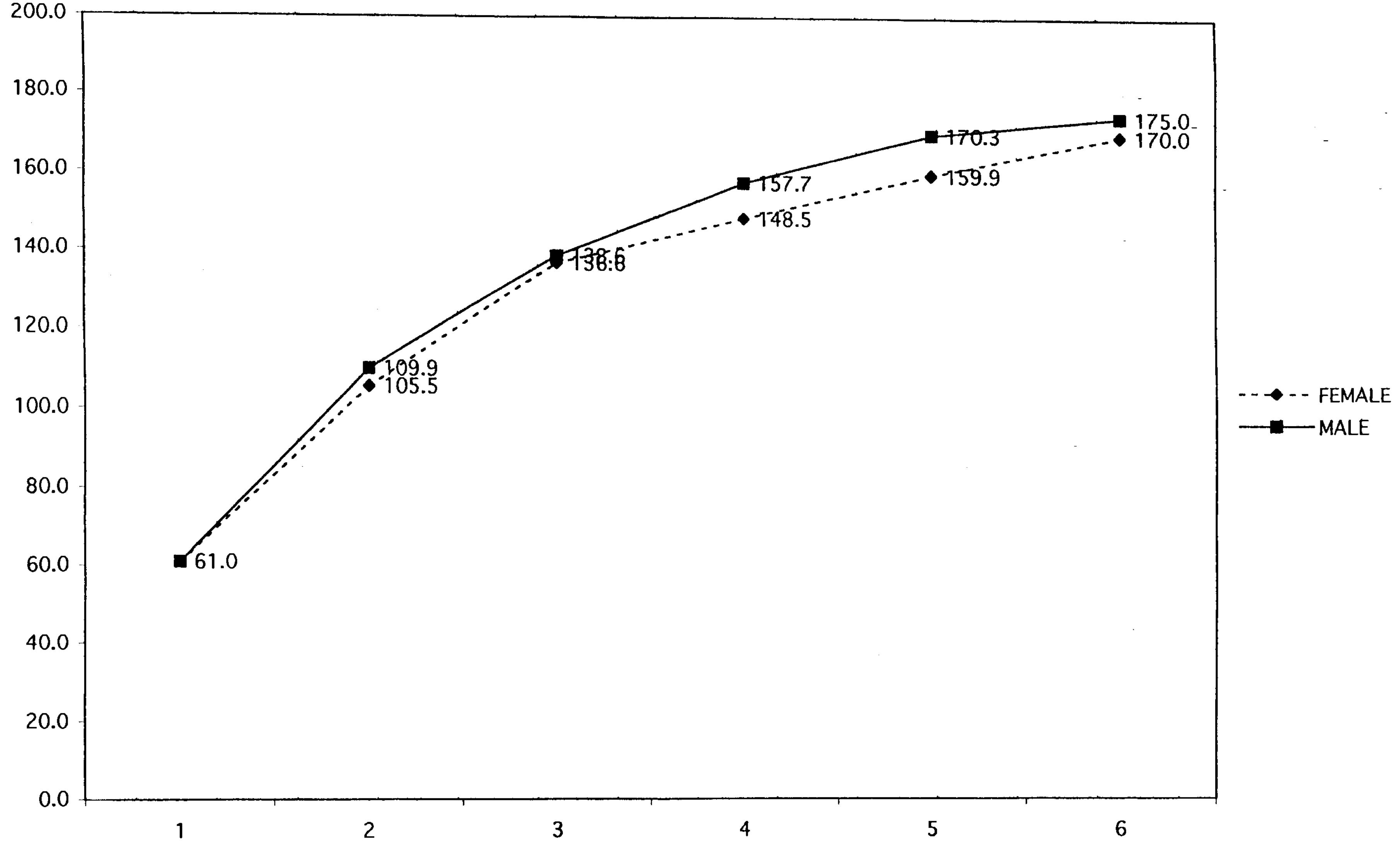

STERLING
TOTAL LENGTH
160
140
120
100
80
60
40
20
0
1
2
3
4
AGE
58.1
86.3
82.3
117.4
110.5
134
115
FEMALE
MALE


WALTON PARK
TOTAL LENGTH
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
AGE
1
2
3
4
5
63.9
108.1
104.5
134.7
121.7
143.3
127.7
149.7
135.6
FEMALE
MALE

WALNUT POINT



WOODS LAKE


200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1
2
3
4
5
6
61.0
109.9
105.5
138.6
136.6
157.7
148.5
170.3
159.9
175.0
170.0
FEMALE
MALE