

AGE AND GROWTH OF LARGEMOUTH BASS AT FRESHWATER LAGOON,
HUMBOLDT COUNTY, CALIFORNIA

by

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ABSTRACT

Age and Growth of Largemouth Bass at Freshwater Lagoon, Humboldt County, California

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The quality of the largemouth bass fishery at Freshwater Lagoon was evaluated by assessing age structure, stock structure, condition, and growth characteristics. A total of 1,511 largemouth bass was sampled from 1986 through 2000 using a boat electroshocker. Scales were collected from 706 fish and assigned ages. Eleven age classes were identified with a maximum age of 10 years. Age assignment precision between two readings was 95%. Paired scale and otolith (sagittae) samples were collected via hook-and-line from 20 largemouth bass in spring and early summer of 2002. The agreement rate of age determination between structures was used as a means of validating the utility of using scales for ageing largemouth bass. The between structure agreement rate was 75%. Scales were found to be a precise and accurate method for estimating age and growth parameters up to age 5. Sectioned otoliths were superior to scales in determining age through all cohorts. From 1987-2000, the population shifted from a greater percentage of older fish to a greater percentage of younger fish. Stock structure assessment using the Relative Stock Density (RSD) index indicated the fishery at the lagoon is of high quality with good numbers of large fish present. However, the lagoon does not produce trophy class fish. Combined results from age and stock structure analyses revealed a well-balanced and stable population and desirable recruitment and mortality levels through all cohorts. The number of old fish (large) peaked in 1993.

Fulton's condition factor (K) was used to assess fish condition. Mean K values at age for Freshwater Lagoon were higher than or equal to those reported for Lake Berryessa, California except for fish aged 0 and 2. The mean K value for all samples combined was higher than those reported for 48 of 50 systems from across the United States. The growth characteristics of largemouth bass from Freshwater Lagoon were generally poor compared to other systems. However, the rate of growth for age 2 and 3 fish was exceptional. The results from this study indicate that the cool climate on the Northcoast of California is capable of producing and sustaining high quality largemouth bass fisheries. The fishery at Freshwater Lagoon should be closely monitored to maintain its high quality.

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INTRODUCTION

The native range of largemouth bass (*Micropterus salmoides*) included states east of the Rocky Mountains from southern Canada south to northeastern Mexico then east to Florida and as far north on the Atlantic seaboard as North Carolina (Hubbs and Lagler 1949). States outside the native range began introductions in the late 1800's.

Populations are now naturalized in all states except Alaska (Boyle 1980).

Northern strain largemouth bass (*Micropterus salmoides salmoides*) were introduced to California in 1874 when they were transported from Quincy, Illinois and released into the Napa River and Alameda Creek (Emig 1966). Florida strain largemouth bass (*Micropterus salmoides floridanus*) were introduced to California in 1959 when they were transported from Pensacola, Florida and released into Upper Otay Reservoir in San Diego County (Pelzman 1980). Populations of both subspecies are now established statewide due to both legal and illegal stockings. As is the case with many exotics, largemouth bass have prospered outside their native range and many systems in California offer excellent angling opportunities. California waters have yielded 21 of the 25 heaviest largemouth bass caught by recreational fisherman (Jones 2001). The collective bass fisheries of California are as good as any in the world.

Largemouth bass support one of the most popular freshwater sport fisheries in North America. Intensive management techniques were developed to protect and enhance bass fisheries as interest in bass fishing increased dramatically in the last half-century. Harvest regulations are an important tool used by managers to manipulate population structure in order to achieve objectives. It is important for managers to identify

objectives and assess key population parameters prior to implementing appropriate regulations if objectives are to be achieved. Age and growth studies yield significant information from gathered data.

Age and growth of largemouth bass has been studied extensively throughout the United States, including California. Many studies conducted in California have focused on *M. s. floridanus* populations in southern California (LaFaunce et al. 1964, Bottroff and Lembeck 1978, Fast et al. 1982). Few comprehensive studies have focused on pure *M. s. salmoides* populations in the northern half of the state. Murphy (1951) reported growth rates of bass aged 0 to 6 for Clear Lake. Growth rates of bass in Clear Lake exceeded those from other regions except Louisiana. Tharratt (1966) focused on growth rates of largemouth bass aged 1 to 6 shortly following impoundment of Folsom Lake. He concluded growth rates increased during the first 2 years following impoundment but decreased thereafter. Baseline growth data for largemouth bass aged 1 to 7 were collected and reported for Millerton and Pine Flat Reservoirs by Miller (1971). Growth rates of bass from both systems were generally poor when compared to other California waters. He also suggested that the presence of threadfin shad might depress the growth of young largemouth bass. Young-of-the-year growth rates were compared between northern and non-northern strain largemouth bass at Clear Lake by Holzhauser (1976). Non-northern bass were found to reach a larger size in the first growing season. There were no differences in diet between the two strains, thus the size difference was attributed to an earlier spawn by non-northern bass. A regulation change and introduction of Mississippi silversides (*Menidia audens*) prompted Emig (1976) to explore growth rates

of largemouth bass aged 1 through 8 in Lake Berryessa. A similar study was conducted by Sak (1989) at Shasta Lake following a regulation change. He reported growth rates of largemouth bass aged 1 through 8 before and after implementation of a minimum size limit. Pre- and post-regulation growth of bass aged 1 through 4 showed no differences. Growth of fish older than age 4 was greater following the regulation change. Following chemical treatment and subsequent restocking of Kaweah and Success Lakes, Johnston (1992) compared growth rates of largemouth bass between the two systems. His focus was on growth rates of bass with (Kaweah) and without (Success) the presence of threadfin shad (*Dorosoma petenense*). However, only growth rates of largemouth bass aged 1 and 2 were reported.

The Northcoast region of California is located in the northwest corner of the state and includes Humboldt and Del Norte Counties. Largemouth bass reside in few systems in this area. Opportunities available to anglers in this area are limited to Freshwater Lagoon and Fish Lake in Humboldt County and Ruth Lake in Trinity County. Based on my knowledge, angler interest in bass fishing on the Northcoast is surprisingly high and increasing. However, opportunities available to these fishermen require significant investment in time and money because most bass fisheries are of considerable distance. This places more fishing pressure on the few local sites. Freshwater Lagoon is of particular importance due to its size, accessibility, and quality of the fishery.

Salmonid fisheries historically have dominated the Northcoast in respect to angler interest and management efforts. Declining stocks, reduced seasons and bag limits, and several state and federal listings have reduced these recreational angling opportunities in

recent years. It seems appropriate for managers to explore the potential of less traditional fisheries in this region. The objective of this project was to evaluate the quality of the largemouth bass fishery at Freshwater Lagoon from a management perspective. This was accomplished by assessing age structure, stock structure, condition, and growth characteristics. This project will: (1) facilitate effective and appropriate management of the bass fishery at Freshwater Lagoon, (2) serve as a template for future management of Northcoast bass populations, (3) bring to attention the validity and potential of less traditional fisheries on the Northcoast, and (4) help in maintaining recreational angling opportunities.

STUDY SITE

Freshwater Lagoon is located on U.S. Highway 101 approximately 64 km (40 mi) north of Eureka, California (Figure 1). U.S. Highway 101 is built on the sand barrier that separates the lagoon from the Pacific Ocean. Historically, breaching of this barrier by the ocean did occur but it was rare and its effects minimal. Breaching no longer occurs and the lagoon functions as a freshwater system. The only drainage feeding the lagoon is Owl Creek which enters the southern end. This creek has minimal flows and precipitation is likely a greater factor affecting seasonal water level fluctuations. The lagoon is shaped like a shallow dish with gently sloping shorelines down to a maximum depth of 5.2 m (17 ft). The average depth is 2.1 m (7 ft) (Kimsey 1952). The basin covers 97.7 ha (241.5 acres), is 2.2 km long (1.3 mi), has a maximum width of 0.7 km (0.4 mi), and has 5.4 km (3.4 mi) of shoreline (Maptech Inc.1998). The lakebed substrate consists mostly of sand with a few areas of scattered rock. Emergent vegetation in the littoral zone is significant and is dominated by bulrush (*Scirpus* sp.) with sedge (*Carex* sp.) and rush (*Juncus* sp.) present in smaller amounts. Submergent vegetation is found throughout the water column consisting primarily of dense mats of waterweed (*Elodea* sp.) with pondweed (*Potamogeton* sp.) and water lily (*Nuphar* sp.) also present. The mats of waterweed can cover the entire lagoon from late spring through fall. Freshwater Lagoon is considered eutrophic and lacks stratification due to its shallow depth.

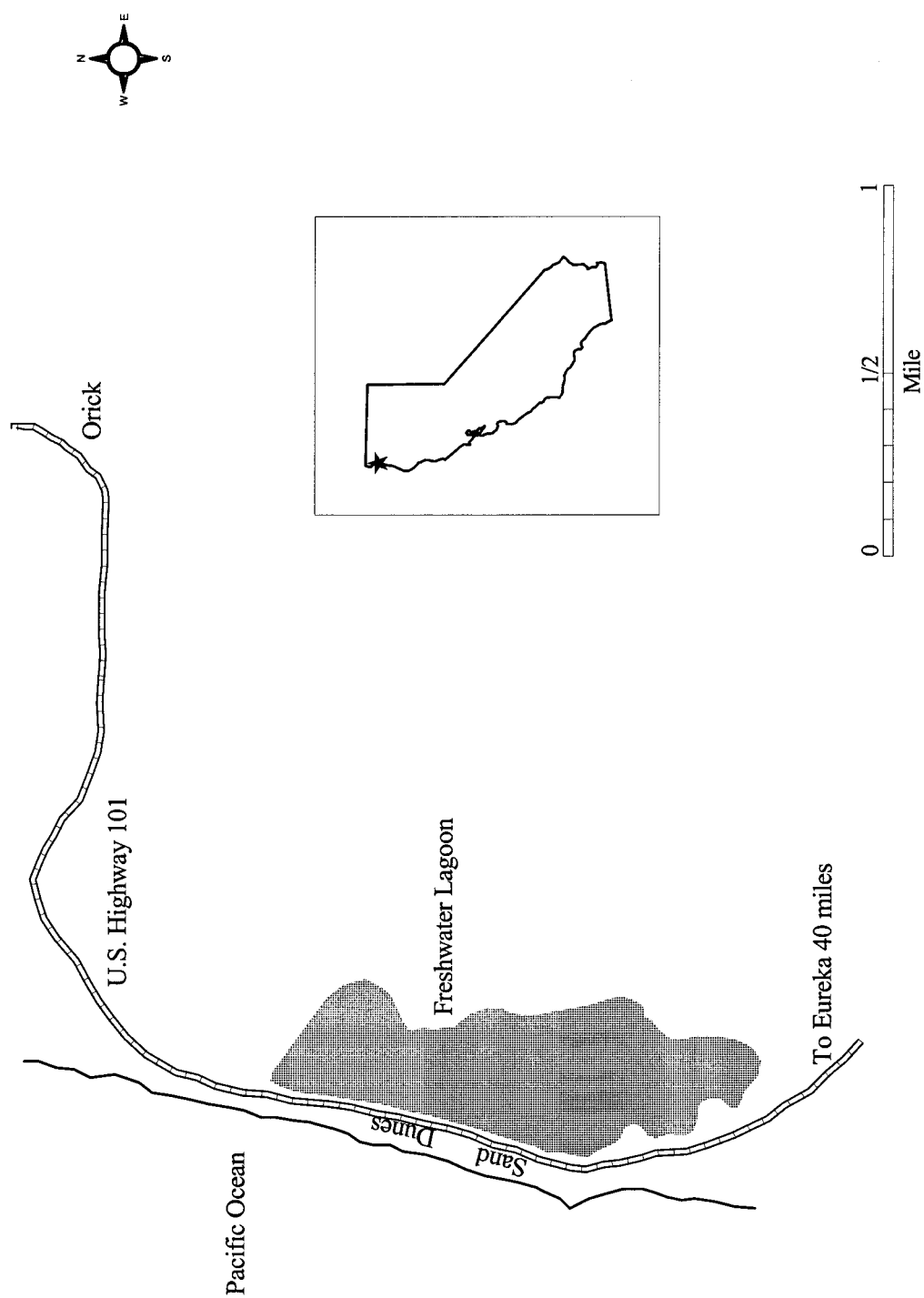


Figure 1. Site map of Freshwater Lagoon, Humboldt County and its geographic location within California.

The climate of the surrounding area remains cool throughout the year because of close proximity to the Pacific Ocean. Mean temperatures in January and June are 8° C (47° F) and 15° C (59° F), respectively (National Park Service 1984). Annual surface water temperatures of the lagoon range from approximately 7° C (45° F) to 21° C (70° F). The rainy season typically occurs between September and May when a range of 76 cm (30 in) to 152 cm (60 in) of precipitation falls. Advection fog is common during the day in warmer months.

Freshwater Lagoon is a state owned public waterway. The western shoreline lies within the boundaries of Redwood National Park and the eastern shoreline is privately owned. The system is administered and managed by both California Department of Fish and Game (CDFG) and the National Park Service (NPS). The construction of U.S. Highway 101 in 1950 across the sand barrier of the lagoon prevented breaching by the ocean (National Park Service 1984). This led to the extirpation of wild salmonid populations. As a result, NPS has little interest in the lagoon and their involvement is limited (personal communication, David Anderson 2002. Redwood National Park, 219 Hilton Road, Orick, California 95555). Management efforts by CDFG are minimal and consist primarily of stocking hatchery-reared trout.

Prior to the 1960's, CDFG stocked Freshwater Lagoon with many different species of fish including steelhead (*Oncorhynchus mykiss*), kokanee (*Oncorhynchus nerka*), Atlantic salmon (*Salmo salar*), rainbow trout (*Oncorhynchus mykiss*), cutthroat trout (*Oncorhynchus clarki*), brook trout (*Salvelinus fontinalis*), and occasionally brown trout (*Salmo trutta*) (Lee 1980). In the early 1960's anglers began voicing concerns of heavily

parasitized fish (Day 1965). CDFG responded to this problem and in 1965 eradicated all fish from the lagoon through chemical treatment in an attempt to rejuvenate the fishery (Lee 1980). Trout stockings resumed shortly afterwards. In 1970, local anglers pressured CDFG to stock largemouth bass to create additional angling opportunities. CDFG denied the effort stating water temperatures in the lagoon were not high enough to sustain a warmwater fishery (Arnett 1970). This prompted anglers to take matters into their own hands. Largemouth bass were illegally stocked into the lagoon in the mid to late-1970's (personal communication, anonymous 2002). The introduction proved successful and a high quality, self-sustaining fishery now exists. Harvest is regulated by the standard statewide recreational fishing regulations for black bass (12-inch minimum, 5 fish a day). Many speculate that Florida strain largemouth bass are present in Freshwater Lagoon. Largemouth were transported from Trinity Lake, Trinity County and illegally stocked into Ruth Lake in the late 1960's (personal communication, anonymous 2002). Largemouth were then transported from Ruth Lake and illegally stocked into Freshwater Lagoon (personal communication, anonymous 2002). There is no evidence or data supporting presence of Florida strain largemouth bass in either Trinity or Ruth Lake. Therefore, it is assumed only pure northern strain largemouth bass inhabit Freshwater Lagoon. For the remainder of this paper, reference to largemouth bass refers to the pure northern strain subspecies.

Other fish species currently present include rainbow trout, cutthroat trout, brown bullhead (*Ameiurus nebulosus*), goldfish (*Carassius auratus*), golden shiner (*Notemigonus crysoleucas*), wakasagi (*Hypomesus nipponensis*; also know as Japanese

smelt), prickly sculpin (*Cottus asper*), and three-spined stickleback (*Gasterosteus aculeatus*). There is no evidence of natural reproduction by trout and their presence is dependant on stocking of hatchery fish by CDFG.

MATERIALS AND METHODS

Data Collection

Sampling began in October 1986 and continued through March 2000 for a total of 15 years. Sampling was conducted during spring (February, March, April) and fall (September, October, November). Only one season was sampled in seven of the fifteen years. Sampling occurred on more than one day during most years.

Fish were collected using a Smith-Root model SR-18 electroshocking boat equipped with standard equipment and a 9 hp generator capable of 5,000 watts of output. Four approximately equal transects were marked along the shoreline accommodating complete sampling of the shoreline. Sampling began at sunset and concluded after one pass had been made on each transect. All species electroshocked were dip netted, held in an aerated livewell, and transported to shore for processing. Length and weight were recorded for all largemouth bass captured. Length was measured using a standard measuring board as fork length or total length (in many instances both) to the nearest mm or cm. Weight was recorded to the nearest gram or ounce using either an Ohaus 700 series triple beam scale, a handheld Pesola scale, or an Ohaus 6000 gram digital scale.

On each sample day, an attempt was made to collect a representative sample of scales from all lengths of largemouth bass sampled. Scales were removed from the area posterior to the pectoral fin and slightly below the lateral line (DeVries and Frie 1996). Scales were stored dry in a coin envelope with date of capture, length, weight,

and a unique identifying number clearly written on the envelope. Non-target fish were identified to species. After processing, all fish were placed in large, water filled containers for recovery and then released at the processing site.

Scale Preparation and Reading

Scale samples were soaked in water for approximately five minutes prior to selection. Dried mucous, dirt, and debris were removed using a small, soft bristled paintbrush. Four non-regenerated, symmetrical scales were selected from each sample using a dissecting microscope at 7x magnification. Each selected scale was fixed, rough side up, on the adhesive side of a small piece of packing tape. Scale impressions were made using a PSI automatic opening scale press (model #PW-225H-X1) with both platens heated to 104°C (220° F). Acetate slides were positioned on top of scale samples, placed between two steel cover plates, and pressed at 16,000-20,000 psi for two minutes. Each impression was labeled with a unique identifying number linking the scale sample to the appropriate weight and length data.

Age determinations were made by projecting scale impressions using a Bell and Howell model C100 microfiche reader (24x). Annuli determinations were based on criteria outlined by Bagenal and Tesch (1978). The nomenclature used to designate ages was consistent with conventions outlined by DeVries and Frie (1996). Ages assigned to fall samples corresponded with the number of annuli present. However, almost all spring scale samples did not exhibit full formation of the most recent annulus. In these cases ages assigned were the number of annuli present plus one. This was because spring

samples had survived past the January 1 birth date but the associated annulus was not yet visible.

The plane in which scale radii measurements were taken was standardized to a line radiating 320° out from the center of the focus and corresponding with the approximate border between the anterior and lateral fields of the scale. This plane was chosen because annuli were most consistently distinguishable in this area. Narrow strips of rigid paper were taped to the microfiche screen while scale impressions were projected. One edge of the paper was aligned with the focus with the perpendicular edge running along the 320° plane. Tick marks were placed on the paper at the margin of each annulus and at the scale edge. Images of the strips of paper were captured within Image-Pro Plus version 4.1.0.1 using a Navitar 7000 TV zoom lens. All scale radii measurements were then made using the Image-Pro Plus software. This last step was done to expedite the measuring and data transcription process, eliminate errors associated with such processes, and to increase precision of measurements.

Verification and Validation

Many authors have stressed the need for verification and validation of ageing techniques used in age and growth studies (Debont 1967, Carlander 1987, DeVries and Frie 1996). Verification refers to the measurement of the precision of age determination between two or more independent readings. All scale samples were read twice. When reading, I had no knowledge of capture date, body length of fish, or age determination of a previous reading. If there was agreement between the two readings then age assignment was assumed to be precise. If disagreement occurred, the structure was

carefully aged a third time until an age determination could be made with confidence. Precision was measured as the percentage of agreement between the first and second readings.

Validation refers to the accuracy of age determination. True validation of age estimates can only be accomplished by ageing known age fish. This was beyond the scope of this study. Instead, length frequency analysis and comparison of age assignments using two different structures (scales and otoliths) were utilized to increase confidence in the accuracy of age determinations (DeVries and Frie 1996). Ageing otoliths also provided information on the maximum number of annuli expected to be identified on scale samples.

Length frequency distributions were constructed by grouping samples into 10 mm length increments. Distributions with spring samples only, fall samples only, and spring and fall samples combined were constructed. Separation of spring and fall samples was necessary because within cohort length between the two seasons was highly variable. This variation could potentially obscure cohort modes making age class delineation difficult, particularly within older age classes.

In spring and early summer 2002, 20 largemouth bass were collected via hook-and-line for age assignment comparisons between scales and otoliths (IACUC #01/02.F.114.A 4/15/02). Age determination accuracy decreases as age of fish increases (Green and Heidinger 1994). This is because decreased growth with age causes annuli to be more closely spaced introducing error in detecting annular marks (Jearld 1983, Beamish and McFarlane 1987). For these reasons greater emphasis was placed on the

accuracy of assigning ages to larger, older fish. Thus, only the largest individuals caught were kept for this comparison. Scale samples and otoliths (sagittae) were taken from each fish. These were stored dry in a coin envelope with date of capture, total length (mm), weight (g), and a unique identifying number written on each envelope. Sampling was spread throughout several months to track and confirm annulus formation. The technique used for otolith extraction is outlined by Secor et al. (1992). Otoliths were sectioned through the nucleus along the transverse plane using a Buehler® Isomet low speed saw equipped with a Buehler® diamond wafering blade #11-4244. Sectioned otoliths were then fixed onto glass slides using Crystalbond® thermoplastic cement (Aremco®). The cut edge of the sectioned otolith was pushed down into the Crystalbond® until it touched the glass slide. The anterior tip was oriented facing up. Sectioned otoliths were ground and polished using techniques consistent with those outlined by Boiano (1999). Each sectioned otolith was viewed through a dissecting microscope (50x) and aged by counting the number of opaque bands. Scales and sectioned otoliths were aged twice for within structure agreement. Between structure agreement rate was determined by comparing the age assignments of both structures. After between structure precision was determined, sectioned otoliths and scales were viewed simultaneously to evaluate the utility of using sectioned otoliths to familiarize scale readers with the characteristics of true annular marks on scales.

Data Analyses

Statistical analyses and descriptive summaries were computed using S+ 2000. All tables and figures were constructed using S+ 2000 and Microsoft Excel 97. Fork length

was converted to total length (mm) for all analyses requiring length measurements.

Carlander (1977) suggested using 1.08 as a conversion factor for largemouth bass. This ratio did not represent the data from this study well. Fork length and total length were often both recorded during sampling (n=356). The average ratio of fork/total length for these samples was 1.034 and this was the conversion factor used. Weight measurements were converted to the nearest g for all analyses.

Histograms were constructed for each study year to assess temporal changes in the age structure of the largemouth bass population at Freshwater Lagoon. The procedure was repeated combining all study years. This was done as a means of assessing stability, recruitment, and mortality of the population through the time period of the study.

