# Age Distribution of White Sturgeon (Acipenser transmontanus) in the Sacramento-San Joaquin Bay-Delta

By

DIANE ELIZABETH SHIRLEY
B.S. (University of California, Berkeley) 1982

THESIS

Submitted in partial satisfaction of the requirements for the degree of

MASTER OF SCIENCE

in

Ecology

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA

DAVIS

Approved:

Gregor M. Cailliet

Committee in Charge

June
1987

## TABLE OF CONTENTS

ABSTRACT

Sections from pectoral fin rays of white sturgeon (*Acipenser transmontanus*) were collected from 252 fish in the San Francisco Bay and Sacramento San-Joaquin River Delta from 1984 to 1986. The fin rays were thin-sectioned and counts of bands assumed to be annual were made by three independent readers for 244 fish. Errors in age determination were evaluated in several ways. Pairwise agreement on ages assigned by each possible pair of readers averaged 50 percent. All three readers, however, agreed on only 81 out of 244 fish aged (33 %). Errors in age determination did not increase with age.

Simulated error rates were applied to a hypothetical age distribution to show how errors in age determination distort these distributions. As errors in age determination increase, peaks in the distribution become shorter and wider while valleys fill in.

An estimate of the age distribution was formed from fish on which at least two out of three readers agreed and fish on which the three readers assigned three consectutive ages (the middle age was assigned). Using this rule, ages were assigned to 216 out of 244 or 85 % of the fish aged. Similar age distributions were developed from past age data from other sources. These age distributions were used to back-calculate recruitment by accounting for gear selectivity and mortality. A pattern similar to the echo

effect can be seen in the recruitment time series developed from fish captured in 1954, 1965-1968, 1973-1976 and 1984-1986. A large year class in the unfished population in 1938 produced another set of large year classes in the early 1950's. As the fishery increased these repeating dominant year classes were damped.

Recruitment since the mid 1950's has been less variable and may be dependent on river flow rates. Correlation of spring and early summer Sacramento River Delta outflow with recruitment from 1965 to 1975 at several lags were evaluated. The highest correlation ($r^2 = 0.44$) was calculated for recruitment with the combined flow of the same year and the previous year. Pre-spawning adult food supply and juvenile habitat and food supply are possible mechanisms controlling recruitment.

## ACKNOWLEDGEMENTS

I would like to thank all of the students and staff of the U.C. Davis Aquaculture and Fisheries Program who assisted with the collection of wild sturgeon. Sampling was made possible by skillfull fishermen Abe and Angelo Cuanang and Eddie Tavasieff. Fin ray sectioning equipment was loaned and instruction was kindly given by Jim Brennan and Dr. Gregor Cailliet of Moss Landing Marine Laboratories. Also, David Kohlhorst of California Department of Fish and Game provided data from past sturgeon aging studies. Special thanks to John Brittnacher, Robert Kope and Chris White for assisting with age determinations. Their patience during a very time-consuming and frustrating study was greatly appreciated. This study was supported by a traineeship from the University of California Sea Grant College Program and a grant from the Marin Rod and Gun Club. Finally, I wish to thank Dr. Louis Botsford who provided invaluable guidance and support throughout the study.

# 1. INTRODUCTION

The population of white sturgeon (Acipenser transmontanus) in the Sacramento-San Joaquin River Delta and San Francisco Bay has undergone major changes in the past hundred years. Prior to the development of a commercial fishery in the late 1870's, only Chinese residents utilized central California sturgeon to any extent. Their use was limited to removing the notochord and discarding the rest of the fish (Cuanang 1984). The destructive commercial fishery that later developed was for caviar only and gill nets and set lines killed large numbers of immature as well as mature fish. Following a substantial reduction of the population in the late 1800's (Kohlhorst 1980) the commercial sturgeon fishery was closed in 1901 (Pycha 1956). It was reopened to limited fishing for eight years from 1910 to 1917, then closed completely to all fishing (Pycha 1956). By the early 1950's, sturgeon were again fairly abundant and on April 1, 1954 California Department of Fish and Game (CDFG) opened an all-year sport fishing season (Chadwick 1959). Initial regulations were a one fish per day bag limit and a minimum size of forty (40) inches total length. Also, in order to learn more about the life history of white sturgeon in this system and to evaluate and improve the fishing regulations, CDFG began a sturgeon life history study in July, 1954 (Pycha 1956).

In the fall of 1954 over 1000 sturgeon were captured with trammel nets in San Pablo Bay, tagged, and released to estimate fishing exploitation. Sections of the anterior or leading fin ray of the pectoral fin were removed from 443 of these fish and from 45 fish caught by fishermen. These fin rays were cross-sectioned and polished and counts of depositional bands assumed to be annual annuli were made. The number of fish in each age class showed tremendous variability (figure 1). Assuming that all of the assigned ages are true ages of the fish and that this is a random sample of the population, the sturgeon population in 1954 was dominated by 16 year old fish, with a fair number of 6, 15, and 17 year old fish. Also, assuming that mortality is relatively constant over time and is similar for all age classes, the recruitment into the population appears to have been extremely variable in the 1930's. For many years there was essentially no recruitment, and then in years like 1938, relatively large numbers of fish were recruited.

Considerable variation in age class strength continued to be seen in population samples collected by CDFG in 1965 through 1970, and 1973 through 1976 (Kohlhorst et al. 1980). However, the variability in numbers in different age classes was not as great as that seen by Pycha (1956). Catch per unit effort by sport fishermen on party boats and CDFG during sturgeon tagging was relatively low from 1967 to 1974 due to low recruitment in the late 1950's and early 1960's (Kohlhorst 1980). Degradation of juvenile habitat, increased

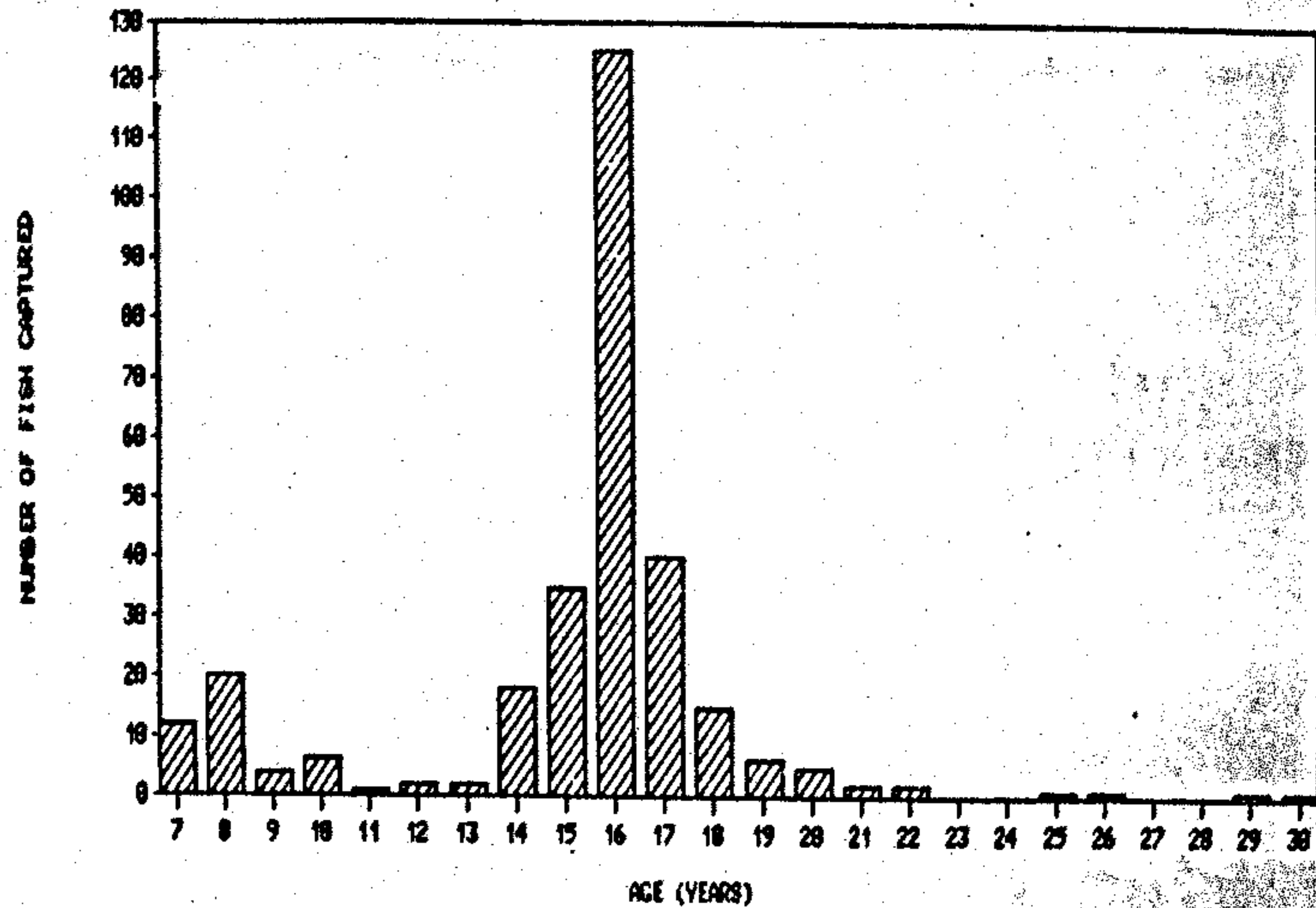



**Figure 1. Age distribution of 443 sturgeon captured in 1954.**

environmental contaminants like polychlorinated biphenyls, reduced spawning stock size and reduced freshwater outflow were suggested as likely causes of poor recruitment during this period (Kohlhorst 1980).

Freshwater outflow was identified as a potential influence on juvenile habitat and therefore, first year survival. Freshwater outflow is thought to influence the survival of juveniles of several other anadromous fish species including chinook salmon (Oncorynchus tshawytscha) (Stevens and Miller 1983) and striped bass (Morone saxatilis) (Stevens et al. 1985) in the Sacramento-San Joaquin system and may also affect sturgeon recruitment. As pointed out by Kohlhorst (1980), Pycha's 1954 data tend to support this idea. Pycha observed relatively high recruitment in 1938 and 1948, and late spring and early summer flows were high in both those years. Also, freshwater outflow and sturgeon recruitment were relatively low from 1959 to 1962.

The relationship between sturgeon recruitment and outflow is still poorly understood because past recruitment is difficult to determine. Using age distributions to backcalculate recruitment requires a random sample of the population and accurate age determinations. Since neither of these conditions were met in past studies, only general statements about trends of recruitment and flow could be made.

CDFG has also estimated fishing mortality (Chadwick 1959, Kohlhorst 1980 and Miller 1972), natural mortality (Kohlhorst 1980 and Miller 1972), and population abundance of catchable fish (Pycha 1956, Kohlhorst 1980, and Miller 1972). The population estimates are of limited value since mark-recapture was done in a relatively small area and the marked fish most likely did not mix with the rest of the population before they were recaptured. However, the population was similarly sampled in 1954 and 1967 and the estimates increased from about 11,000 to over 100,000 (Kohlhorst 1980). It can probably be safely assumed that the population did increase significantly during this time.

Kohlhorst et al. (1980) utilized three independent readers to determine the ages of fish in the 1965-1970 and 1973-1976 samples. When two out of three readers agreed on the age of the fish this age was assigned to the fish. Using this two-thirds rule, Kohlhorst et al. (1980) were able to assign ages to 74 % of over 2000 fish aged. Agreement on the ages of fish 10 years old and older, however, was only 63 %.

The true age of any fish is still unkown even when all three readers agree on the age. Independent validation by mark-recapture or use of known age fish is required to validate age determination methods (Beamish and McFarlane 1983). Preliminary results of current mark-recapture studies with sturgeon injected with tetracycline indicate that the b  is counted for age determinations are, in fact, annual annuli (Brennan, 1987). Tetracycline is taken up by calcifying bone at the time of injection and this bone will later fluoresce under ultraviolet light. This fluorescence can then be used as a reference mark for verification of how depositional bands relate to time when the fish is caught after several months or years. For this study, annuli are assumed to be annual.

The purpose of this study was to collect a random sample of the white sturgeon population and estimate the current age distribution. From this, relative recruitment in past years was estimated and statisitcal relationships with river flow rates in late spring and early summer were evaluated. Other time series of estimated recruitment from age data collected by CDFG in the past were also developed. These series were compared with each other and with the new recruitment time series to see if a long term recruitment time series could be developed. Additionally, this study provides further analysis of aging agreement between readers and the effects that errors in age determinations might have on age distributions. Since the true age of fish is unkown, accuracy in age determinations can not be evaluated. Precision, however, as evaluated by looking at agreement between readers also gives some indication of how good this method of determining ages is.

# 2. METHODS

## 2.1. POPULATION SAMPLING:

Population sampling was conducted in February and March, 1984 and 1985 and May 1986 in the San Francisco Bay near Candlestick Park, Tiburon and Carquinez Straits (figure 2). In 1984 and 1985 large groups of fish were located by sonar in areas where they were congregating and feeding on herring roe. They were caught by angling with pieces of herring or by snagging with large treble hooks pulled through groups of fish. All fish caught were brought alive to a processing station either on a boat near the fishing site or on shore. At the processing station total length (TL) and fork length (FL) were measured to the nearest millimeter and most of the fish were sexed by making a 2-3 cm. incison on the ventral surface near the pelvic fins and examining the gonads as described by Doroshov et al. (1983). After the incison was sutured the fish were placed on their sides and a 2-5 cm. piece of the marginal (anterior) fin ray was removed by either sawing through the ray at each end of the section with a small hacksaw or by clipping through it with pruning sheers and then separating the ray section from the rest of the fin with a scalpel. The sections were taken as close as possible to the articulation to insure inclusion of the first annulus of the fin ray. Sections were not

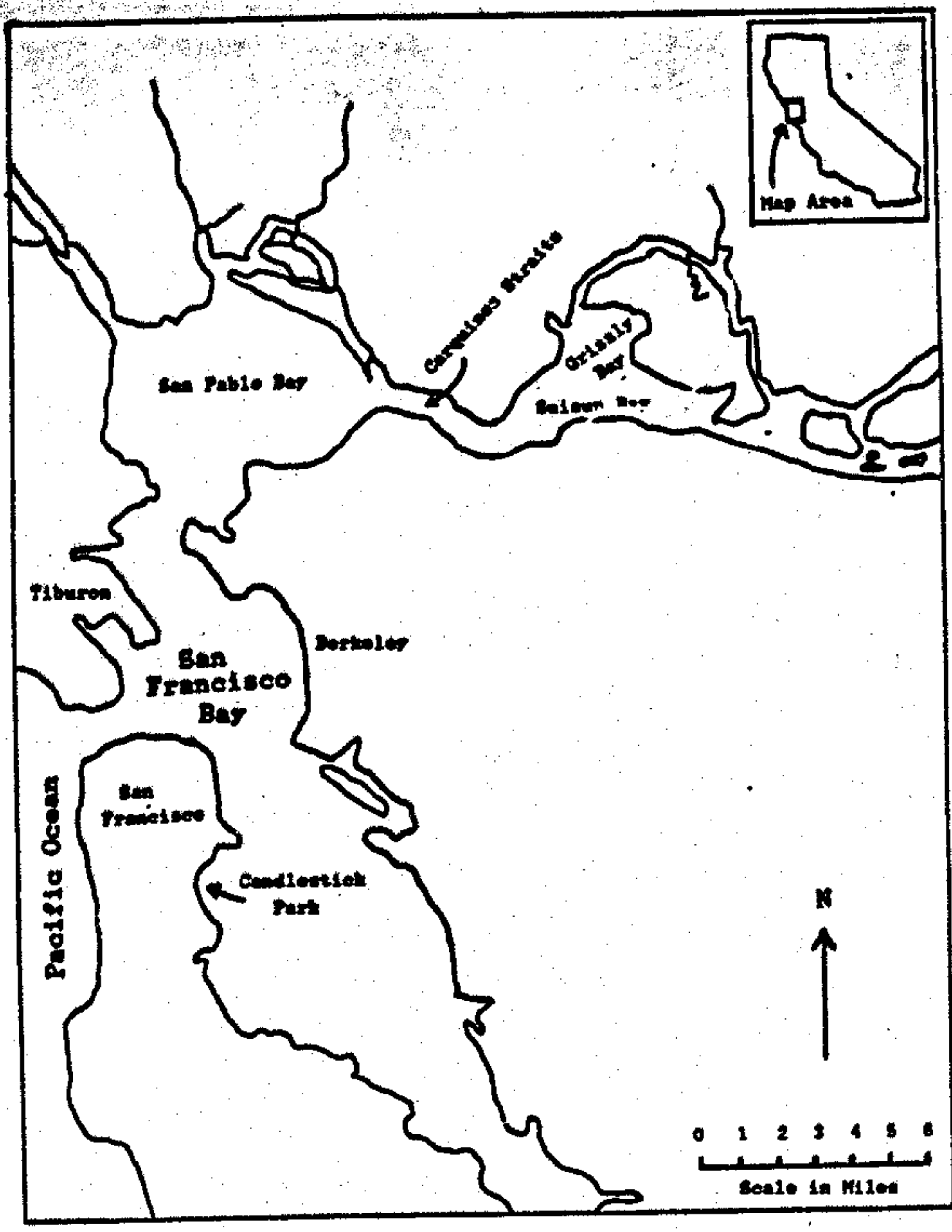



Figure 2. Lower Sacramento River Delta and San Francisco Bay. 1984-1986 population sampling was conducted near Tiburon, Candlestick Park and San Pablo Bay.

systematically taken from either the left or right pectoral fin, and the choice was often made when the fish flipped over onto one side or the other.

In May, 1986, entire fins were removed from 24 dead fish caught at a sturgeon derby held at Glen Cove Marina, near Carquinez Straits. Total length of all fish caught was measured to the nearest millimeter and fish were weighed to the nearest pound.

Fin rays were collected from 252 fish in 1984, 1985, and 1986. Ages were not assigned to 36 of these fish because the fin ray section was cut too far away from the body to include the first year's annulus or growth bands were too indistinct to count. The remaining 216 fish are listed in table 1 by date of capture, location and assigned sample identification number.

## 2.2. FIN RAY SECTIONING:

The fin ray sections and whole fin rays were thoroughly air dried and mounted with clear epoxy onto pieces of wood approximately 2" x 3/4" x 1/4". A Buehler Isomet low speed saw with diamond-coated circular blades was used to section the fins. This saw has adjustments for the width of separation between the blades and the speed at which they rotate. The sample is mounted on a lever arm which lowers the material to be sectioned onto the top of the rotating blades with an adjustable amount of weight applied to the sample. The bottom of the blades turn

Table 1. Dates, location, number of fish caught, sample identification numbers and location of capture for 216 sturgeon included in 1984-1986 age data set.

| DATES | NUMBER OF FISH | SAMPLE ID NUMBERS | CAPTURE LOCATION |
|---|---|---|---|
| Feb-Mar, 1984 | 12 | 1040-1055 | CANDLESTICK PARK |
| Feb-Mar, 1984 | 21 | 1070-1094 | SAN PABLO BAY |
| Feb. 1985 | 88 | 1150-1267 | TIBURON |
| Feb-Mar, 1985 | 71 | 1268-1356 | CANDLESTICK PARK |
| May, 1986 | 24 | 1123-1146 | SAN PABLO BAY |

through a mild soap bath. A variety of settings of blade separation width, rotation speed, and weight were used to section the fin rays. In general, heavy weight and fast rotation speeds make growth bands in the sections less clear. Lower speeds and less weight provides a more evenly cut and finely polished section with more interpretable growth bands. The amount of time it takes to cut a section increases as rotation speed and weight decrease and as the amount of wear on the saw blades increases. Most sections were cut with the saw set near 200 revolutions per minute, and with approximately one ounce of weight on top of the fin ray it took between eight and thirty minutes to cut a section. Sections were taken from as close to the articulation as possible to insure inclusion of the first annulus, but far enough from the articulation to avoid the more curved area of the fin ray where depositional bands are less distinct when sectioned perpendicularly to the long axis of the fin ray (figure 3). Sections ranged in thickness from 0.25 to 0.75 mm and many fin rays had several sections of different thicknesses prepared when the bands appeared indistinct. Cut sections were mounted on microscope slides with clear fingernail polish both underneath and on top of the sections.