Stock structure was assessed using Relative Stock Density (RSD) as described by Gabelhouse (1984). This length-categorization system places fish in one of five categories based on total length. Values are expressed as the percentage of the total sample within each length category. The length categories are stock (203-304 mm; 8-11.99 in), quality (305-380 mm; 12-14.99 in), preferred (381-507; 15-19.99 in), memorable (508-634 mm; 20-24.99 in), and trophy (greater than or equal to 635 mm or 25 in). It is important to note that fish under stock length (less than 203 mm or 8 in) are not included in the formulas used to compute RSD values. RSD tables were constructed for each year. The procedure was repeated combining all years.

The weight-to-length relationship was calculated using Fulton's condition factor (K) formula:

$$K = \frac{W \times 10^5}{L^3} \quad ; \text{ where}$$

W = fish weight at capture

L = fish length at capture.

Mean K values were computed for each age with all sample years combined. The procedure was repeated combining all ages in each sample year.

The relationship between body length and scale radius was computed to (1) determine if scale radius was a good predictor of body length, and (2) determine the correction factor (y-intercept) needed for estimates of length at previous age. This relationship was computed separately for each sample year. A line of the form $L = a + b(S)$ was fitted to the data using least-squares linear regression (Hankin 1980) where:

L = total body length at capture

S = total scale radius at capture.

To simplify further analyses, an attempt was made to pool all regression slopes.

ANCOVA was used to test the regression slopes for homogeneity among years. Scale radii measurements were determined to be a good predictor of body length if r-squared was greater than 0.8. Lengths at previous age were back-calculated using the formula developed by Fraser (1916) and Lee (1920):

$$L_i = \frac{L_c - a}{S_c} (S_i) + a \quad ; \text{ where}$$

L_i = length of fish at formation of annulus i

- L_c = length of fish at capture
 S_i = the radial measurement of annulus i
 S_c = the total scale radius at time of capture
 a = a correction factor (y-intercept of the regression line for the body-scale relationship).

For all back-calculations, the correction factor used for each sample was the y-intercept of the body length-scale radius regression from the corresponding year the sample was collected. Samples were grouped into respective birth years. For each birth year mean calculated length at age was computed. Mean and weighted mean calculated total lengths at age combining all years were computed to provide a way to compare to other systems. Mean annual growth increment at age was determined for each growth year using the mean calculated lengths at age reported for each birth year. For example, fish from the 1979 year class at age 1 averaged 133 mm total length and at age 2 averaged 345 mm total length. Therefore, the mean annual growth increment for age 1 fish in 1980 and age 2 fish in 1981 was reported as 133 and 212 mm, respectively. The weighted mean annual growth increment for each age was computed. The mean annual growth increment for each age was determined for all years combined using all samples (not the mean of means).

RESULTS

A total of 1,511 largemouth bass was captured via electrofishing (Table 1). These samples were used to assess age structure, stock structure, condition, and growth characteristics. Sample sizes used for the analysis of each population parameter varied because the type of data collected during each sampling effort was inconsistent.

Scale Reading

Scales from 706 fish were collected, read and assigned ages. Scale samples were collected in all sample years except 1986 and 1992 (Table 2). Age assignment was complicated by the presence of multiple false annuli. False annular marks formed following the second annulus and were present thereafter. They were most easily distinguished in the transition zone between the anterior and lateral fields of the scale and always followed true annular marks. A clear compaction zone encompassing the entire scale characterized true annular marks. Cutting over was also characteristic of true annuli. This characteristic was not in itself diagnostic but, when combined with other characteristics, was found to be very helpful. False annular marks were characterized by compacted and irregular circuli that curled towards and joined the preceding annulus on either side of the transition zone between anterior and lateral fields. The presence of checks was assumed to be the result of stress due to spawning activity. Complete formation of annuli occurred during different months for different ages. Younger age classes exhibited completely formed annuli earlier in the year than did older age classes.

Table 1. Sample dates and sample sizes of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1986-2000.

Year	Month	Day	No. of Largemouth Bass Sampled
1986	October	31	47
	November	1	21
1987	February	26	19
	April	14	12
	October	15	31
		17	17
		31	30
1988	February	25	33
	April	11	32
	October	17	15
		30	15
1989	April	3	34
		20	21
		28	19
	October	3	19
		31	17
1990	February	26	16
	March	19	31
	April	9	54
1991	October	11	17
1992	March	16	17
1993	March	29	86
	September	20	7
1994	April	4	1
		22	31
	October	21	38
		22	26
1995	October	20	153
		21	38
1996	April	12	30
	October	30	144
1997	April	9	50
	October	21	176
1998	April	21	2
		28	36
	September	15	103
1999	September	24	10
2000	March	7	20
		21	43
Total =			1,511

Table 2. Sample dates and number of scale samples collected from largemouth bass at Freshwater Lagoon, Humboldt County, California, 1987-2000.

Year	Month	Day	No. of Scale Samples Collected
1987	April	14	11
1988	February	25	26
	April	11	31
	October	17	11
		30	15
1989	April	3	1
		20	17
		28	14
	October	31	15
1990	February	26	4
	March	19	24
	April	9	25
1991	October	11	16
1993	March	29	82
	September	20	6
1994	April	22	14
	October	21	36
		22	24
1995	October	20	96
		21	22
1996	April	12	18
	October	30	53
1997	April	9	23
1998	April	28	28
	September	15	27
1999	September	24	9
2000	March	7	18
		21	40
Total =			706

The most recent annulus was almost completely formed, enough to account for in back calculations, in a small percentage of samples aged 1 through 4 by April 12, March 29, April 11, and April 11, respectively. There were no samples aged 5 through 10 that had fully formed annulus up to the latest spring sample date of April 28.

Precision of age assignment was verified by reading all scales twice. There were 37 samples assigned different ages between the two readings for a 95% precision rate. In all instances of disagreement the assigned ages differed by one year and was the result of misinterpreting the first or last annulus, but most frequently the last. Disagreements occurred with ages 2 through 10, but most frequently with ages 5 through 10. A third reading resolved disagreements in all 37 samples.

An attempt was made to increase the confidence in age assignment accuracy through (1) length frequency analysis, and (2) comparison of age assignment from two different structures. Length frequency distributions were constructed for spring samples, fall samples, and spring and fall samples combined. The observed mean total length (mm) for each age is included in each distribution. Little was learned from these distributions because there are few distinct peaks. The spring sample distribution (Figure 2) shows three major peaks. The first two peaks are consistent with the observed mean total length (mm) of fish aged 1 and 2. The third peak does not reveal additional age classes because it includes mean total lengths for all remaining cohorts. The fall sample distribution (Figure 3) shows approximately six different peaks. Except for age 0, assigning incremental ages to these peaks would be misleading because they are not consistent with

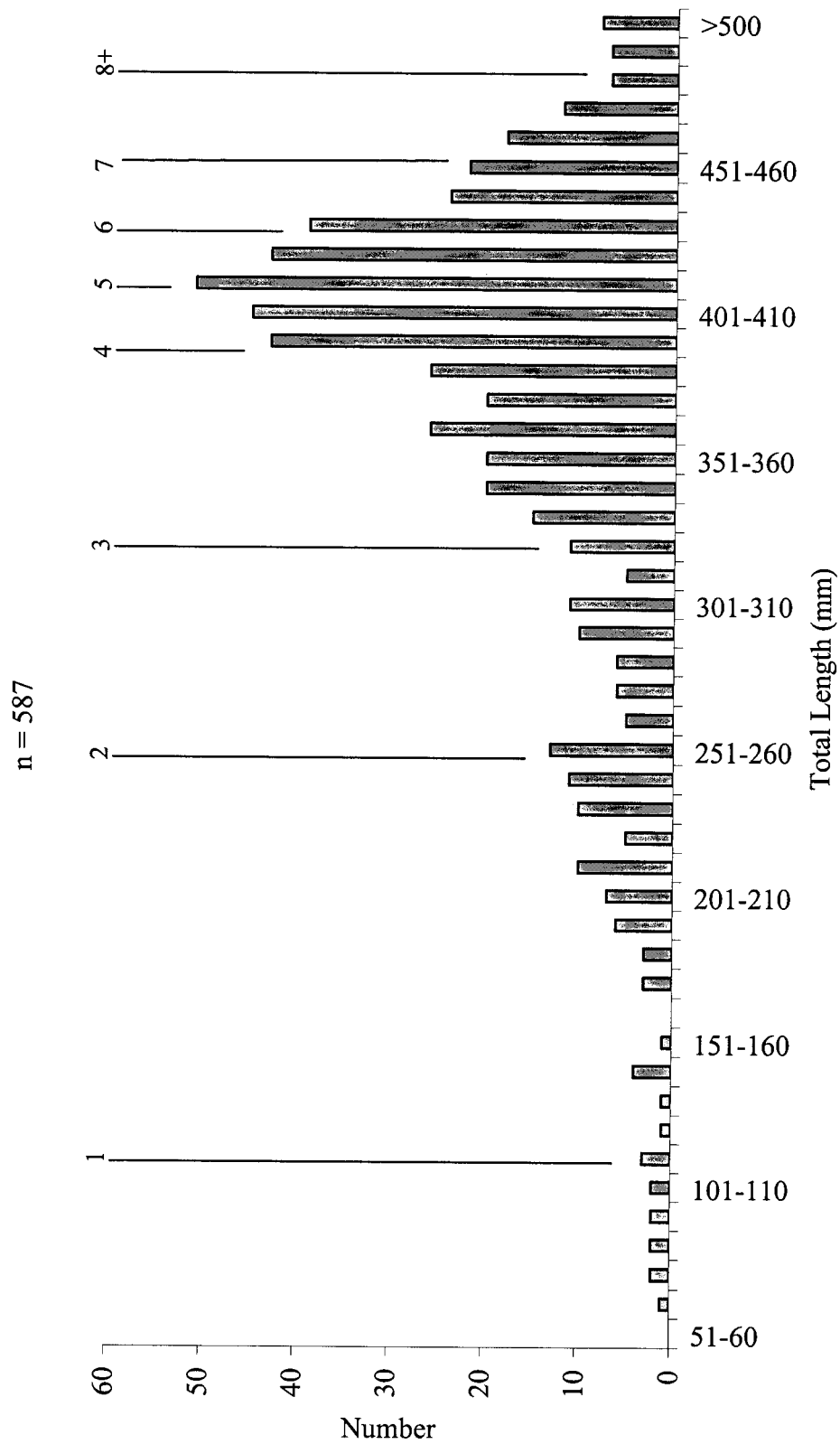


Figure 2. Length frequency distribution of largemouth bass sampled in spring 1986-2000 at Freshwater Lagoon, Humboldt County, California. The observed mean total length for each cohort is included.

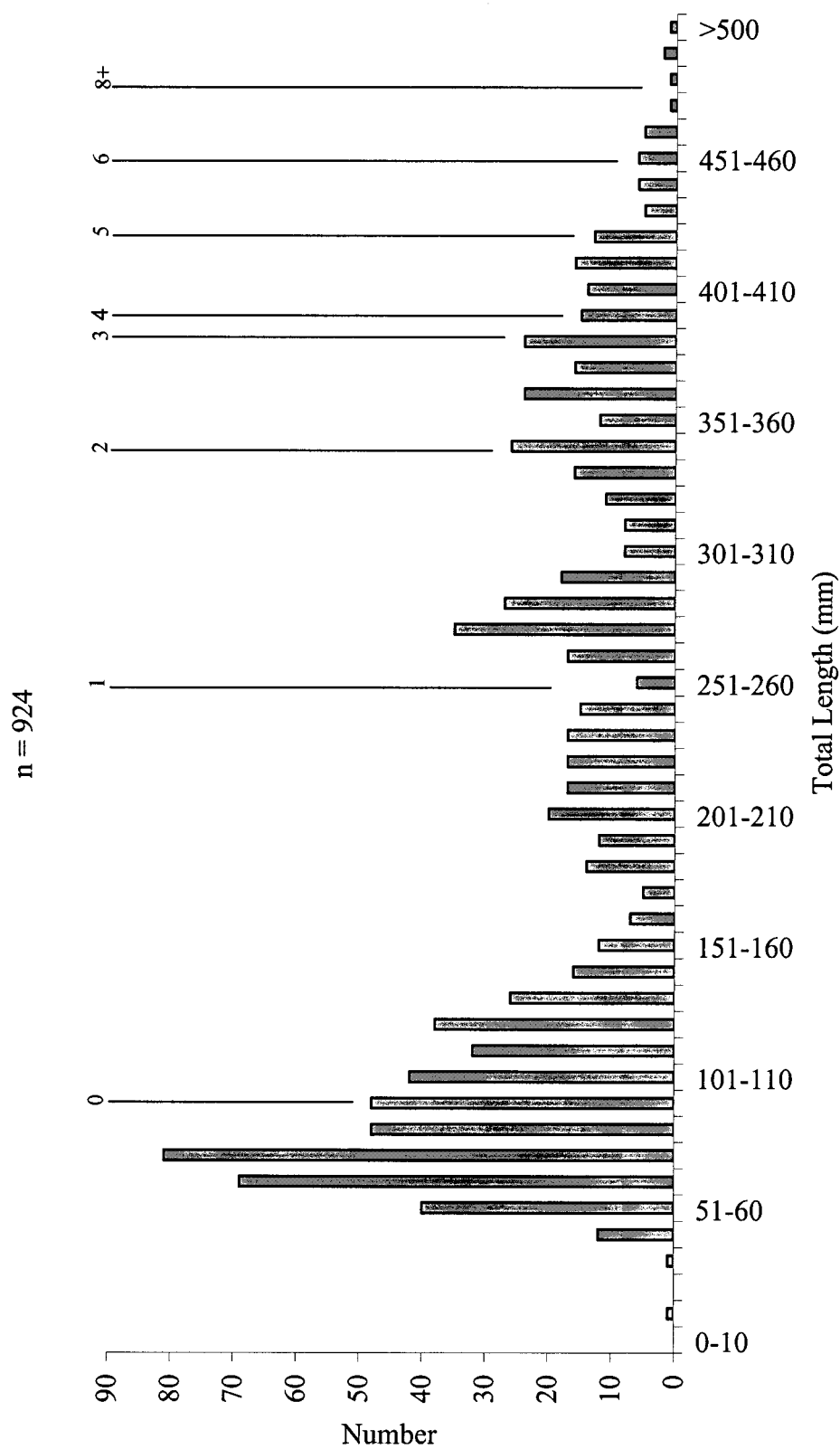


Figure 3. Length frequency distribution of largemouth bass sampled in fall 1986-2000 at Freshwater Lagoon, Humboldt County, California. The observed mean total length for each cohort is included.

the corresponding observed mean total lengths for all remaining cohorts. The combined results for both spring and fall samples (Figure 4) reveals similar results. There are approximately five different peaks with the first three roughly corresponding with the observed total length of ages 0 through 2. However, the remaining distribution is not useful in determining length ranges of the remaining cohorts.

Twenty paired otolith and scale samples were collected from April 22 through July 7, 2002 (Table 3). Fish ranged in age from 5 to 9 years. The agreement rate of assigned ages between structures was 75%. It was assumed that ages assigned to sectioned otoliths represented the true age of the fish. Disagreements in age assignment occurred in fish aged 7 and 9. Annuli counts between structures differed by a maximum of 3. Scales underestimated the age of fish in all instances of disagreement except one. Annuli were much more easily identified on sectioned otoliths than on scales (Figure 5). The last annulus was first visible on otoliths on June 2 and completely formed in all samples by June 27. The last annulus was first visible on scales on June 20 and completely formed in all samples by July 7. Paired otoliths and scales were viewed simultaneously for samples where ages assigned differed between structures. Correctly identifying scale annuli was much easier with the aid of a sectioned otolith.

Age Structure

Seven hundred and six samples were used to construct age structure histograms representing 13 years (Figures 6-18). Fish ranged from 0 to 10 years old with all cohorts

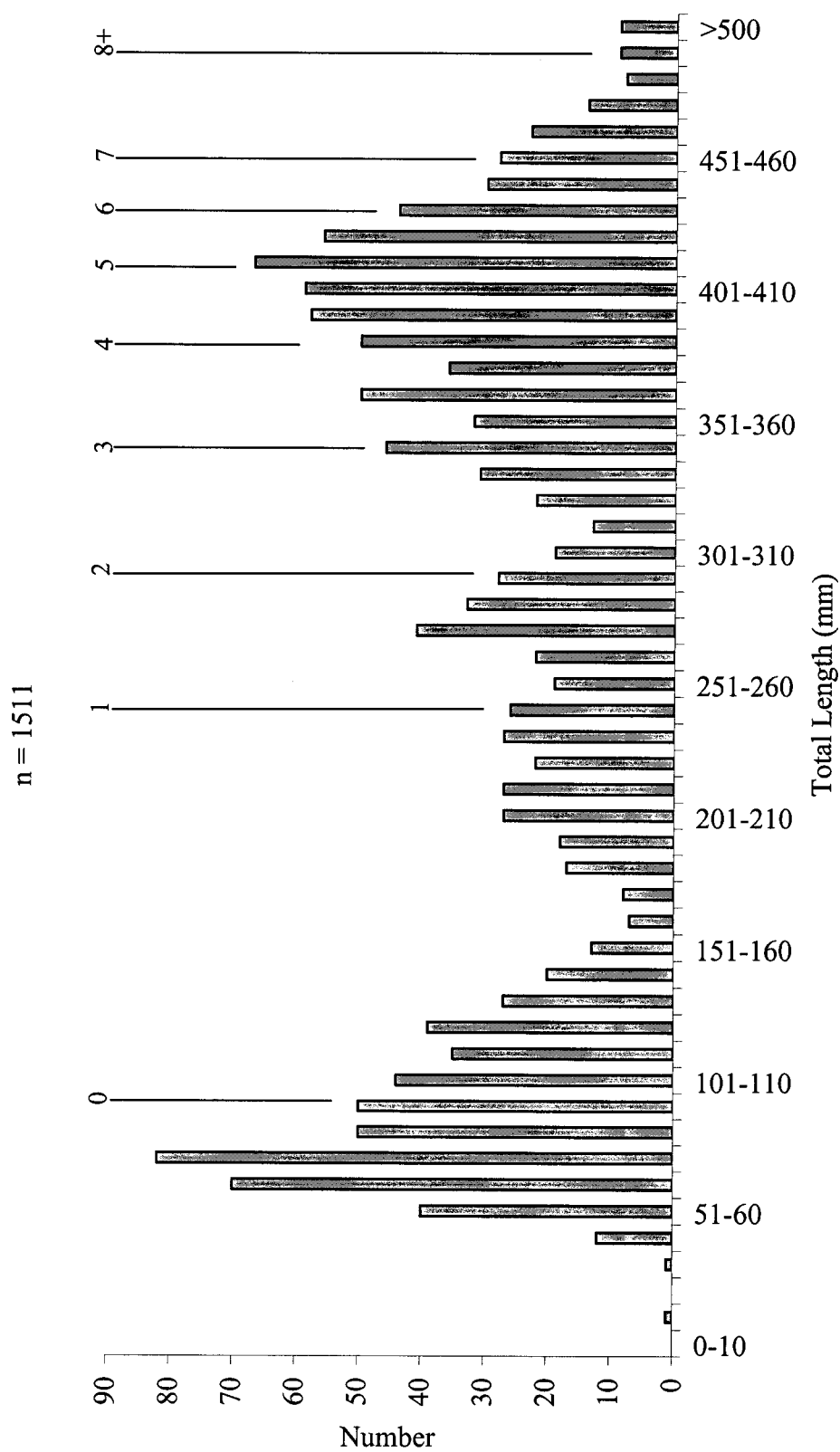


Figure 4. Length frequency distribution of largemouth bass sampled in spring and fall 1986-2000 at Freshwater Lagoon, Humboldt County, California. The observed mean total length for each cohort is included.

Table 3. Sample dates and sample sizes of paired otolith and scale samples collected from largemouth bass at Freshwater Lagoon, Humboldt County, California, 2002.

Month	Day	No. Fish Collected
April	22	2
May	7	1
	21	3
June	2	3
	20	4
	27	5
July	7	2

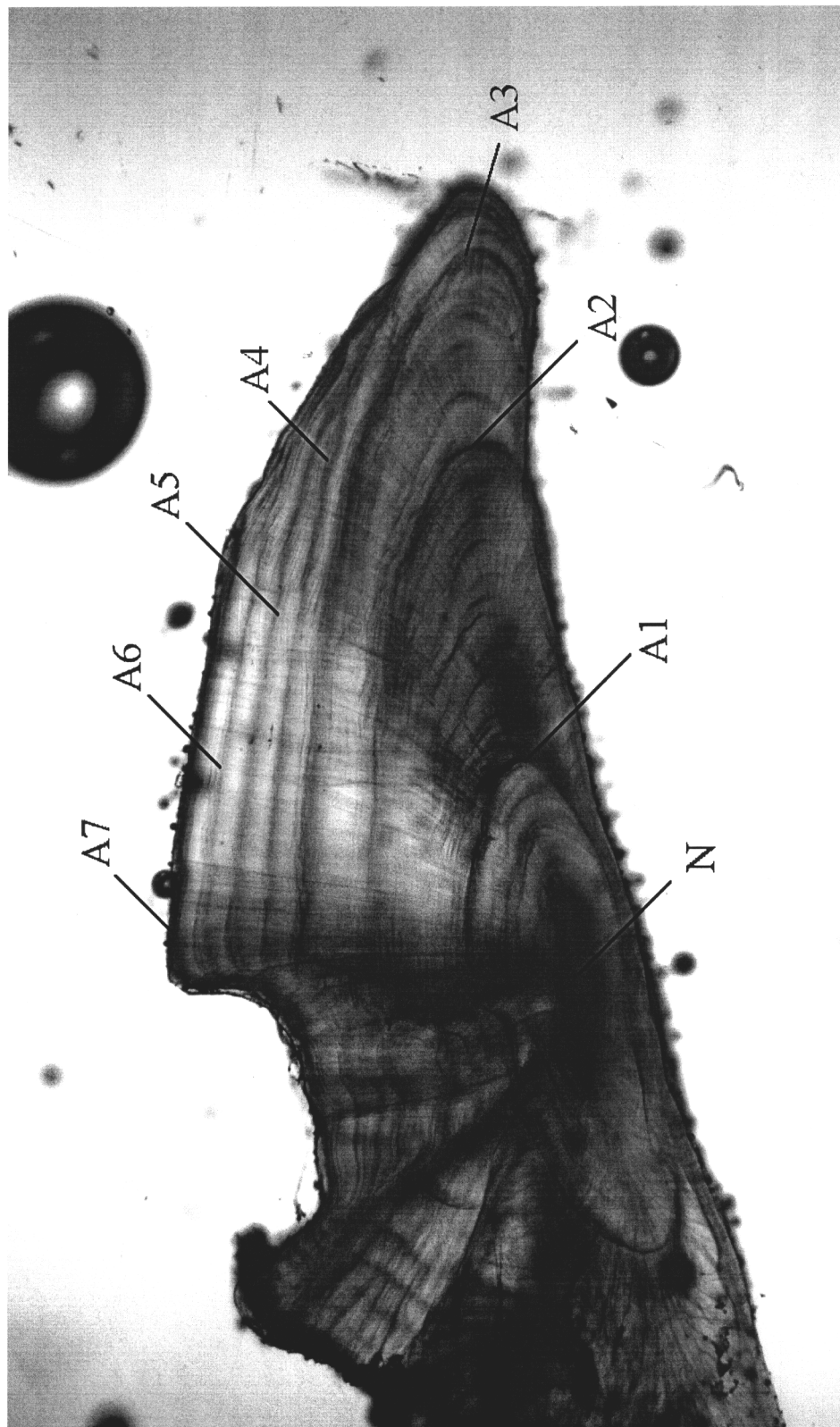


Figure 5. Sectioned otolith (100x) from a 7 year old largemouth bass collected on June 20, 2002 from Freshwater Lagoon, Humboldt County, California. The 7th annulus is coming in on the structure edge. N = nucleus, A = annulus number.

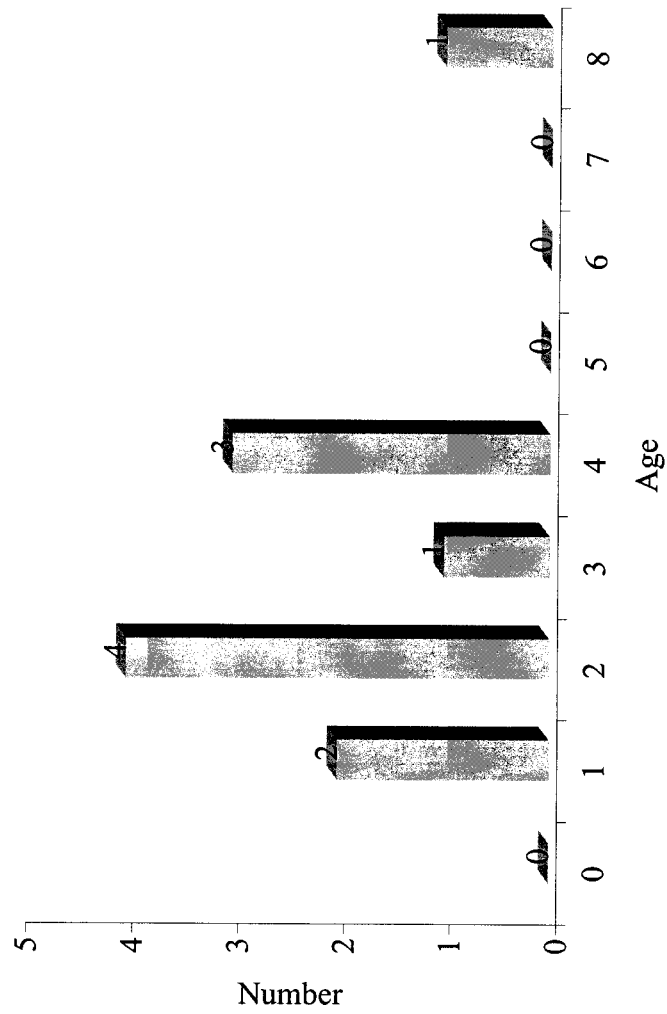


Figure 6. Age structure of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1987.

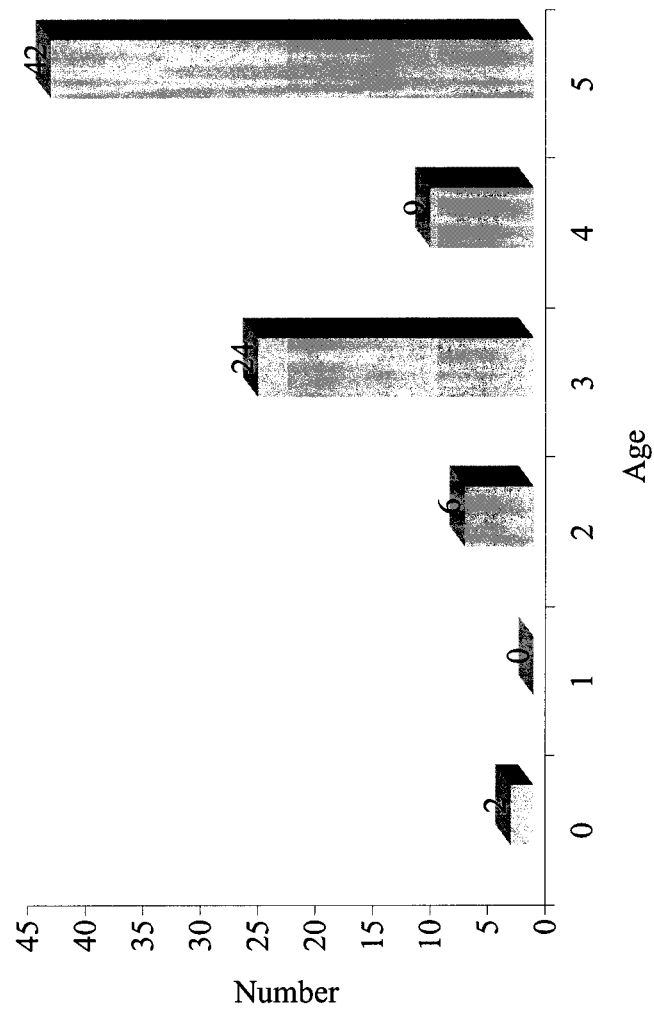


Figure 7. Age structure of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1988.

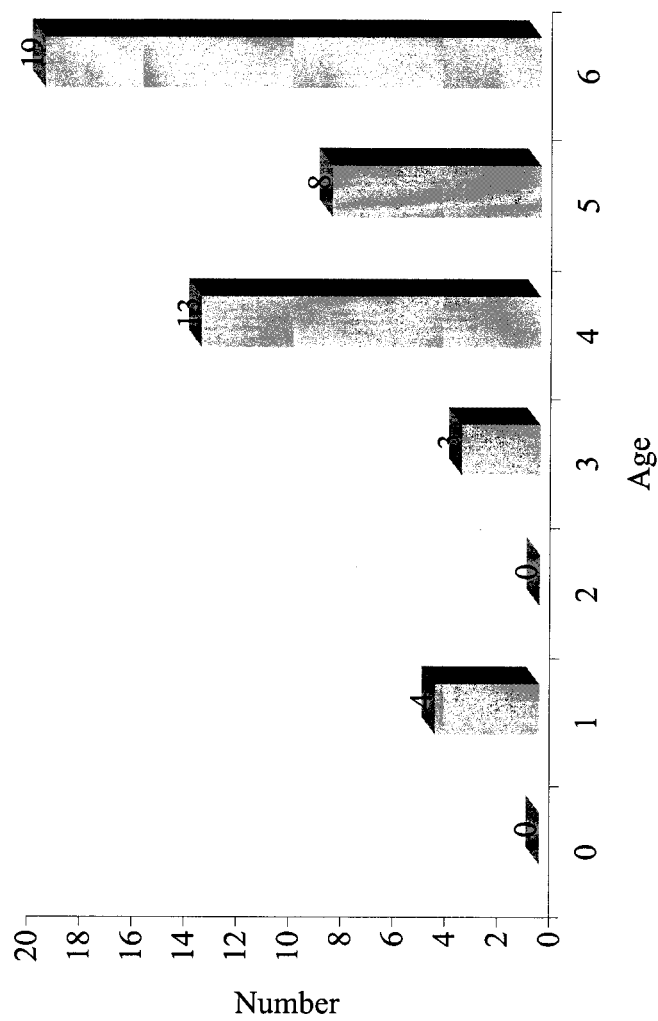


Figure 8. Age structure of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1989.

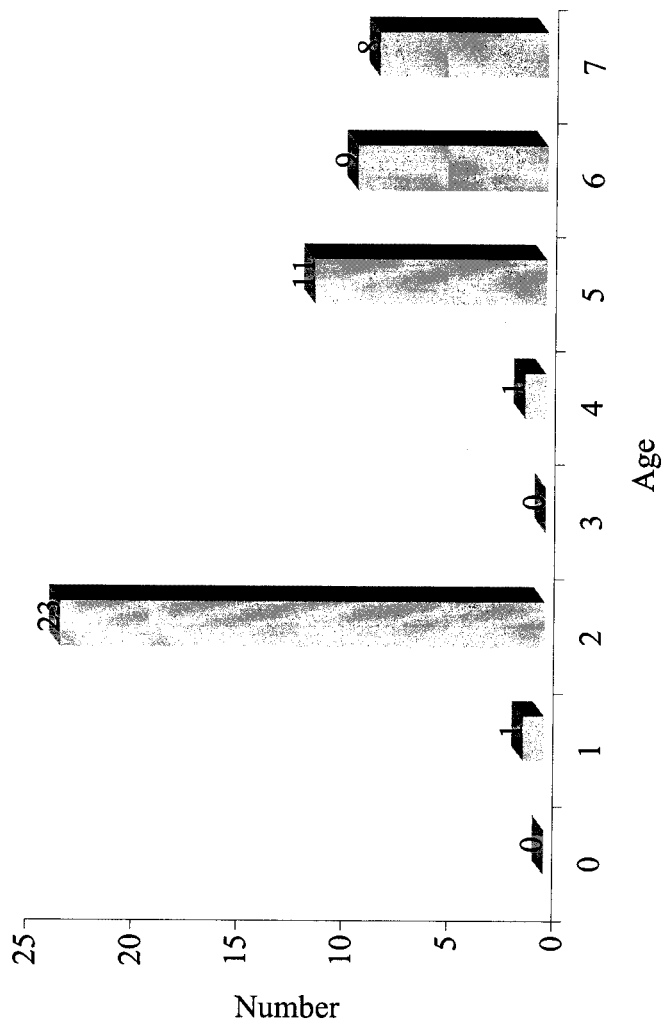


Figure 9. Age structure of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1990.

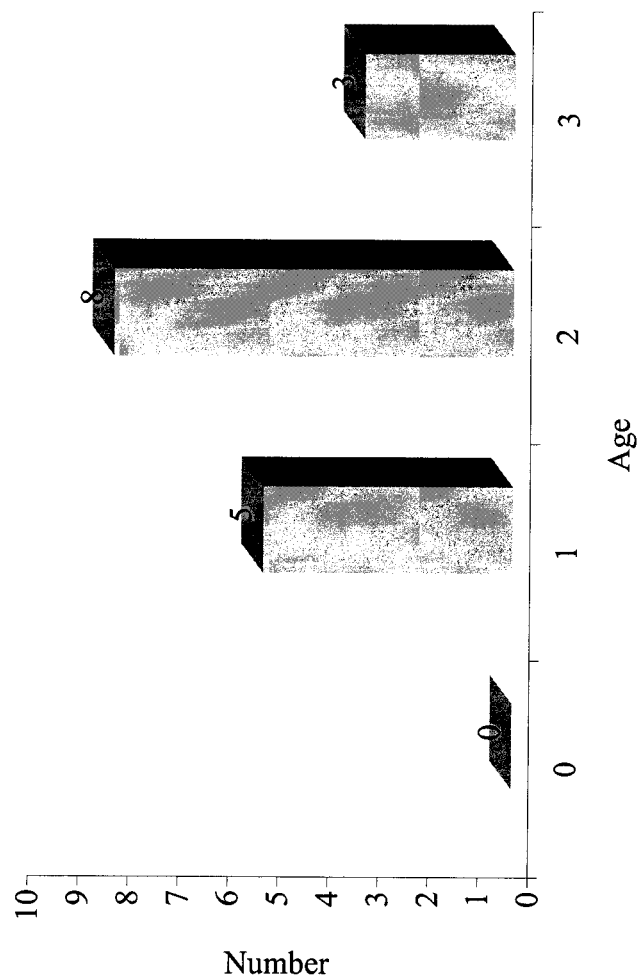


Figure 10. Age structure of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1991.

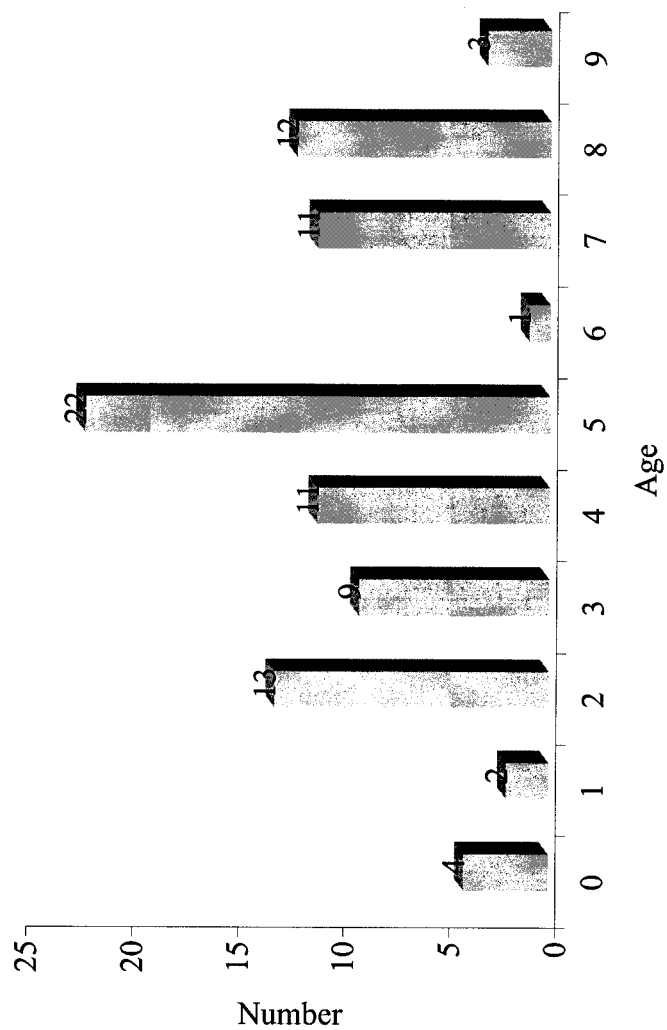


Figure 11. Age structure of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1993.

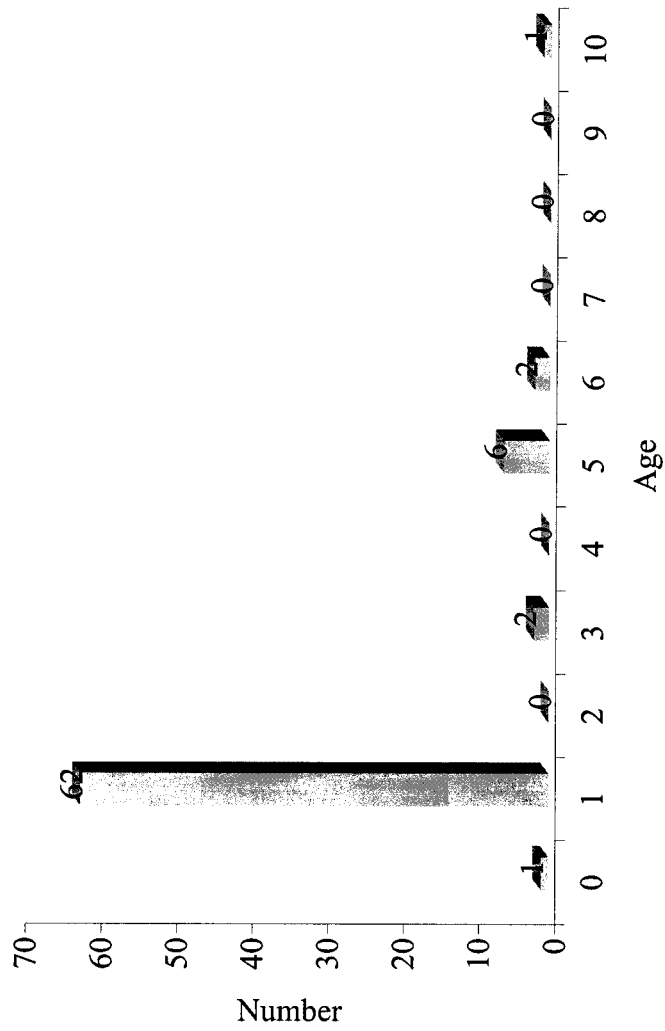


Figure 12. Age structure of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1994.

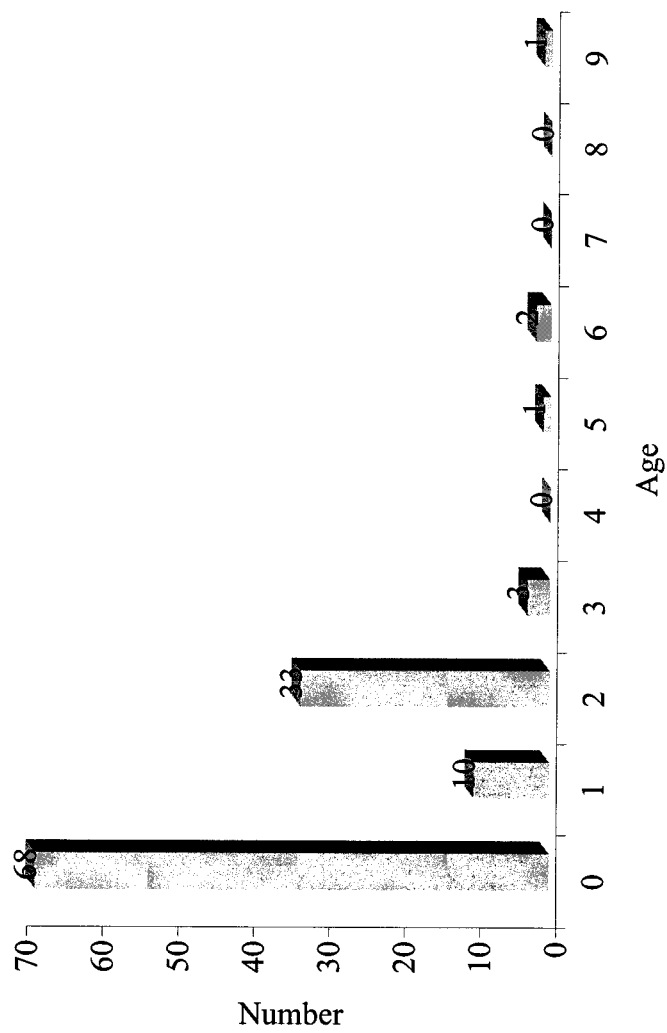


Figure 13. Age structure of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1995.

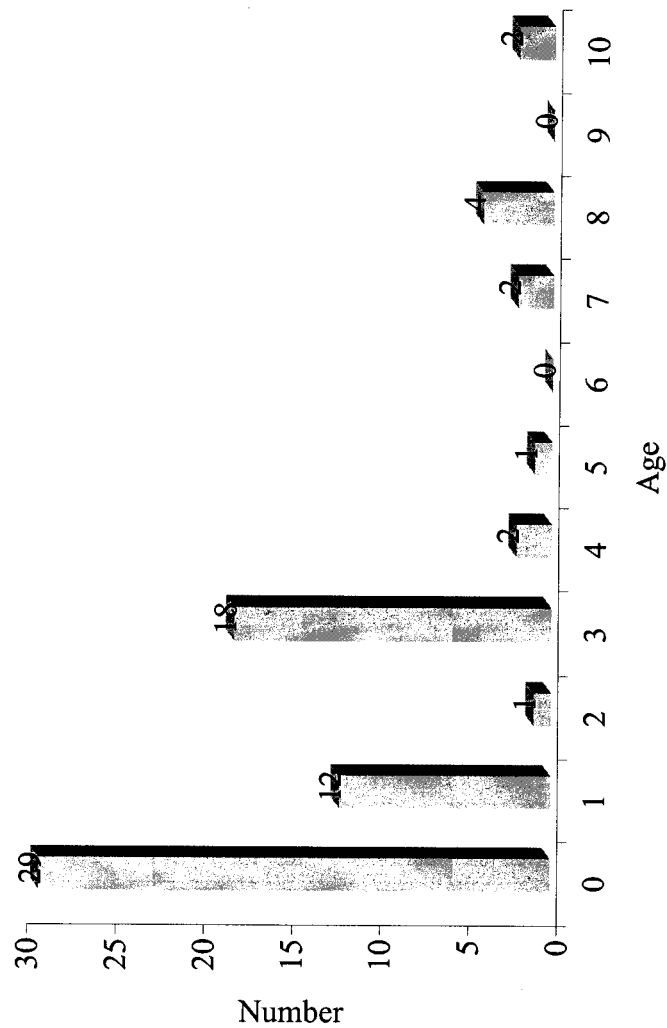


Figure 14. Age structure of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1996.

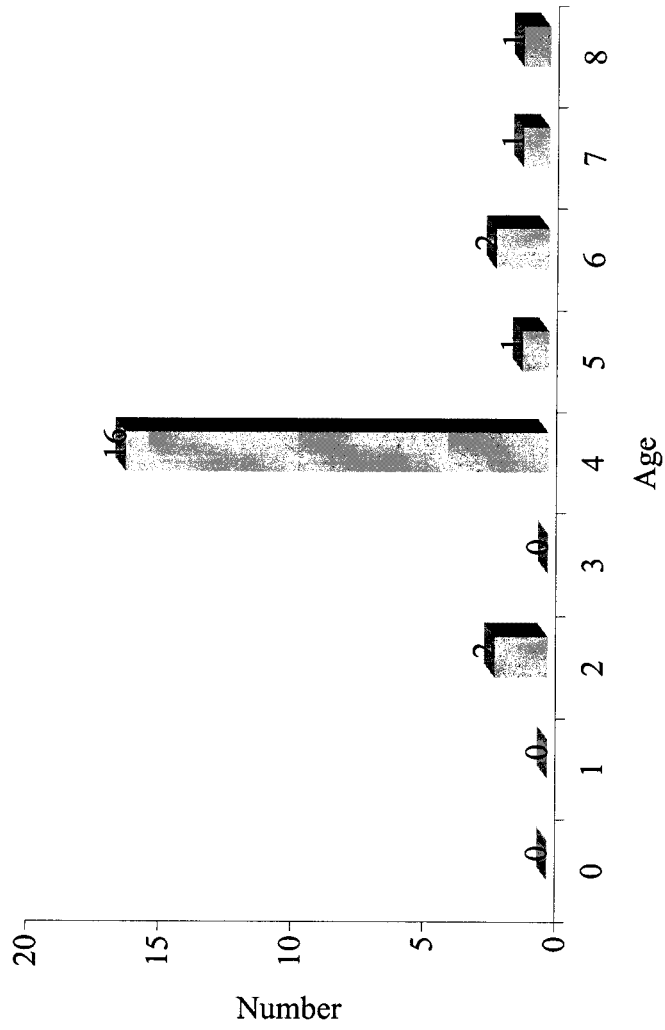


Figure 15. Age structure of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1997.