By way of comparison, Pycha (1955) glued sections sanded down to 0.015 inch (0.38mm) thick onto cellulose acetate slides with "Duco" cement. California Deaprtment of Fish and Game (CDFG) samples from 1965 through 1970 were

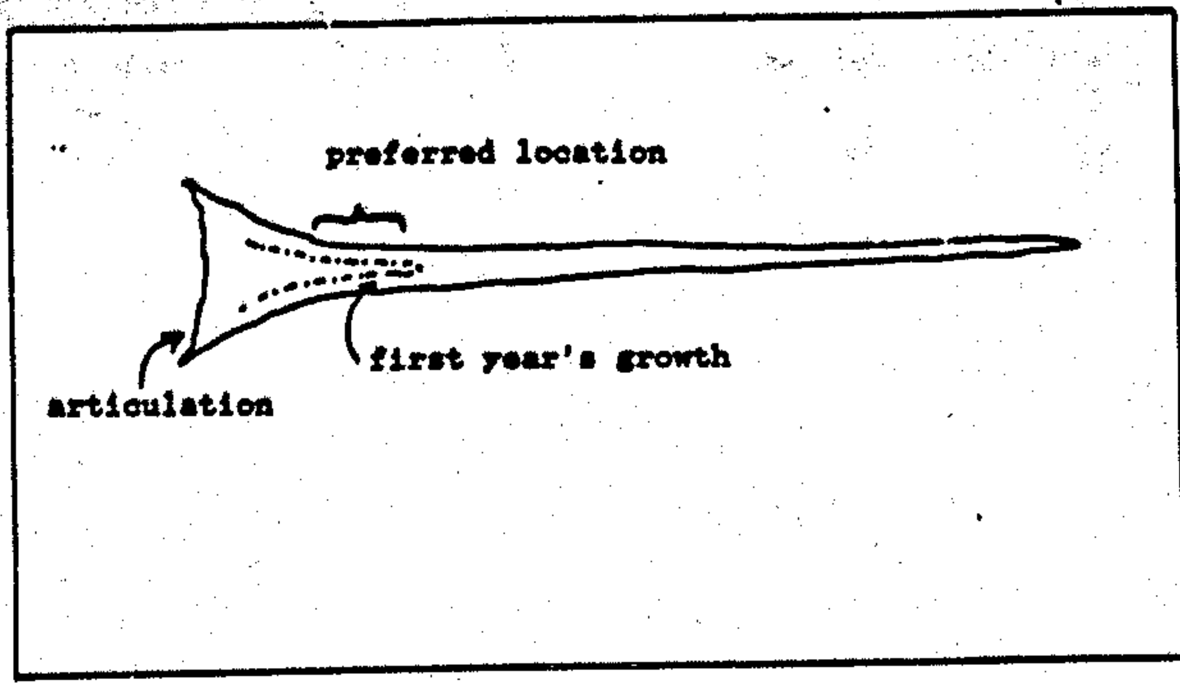



Figure 3. Pectoral fin ray. Sections for age determination are taken as close to the articulation as possible to include the first annual annulus, yet far enough away from the articulation to avoid the curved area of the fin ray.

sectioned with saw blades mounted 0.9 mm apart and then the sections were polished with fine sandpaper. CDFG samples from 1973 through 1976 were not polished because the rays were sectioned with blades mounted 0.5 mm apart and annuli were visible without polishing. All CDFG samples were mounted on plastic or glass microscope slides with clear fingernail polish.

2.3. AGE DETERMINATION:

Fin ray sections were projected onto a piece of white cardboard using a Lietz Wetzlar Neo-PROMAR microprojector (model # 31.047.500). Projections ranged in size from about one-half to one meter in diameter depending on the size of the fin ray section. Initial instructions to three readers were limited to a group examination of about 5 sections to orient readers to the general patterns of bands on the sections. No specific aging criteria were established prior to the first set of age determinations--readers were told to start in the middle and count the narrow light or translucent bands that appear with transmitted light. These bands are thought to be laid down during periods of slow growth (Kohlhorst et al. 1980) and are interpreted as annual annuli for this study. The projections were then independently examined from between one and three meters away by three readers who will be referred to as Readers A, B, and C. A total of 224 sections were aged.

After noting substantial disagreement on ages among readers (see results) ageing criteria were established to reduce subjective decisions. Readers were instructed to follow these specific rules:

1. Identify the first year's annulus: The first years's growth is dark and has a mottled, irregular or "sponge-like" appearance. The central, triangular region should have this type of texture and is bordered by a distinct light band. Periods of rapid growth after this first year are also dark, but solid and smooth in appearance, never textured like the central part. The first year's annulus must be clearly identifiable for a count to be made.

2. Count the light bands only: The bands should appear clearly on both major lobes of the section. Frequently, light bands are arranged in pairs with two light bands very close together separated from another such pair by a much thicker dark band. When two light bands are very close together like this, it might represent either one or two years of growth. Kohlhorst et al. (1980) used a rule that bands must appear in both the major lobes and also in the dorsal and ventral portions to be counted. Thus "false" annual annuli which show up in the lobes are not counted since the pairs usually join together in the dorsal or ventral areas. Since bands are more difficult to interpret in

these dorsal and ventral areas, ageing in this study is restricted to the major lobes. When two light bands are very close together they should be counted as two only when a continuous dark band separates the light bands throughout the major lobes.

3. If the outermost band is dark, add one year to the count. If it is light, it is the last band counted. The fish in the 1984 and 1985 samples were all caught in January, February or March and should have been laying down a light band. Fish in the 1986 sample, on the other hand, were caught in May and should have been laying down a dark band. Kohlhorst et al. (1980) assigned a marginal annulus if one was not visible on fish caught between April 1 and July 1. This was necessary because annual annuli formed in the spring were not usually apparent until after more rapid growth resumed. By July 1, the spring annulus was visible near the edge of the section and it was the final one counted.

In 1986, two of the readers from the first reading (readers B and C) and one new reader aged 244 fin ray sections following these rules. Twenty-four new sections were from May 1986 sampling at a sturgeon derby at Glen Cove Marina and eight old sections from the 1985 aging were omitted because the sections did not include the first annulus.

## 2.4. ERRORS IN AGE DETERMINATION:

### 2.4.1. AGEING AGREEMENT BETWEEN PAIRS OF READERS:

Ages were compared pairwise between readers, A-B, B-C, and A-C for both the 1985 and 1986 sets of ages. To determine whether one reader generally assigned higher or lower ages, the sum of differences and the average difference between ages assigned by each possible pair of readers was calculated. The sum of absolute differences and the average absolute difference between ages assigned by two readers were also calculated. Number and percent of exact agreements, agreements within one year and agreements within two years were calculated for each pair of readers. Of the fish that were aged twice by readers B and C, the ages from 1985 were plotted against those from 1986 to see how consistent each reader was from one year to the next.

### 2.4.2. AGEING AGREEMENT AMONG THREE READERS:

The agreement between all three readers in the 1985 and 1986 ageing was evaluated by determining the number and percent of times that (1) all 3 readers agreed exactly on the age of a fish, (2) two out of three readers agreed or all three readers agreed, (3) two out of three readers agreed or all three readers agreed or the three readers assigned three consecutive ages. Sets of ages that did not fit into any of these categories were grouped together in a poor-agreement category. Fish with such poor agreement of ages among readers were not used in generating an age distribution since their ages are so uncertain. Fish with better but not exact agreement between the three readers had an age assigned to them so that they could be included in the age distribution along with fish with exact agreement. When two out of three readers agreed, that age was assigned. (cf. Kohlhorst et al. 1980). Also, for the 1986 ageing, when the three readers assigned three consecutive ages, the middle age was considered to be the true age.

2.4.3. DISTRIBUTION OF ERRORS IN AGE DETERMINATION:

The average age of the three reader's ages was calculated for each of 224 fish from the 1985 ageing and 244 fish from the 1986 ageing. This average age was then subtracted from each reader's age, and the residuals were plotted against the average age of the fish to determine how errors in age determinations are distributed with age. The squares of the residuals were regressed against the average age of the fish.

2.4.4. EFFECTS OF ERRORS IN AGE DETERMINATION ON THE SHAPE OF AN AGE STRUCTURE:

To determine qualitatively how errors in age determination change an age distribution, several different simulated error rates were applied to a hypothetical "true" age distribution. For this hypothetical age distribution, I used a subsample of fish ages 9 thru 19 from the 1986 ageing. Error rates were simulatod as follows:

Case 1: One-third of the fish in each age class were moved up one age class, one-third were moved down one age class and one-third were left as assigned.

Case 2: One-fifth of the fish in each age class were moved up one age class, one-fifth were moved down one age class and three-fifths were left as assigned.

Case 3: One-tenth of the fish in each age class were moved up one age class, one-tenth were moved down one age class and four-fifths were left as assigned.

Case 4: 16 % of the fish in each age class were moved up one age class, 16 % were moved down one age class and 68 % were left as assigned.

The last error rate was estimated from rates of pairwise agreement from the 1986 ageing. The average percent of exact agreements, agreements within one year and agreements within two years between pairs of readers were used as probabilities of a reader assigning the correct age to a fish. For example, pairs of readers assigned the same age to approximately 50 % of fish aged in 1986 (see results). Therefore, it is assumed that each reader has a probability of 0.50 of assigning the correct age to a fish. Combinations of probabilities that would yield an assigned age (an age could be assigned when at least two out of three readers agree or the three readers assign three consecutive ages) to be exact or off by one year were calculated.

Details of these calculations are presented in appendix 6.1. The resulting probability of an assigned age being off by one year from the correct age was 32 %, and therefore 16 % of fish assigned to each age class were moved up and down one age class. Since the probabilty of an assigned age being off by two years from the correct age was only 5 %, this was ignored in estimating an error rate. 68 % of the fish assigned to each age class were, therefore, left as assigned. Numbers of 8 and 20 year old fish in the unadjusted age distribution were also needed to calculate the new number of 9 and 19 year old fish. The old and new age structures were then compared.

2.5. AGE DISTRIBUTIONS FROM AGEING DATA:

Age structures were generated from 1986 ageing of 244 fish for the following subsets of ageing data:

1. Fish on which all three readers agreed.
2. Fish on which at least two out of three readers agreed.
3. Fish on which at least two out of three readers agreed or three consecutive ages are assigned (the middle one is used).
4. Poor agreement fish (those not in 1-3 above).
5. Reader A's ages only.
6. Reader B's ages only.
7. Reader C's ages only.

These seven age structures were compared for general shape and similarity.

The age data set including exact agreements, two out of three agreements and the middle of three consecutive ages will be referred to as the 1984-1988 raw age data and is used to backcalculate recruitment. This data set is relatively large and simulations indicate computed errors in age determinations cause relatively little distortion of the age distribtuion. Age distributions of this sample (n=216) and the poor-agreement fish (n=28) and both combined (n=244) were compared to see if the ages of the fish thrown out were distributed similarly to those included in the sample. The average age of the three readers rounded down to the next lowest integer ( = integer average age) was used for these three age structures because the poor-agreement fish do not have assigned ages. A Kolmogorov-Smirnov non-parametric test for observed distributions coming from the same population were performed for the total sample (n = 244) with the good agreement sample (n = 216) and the poor agreement sample (n = 28). Kolmogorov-Smirnov tests were also used to compare distributions of ages assigned by each reader.