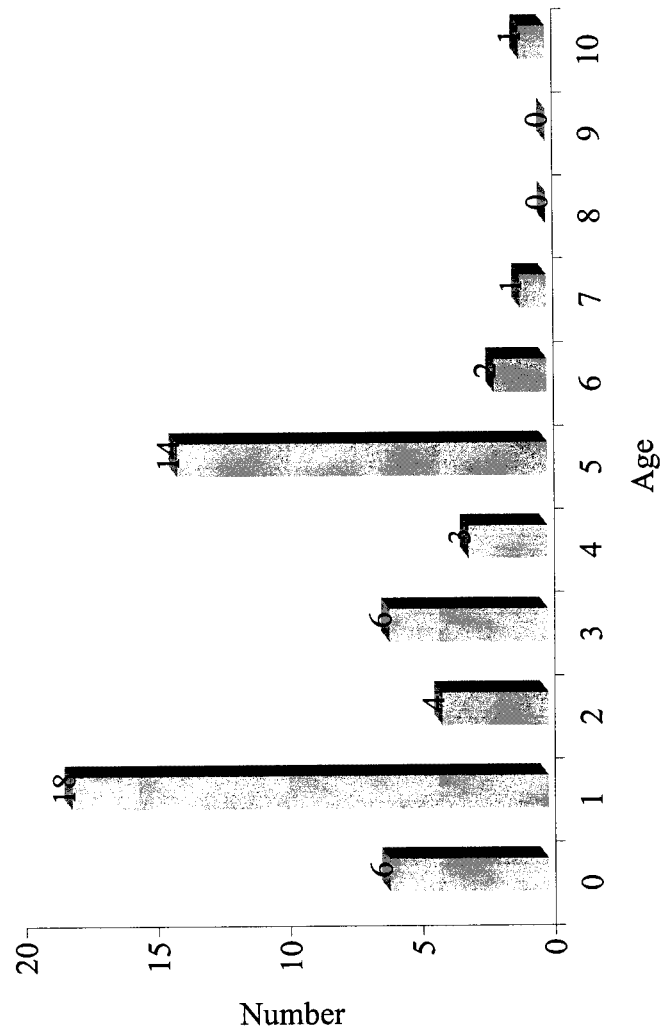


Figure 16. Age structure of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1998.

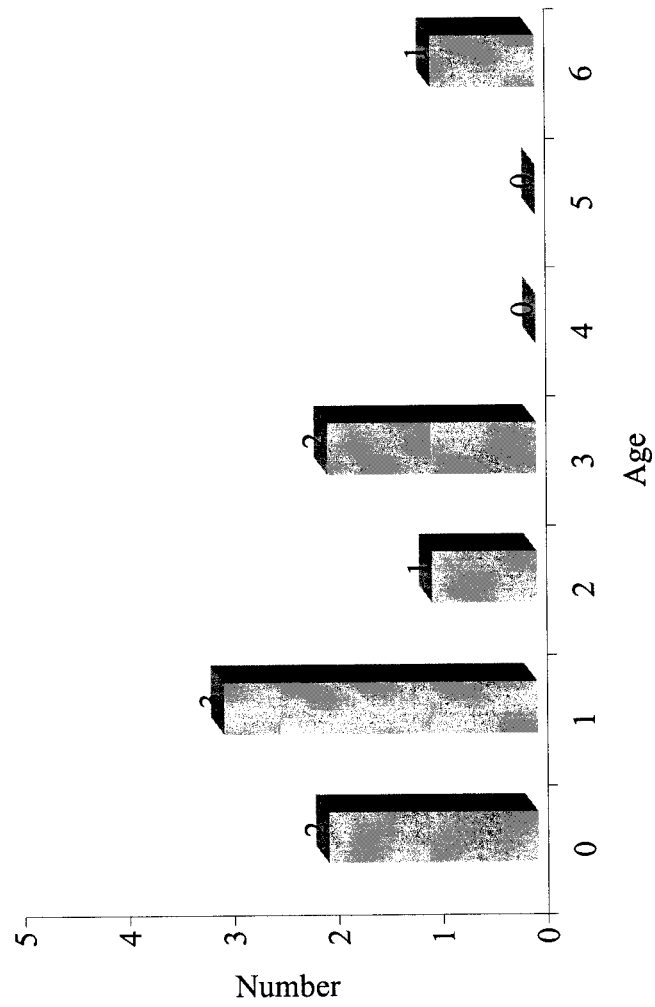


Figure 17. Age structure of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1999.

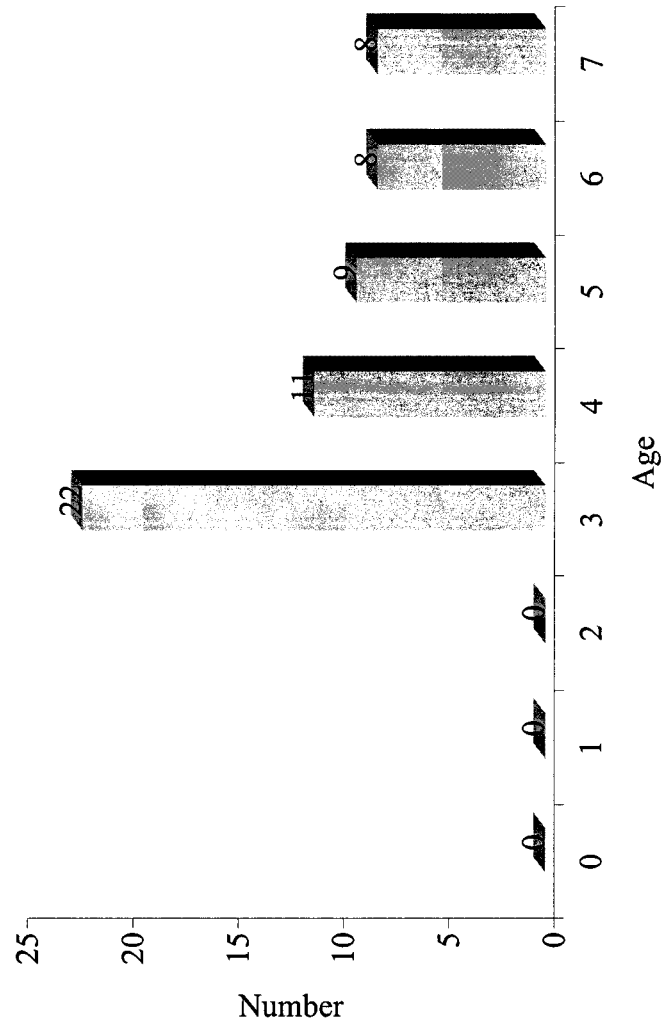


Figure 18. Age structure of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 2000.

present. However, not all cohorts were sampled in each year. The general trend in the age structure of the largemouth bass population from 1987-2000 was a shift from a greater percentage of older fish to a greater percentage of younger fish. Fish aged 4 through 7 accounted for the highest percentage of the total sample from 1988 through 1990. Fish aged 0 through 3 accounted for the highest percentage in 1987 and 1991. However, sample sizes for both 1987 and 1991 were very small. In 1988, 82% of the sample consisted of fish aged 3 through 5. These cohorts were recruited in 1989 and 1990 when samples were dominated by fish aged 4 through 6 (85%) and 5 through 7 (54%), respectively. The 1993 sample shows a more balanced age structure with 44% of fish at ages 0 through 4 and 56 % at ages 5 through 9. In 1993 fish of ages 8 and 9 were most numerous. It appears that 1993 represents the year the population began changing from an age structure skewed towards older cohorts to one skewed towards younger cohorts. Fish aged 0 through 4 accounted for the highest percentage of the total sample from 1994 through 1999. During this time period a sharp increase occurred in the number of young-of-the-year fish (age 0) sampled. Large numbers of new recruits were added to the population in 1995 and 1996. All years were combined to provide a 14-year trend in the age structure of the population (Figure 19). Fish of ages 0 through 5 represent 85 % of the total sample. Ages 0, 1, and 5 account for the highest individual totals representing 16%,17%, and 16% of the total sample, respectively. Fish aged 8 through 10 collectively accounted for only 4% of the total sample.

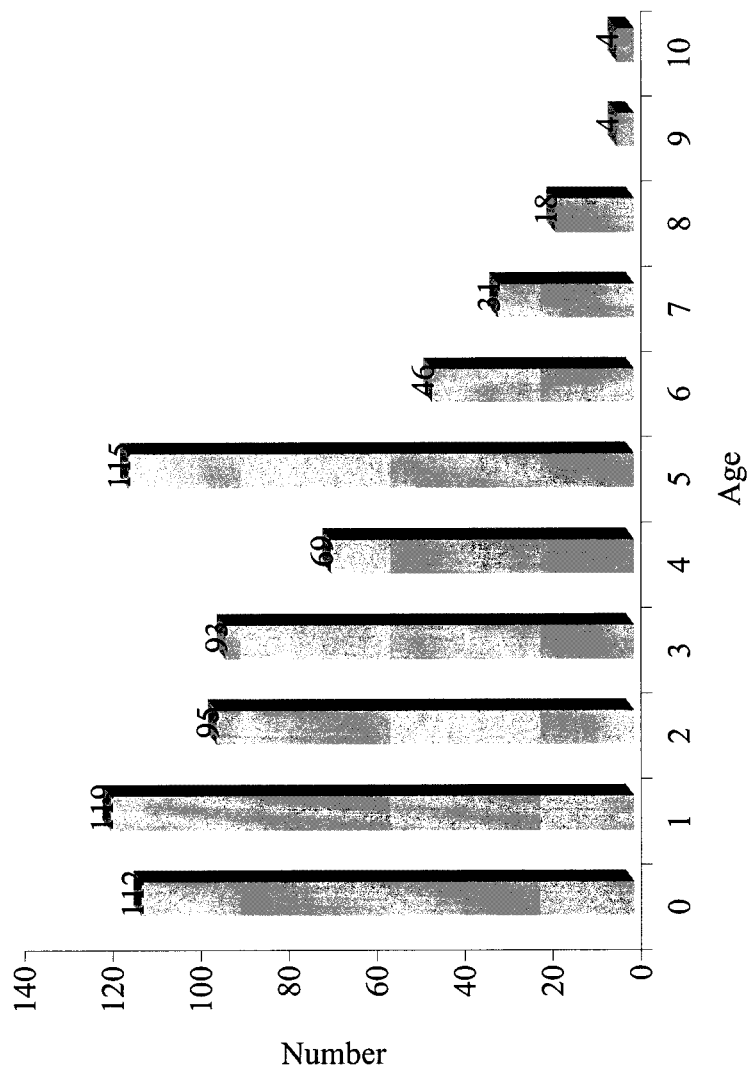


Figure 19. Age structure of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1987-2000.

Stock Structure

Relative Stock Density (RSD) was used to assess the stock structure of the largemouth bass population at Freshwater Lagoon. This index places fish in one of five categories based on total length. Index values are expressed as the percentage of the total sample within each length category. The five length categories are (1) RSD Stock-Quality 203-304 mm (RSD S-Q 8-11.99 in), (2) RSD Quality-Preferred 305-380 mm (RSD Q-P 12-14.99 in), (3) RSD Preferred-Memorable 381-507 mm (RSD P-M 15-19.99 in), (4) RSD Memorable-Trophy 508-634 mm (RSD M-T 20-24.99 in), and (5) RSD Trophy greater than or equal to 635 mm (RSD T greater than or equal to 25 in). RSD values for each size category are compared to values for three suggested management objectives to determine the role largemouth bass play in the management objectives of a particular fish community. The management objective categories used for interpretation of RSD values are (A) create a high density bass population to produce preferred-length panfish, (B) create a moderate density bass population in which bass are one species of equal importance in a balanced community, and (C) create a low density bass population in which bass are the single most important species with large individuals desired (Table 4). Total sample size for this analysis was 970 and all years (1986 through 2000) had representative samples. Sample sizes and RSD values for each year, all years combined, and corresponding management objectives are summarized in Table 4. Interpretation of RSD values for Freshwater Lagoon was not straight forward because in most years values for each category were intermediate

Table 4. Relative Stock Density (RSD) sample sizes, values, and corresponding management objectives of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1986-2000. Sample sizes in parentheses. The recommended RSD percentages of largemouth bass in a body of water to achieve three management objectives are listed at the bottom of the table (from Gabelhouse 1984).

Year	n	RSD S-Q 203-304 mm (8-11.99 in)	RSD Q-P 305-380 mm (12-14.99 in)	RSD P-M 381-507 mm (15-19.99 in)	RSD M-T 508-634 mm (20-24.99 in)	RSD T 635 mm ≤ (25 in ≤)	Mgt. Objective
1986	58	45 (26)	34 (20)	21 (12)	0 (0)	0 (0)	B
1987	104	26 (27)	32 (33)	42 (44)	0 (0)	0 (0)	B - C
1988	92	4 (4)	32 (29)	63 (58)	0 (0)	1 (1)	B - C
1989	106	9 (10)	22 (23)	69 (73)	0 (0)	0 (0)	B - C
1990	98	27 (26)	9 (9)	64 (63)	0 (0)	0 (0)	B - C
1991	17	41 (7)	47 (8)	12 (2)	0 (0)	0 (0)	B
1992	15	20 (3)	47 (7)	33 (5)	0 (0)	0 (0)	B
1993	88	18 (16)	19 (17)	56 (49)	7 (6)	0 (0)	C
1994	83	69 (57)	8 (7)	23 (19)	0 (0)	0 (0)	A - B
1995	69	23 (16)	61 (42)	16 (11)	0 (0)	0 (0)	B
1996	56	23 (13)	30 (17)	47 (26)	0 (0)	0 (0)	B - C
1997	58	47 (27)	3 (2)	50 (29)	0 (0)	0 (0)	B - C
1998	59	44 (26)	19 (11)	37 (22)	0 (0)	0 (0)	B - C
1999	4	25 (1)	25 (1)	50 (2)	0 (0)	0 (0)	B - C
2000	63	13 (8)	38 (24)	49 (31)	0 (0)	0 (0)	B - C
1986 - 2000	970	28 (267)	26 (250)	46 (446)	0 (6)	0 (1)	B - C

Management Objective	RSD S-Q	RSD Q-P	RSD P-M	RSD M-T	RSD T
A.) Create a high density bass population to produce preferred-length panfish	60 - 80	20 - 40	0 - 10		
B.) Create a moderate density bass population in which bass are one species of equal importance in a balanced community	30 - 60	30 - 60	10 - 30	0 - 10	
C.) Create a low density bass population in which bass are the single most important species with large individuals desired	20 - 50	20 - 50	20 - 40	10 - 20	0 - 5

between two of the management objectives. The stock structure of the 1986 sample most closely resembles those listed under objective B. From 1987 through 1990 the population had values intermediate between objective B and C. The RSD P-M values for the 1988, 1989, and 1990 sample years were the highest. The 1988 sample included the only fish considered of trophy length (RSD T). The 1991 and 1992 sample had values most closely aligned with objective B although sample sizes were small for both years. The 1993 sample was the only year having values falling under objective C and the only year having fish in the RSD M-T category. It appears the stock structure peaked in 1993 when longer (larger) fish comprised the highest percentage of the population. The 1994 sample was the only year having values intermediate between objective A and B. This was followed by the 1995 sample falling under objective B then all remaining sample years (1996 through 2000) having values intermediate between B and C. The 15-year trend shows a population which increased in length from 1986 through 1992, peaked in 1993, showed a slight decrease in 1994 and 1995, and then increased and stabilized in the remaining sample years. The RSD values are intermediate between objective B and C when all sample years are combined.

Condition

A total of 444 samples representing all years except 1986 and 1992 were used to determine mean Fulton's condition factor (K) for each age with all sample years combined (Figure 20). Table 5 lists sample sizes by age and year used to determine the cumulative sample sizes. The age 0 cohort had the lowest mean condition factor of 1.38.

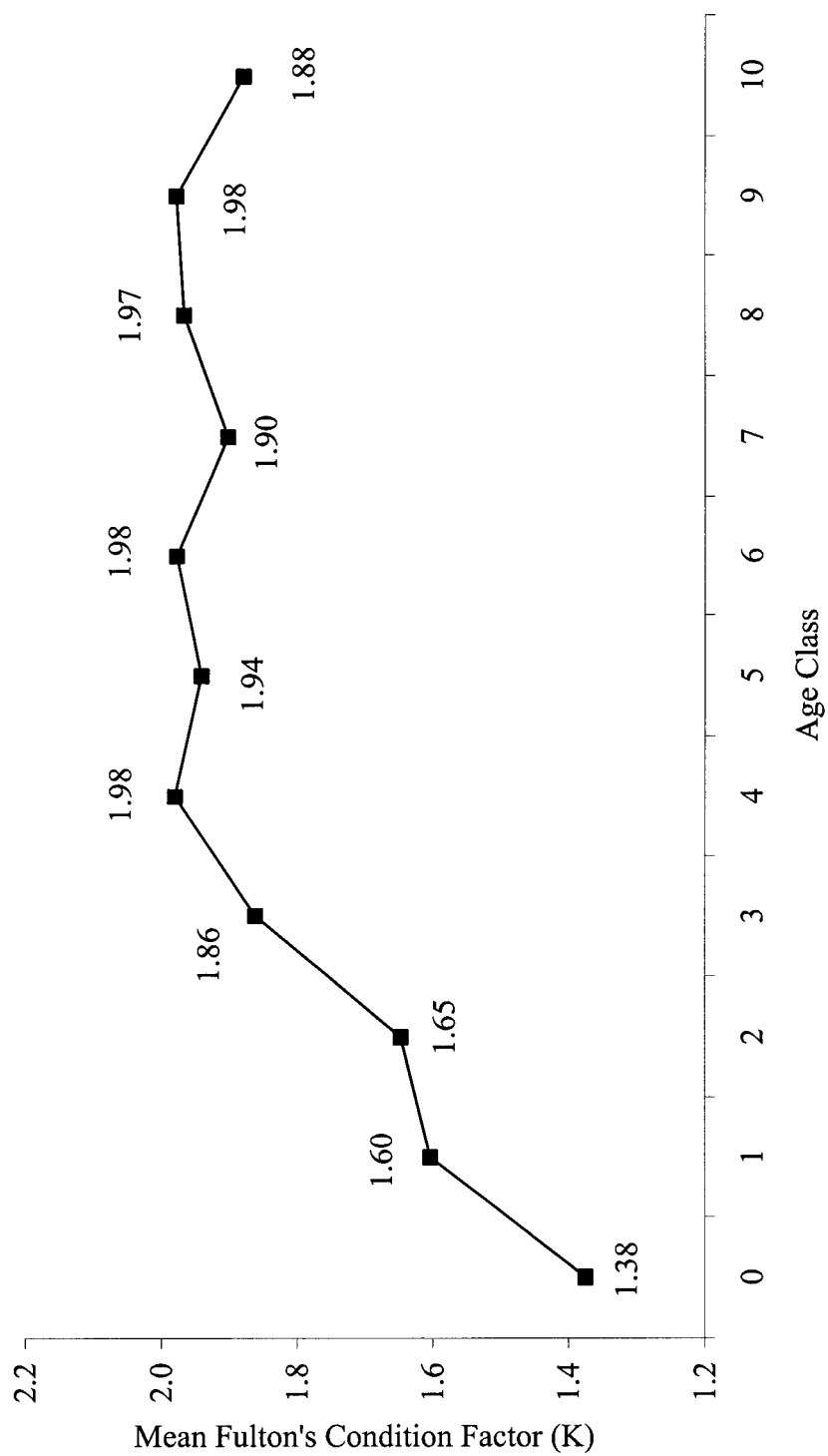


Figure 20. Mean Fulton's condition factor (K) at age with all sample years combined of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1986-2000.

Table 5. Sample sizes by age and year used to determine mean Fulton's condition factor (K) at age of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1987-2000.

Sample Year	Age Class													
	0	1	2	3	4	5	6	7	8	9	10			
1987	0	2	4	1	3	0	0	0	1	0	0			
1988	0	0	5	24	9	42	0	0	0	0	0			
1989	0	0	0	2	8	4	17	0	0	0	0			
1990	0	1	11	0	1	5	5	5	0	0	0			
1991	0	6	8	3	0	0	0	0	0	0	0			
1993	4	2	13	9	11	22	1	11	12	3	0			
1994	0	5	0	2	0	5	1	0	0	0	1			
1995	0	8	15	1	0	1	2	0	0	0	0			
1996	0	3	0	5	1	0	0	0	0	0	0			
1997	0	0	2	0	14	1	2	1	1	0	0			
1998	6	18	4	6	3	14	2	1	0	0	1			
1999	0	2	1	2	0	0	1	0	0	0	0			
2000	0	0	0	22	10	9	8	8	0	0	0			
1987 - 2000	10	47	63	77	60	103	39	26	14	3	2			

Ages 4, 6, and 9 had the highest mean condition factor of 1.98. Cohort condition increased steadily from age 0 through age 4. From age 4 through age 10 condition factors showed little variation with a range between 1.88-1.98. A total of 827 samples representing all years except 1992 were used to determine mean K factors for each year with all ages combined (Figure 21). Table 6 lists sample sizes by year. Ages were combined for each year to determine the population trend through the sampling time period. The 1998 sample had the lowest yearly mean condition factor of 1.60. The 1996 sample had the highest mean condition factor of 2.24. In 1988 the population showed a slight peak in condition followed by two years of decreasing factors. Condition began rising steadily from 1991 until a second peak was reached in 1996. In 1997 and 1998, fish condition steadily decreased while the trend began an upswing in 1999 and 2000. Overall, there are no clear temporal population trends in condition rates.

Growth Characteristics

The body length-scale radius relationship was computed for all years except 1986 and 1992. Scale samples were not taken during either of these sample years. The regression lines with associated equations and r-squared values for these relationships are shown in Figures 22-34. In all years, the relationship was represented by a straight line. R-squared values ranged from 0.66 (1997) to 0.97 (1996, 1999). The r-squared values for the 1988, 1989, 1997, and 2000 sample were below 0.80. The 1994 sample year had an r-squared value of 0.80. The remaining sample years had r-squared values exceeding 0.90. All

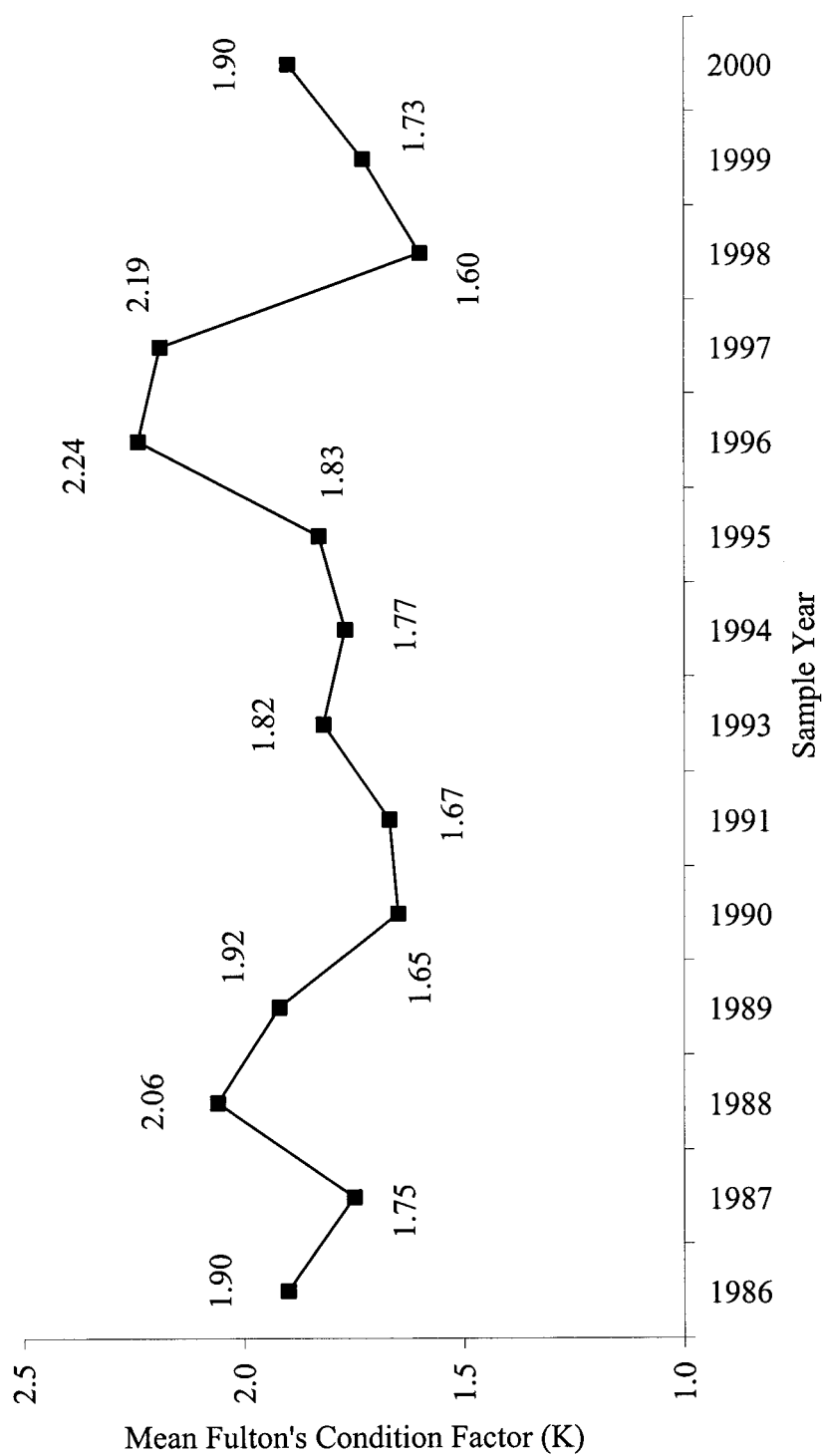


Figure 21. Mean Fulton's condition factor (K) for each sample year with ages combined of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1986-2000.

Table 6. Sample sizes used to determine mean Fulton's condition factor (K) for each sample year with ages combined of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1986-2000.

Year	Number of Fish Sampled
1986	67
1987	109
1988	92
1989	92
1990	47
1991	17
1993	93
1994	33
1995	38
1996	11
1997	28
1998	133
1999	6
2000	61

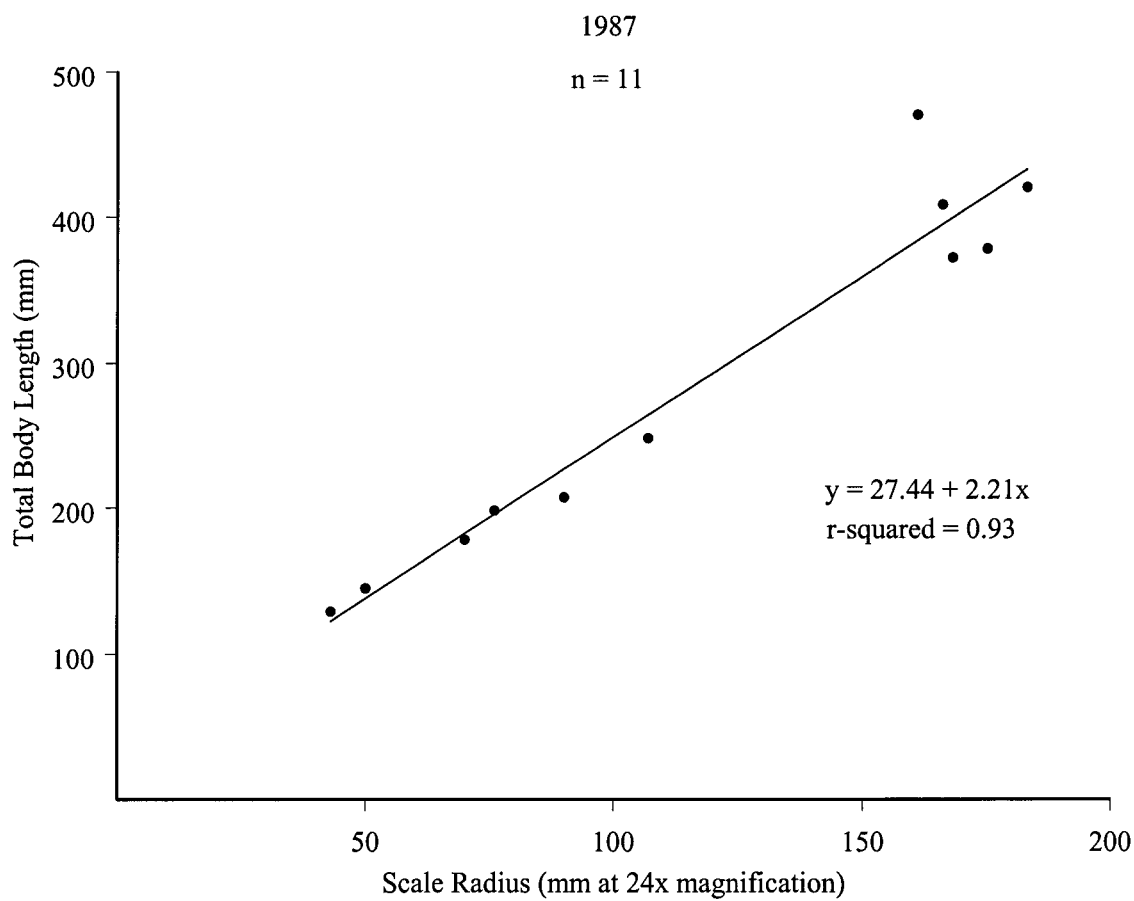


Figure 22. The relationship between total body length (mm) and scale radius (mm) of largemouth bass sampled in 1987 at Freshwater Lagoon, Humboldt County, California.

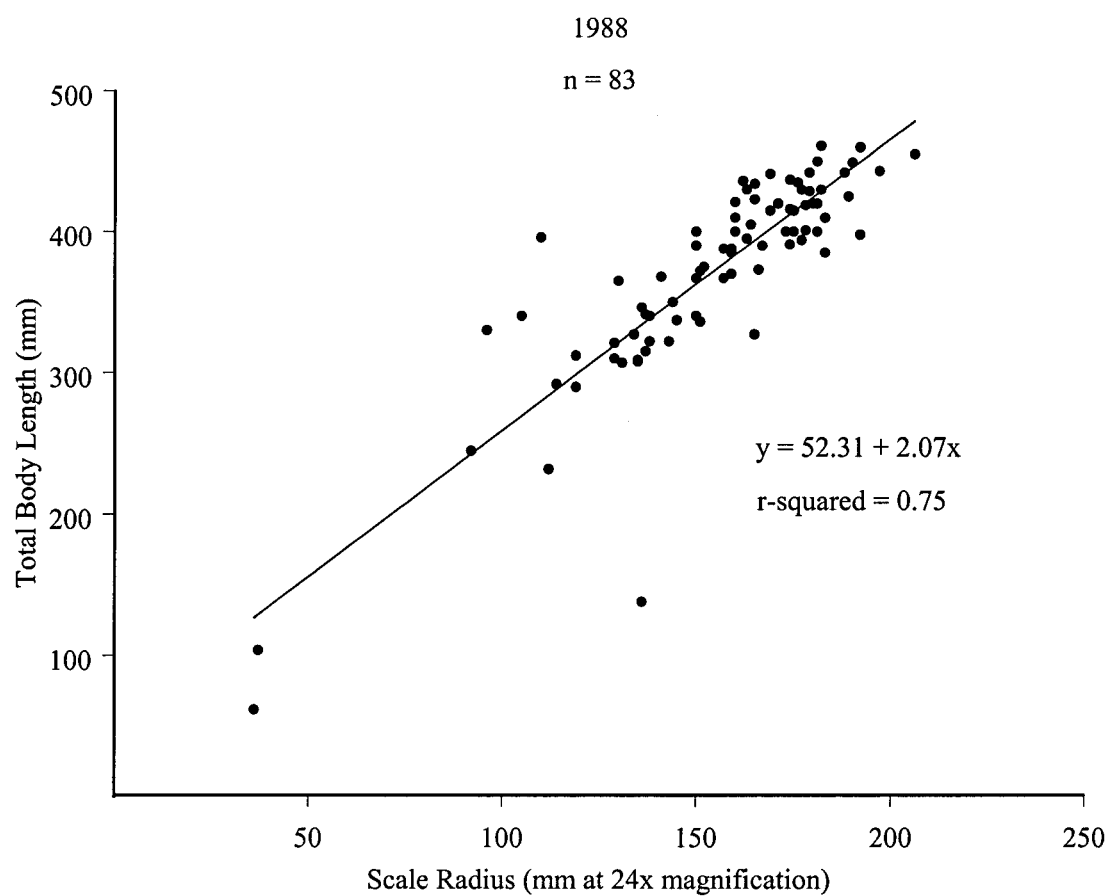


Figure 23. The relationship between total body length (mm) and scale radius (mm) of largemouth bass sampled in 1988 at Freshwater Lagoon, Humboldt County, California.

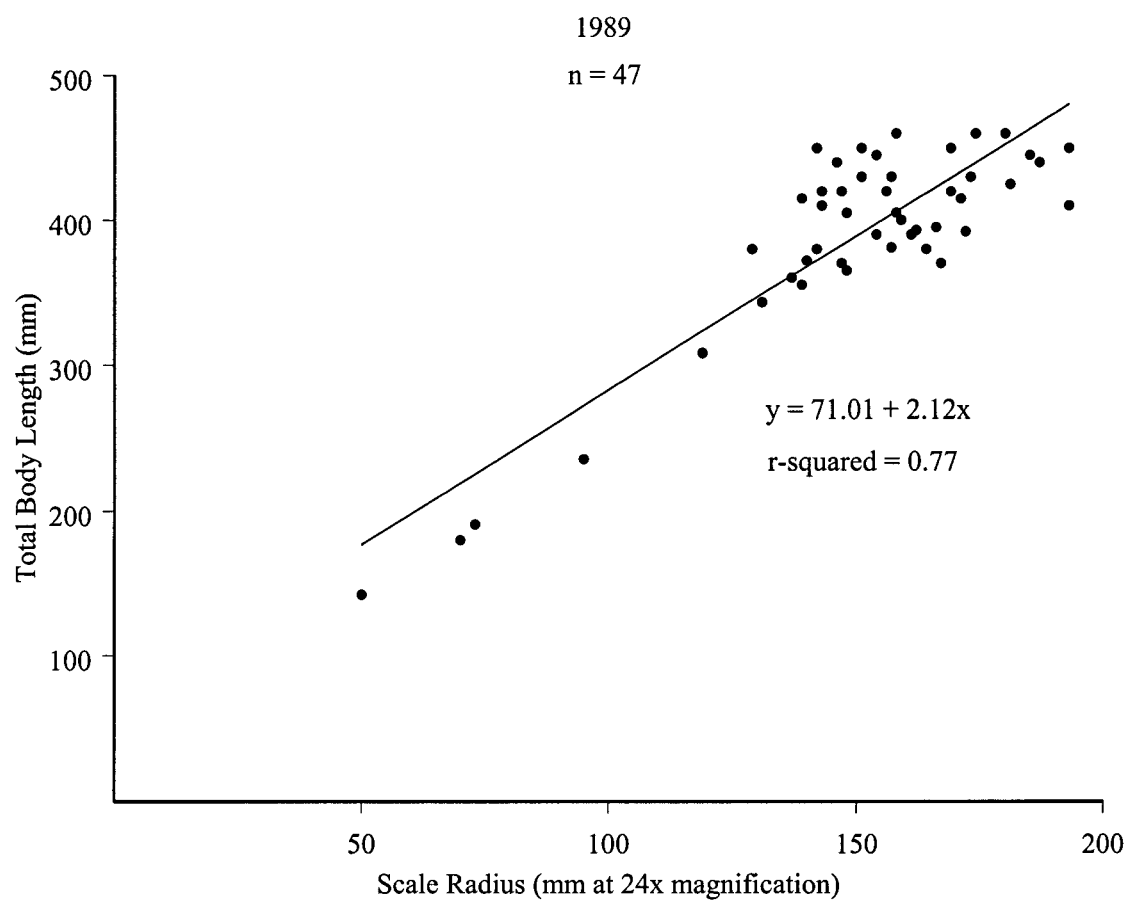


Figure 24. The relationship between total body length (mm) and scale radius (mm) of largemouth bass sampled in 1989 at Freshwater Lagoon, Humboldt County, California.

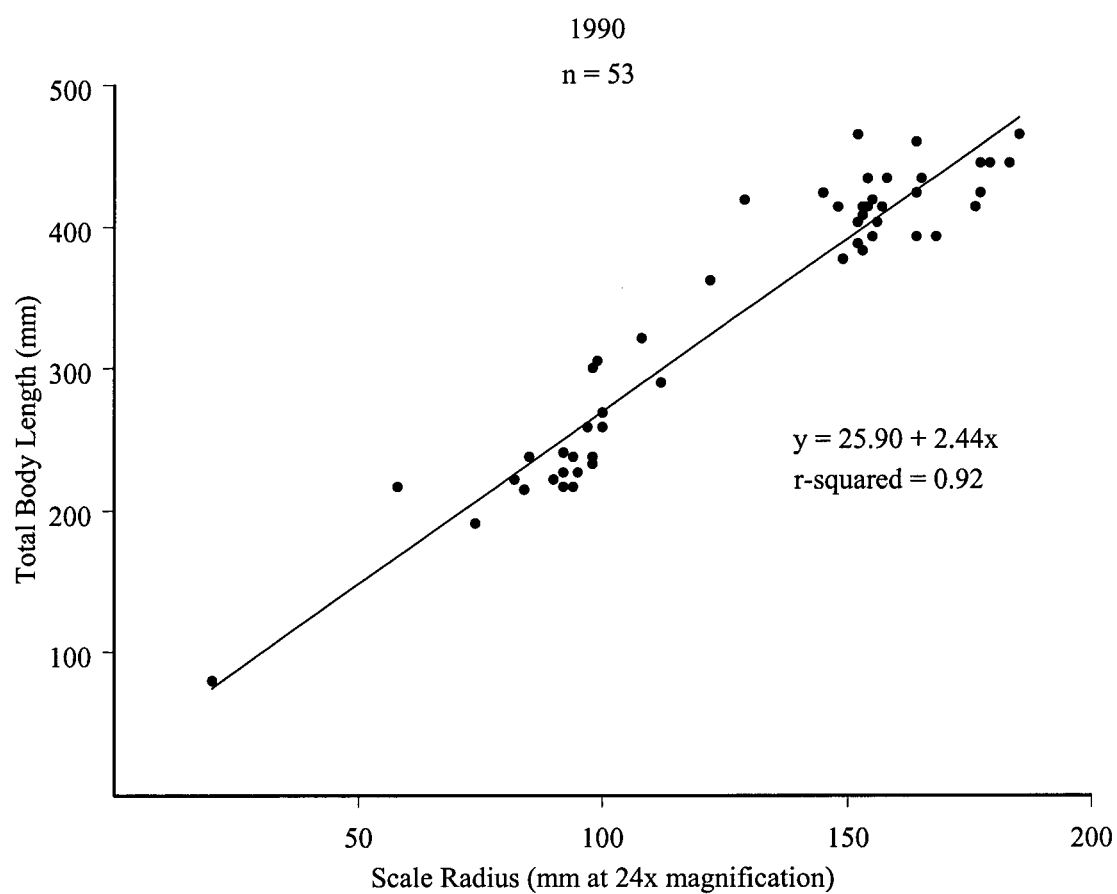


Figure 25. The relationship between total body length (mm) and scale radius (mm) of largemouth bass sampled in 1990 at Freshwater Lagoon, Humboldt County, California.

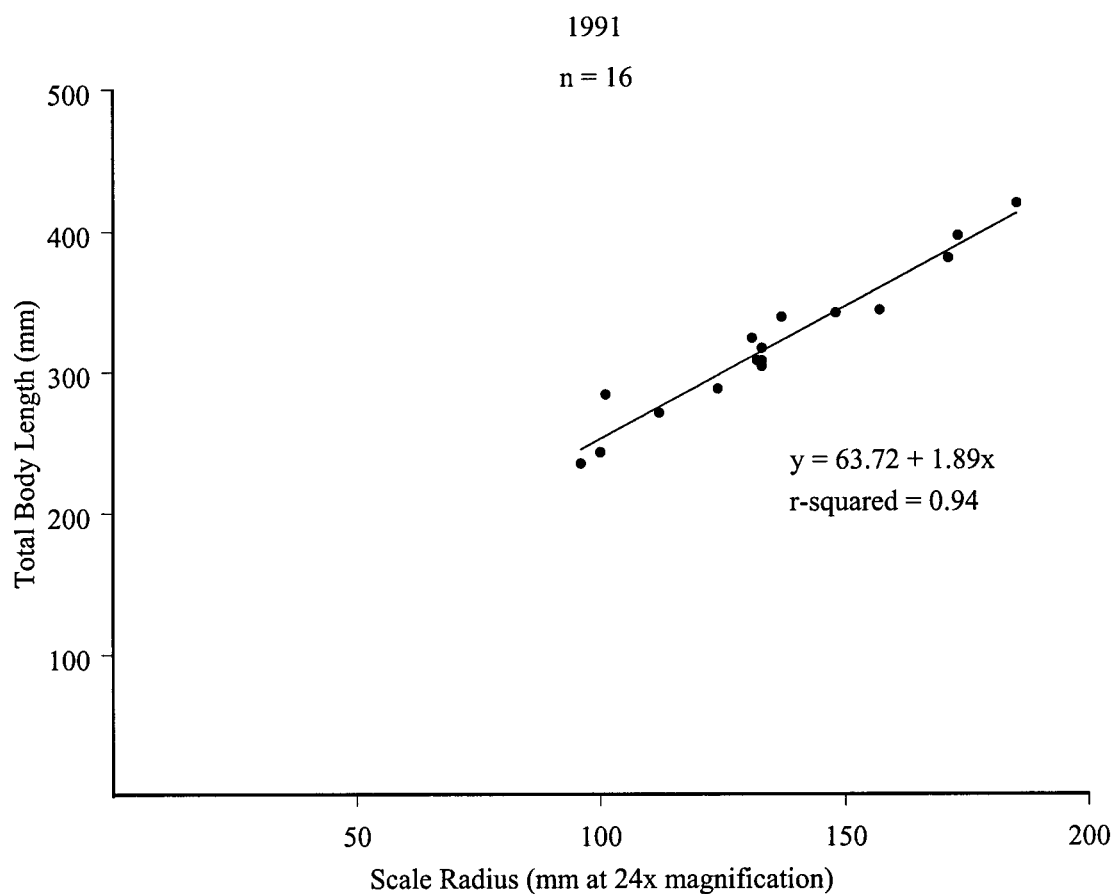


Figure 26. The relationship between total body length (mm) and scale radius (mm) of largemouth bass sampled in 1991 at Freshwater Lagoon, Humboldt County, California.