## 2.6. OTHER SOURCES OF DATA:

The oldest set of age and length data was from fish caught by anglers in the bay and delta and by California Department of Fish and Game (CDFG) sturgeon tagging operations in San Pablo Bay in the fall of 1954 (Pycha 1956). Fin rays were removed from 520 fish and 125 fin sections were damaged or considered to be too questionable to be included in the results. These 125 fins were reported to come "from fish scattered throughout nearly the entire size range." The set of 395 aged fish were then considered a random sample of the population of fish large enough to be caught in the trammel net used for sampling, or large enough to be kept by an angler. The trammel net was 7 1/2 - 9 1/2" mesh and fish over 40" total length were thought to be fully vulnerable to capture.

Data from CDFG surveys in 1965-1968 and 1973-1976 were used to generate age distributions in the 1960's and 1970's. These fish were collected by trammel nets in San Pablo Bay, by sport fishermen on party boats throughout the bay and delta and by other CDFG netting operations in the bay and delta. Size data collected during sturgeon tagging in San Pablo Bay in fall, 1984 by CDFG was used to develop a current size distribution. Table 2 shows the number of fish by year used to generate age distributions.

## 2.7. AGE DISTRIBUTIONS OF FISH CAPTURED AT DIFFERENT LOCATIONS:

The 1984-1986 raw age data were further broken down by capture location to determine whether the age structures generated by sampling at different locations are similar. The integer average ages were adjusted for fish collected in

Table 2. Number of fish used to generate age distributions for 1954, 1965-1968 and 1973-1976, listed by year of capture.

| YEAR OF CAPTURE | NUMBER OF FISH |
|---|---|
| 1954 | 395 |
| 1965 | 216 |
| 1966 | 191 |
| 1967 | 59 |
| 1968 | 50 |
| 1973 | 235 |
| 1974 | 493 |
| 1975 | 213 |
| 1976 | 558 |

1984 and 1986 (one year added to and subtracted from, respectively) to make the ages equivalent to those of the majority of fish captured in 1985. The fish were divided into three groups:

1. 88 fish captured near Tiburon
2. 45 fish captured near San Pablo Bay and Carquinez Straits.
3. 83 fish captured near Candlestick Park.

Age structures for these three subsamples of the 1984-1986 fish caught at different locations were compared for general shape and mean age of each sample were compared. A Kolmogorov-Smirnov test (Hogg and Tannis 1983) was done for the three pairs of locations to see if the observed age distributions came from the same population with a specified distribution.

Combining samples from different years to give an effectively larger sample is valid only when the population is being randomly sampled each time. The CDFG samples from 1965-1968 and 1973-1976 include fish caught by several methods at different locations. To assess the randomness of samples collected at different locations, age distributions of fish collected in 1973, 1974, 1975 and 1976 were separated by capture location. The age distribution of fish collected in San Pablo Bay and Carquinez Straits each year was compared to one of fish collected in Suisun and Grizzly Bays the same year. Kolmorogov-Smirnov tests were performed to determine the probabilty that the two observed age distributions came from the same population.

2.6. BACK-CALCULATING RECRUITMENT FROM AGE STRUCTURES:

Assuming that post-recruitment natural mortality is not time-varying and harvest rates are known, an age structure generated from a random sample of a population can be used to estimate recruitment in the past. Several steps are taken to adjust current age distributions to reflect recruitment in the past. First, samples have to be adjusted for capture method, so that only fish fully vulnerable to the capture method are included in the sample. Distributions from several years are combined to make one large sample, and then adjustments need to be made for differential mortality from both fishing and natural causes experienced by fish of different age classes

2.6.1. ADJUSTMENTS FOR SELECTIVITY OF CAPTURE GEAR AND COMBINING SAMPLES:

It is assumed that in 1984, 1985 and 1986, fish over the age of 9 were fully vulnerable to capture since only age 9 and over were caught in large numbers. One year was added to the assigned age and subtracted from the assigned age of fish captured in 1984 and 1986, respectively to make them equivalent in age to the majority of fish caught in 1985. Assigned age was then subtracted from 1985 to give the year of recruitment. For example, 10 year-old fish were hatched in spring, 1975.

Similar age cut-off points for capture gear selectivity were applied to age distributions from CDFG data from 1965-1968 and 1973-1976. Pycha's (1956) 1954 collection was adjusted to exclude fish 6 years old and younger. 7 year old fish had an average length of 39.8", and Pycha considered fish over 40 inches fully vulnerable to the net used to collect fish in 1954. Assigned ages were subtracted from 1954 to give the year of recruitment.

Fish from CDFG samples from 1965, 1966, 1967, and 1968 were cut off to include 7, 8, 9, and 10 year-olds and older fish, respectively. The samples had 1 year subtracted from the assigned ages of fish captured in 1968, and one and two years added to the assigned ages of fish captured in 1965 and 1966, respectively to make them equivalent in age to fish caught in 1967. Year of recruitment was calculated by subtracting assigned ages from 1967.

CDFG samples from 1973, 1974, 1975, and 1976 were cut off to include ages 3, 7, 5, and 2 year-olds and older, respectively. These cut off ages were based on the size of the nets used for capture in different years, and the age classes that were caught in large numbers. For example, in 1973 and 1976, fair numbers of sturgeon between the ages of 2 and 6 were captured in gill nets set up to sample striped bass and salmon. One year was added to the assigned ages of the fish captured in 1973, and 1 and 2 years, repectively were subtracted from the assigned ages of fish captured in 1975 and 1976 to make them equivalent in age to the fish caught in 1974. Year of recruitment was calculated by subtracting assigned ages from 1974.

The samples from different years for 1965 through 1968 and 1973 through 1976 were combined by addition and weighting. The number of fish recruited each year from samples collected in 1965-1968 are combined, and those collected in 1973-1976 are combined. The total number of fish recruited each year is the sum of the number of fish recruited each year from each sample divided by the number of samples that include fish of that age class. For example, in the 1973-1976 samples, fish recruited in 1968-1970 were represented in only three of the four samples. In 1974, relatively younger fish were not captured. The number of fish recruited these years is the sum of the number ftom each sample divided by three. For fish recruited in 1967 and earlier, however, all four samples include these age groups and the sum is divided by four.

## 2.8.2. ADJUSTMENTS FOR MORTALITY:

Chadwick (1959) estimated annual fishing mortality for catchable sized fish at between 2 % and 10 %. Miller (1972) later estimated annual fishing mortality of 7.3 % in 1967 and 6.5 % in 1968. In 1974, Kohlhorst (1980) estimated an exploitation rate of 5.6 %. He also reported an annual survival rate from 1967 to 1974 ranging from 84 % to 88 %.

Adjustments to the four recruitment series from data collected in 1954, 1965-1968, 1973-1976 and 1984-1986 for differential natural and fishing mortality were made using a constant instantaneous natural mortality rate of 0.08 and a constant instantaneous fishing mortality rate of 0.07 applied to fish after their eighth year when most become vulnerable to capture. An instantaneous fishing mortality rate of 0.07 corresponds to an annual harvest of 6.8 %, while the natural mortality rate of 0.08 corresponds to an annual survival of 92.3 %. These combined rates of natural and fishing mortality correspond to an annual survival rate of 86 %. Since the age data have already been combined to make one recruitment series from several years of data, the mortality adjustments were made to all the fish in a series as if they were captured in the same year. For the 1965-1968 samples, all fish were assumed to have been captured in 1967 and for the 1973-1976 samples, all fish were assumed to have been captured in 1974. Fish from the 1984-1986 samples were assumed to have been captured in 1985.

2.8.3. COMBINING DIFFERENT TIME SERIES OF RECRUITMENT:

Time series of recruitment developed from the four samples from 1954, 1965-1968, 1973-1976, and 1984-1986 were plotted on the same axis to determine the degree of overlap. Estimates from fish over about 20 years old were omitted from these time series because of the small sample size of these older fish. Thus, the recruitment series from fish collected in 1954, 1965-1968, 1973-1976 and 1984-1986 were cut off at 1934, 1946, 1954 and 1965, respectively. In years when recruitment was estimated from two samples, the two estimates were compared. For each year the estimates overlapped, ratios of the estimate from the older sample to the estimate from the more recent sample were calculated. Geometric means of these ratios for sets of overlapping years were calculated and used to weight the four recruitment series. In years of overlap, the two estimates were averaged and a long time series was developed from the four weighted recruitment series.

2.9. SIZE DISTRIBUTIONS:

Four data sets were used to generate four size distributions from fish collected in 1954, 1965-66, 1973-74, and 1984. Fish were grouped into three-inch size classes 30 to 32.9 inches, 33 to 35.9 inches, etc. Size distributions of the number of fish in each of these size classes were compared to see how the size distribution has changed through time. The general shapes of the size and age distributions of each of the samples are also compared. Assigned age versus total length was plotted for 216 fish in the 1984-1986 data set. This plot and Pycha's (1956) age-length table are used to estimate the age at which most fish enter the fishery.

2.10. CORRELATION OF ESTIMATED RECRUITMENT AND FLOW:

Correlations between time series of recruitment estimated from data collected in 1984-1986 and Sacramento River outflow from January through June were computed for 1965 to 1975. Average monthly outlfow of the Sacramento River at Chipp's island (source: L. Miller, personal comm.) were correlated with recruitment the same year, one and two years before and one and two years later. Since relatively high correlations were observed for recruitment with flow the same year and the previous year, a multiple linear regression of recruitment on these two variables was computed. Estimated recruitment, outflow the same year and outflow the previous year were also plotted against time.

# 3. RESULTS

## 3.1.1. AGEING AGREEMENT BETWEEN PAIRS OF READERS:

Agreement betweeu pairs of readers was higher in 1986 than in 1985 (table 3). In 1985 the total sum of differences between ages assigned by readers A and B was -222 out of 244 fish aged, or reader B assigned ages an average of 0.99 year higher than reader A. Readers A and C had similar bias but neither B nor C assigned consistently higher or lower ages than the other. In 1986, the total sums of differences between ages assigned by all three pairs of readers were smaller, ranging from 27 to 79. The largest average difference between ages assigned by a pair of readers was 0.32 years between readers A and C. In 1986, the percent of exact agreements between pairs of readers ranged from 43.9% to 52.0%, which is approximately twice the 1985 values ranging from 18.8% to 28.6%. The ages assigned to the 244 fish by readers A, B and C in 1986 are listed in Appendix 6.2.

In 1985, pairs of readers agreed either exactly, or within 1 or 2 years for 70.1%, 71.8% and 80.3% of the 224 fish aged by pairs A & B, A & C and B & C, respectively. In 1986, pairwise agreement within 2 years ranged from 90.1% to 94.3% for the 244 fish aged. Readers B and C aged 220 of the same fish in both 1985 and 1986. The same age was assigned to 37 % and 30 % of the fish aged by readers B and C, respectively. Correlation coefficients of ages assigned

Table 3. Summary of comparisons of ages assigned by each pair of readers in 1985 and 1986.

| 1985 Age Determination | Differences in ages | | | Absolute differences | | |
|---|---|---|---|---|---|---|
| | A-B | B-C | A-C | [A-B] | [B-C] | [A-C] |
| Sum of differences | -222 | -11 | -223 | 450 | 341 | 509 |
| Average difference | -0.99 | -0.05 | -1.04 | 2.01 | 1.52 | 2.27 |
| Agreement: | | | | | | |
| (1) Exact: | | | | | | |
| Number: | | | | 50 | 64 | 42 |
| Percent: | | | | 22.3 | 28.6 | 18.8 |
| (2) 1 year apart: | | | | | | |
| Number: | | | | 63 | 85 | 71 |
| Percent: | | | | 28.1 | 37.9 | 31.7 |
| (3) 2 years apart: | | | | | | |
| Number: | | | | 48 | 31 | 44 |
| Percent: | | | | 21.4 | 13.8 | 19.6 |
| (4) Percent agreement within 2 years: | | | | 71.8 | 80.3 | 70.1 |

| 1986 Age Determination | Differences in ages | | | Absolute differences | | |
|---|---|---|---|---|---|---|
| | A-B | B-C | A-C | [A-B] | [B-C] | [A-C] |
| Sum of differences | 52 | 27 | 79 | 184 | 213 | 233 |
| Average difference | 0.21 | 0.11 | 0.32 | 0.75 | 0.87 | 0.95 |
| Agreement: | | | | | | |
| (1) Exact: | | | | | | |
| Number: | | | | 127 | 123 | 107 |
| Percent: | | | | 52.0 | 50.4 | 43.9 |
| (2) 1 year apart: | | | | | | |
| Number: | | | | 67 | 66 | 77 |
| Percent: | | | | 27.5 | 27.0 | 31.6 |
| (3) 2 years apart: | | | | | | |
| Number: | | | | 36 | 31 | 40 |
| Percent: | | | | 14.8 | 12.7 | 16.4 |
| (4) Percent agreement within 2 years: | | | | 94.3 | 90.1 | 91.9 |

in 1985 and 1986 were 0.96 for reader B and 0.92 for reader C (figure 4).

3.1.2. AGEING AGREEMENT AMONG THREE READERS:

In 1986, all three readers assigned the same age to 81 of 244 fish, while in 1985 all three readers agreed on the ages of only 19 out of 224 fish. Table 4 summarizes the number and percent of fish from the 1985 and 1986 aging that either (1) all three readers agreed on the age, (2) only two out of three readers agreed and (3) the three readers assigned three consecutive ages. Agreement was considerably better in 1986 when only 11.5 % of 244 fish aged fell into none of the above three categories, compared to 34.4 % of 224 fish aged in 1985.

In 1986, 80 % of 244 fish aged had at least two out of three readers agree on the age while in 1985, only 52 % of 224 fish aged had this much agreement.

3.1.3. DISTRIBUTION OF ERRORS IN AGE DETERMINATION:

Errors in age determinations increased with age in 1985 but not in 1986. This is demonstrated by residual plots of average assigned age subtracted from each reader's assigned age against average assigned age (figure 5). In 1985, the absolute value of the residuals increased with age and the plot was consequently triangular. The 1986 plot, on the other hand, was essentially rectangular. The squares of the

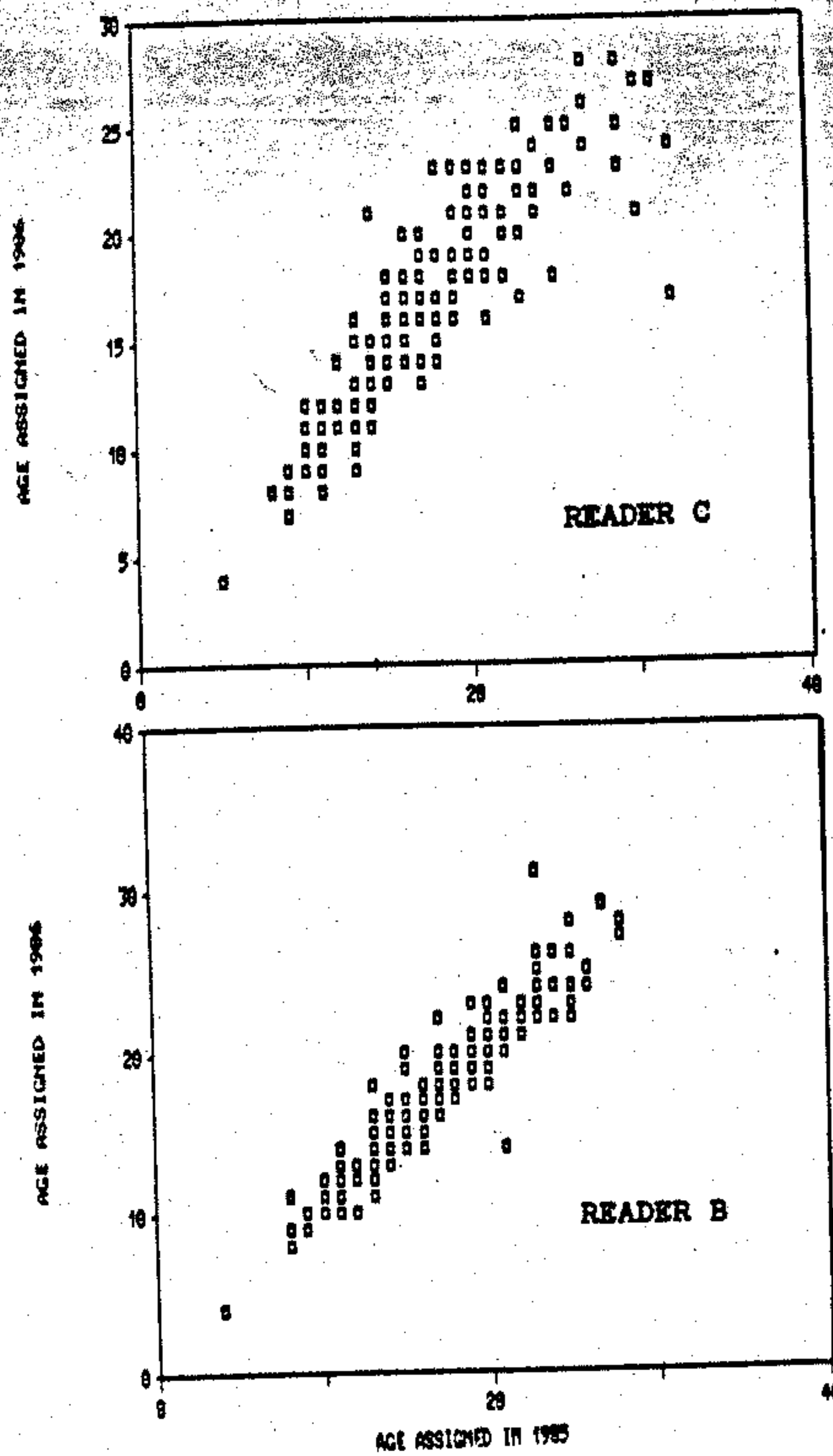



Figure 4. Plots of ages assigned in 1985 and 1986 to the same fish aged twice by reader B (above) and C. Correlations were 0.96 and 0.92 for readers B and C, respectively.

Table 4. Number and percent of fish aged in 1986 on which either all three readers agreed, only two out of three readers agreed or the readers assigned three consecutive ages. Other combinations of ages are grouped into a "none of the above" category.

| | 1985 | | 1986 | |
|---|---|---|---|---|
| | NUMBER | PERCENT | NUMBER | PERCENT |
| 3 readers agreed | 19 | 8.5 | 81 | 33.2 |
| 2 of 3 readers agreed | 98 | 43.7 | 114 | 46.7 |
| Readers assigned three consecutive ages | 30 | 13.4 | 21 | 8.6 |
| None of the above | 77 | 34.4 | 28 | 11.5 |
| Total | 224 | 100.0 | 244 | 100.0 |

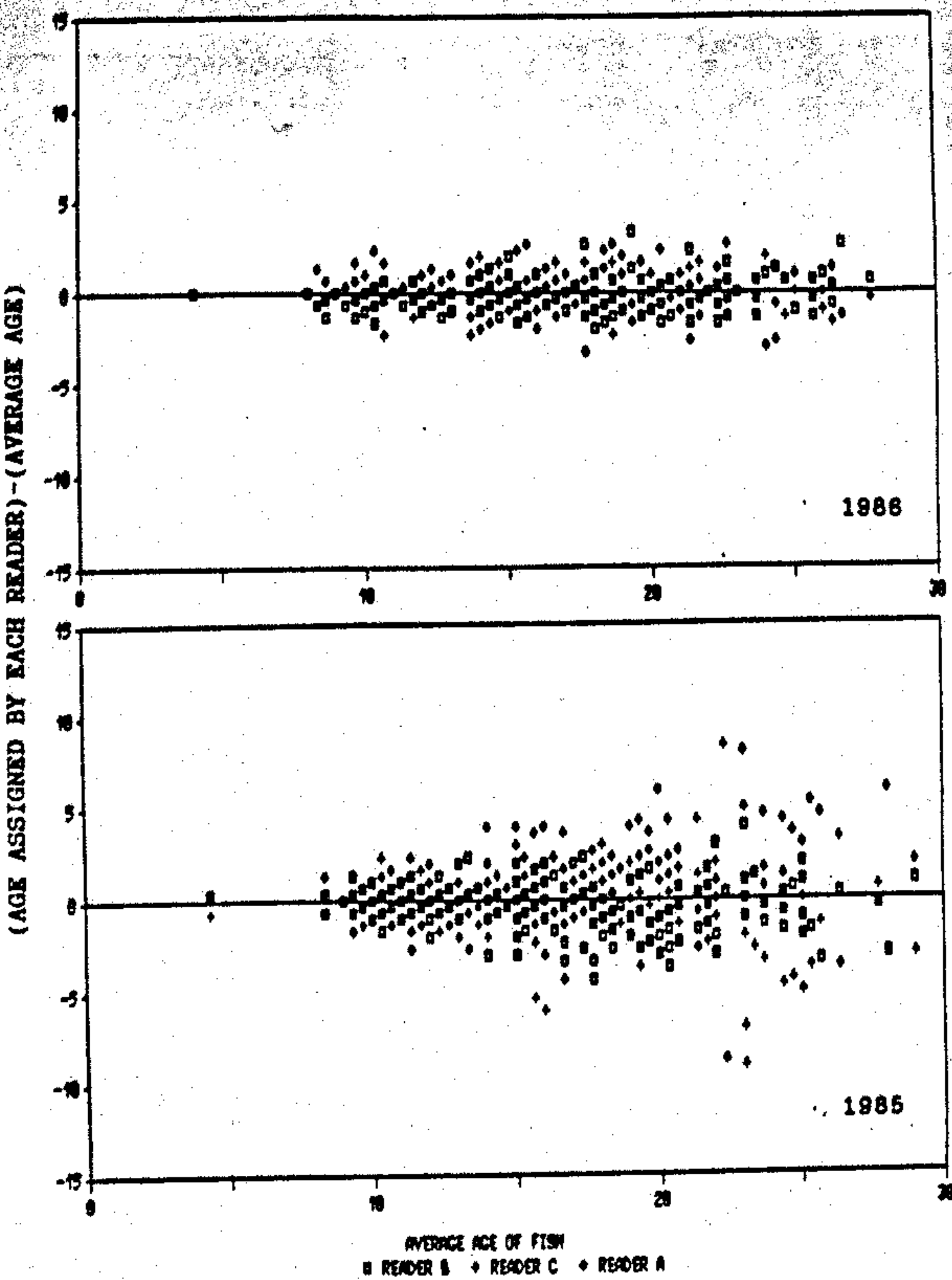



Figure 5. Residual plots of average assigned age subtracted from each reader's assigned age in 1985 (above) and 1986.

residuals regressed against average assigned age gave lines with the following equations:

$$1985: \quad y = 0.50x - 5.09$$

$$1986: \quad y = 0.06x - 0.36$$

The slopes of 0.50 and 0.06 reflect that errors in age determinations increased ($p < 5$ %) with age in 1985, but not in 1986.