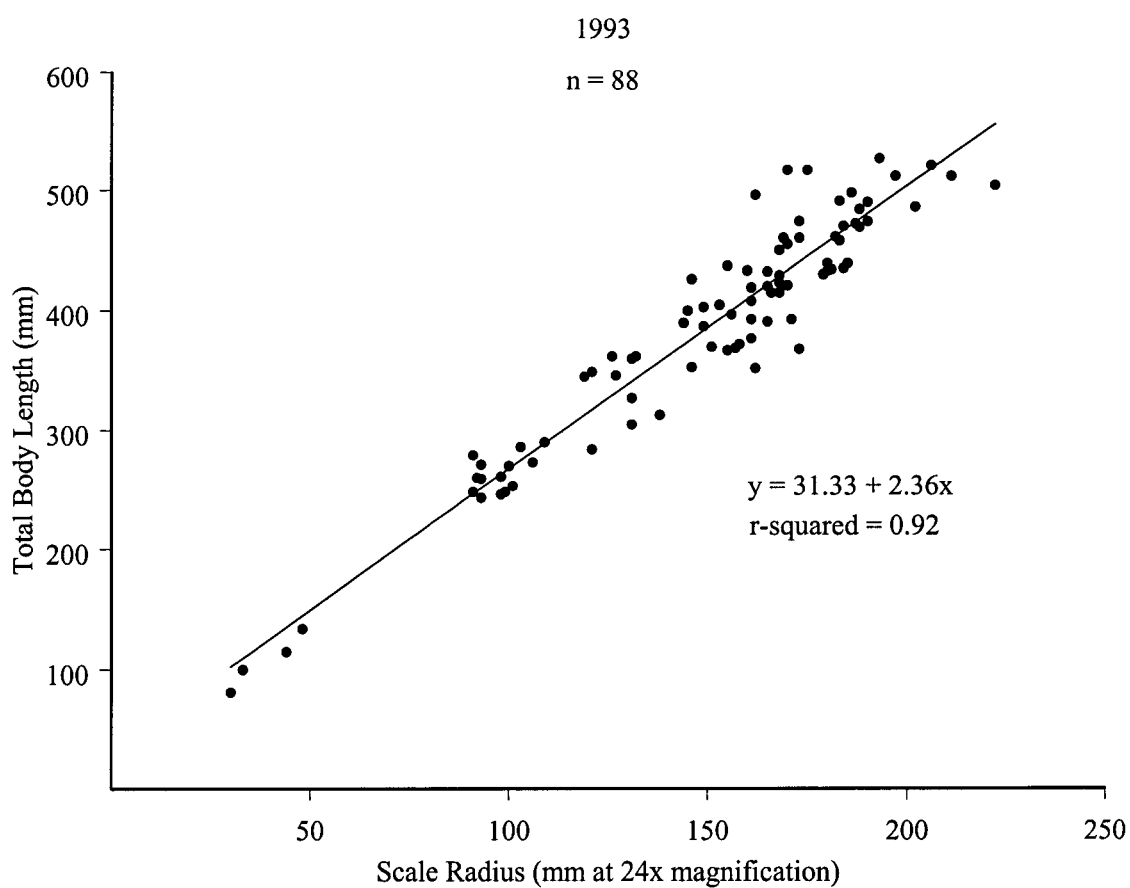


Figure 27. The relationship between total body length (mm) and scale radius (mm) of largemouth bass sampled in 1993 at Freshwater Lagoon, Humboldt County, California.

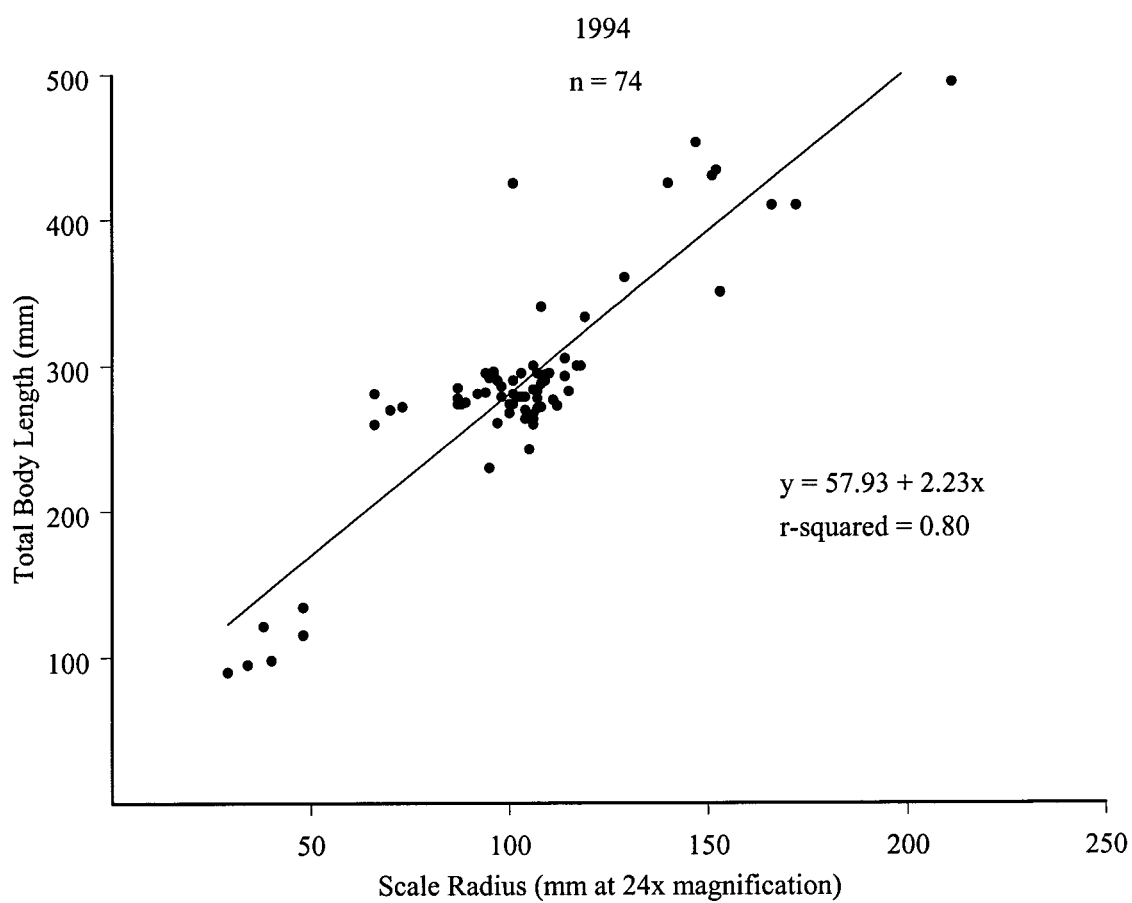


Figure 28. The relationship between total body length (mm) and scale radius (mm) of largemouth bass sampled in 1994 at Freshwater Lagoon, Humboldt County, California.

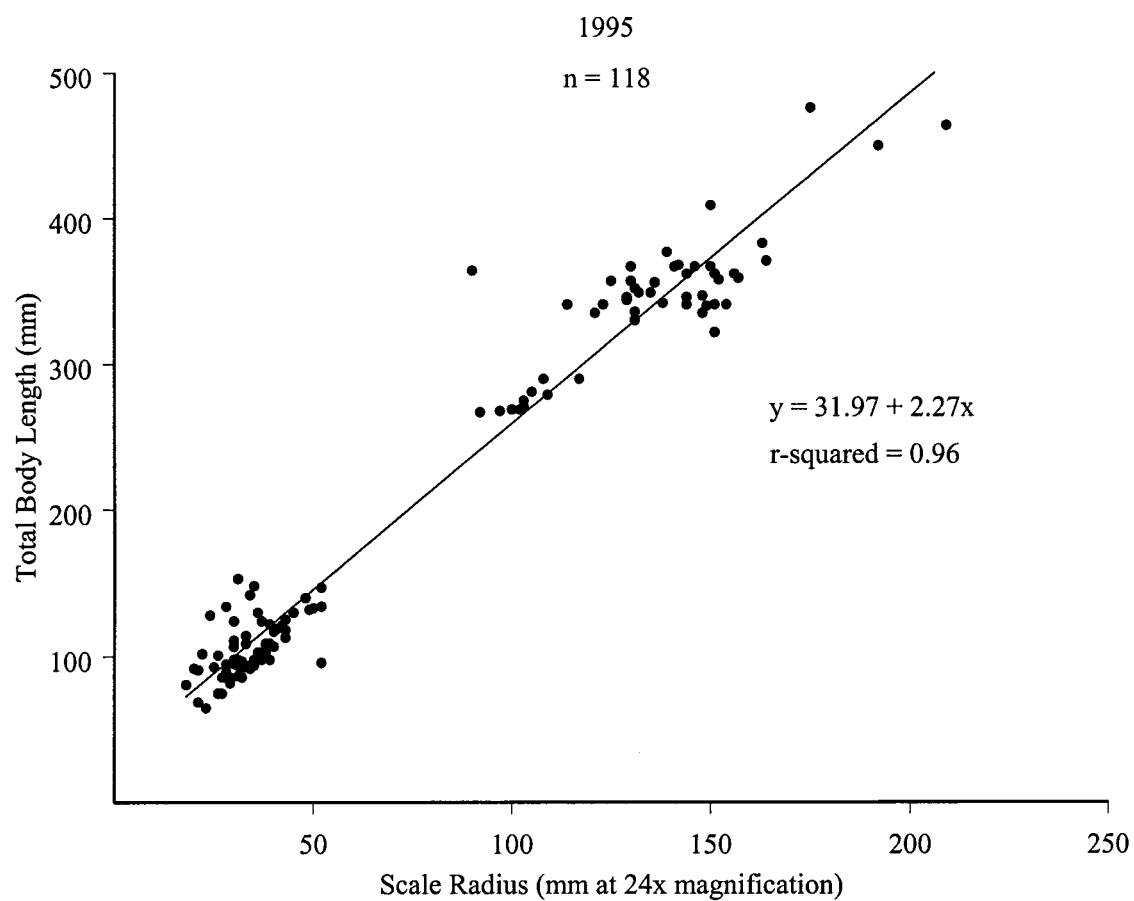


Figure 29. The relationship between total body length (mm) and scale radius (mm) of largemouth bass sampled in 1995 at Freshwater Lagoon, Humboldt County, California.

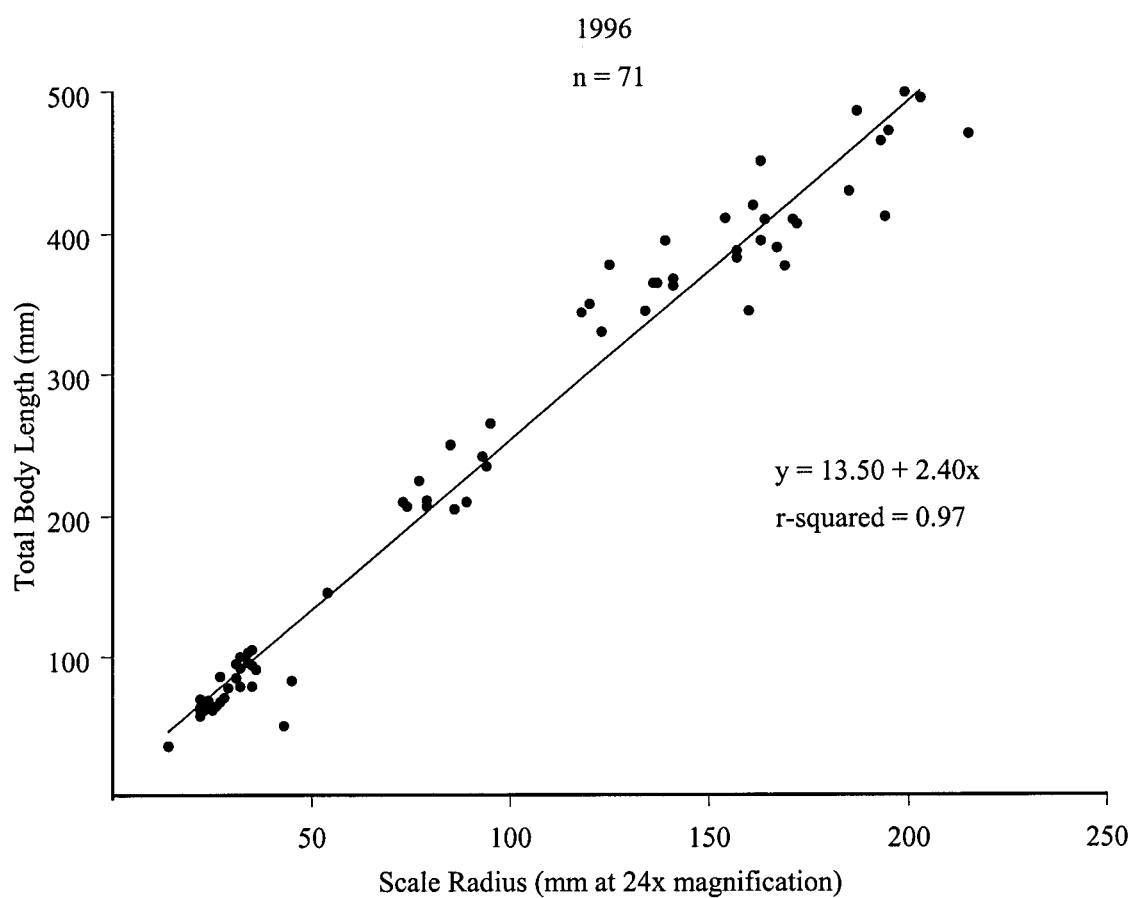


Figure 30. The relationship between total body length (mm) and scale radius (mm) of largemouth bass sampled in 1996 at Freshwater Lagoon, Humboldt County, California.

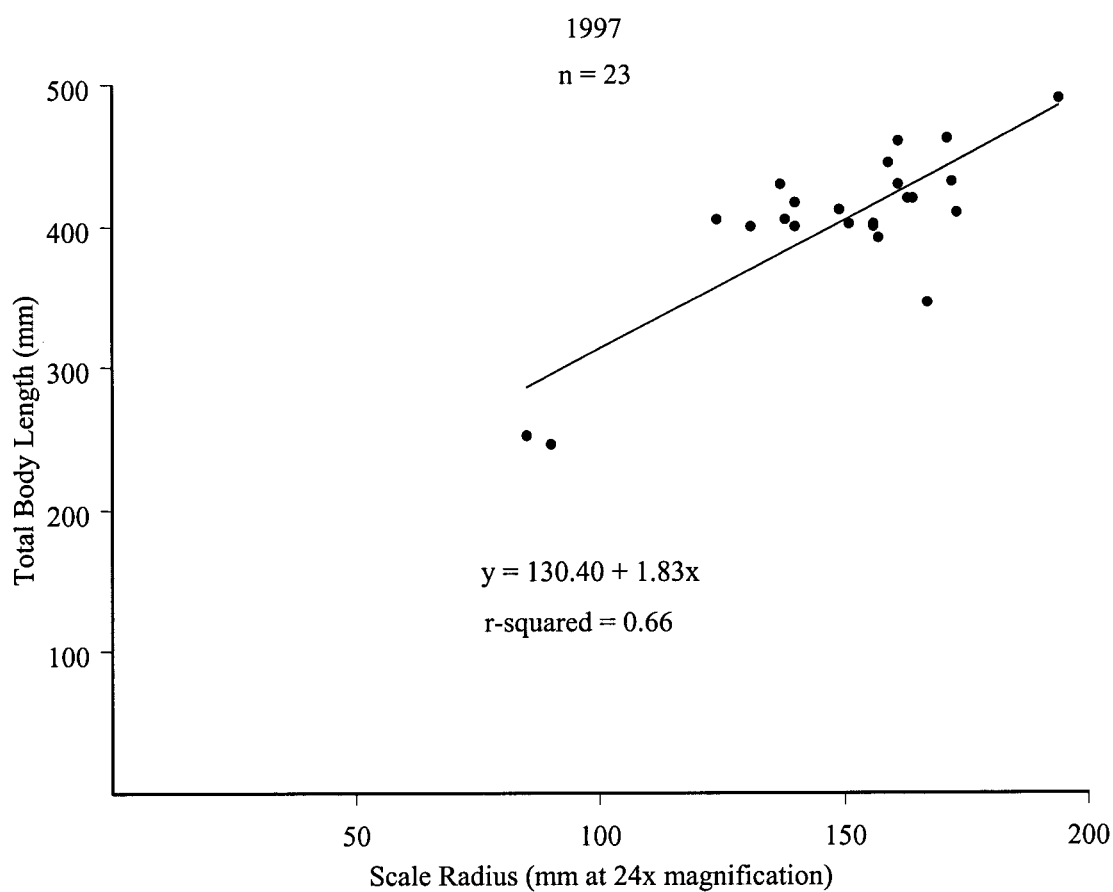


Figure 31. The relationship between total body length (mm) and scale radius (mm) of largemouth bass sampled in 1997 at Freshwater Lagoon, Humboldt County, California.

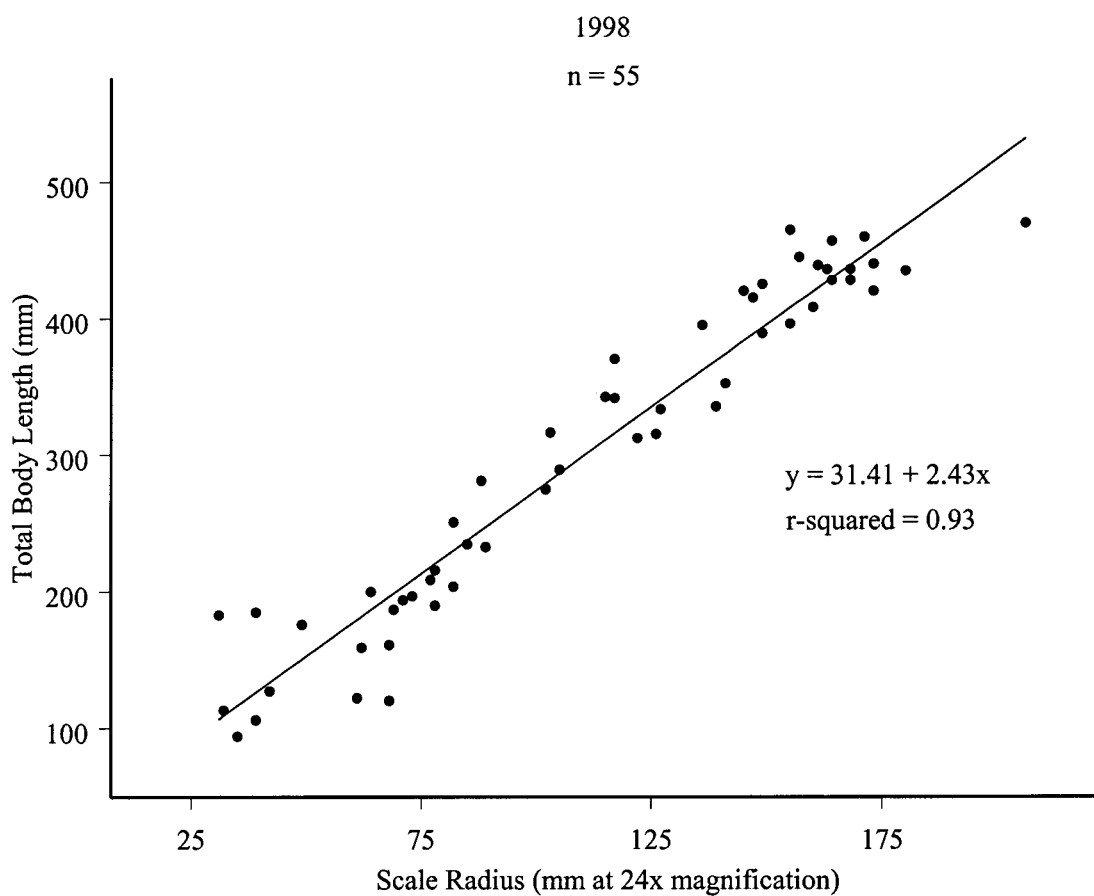


Figure 32. The relationship between total body length (mm) and scale radius (mm) of largemouth bass sampled in 1998 at Freshwater Lagoon, Humboldt County, California.

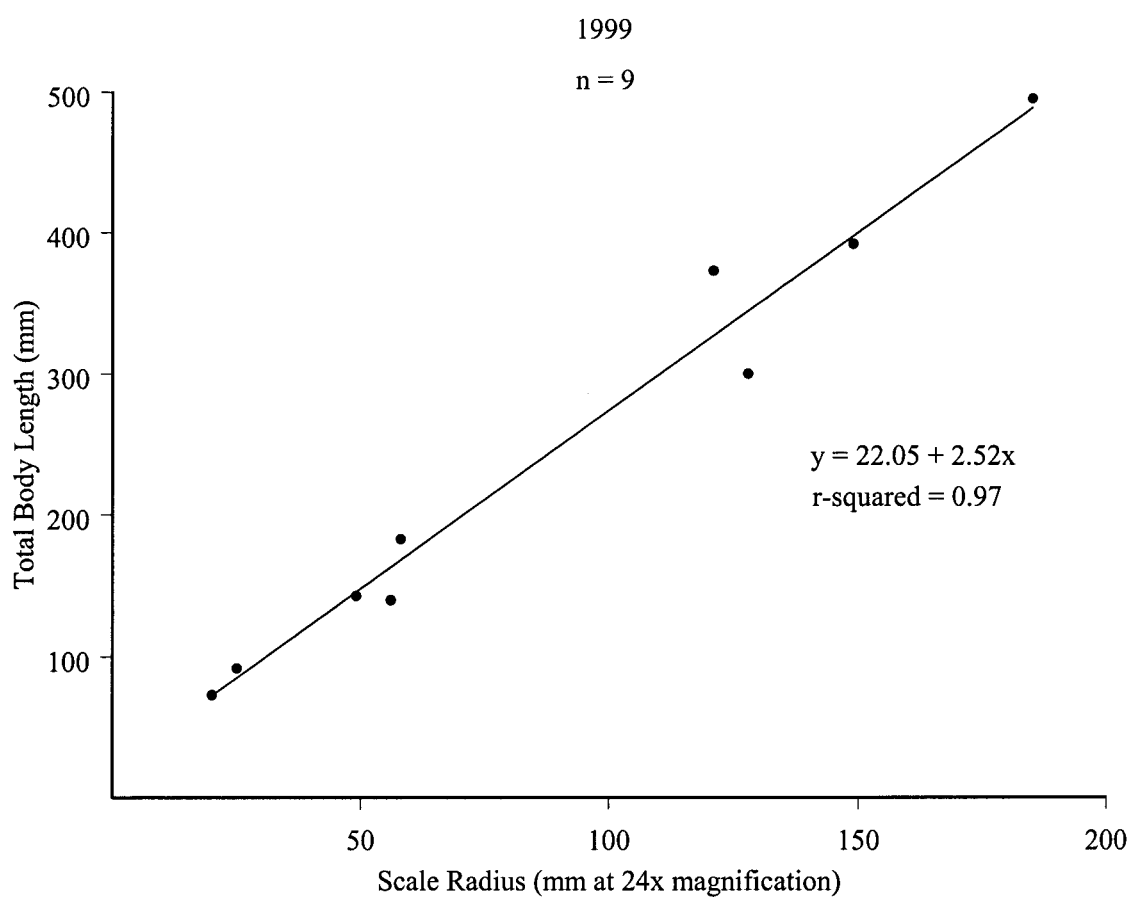


Figure 33. The relationship between total body length (mm) and scale radius (mm) of largemouth bass sampled in 1999 at Freshwater Lagoon, Humboldt County, California.

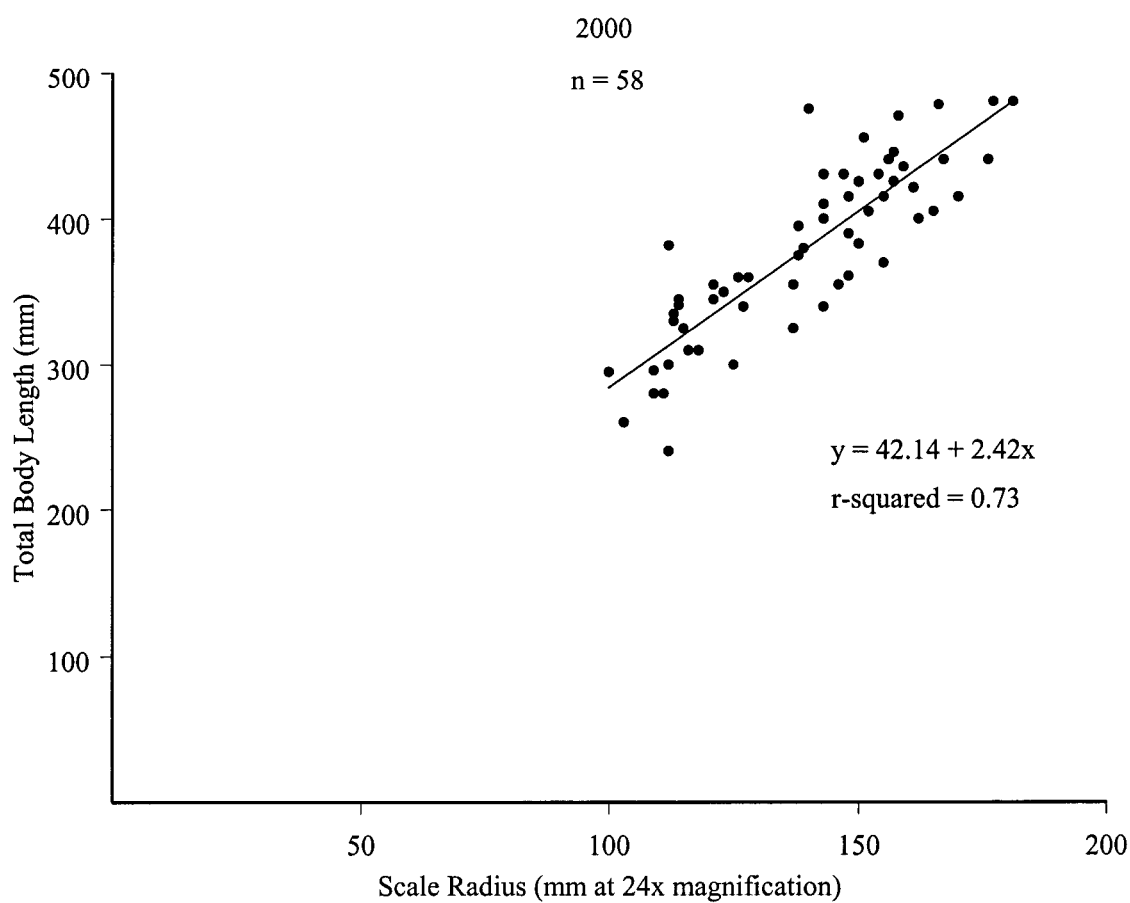


Figure 34. The relationship between total body length (mm) and scale radius (mm) of largemouth bass sampled in 2000 at Freshwater Lagoon, Humboldt County, California.

sample year regressions having r-squared values below 0.80 had unequal representation of fish lengths with the exception of the 2000 sample year. In particular, there was a lack of shorter fish in those samples. Sample years having a high correlation had much more equal representation of fish lengths. When all sample years were combined the r-squared value was 0.93 (Figure 35). However, this model was not used in back-calculations because ANCOVA revealed unequal slopes among sample years ($F = 1.769$, $p = 0.496$) and data could not be pooled.

The calculated mean total length (mm) at age for each year class and associated standard deviations are shown in Table 7. There are 18 year classes present in the dataset, the earliest 1979 and the latest 1999. The growth history of the 1999 year class could not be determined because only fish aged 0 were sampled from this birth year. The 1979, 1987, and 1998 year classes were represented by small sample sizes (1-3) and were not used in assessing growth trends. The highest mean total length for ages 1 through 4 occurred within the 1990, 1992, 1994, and 1994 year class, respectively. The lowest mean total length for ages 1 through 4 occurred within the 1996, 1985, 1997, and 1989 year class, respectively. The highest mean total length for ages 5 and 6 occurred within the 1985 year class. The lowest mean total length for age 5 occurred within the 1988 year class and for age 6 within the 1988, 1991, and 1993 year classes.

Consecutive years having the highest and lowest mean total lengths were identified to determine temporal growth trends within each cohort. The highest mean total lengths for ages 1 through 3 occurred within the 1992-1994 year classes. The highest mean total

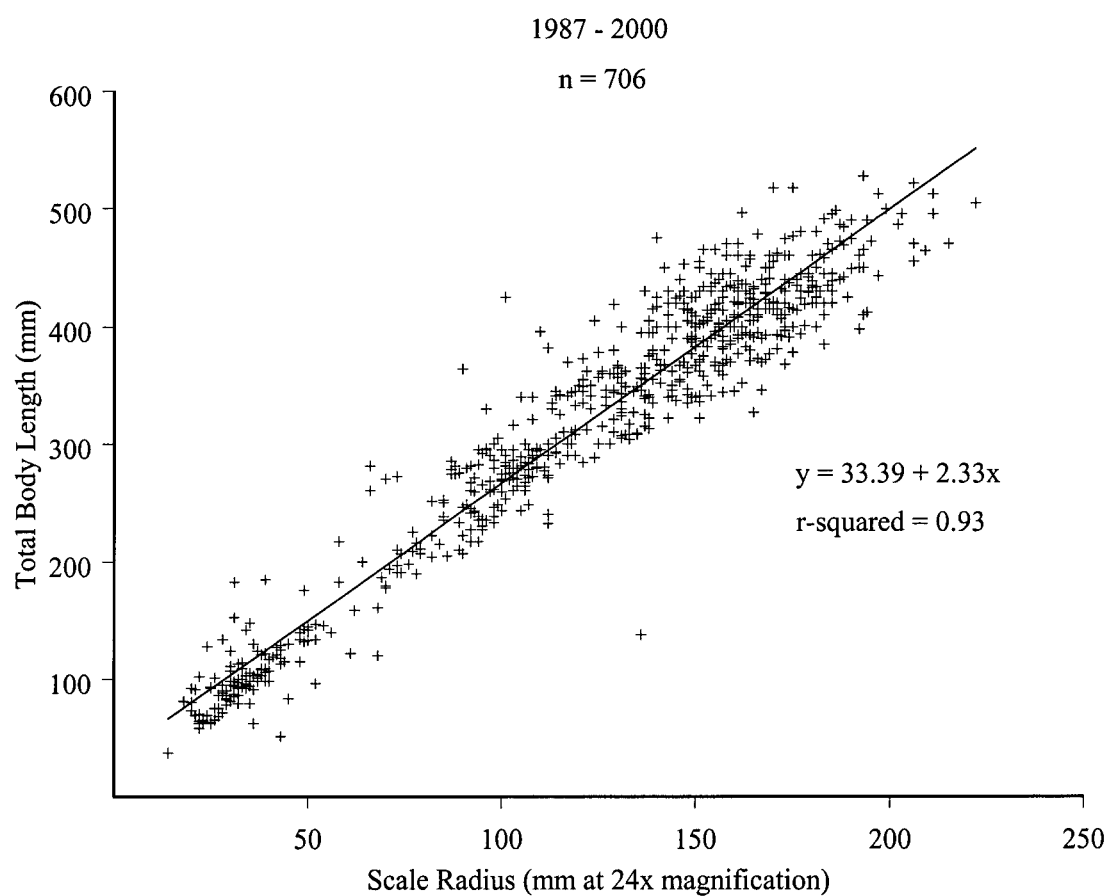


Figure 35. The relationship between total body length (mm) and scale radius (mm) of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1987–2000.

Table 7. Calculated mean total length (mm) at age for each year class of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1987-2000. Standard deviations in parentheses.

Birth Year	n	Annulus							
		1	2	3	4	5	6	7	8
1979	1	133	345	397	417	431	447	458	
		-	-	-	-	-	-	-	
1983	72	99	241	348	389	418	429		
		(14.8)	(21.9)	(18.4)	(19.4)	(19.9)	(18.3)		
1984	31	111	257	355	390	407	435	454	470
		(25.4)	(27.6)	(21.1)	(25.3)	(22.5)	(27.0)	(23.4)	(22.9)
1985	64	100	225	326	380	437	461	483	
		(24.7)	(33.6)	(32.7)	(34.2)	(21.5)	(23.9)	(23.8)	
1986	26	106	227	332	380	414	440	425	452
		(34.7)	(38.6)	(26.9)	(29.8)	(29.9)	(28.0)	(19.5)	(14.6)
1987	1	89	228	335	400	447			
		-	-	-	-	-			
1988	59	99	243	358	395	402	426	447	463
		(30.0)	(32.2)	(26.1)	(26.3)	(12.2)	(16.2)	(20.2)	(21.6)
1989	30	96	245	344	379	407	432	451	
		(29.9)	(30.4)	(23.0)	(27.8)	(20.4)	(21.9)	-	
1990	16	151	267	364	394	412	452		
		(35.3)	(36.3)	(31.8)	(41.7)	(32.5)	-		
1991	19	102	256	349	398	428	426		
		(42.7)	(35.6)	(44.7)	(52.3)	(47.6)	-		
1992	10	134	304	352	397	429			
		(49.3)	(43.9)	(33.0)	(26.7)	-			
1993	152	130	293	368	396	412	426		
		(30.6)	(27.1)	(26.9)	(31.6)	(35.3)	(38.3)		
1994	22	137	298	370	411	436			
		(20.7)	(33.6)	(29.4)	(25.4)	(28.3)			
1995	29	98	233	351	389				
		(29.3)	(41.8)	(25.5)	(18.2)				
1996	17	91	229	333					
		(20.5)	(37.2)	(22.5)					
1997	41	118	236	291					
		(42.3)	(45.7)	(50.7)					
1998	3	58							
		(6.2)							
Mean S.D.		33.5	40.6	30.8	26.9	25.6	27.5	29.1	19.7
									13.8

total length for age 4 occurred within the 1991-1994 year classes. Fish aged 1 through 4, on average, grew to longer lengths from 1993-1998. The lowest mean total lengths for ages 1 through 4 occurred within the 1983-1986 year classes. Fish aged 1 through 4, on average, grew less from 1984-1990. The highest mean total lengths for age 5 occurred within the 1991-1994 year classes and the lowest within the 1986-1990 year classes. Age 5 fish, on average, were longer from 1996-1999 and shorter from 1991-1995. The highest mean total lengths for age 6 occurred within the 1983-1986 year classes and the lowest the 1988-1991 year classes. Age 6 fish, on average, were longer from 1989-1992 and shorter from 1994-1997. Fish aged 1 through 5, on average, reached longer lengths later in the study period while age 6 fish reached longer lengths earlier in the study period. Trends were difficult to identify for fish aged 7 through 9 because few birth years had fish surviving to these ages. However, in all of these ages greatest mean lengths occurred earlier in time. This suggests growth for fish aged 7 through 9 is declining with time.

Mean total length for ages 1 through 3 showed the most variation. Age 2 fish showed the highest variation among cohorts while age 9 showed the least.

Table 8 lists calculated mean total length, observed total length, and minimum and maximum length ranges. Calculated weighted and unweighted mean total lengths were identical for each cohort. The greatest difference between calculated and observed mean total length was with age 1 and 2 fish. Differences were slight for age 3 through age 6.

Table 8. Calculated mean total length, observed length, range, and mean annual growth increment (mm) of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1987-2000. Inches in parentheses.

	<u>Age</u>									
	1	2	3	4	5	6	7	8	9	10
Calculated weighted mean total length at age	112 (4.4)	254 (10.0)	347 (13.7)	390 (15.4)	418 (16.5)	438 (17.2)	463 (18.2)	463 (18.2)	469 (18.5)	
Calculated mean total length at age	112 (4.4)	254 (10.0)	347 (13.7)	390 (15.4)	418 (16.5)	438 (17.2)	463 (18.2)	463 (18.2)	469 (18.5)	
Mean observed total length at age	244 (9.6)	295 (11.6)	344 (13.5)	389 (15.3)	417 (16.4)	437 (17.2)	450 (17.7)	486 (19.1)	481 (18.9)	488 (19.2)
Range minimum	80 (3.1)	138 (5.4)	240 (9.4)	333 (13.1)	350 (13.8)	388 (15.3)	412 (16.2)	451 (17.8)	461 (18.1)	470 (18.5)
Range maximum	333 (13.1)	383 (15.1)	430 (16.9)	442 (17.4)	517 (20.4)	495 (19.5)	496 (19.5)	527 (20.7)	512 (20.2)	499 (19.6)
Calculated weighted mean annual growth increment at age	112 (4.4)	143 (5.6)	97 (3.8)	40 (1.6)	28 (1.1)	21 (0.8)	17 (0.7)	19 (0.7)	12 (0.5)	
Calculated mean annual growth increment at age	112 (4.4)	142 (5.6)	94 (3.7)	40 (1.6)	26 (1.0)	21 (0.8)	20 (0.8)	20 (0.8)	15 (0.6)	

Differences for the remaining cohorts were moderate. For all cohorts, there were considerable differences between minimum and maximum lengths. Much overlap occurred in total length among cohorts. Overlap in total length occurred through three successive age groups for ages 1, 2 and 4. Total length for age 3 overlapped with ages 4 through 7. Overlap in total length was present throughout ages 5 through 10.

Calculated mean annual growth increment at each age is shown in Table 8. Aged 2 fish showed the highest annular growth and aged 9 fish showed the least. Annular growth from age 1 through age 3 was very rapid. A sharp decrease in growth rate occurred between age 3 and 4. Differences in annular growth were small from age 5 through age 9. Annular growth decreased with increased age in all except aged 2 fish.

The calculated mean annual growth increment at age for each year of growth is shown in Table 9. Temporal trends in annular growth increments are few among cohorts. Age 1 and 2 fish showed greater annular growth, on average, from 1993 through 1994 than they did from 1984 through 1992. This pattern was reversed for age 3 fish when greater annular growth occurred from 1986 through 1992. There are no clear temporal trends for fish aged 4 through 9. There are also no clear trends for any particular year. Greatest growth among cohorts occurred in many different years as did the lowest growth. There were three instances where successive growth was negative. In each case sample size was very small (1-3).

Table 9. Calculated mean annual growth increment (mm) at age of largemouth bass sampled at Freshwater Lagoon, Humboldt County, California, 1987-2000. The staggered line follows the growth of the 1984 year class. Sample sizes in parentheses.

		Year of Growth																				n	
Age		80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	
1	133 (1)				99 (72)	111 (31)	100 (64)	106 (26)	89 (1)	99 (59)	96 (30)	151 (16)	102 (19)	102 (10)	134 (152)	130 (22)	137 (29)	98 (17)	91 (41)	118 (3)	58		593
2	212 (1)				142 (72)	146 (31)	125 (64)	121 (23)	139 (1)	144 (42)	149 (30)	116 (11)	154 (18)	170 (8)	163 (90)	161 (12)	135 (16)	118 (23)					458
3	52 (1)					107 (72)	98 (31)	101 (51)	105 (16)	107 (1)	115 (32)	99 (22)	97 (2)	93 (5)	48 (8)	75 (48)	72 (11)	104 (10)	104 (13)	55 (8)			331
4	20 (1)						41 (70)	35 (26)	54 (29)	48 (14)	65 (1)	37 (29)	35 (11)	30 (2)	49 (4)	45 (4)	28 (23)	41 (8)	38 (9)				231
5	14 (1)							29 (40)	17 (17)	57 (12)	34 (14)	47 (1)	7 (7)	28 (6)	18 (2)	30 (3)	32 (1)	16 (10)	25 (8)				122
6	16 (1)								11 (10)	28 (4)	24 (12)	26 (14)		24 (6)	25 (5)	40 (1)	-2 (1)	14 (9)					63
7						11 (1)					19 (4)	22 (12)	-15 (3)		21 (5)	19 (1)							26
8												16 (4)		27 (3)		16 (3)							10
9														12 (1)	20 (3)	-14 (1)							5
n	1	1	1	1	73	104	168	191	141	132	103	109	112	52	182	139	101	70	85	65	8		1839

Age

DISCUSSION

Scales have traditionally been used to determine age and growth parameters of largemouth bass. This method is desirable because fish are not sacrificed, large samples can be obtained efficiently, and processing of structures is relatively simple and requires little time. However, many studies have demonstrated that age determination using scales is unreliable and inaccurate and may lead to erroneous conclusions (Prather 1967, Carlander 1987).

The quality of age and growth data rests on the accuracy of age determinations. It is therefore necessary to verify and validate methods used for age assignment (DeVries and Frie 1996). Verification refers to the precision of age assignment between multiple readings. In this study, scales were used to assign ages to samples. Precision of age assignment was measured as the agreement rate between two readings. This process revealed a high level of precision in age assignment.

Validation refers to the accuracy of age assignment. True validation of assigned ages can only be accomplished through comparisons with known-aged fish. This process is costly and extremely time consuming. Many authors have suggested alternative means of validation. These methods include using length frequency distributions, comparison of age assignments using different structures, correlation between age and length, similarity between calculated lengths of year classes sampled in different years, and similarity between observed and calculated lengths for each cohort (Hile 1941, DeVries and Frie

1996). All of these methods were used to increase confidence in the accuracy of age determinations made in this study.

Length frequency distributions were ineffective in correlating length to age beyond age 2. This is often the case with length frequency distributions (Perry and Tranquilli 1984, Crumpton et al. 1988, DeVries and Frie 1996). Factors enhancing mode differentiation include large samples with equal representation of fish lengths, brief spawning period, and uniform, rapid growth among individuals within age classes (DeVries and Frie 1996). Largemouth bass scales from Freshwater Lagoon revealed, in many years, there were several different and distinct groups in length measurement from the focus to the first annulus. This suggests that an extended spawn occurs in certain years at the lagoon. Largemouth bass were observed guarding beds and engaging in spawning behavior from late March through July in 2002. This prolonged spawning period may account for the high variation in lengths and overlap in length ranges within and among cohorts (Table 8). This characteristic, combined with relatively slow growth rates of fish greater than 4 years old (Table 8), likely accounted for the limited amount of information gained from length frequency analysis.

Sagittal otoliths were chosen as a means of validating the accuracy of age assignments derived from scales. Formation of annual growth rings has been verified in otoliths of largemouth bass (Taubert and Tranquilli 1982). Growth histories of otoliths are generally regarded as representing the true age of fish. This is because otoliths continue to grow as fish age and they are not reabsorbed during periods of stress (Campana and Neilson 1985, Beamish and McFarlane 1987). Therefore, otoliths provide a more reliable and accurate

means of interpreting annual growth, particularly with older fish (Boucher 1998, Besler 1999). The 75% between structure agreement rate of age assignment reported for this study was higher than those reported for other studies (Boucher 1998, Besler 1999).

In this study, there was high precision of age assignment within and between structures, back calculations showed that ages were consistent with fish length (Table 7), calculated lengths were similar within cohorts across all sample years (Table 7), and observed lengths were very close to calculated lengths for all cohorts (Table 8). These results effectively gave a high level of confidence in (1) the accuracy of utilizing scales to assign fish age, (2) my ability to consistently identify true annular marks, and most importantly, (3) the results of this study, based on interpretation of growth histories of scales, likely representing true population parameters.

Evaluating changes in age structure over time provides information about such things as recruitment and mortality. In any study, sampling bias can strongly influence conclusions and caution needs to be taken. Valid inferences of population structure rely on equal vulnerability of capture across fish lengths for chosen sampling techniques (Weithman et al. 1980). It has been well established that electrofishing is size selective towards larger individuals (Reynolds 1996). In addition, larger individuals are more visible to personnel netting stunned fish. This can introduce additional size bias (Twedt et al. 1992). It is difficult to assess the degree of influence sampling bias had on the yearly age structures (Figures 6-18) in this study because temporal trends are clearly evident. It seems unlikely these trends are the result of random chance. For example, the age structure of the 1988 sample consisted mostly of 3 to 5 year old fish (82%).

Recruitment of these cohorts was high in the following two years. The 1989 sample consisted largely of 4 to 6 year old fish (85%) and the 1990 sample of 5 to 7 year old fish (54%). This trend continues through 1993 as the age structure consistently skews towards a larger percentage of older fish. Following 1993, the age structure shifts towards a higher percentage of younger fish. The number of old fish present peaked in 1993. Largemouth bass populations typically experience such a peak 12-15 years after introduction. Largemouth bass were introduced into Freshwater Lagoon in the mid to late-1970's (personal communication, anonymous 2002). Thus, 1993 is a likely candidate year for this type of peak to occur.

The influence of sampling bias is probably less of a factor when the age structure for all sample years combined (Figure 19) is considered because all age classes (and therefore lengths) are well represented. Recruitment from one age class to the next is never 100% due to mortality. The shape of an age structure curve should show decreasing numbers with increased age. Recruitment and mortality are reflected in the relative decrease in numbers between cohorts. Figure 19 shows that recruitment, through the time period of this study, is high among all cohorts. Thus, mortality is not excessive. The number of fish sampled that were 1 and 5 years old show their numbers increased from the preceding age class. These age classes were disproportionately sampled because it is impossible to realize gains in fish numbers from younger to older age classes provided samples are representative of the population. This is a result of sampling bias associated with electrofishing or chosen sample dates. The largemouth bass population at Freshwater Lagoon is well balanced and stable with good recruitment through all cohorts.

The Relative Stock Density (RSD) index developed by Gabelhouse (1984) was used to assess stock structure in terms of length. The Proportional Stock Density (PSD, Anderson 1976) index has traditionally been used to do this. Stock structure assessment using RSD is more precise because three new size categories were developed to accompany categories established for PSD (Gabelhouse 1984). The RSD index is an excellent management tool because it offers a quick and easily understood means for managers to (1) gauge if management objectives are being met and (2) evaluate the quality of a fishery as perceived by the fishing public. In most years, the RSD values for Freshwater Lagoon were intermediate between management objective B and C (Table 4). The only reason the values for these years did not fall solely under objective C is because few fish recruited into the RSD M-T category. Fish recruited to memorable length only in 1993 when longer fish were present in greatest numbers. This finding is consistent with conclusions made based on age structure and lends credence to the idea that a population peak occurred in 1993. Populations typically experience a crash following peak years and this happened in 1994, the only year having RSD values falling under objective A. The quality of the largemouth bass fishery remained very stable from 1986 through 2000. This reflects desirable recruitment and mortality levels (Gabelhouse 1984). The stock structure at Freshwater Lagoon suggests management efforts are geared towards providing a moderate to low-density population in which largemouth bass are the primary focus with larger individuals desired (Table 4).