### 3.1.4. EFFECTS OF ERRORS IN AGE DETERMINATION ON THE SHAPE OF AN AGE STRUCTURE:

Plots of a hypothetical assumed "true" agr distribution and resultant age distributions after four error rates were applied show how errors in age determination like these affect an age distribution (figure 6). As the error rate increased, the age distribution flattened out; the peaks were reduced and the valleys were filled in. The age distribution after the estimated 1986 error rate for age determinations was applied was still similar to the original distribution in the sense that rank order of the age classes was preserved. For the example where the error rate left 60 % of the fish as assigned, however, the rank order of age classes changed (figure 6d).

## 3.2. AGE DISTRIBUTIONS FROM AGEING DATA:

Distributions of ages assigned by each reader to 244 fish in 1986 (figure 7) were quite similar. Kolmogorov-Smirnov tests showed ($p < 5$%) that these three distributions

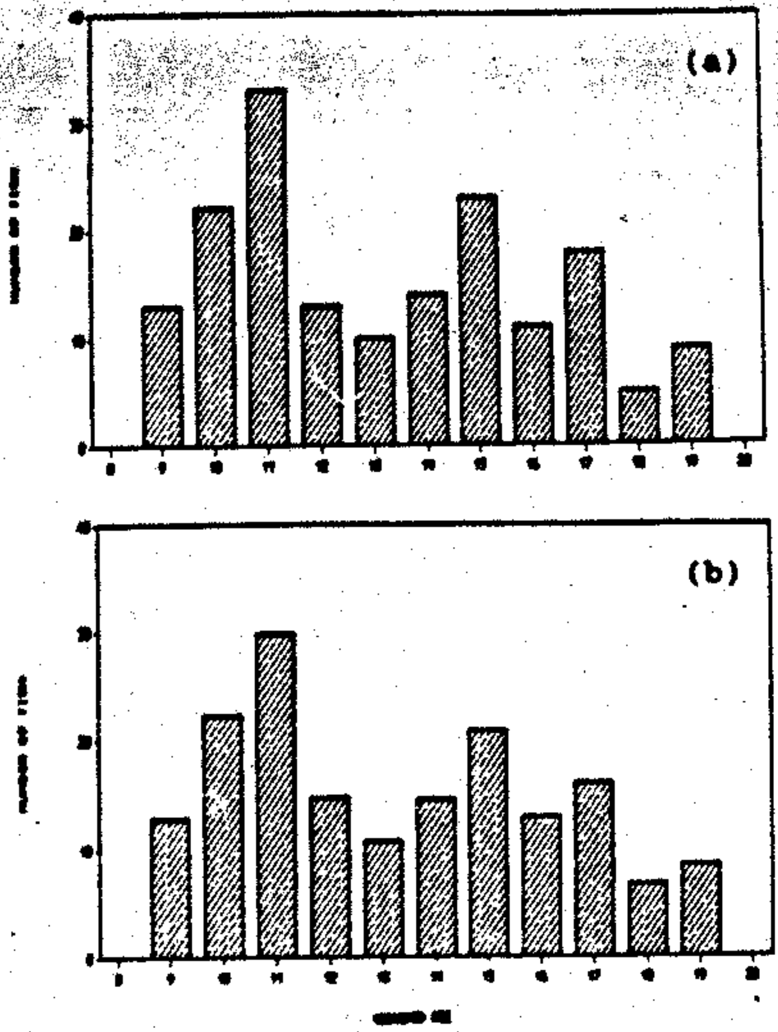
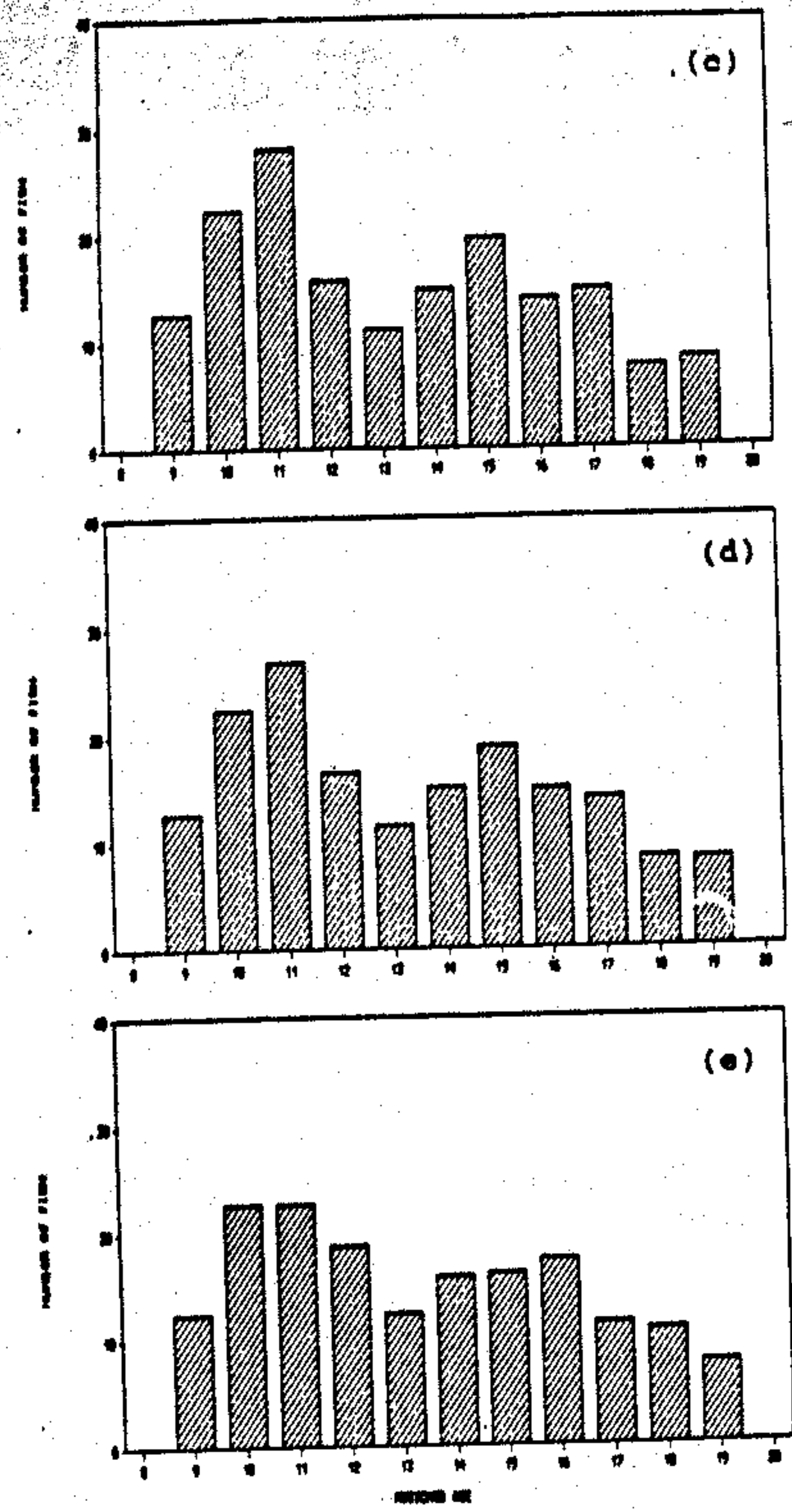



Figure 6. Age distribution of 9 through 19 year old sturgeon in 1986 (a). Same distribution after four increasingly large error rates were applied (b-e). First, 1/10 of the fish in each age class were moved up and 1/10 were moved down one age class (b). Similarly, 16 %, or the estimated rate from 1986 ageing, were moved one year each way (c), 1/5 were moved each way (d) and 1/3 were moved each way (e).