Harvest regulations at the lagoon have been effective in providing and maintaining a high quality fishery with good numbers of large fish present. However, the lagoon does

not produce trophy class fish. This is likely a function of a short growing season due to relatively low annual water temperatures. Many people speculate whether largemouth bass in Freshwater Lagoon prey on the large number of trout annually stocked by CDFG. It has been well documented in California waters that largemouth bass populations utilizing trout as primary prey items have high growth rates producing very large individuals. It seems likely if largemouth bass at Freshwater Lagoon consistently preyed on trout that trophy individuals would have been sampled considering the duration of this study.

The relationship between body length and weight, referred to as condition, has been used extensively in the assessment of fish populations. Condition is a measure of fish plumpness, fitness, or well-being (Anderson and Neuman 1996). Individuals that are heavier at a given length are perceived to be healthier. Condition indices are most often used to assess temporal changes in feeding rate or food supply, evaluate inter- and intra-specific interactions, determine the effects of environmental variables, and to compare between systems (Stucky and Klaassen 1971, Booth and Keast 1986, Bolger and Connolly 1989). Analysis and measurement of condition has been performed using a wide variety of statistical procedures and condition indices (Bolger and Connolly 1989, Cone 1989, Gutreuter and Childress 1990). Many condition indices are not statistically valid and do not reflect the true length–weight slope (Cone 1989, Bolger and Connolly 1989).

A review of the appropriate use and validity of condition indices was not an objective of this study. Fulton's condition factor (K) was used in this study because of its frequent

and widespread use (Bolger and Connolly 1989, Gutreuter and Childress 1990). Data was pooled for each age class across sample years (Figure 20). K values increased steadily from age 0 through age 3 then remained high with little variation through age 10. The increase in condition in the first four cohorts is likely the result of progressive growth enabling bass to more efficiently prey on the predominant size of prey available. Annual mean K values, with all ages combined, indicate higher variation (Figure 21). This is probably due to annual fluctuations in prey densities. The results from electrofishing showed large fluctuations in yearly numbers of wakasagi, three-spined stickleback, and prickly sculpin. These species are probably the primary prey item utilized by largemouth bass in Freshwater Lagoon. Mean K values among cohorts and among sample years are high and relatively stable with little variation. This is characteristic of a well balanced population having an ample and stable prey base.

Many studies conducted in California have reported K values for largemouth bass populations. However, most of them assigned K values to length ranges and not age classes. Therefore, I could not compare my results to these studies. Emig (1976) reported K values for largemouth bass aged 0 through 8 from Lake Berryessa, Napa County, California. Values from Freshwater Lagoon were higher than those from Lake Berryessa for all age classes except age 0 and age 2 (Table 10). Both systems had identical values for age 7. The mean K value when all age classes were combined is also higher for Freshwater Lagoon. Carlander (1977) reported K values for 50 systems from across the United States. Mean total length values were assigned to either length ranges

Table 10. Mean Fulton's condition factor (K) for ages 0 through 8 of largemouth bass at Freshwater Lagoon and Lake Berryessa, California. Sample sizes in parentheses.

Age	Freshwater Lagoon	Lake Berryessa
	present study	Emig 1976
0	1.38 (10)	1.48 (3)
1	1.60 (47)	1.45 (20)
2	1.65 (63)	1.67 (70)
3	1.86 (77)	1.70 (37)
4	1.98 (60)	1.76 (36)
5	1.94 (103)	1.83 (16)
6	1.98 (39)	1.68 (7)
7	1.90 (26)	1.90 (11)
8	1.97 (14)	1.88 (7)
Mean	1.81 (439)	1.70 (207)

or age classes depending on the particular study. The mean K value for Freshwater Lagoon was higher than those of 48 of the 50 studies Carlander referenced.

Sexual maturity in largemouth bass is more a function of length than age (Heidinger 1975). James (1939) reported that female bass reached sexual maturity at approximately 250 mm while male bass matured at slightly smaller sizes. Other authors have reported maturity in terms of age. Largemouth bass have successfully spawned at age 1 in Florida (Clugston 1964), North Carolina (Pardue and Hester 1967), and California (LaFaunce et al. 1964); at age 2 in Arkansas (Bryant and Houser 1971) and Oregon (Grenfell 1959); and at age 3 in Ontario (Stocek and McCrimmon 1965). Thus, it is likely the majority of largemouth bass are sexually mature by age 2 at Freshwater Lagoon. The formation of a false annulus immediately following the second annulus supports this conclusion. However, a small percentage of age 1 fish could conceivably spawn based on length range.

DeVries and Frie (1996) point out there is a difference between amount of growth and rate of growth. Amount of growth, or simply growth, refers to the length of fish at each age. Rate of growth refers to incremental growth between successive age classes. The mean calculated length and annual growth increment at age for various systems, including Freshwater Lagoon, are shown in Table 11. First year growth of largemouth bass at Freshwater Lagoon is relatively poor compared to other California systems and Lewis Smith Reservoir but better than that of bass from Pine Flat Reservoir and Oregon waters. This growth deficit is never compensated for and the amount of growth through all age classes at Freshwater Lagoon is less than those of other California waters and

Table 11. Growth histories of largemouth bass from various systems.

System and Reference	Age Class								
	1	2	3	4	5	6	7	8	9
Lake Shasta, CA	163 ¹	317	361	396	432	454	447	412	
Sak, 1989 ³	163 ²	154	44	35	36	22			
Folsom Lake, CA	154	285	351	398	433	466			
Tharratt, 1966 ³	154	131	66	47	35	33			
Lewis Smith Reservoir, AL	147	275	358	402	442	485	518	547	568
Webb and Reeves, 1975	147	128	83	44	40	43	33	29	21
Lake Berryessa, CA	136	250	312	369	408	438	467	486	
Emig, 1976	136	114	62	57	39	30	29	19	
Freshwater Lagoon, CA	112	254	347	390	418	438	463	463	469
Present study ⁴	112	143	97	40	28	21	17	19	12
Pine Flat Reservoir, CA	107	230	332	390	447	557	584		
Miller, 1971 ³	107	123	102	58	57	110	27		
Various waters, OR	76	175	259	318	361	401	439	470	498
Grenfell, 1962 ⁵	76	99	84	59	43	40	38	31	28

¹Mean total length (mm)²Annual growth increment (mm)³Originally reported as fork length, converted to total length here using 1.08 as suggested by Carlander (1977)⁴Annual growth increment reported as the calculated weighted mean, all others determined by subtracting successive length⁵Represents the mean of pooled data for 96 different systems in Oregon

Lewis Smith Reservoir. The exception to this is Lake Berryessa. Growth at age for fish from Freshwater Lagoon exceeds that for fish from Lake Berryessa from ages 2 through 5 and is similar from ages 6 through 8. The growth advantage bass from Freshwater Lagoon have over bass from Oregon waters is maintained through all cohorts. This is not the case for Pine Flat Reservoir. This system quickly compensates for early growth deficits and, by age 5, growth is much faster than that of bass from Freshwater Lagoon.

The growth rate of age 1 largemouth bass at Freshwater Lagoon is slower than all of the systems used for comparison except Pine Flat Reservoir and Oregon waters. This deficit is quickly compensated for and at age 2 only Lake Shasta bass exhibit a faster rate of growth than that of bass from Freshwater Lagoon. This accelerated rate of growth is maintained at age 3 when only Pine Flat Reservoir exceeds Freshwater Lagoon. The growth rate of largemouth bass at Freshwater Lagoon decreases sharply at age 4. From ages 5 through 9 they are the slowest of all the systems used for comparison.

Overall, the amount of growth and rate of growth at Freshwater Lagoon are poor compared to other systems. However, the rate of growth realized at age 2 and age 3 is excellent. With the exception of Lake Berryessa, the California waters used as a means of comparison originally reported growth in terms of fork length. These lengths were converted to total length using 1.08 as a conversion factor. Carlander (1977) suggested using this conversion factor when the fork/total length ratio is not reported. This ratio is much higher than those reported for other waters (Ruhr 1952, Thompson 1965, Emig 1976, Carlander 1977) including Freshwater Lagoon. Therefore, the total lengths and annual growth increments at age found in Table 11 may be overestimated for Lake

Shasta, Folsom Lake and Pine Flat Reservoir. To some degree this may account for the greater growth achieved by bass from these systems when compared to Freshwater Lagoon. Regardless, the growth characteristics of largemouth bass at Freshwater Lagoon are respectable considering the small size of the lagoon and the low mean annual temperatures of the surrounding climate.

CONCLUSION

Scales were a precise and accurate method for estimating age and growth parameters up to age 5. This conclusion is based on the high agreement rates of within and between structure age assignment for ages 0 through 5. Disagreements in age assignment were most often the result of misinterpreting the last annulus. Scheduling sampling beyond the date on which annulus formation is complete (late June to Early July for this study) would eliminate this problem increasing precision and accuracy of estimates. Sectioned otoliths were found to be superior to scales in determining the age of largemouth bass. When scales are used to age largemouth bass it would be very useful to collect a small sample of otoliths as a means of familiarizing readers to the growth characteristics of scales if sacrificing some fish is an option. Scales would provide reliable age and growth estimates for management purposes in California. This conclusion is based on the facts that: (1) largemouth bass harvest regulations in California rarely include fish exceeded 15 inches, and (2) for all California studies that I reviewed, largemouth bass grew beyond 15 inches by age 5. Thus, most managers in California need not be concerned with ageing bass beyond 4 or 5 years old.

The amount of growth and rate of growth were reported as total length in this study because this is the convention used most often in the United States. However, fork length is used most often in California. This made it difficult to compare my results to other systems in California. This may have led to inaccurate conclusions. There is a need to standardize methods for reporting and measuring lengths of largemouth bass in

California. Total length should be used instead of fork length because (1) this is the convention used most frequently, (2) harvest regulations are written in terms of total length, and (3) errors associated with conversions would be eliminated.

Results from this study indicate that the cool climate on the Northcoast of California is capable of producing and sustaining high quality bass fisheries. These fisheries can supplement recreational angling opportunities in this region. Freshwater Lagoon provides a high quality largemouth bass fishery with a well balanced and stable population structure. Harvest regulations have been successful in maintaining the quality of this fishery. However, overharvest is a possibility because of the small size of the lagoon and the increasing popularity of the fishery. To prevent degradation, the fishery should be closely monitored. Changes should be made to harvest regulations when warranted.

REFERENCES

- Anderson, R.O. 1976. Management of small warm water impoundments. *Fisheries* 1(6):5-7, 26-28.
- Anderson, R.O. and R.M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447-482 in B.R. Murphy and D.W. Willis, editors. *Fisheries techniques*, second edition. American Fisheries Society, Bethesda, Maryland. 732 pp.
- Arnett, G.R. 1970. Unpublished memorandum to Mr. Fred Mathis from the California Department of Fish and Game, Sacramento, California.
- Bagenal, T. and F.W. Tesch. 1978. Age and growth. Pages 101-136 in T. Bagenal, editor. *Methods for assessment of fish production in fresh waters*. IBP Handbook No. 3, third edition. Blackwell Scientific Publications, Oxford, London, Edinburgh, Melbourne. 365 pp.
- Beamish, R.J. and G.A. McFarlane. 1987. Current trends in age determination methodology. Pages 15-42 in R.C. Summerfelt and G.E. Hall, editors. *Age and growth of fish*, first edition. Iowa State University Press, Ames, Iowa. 544 pp.
- Besler, D.A. 1999. Utility of scales and whole otoliths for aging largemouth bass in North Carolina. *Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies* 53:119-129.
- Boiano, D.M. 1999. Predicting the presence of self-sustaining trout populations in high elevation lakes of Yosemite National Park, California. Master's thesis, Department of Fisheries, Humboldt State University, Arcata, California. 56 pp.
- Bolger, T. and P.L. Connolly. 1989. The selection of suitable indices for the measurement and analysis of fish condition. *Journal of Fish Biology* 34:171-182.
- Booth, D.J. and J.A. Keast. 1986. Growth energy partitioning by juvenile bluegill sunfish, *Lepomis macrochirus* Rafinesque. *Journal of Fish Biology* 28:37-45.
- Bottroff, L.J. and M.E. Lembeck. 1978. Fishery trends in reservoirs of San Diego County, California, following the introduction of Florida largemouth bass, *Micropterus salmoides floridanus*. *California Fish and Game* 64:4-23.

- Boucher, D.P. 1998. Precision and relative accuracy of Maine black bass age estimates from scales and otolith sections. Maine Department of Inland Fisheries and Wildlife, Fisheries and Hatchery Division, Fishery Progress Report Series No. 98-1, Augusta, Maine.
- Boyle, R.H. 1980. Bass, first edition. W.W. Norton Company, Inc., New York, New York. 160 pp.
- Bryant, H.E. and A. Houser. 1971. Population estimates and growth of largemouth bass in Beaver and Bull Shoals Reservoirs. American Fisheries Society, Special Publication 8:349-357.
- Campana, S.E. and J.D. Neilson. 1985. Microstructure of fish otoliths. Canadian Journal of Fisheries and Aquatic Sciences 42:1014-1032.
- Carlander, K.D. 1977. Handbook of freshwater fishery biology, volume two. Iowa State University Press, Ames, Iowa. 431 pp.
- Carlander, K.D. 1987. A history of scale age and growth studies of North American freshwater fish. Pages 3-14 in R.C. Summerfelt and G.E. Hall, editors. Age and growth of fish, first edition. Iowa State University Press, Ames, Iowa. 544 pp.
- Clugston, J.P. 1964. Growth of the Florida largemouth bass, *Micropterus salmoides floridanus* (LeSueur), and the northern largemouth bass, *M. s. salmoides* (Lacepede), in subtropical Florida. Transactions of the American Fisheries Society 93:146-154.
- Cone, R.S. 1989. The need to reconsider the use of condition indices in fishery science. Transactions of the American Fisheries Society 118:510-514.
- Crumpton, J.E., M.M. Hale, and D.J. Renfro. 1988. Bias from age-grouping black crappie by length-frequency as compared to otolith aging. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 40(1986):65-71.
- Day, J.S. 1965. Proposed management plan - Freshwater Lagoon, Humboldt County. Unpublished memorandum, California Department of Fish and Game, Eureka, California. 2 pp.
- DeBont, A.F. 1967. Some aspects of age and growth of fish in temperate and tropical waters. Pages 67-88 in S.D. Gerking, editor. The biological basis of freshwater fish production. Wiley, New York, New York. 495 pp.

- DeVries, D.R. and R.V. Frie. 1996. Determination of age and growth. Pages 483-512 in B.R. Murphy and D.W. Willis, editors. Fisheries techniques, second edition. American Fisheries Society, Bethesda, Maryland. 732 pp.
- Emig, J.W. 1966. Largemouth bass. Pages 332-353 in A. Calhoun, editor. Inland fisheries management. California Department of Fish and Game, Sacramento, California. 546 pp.
- Emig, J.W. 1976. Age and growth of black bass in Lake Berryessa, California. Master's thesis, Department of Biology, California State University, Sacramento, California. 60 pp.
- Fast, A.W., L.H. Bottroff, and R.L. Miller. 1982. Largemouth bass, *Micropterus salmoides*, and bluegill, *Lepomis machrochirus*, growth rates associated with artificial destratification and threadfin shad, *Dorosoma petenense*, introductions at El Capitan Reservoir, California. California Fish and Game 67:4-20.
- Fraser, C.M. 1916. Growth of the spring salmon. Transactions of the Pacific Fisheries Society 1915:29-39.
- Gabelhouse, D.W., Jr. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management 4:273-285.
- Green, D.M and R.C. Heidinger. 1994. Longevity record for largemouth bass. North American Journal of Fisheries Management 14:464-465.
- Grenfell, R.A. 1959. Warm-water game fish. Oregon State Game Commission, Fisheries Division Annual Report 1958, Portland, Oregon.
- Grenfell, R.A. 1962. Warm-water game fish. Oregon State Game Commission, Fisheries Division Annual Report 1962, Portland, Oregon.
- Gutreuter, S. and W.M. Childress. 1990. Evaluation of condition indices for estimation of growth of largemouth bass and white crappie. North American Journal of Fisheries Management 10:434-441.
- Hankin, D.G. 1980. Introductory fish population dynamics. Department of Fisheries, Humboldt State University, Arcata, California. 123 pp.

- Heidinger, R.C. 1975. Life history and biology of the largemouth bass. Pages 11-20 in H. Clepper, editor. Black bass biology and management. Sport Fishing Institute, Washington, D.C. 534 pp.
- Hile, R. 1941. Age and growth of the rock bass, *Ambloplites rupestris* (Rafinesque), in Nebish Lake, Wisconsin. Transactions of the Wisconsin Academy of Science, Arts and Letters 33:189-337.
- Holzhauser, N.J. 1976. Factors affecting the diet and growth of largemouth bass in Clear Lake, Lake County, California. Master's thesis, Department of Ecology, University of California, Davis, California. 34 pp.
- Hubbs, C.L. and K.F. Lagler. 1949. Fishes of the Great Lakes region. Bulletin No. 26. Cranbrook Institute of Science. Bloomfield Hills, Michigan. 186 pp.
- James, M.F. 1939. Studies on starvation in largemouth bass. Transactions Illinois State Academy of Science 32:220-221.
- Jearld, A.J., Jr. 1983. Age determination. Pages 301-324 in L.A. Nielsen and D.L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland. 468 pp.
- Johnston, H.D. 1992. Growth rate and condition of largemouth bass in two central California reservoirs: a comparative study. Master's thesis, Department of Biology, California State University, Fresno, California. 102 pp.
- Jones, M. 2001. California adds another giant to the list. Bassmaster 34(6):12.
- Kimsey, J.B. 1952. A survey of Freshwater Lagoon, Humboldt County. Unpublished report, Bureau of Fish Conservation, California Department of Fish and Game, Eureka, California. 7 pp.
- LaFaunce, D.A., J.B. Kimsey, and H.K. Chadwick. 1964. The fishery at Sutherland Reservoir, San Diego County, California. California Fish and Game 50:271-291.
- Lee, R.M. 1920. A review of the methods of age and growth determination in fishes by means of scales. Fisheries Investigations, Series II, Marine Fisheries, Great Britain Ministry of Agriculture, Fisheries, and Food 4:1-32.

- Lee, D.P. 1980. 1974-76 tagging studies at Freshwater Lagoon, Humboldt County. California Department of Fish and Game, Inland Fisheries Administrative Report 80-3, Sacramento, California.
- Maptech Inc. 1998. Maptech Terrain Navigator software version 3.01. Maptech Inc., 655 Portsmouth Avenue, Greenland, New Hampshire 03840.
- Miller, E.E. 1971. The age and growth of centrarchid fishes in Millerton and Pine Flat Reservoirs, California. California Department of Fish and Game, Inland Fisheries Administrative Report 71-4, Sacramento, California.
- Murphy, G.I. 1951. The fishery of Clear Lake, Lake County, California. California Fish and Game 51:439-484.
- National Park Service. 1984. Development concept plan, environmental assessment: Freshwater Lagoon spit, Redwood National Park, California. United States Department of the Interior, National Park Service, Denver, Colorado.
- Pardue, G.B. and F.E. Hester. 1967. Variation in the growth rate of known-age largemouth bass (*Micropterus salmoides* Lacepede) under experimental conditions. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 20:300-310.
- Pelzman, R.J. 1980. Impact of Florida largemouth bass, *Micropterus salmoides floridanus*, introductions at selected northern California waters with a discussion of the use of meristics for detecting introgression and for classifying individual fish of intergraded populations. California Fish and Game 66:133-162.
- Perry, L.G. and J.A. Tranquilli. 1984. Age and growth of largemouth bass in a thermally altered reservoir, as determined from otoliths. North American Journal of Fisheries Management 4:321-330.
- Prather, E.E. 1967. A note on the accuracy of the scale method in determining the ages of largemouth bass and bluegill from Alabama waters. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 20:483-486.
- Reynolds, J.B. 1996. Electrofishing. Pages 221-253 in B.R. Murphy and D.W. Willis, editors. Fisheries techniques, second edition. American Fisheries Society, Bethesda, Maryland. 732 pp.

- Ruhr, C.E. 1952. Fish population of a mining pit lake, Marion County, Iowa. Iowa State College Journal of Science 27:55-77.
- Sak, T.J. 1989. Effects of a 305-mm minimum length limit on growth of largemouth bass and smallmouth bass in Shasta Lake, California. Master's thesis, Department of Fisheries, Humboldt State University, Arcata, California. 46 pp.
- Secor, D.H., J.M. Dean, and E.H. Laban. 1992. Otolith removal and preparation for microstructural examination. Pages 19-57 in D.K. Stevenson and S.E. Campana, editors. Otolith microstructure examination and analysis. Canadian Special Publications of Fisheries and Aquatic Sciences 117. 126 pp.
- Stocek, R. and H.R. McCrimmon. 1965. The co-existence of rainbow trout (*Salmo gairdneri* Richardson) and largemouth bass (*Micropterus salmoides* Lacepede) in a small Ontario lake. Canadian Fish-Culturist 35:37-58.
- Stucky, N.P. and H.E. Klaassen. 1971. Growth and condition of the carp and the river carpsucker in an altered environment in western Kansas. Transactions of the American Fisheries Society 100:276-282.
- Taubert, B.D. and J.A. Tranquilli. 1982. Verification of the formation of annuli in otoliths of largemouth bass. Transactions of the American Fisheries Society 111:531-534.
- Tharratt, R.C. 1966. The age and growth of centrarchid fishes in Folsom Lake, California. California Fish and Game 52:4-16.
- Thompson, J.D. 1965. Age and growth of largemouth bass in Clear Lake, Iowa. Proceedings of the Iowa Academy of Science 71:252-258.
- Twedt, D.J., W.C. Guest, and B.W. Farquhar. 1992. Selective dipnetting of largemouth bass during electrofishing. North American Journal of Fisheries Management 12:609-611.
- Webb, J.F. and W.C. Reeves. 1975. Age and growth of Alabama spotted bass and northern largemouth bass. Pages 204-215 in H. Clepper, editor. Black bass biology and management. Sport Fishing Institute, Washington, D.C. 534 pp.
- Weithman, A.S., J.B. Reynolds, and D.E. Simpson. 1980. Assessment of structure of largemouth bass stocks by sequential sampling. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 33(1979):415-424.