(c)
(d)
(e)

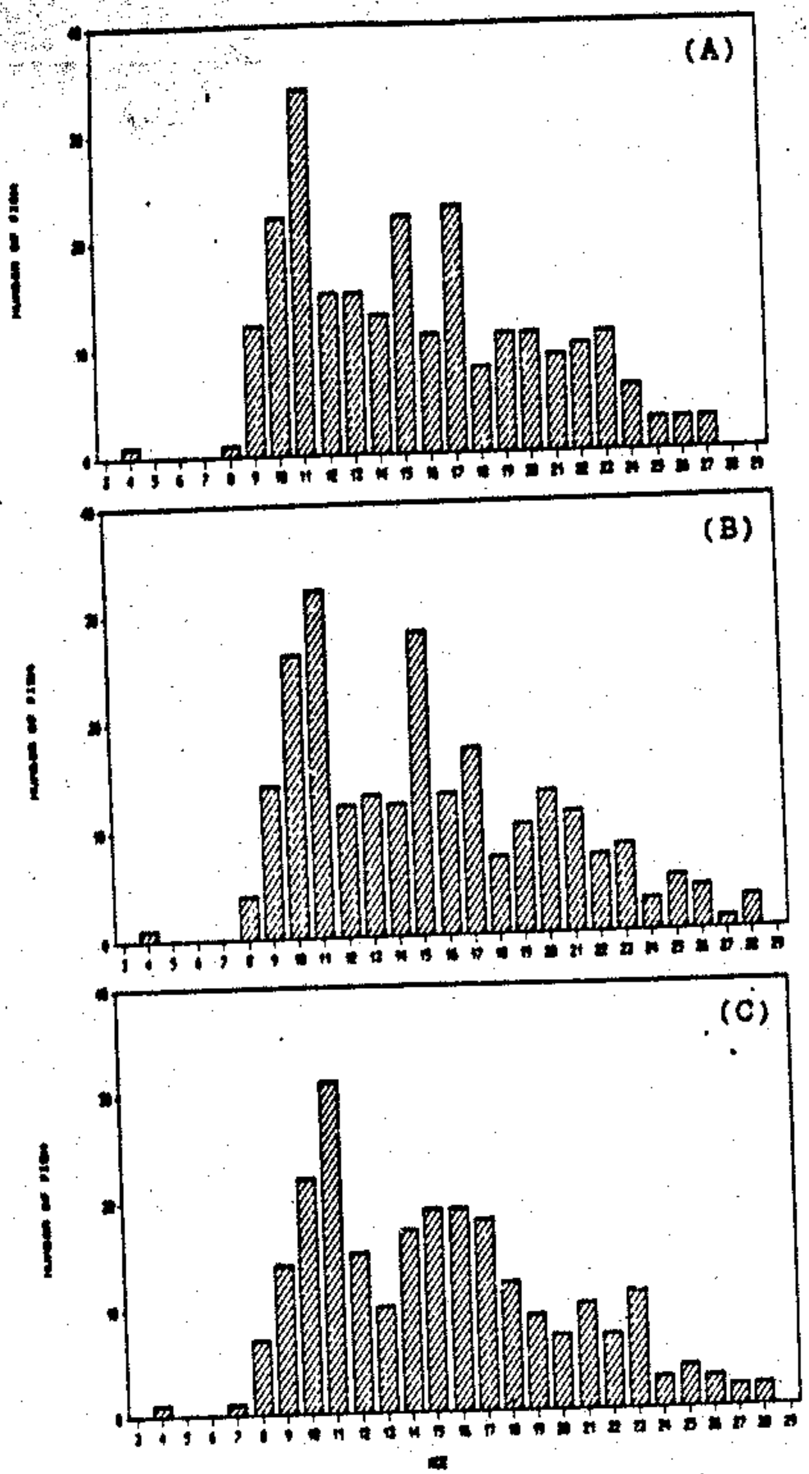



Figure 7. Distribution of ages assigned by reader A (A), reader B (B) and reader C (C) in 1986.

could have come from the same distribution. Similar numbers of 9, 10, and 11 year old fish occurred in all three distributions. The age distributions of reader A and B had relatively fewer 16 year old fish than 15 and 17 year old fish, while reader C's distribution had about the same number of 15, 16 and 17 year old fish.

Age distributions for (1) 81 fish on which all three readers agreed in 1986, (2) 195 fish on which at least two out of three readers agreed, and (3) 216 fish on which either at least two out of three readers agreed or the three readers assigned three consectuive ages had the same general shape with similar relative numbers in each age class (figure 8). This was, of course, expected when the second and third distributions were compared since they differed by only 21 fish. More importantly, relative age class strengths of the first and third distributions were quite similar for age classes 8 through 15. Relative numbers of 16 through 19 year old fish were also somewhat similar. When including fish on which all three readers did not agree into the age distribution of fish on which all three readers agreed by assigning an age according to partial agreement, the sample size of the distribution increased from 81 to 216 fish.

Kolmogorov-Smirnov tests showed ($p < 5$ %) that the poor agreement fish ($n = 28$) and the good agreement fish ($n = 216$) could have both been from a sample with an age distribution like that of the 244 fish sample. Since the

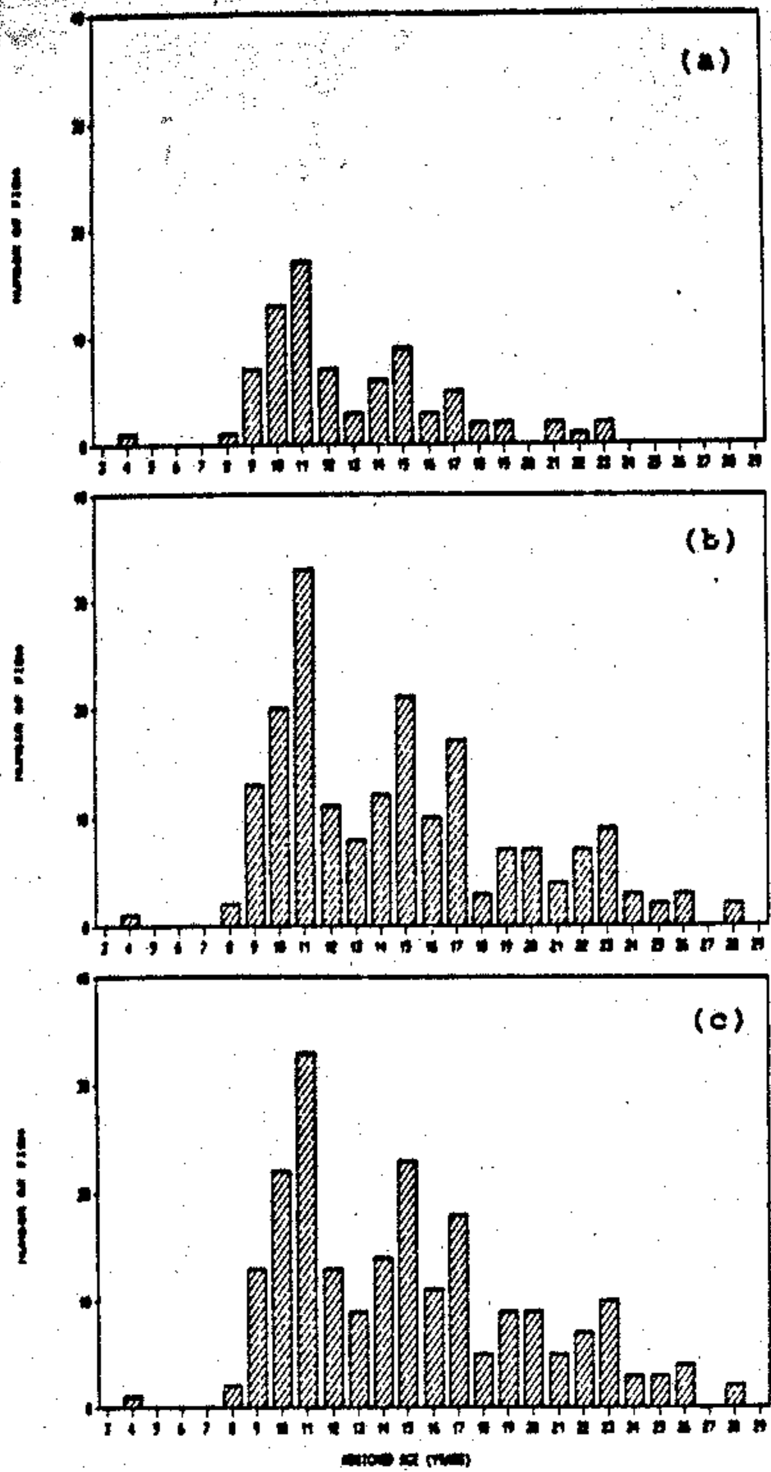


Figure 6. Age distributions for 81 fish on which all three readers agreed in 1986 (a), 195 fish on which at least two out of three readers agreed (b), and 216 fian on which at least two out of three readers agreed or the three readers assigned three consecutive ages (c).

subsample of 216 of the 244 fish randomly caught in 1984 through 1986 was used in backcalculating recruitment, the ages of the 28 fish excluded from the recruitment subsample were examined to see how omitting these fish might bias the resultant age distribution. The average of the assigned ages of the three readers rounded down to the next integer was used to make the age distributions for all 244 fish, and the 216 and 28 fish subsamples shown in figure 9. 16, or over 50 % of the fish thrown out were 18 years old and older while this age group made up only 30 % of the sample of 244 fish. Omitting these poor agreement fish reduced the relative numbers of older fish in the distribution.

## 3.3. AGE DISTRIBUTIONS OF FISH CAPTURED AT DIFFERENT LOCATIONS:

A Kolmorogov-Smirnov non-parametric test for observed distributions coming from the same population showed ($p < 5$ % ) that the Tiburon distribution came from a significantly different population than the other two (figure 10). Clearly, relatively younger fish dominate the Candlestick Park, Carquinez Straits and San Pablo Bay distributions. Only three fish over 20 years old were captured near Candlestick Park and only two were captured in San Pablo Bay. The Tiburon age distribution, on the other hand, included 34 fish 20 years old and older.

A Kolmogorov-Smirnov non-parametric test for observed distributions showed ( $p < 1$ % ) that in both 1973 and 1976,

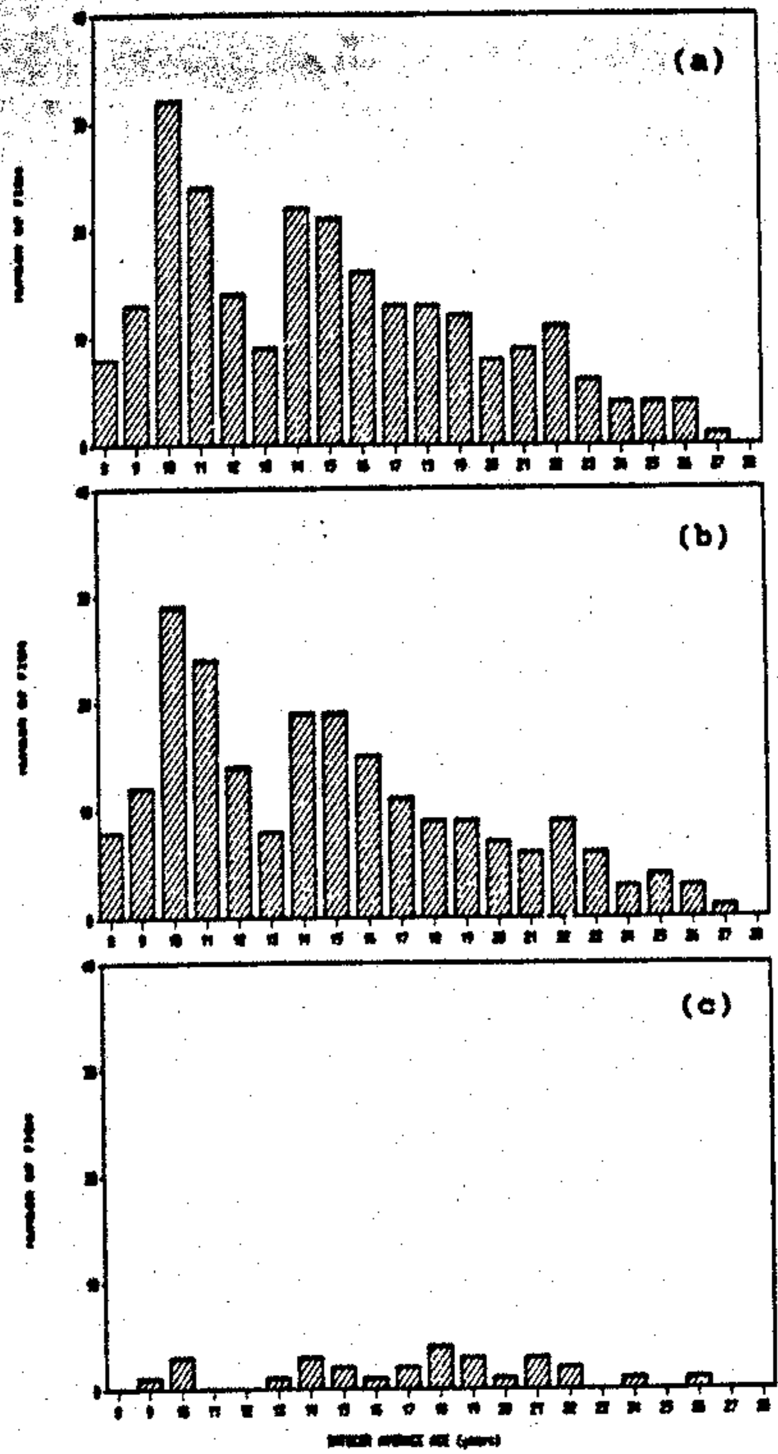



Figure 9. Age distributions of all 244 fish aged in 1986 (a), 216 fish aged with good agreement (b), and 28 fish aged with poor ageement (c).

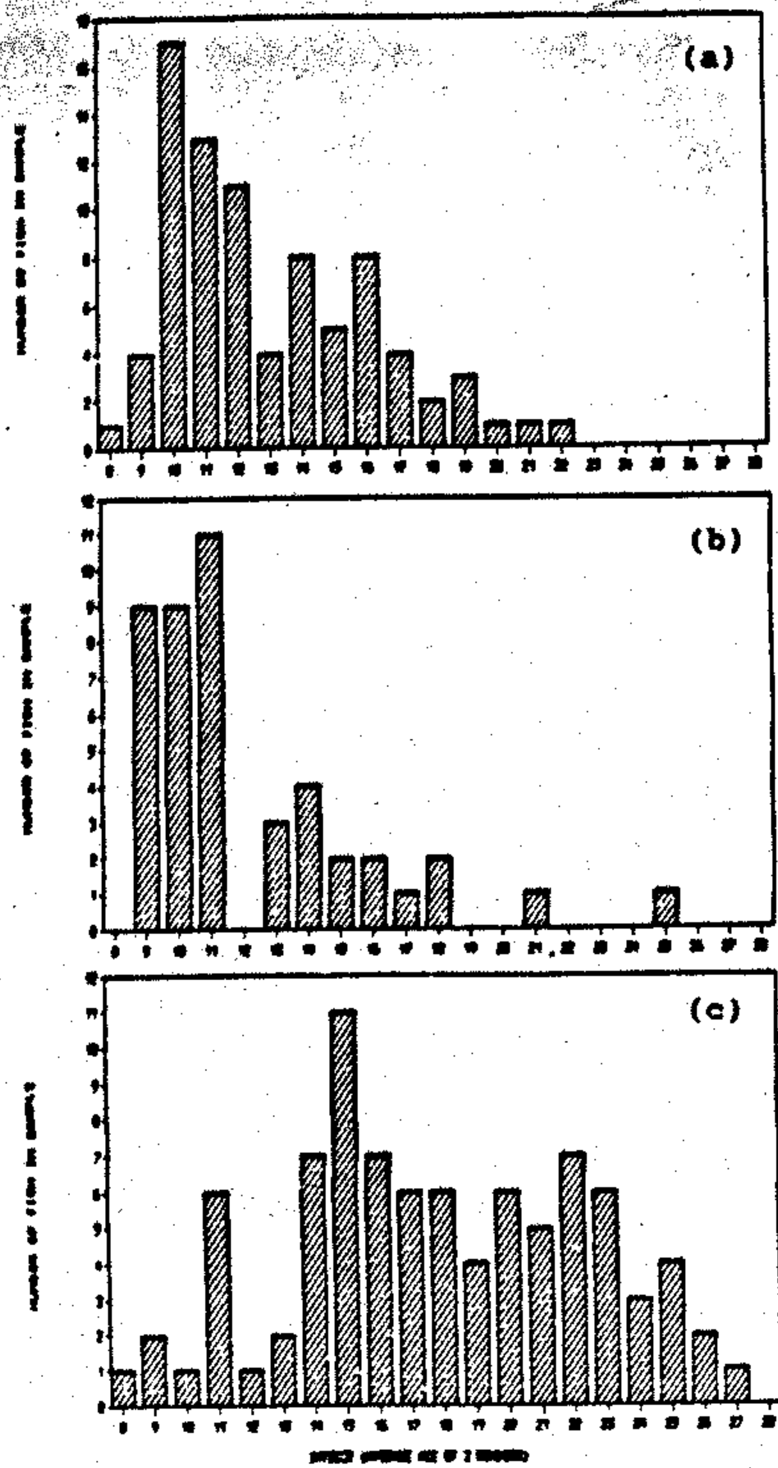


Figure 10. Age distribution of 83 fish caught near Candlestick Park (a), 45 fish caught near Carquinez Straits (b), and 88 caught near Tiburon (c) in 1984-1986.

distributions of fish captured at different locations came from different populations. In 1973, 98 fish in the sample between the ages of 3 and 21 were captured in San Pablo Bay and Carquinez Straits and 127 between the ages of 2 and 20 were captured in Grizzly or Suisun Bays. Plots of these age distributions (figure 11) show that relatively few old fish were captured in Suisun and Grizzly Bays. In 1976, similar distributions were observed at the two locations.

3.4. RECRUITMENT TIME SERIES:

The earliest recruitment time series generated from fish captured in 1954 showed a spike of recruitment in the late 1930's and relatively low recruitment at other times (figure 12). The time series generated from the 1965-1968 samples showed a similar, but slightly wider peak of recruitment in the early 1950's. The recruitment series from fish captured in 1973-1976 showed three peaks of recruitment in the mid 1950's, middle-late 1960's and in 1974. The most recent recruitment series from fish captured in 1984-1986 also showed a large number of fish recruited in 1974 and relatively high recruitment in the late 1960's.

When these four recruitment series were cut off to include only fish 20 years old and younger at the time of capture and plotted on the same axis, peaks of recruitment appeared in the late 1930's, early 1950's late 1960's and 1974 (figure 13). The relative magnitude of these peaks, however, is unknown since the four time series were

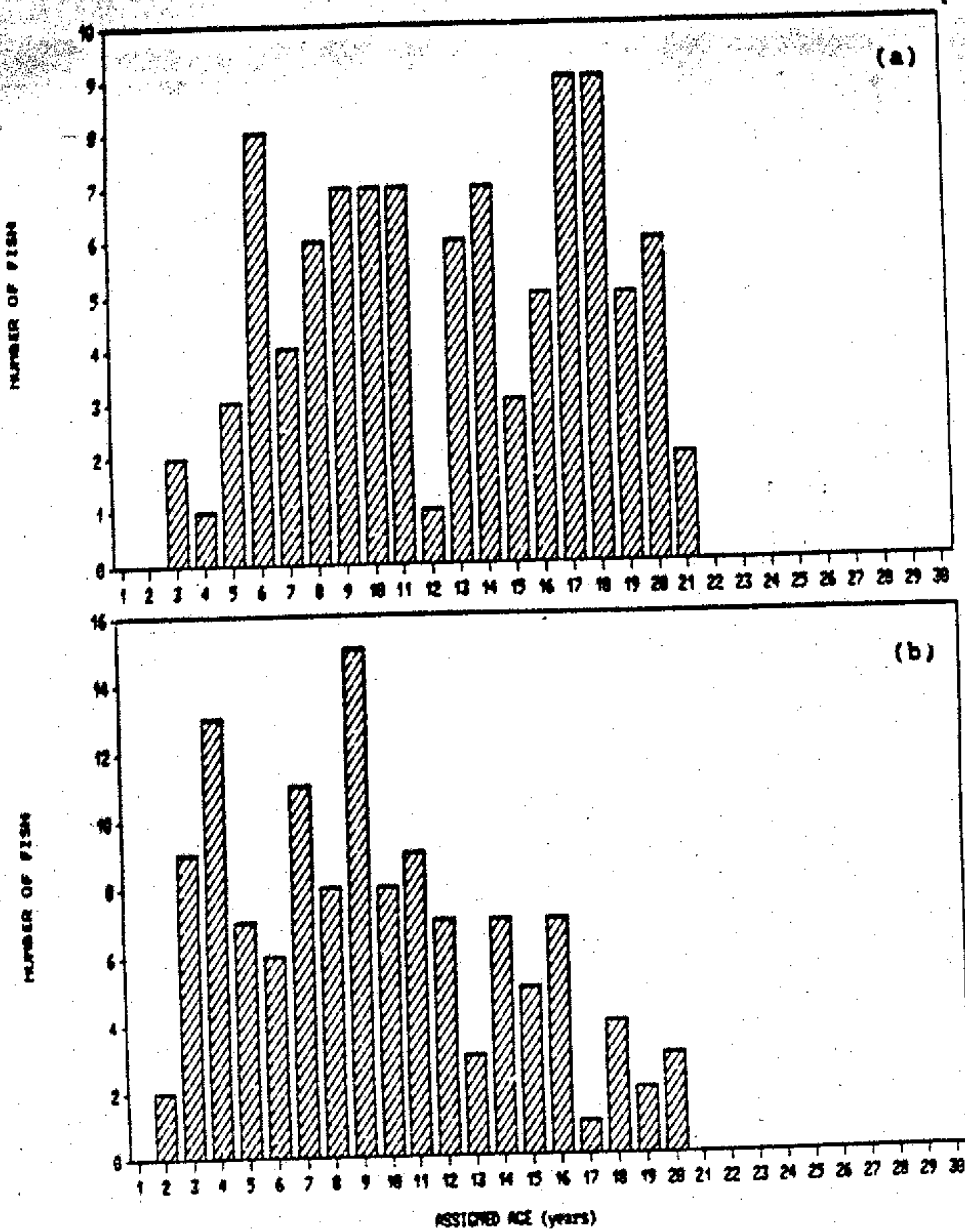



Figure 11. Age distribution of 98 fish caught in San Pablo Bay or Carquinez Straits (a) and 127 fish caught in Grizzly or Suisun Bays (b) in 1973.

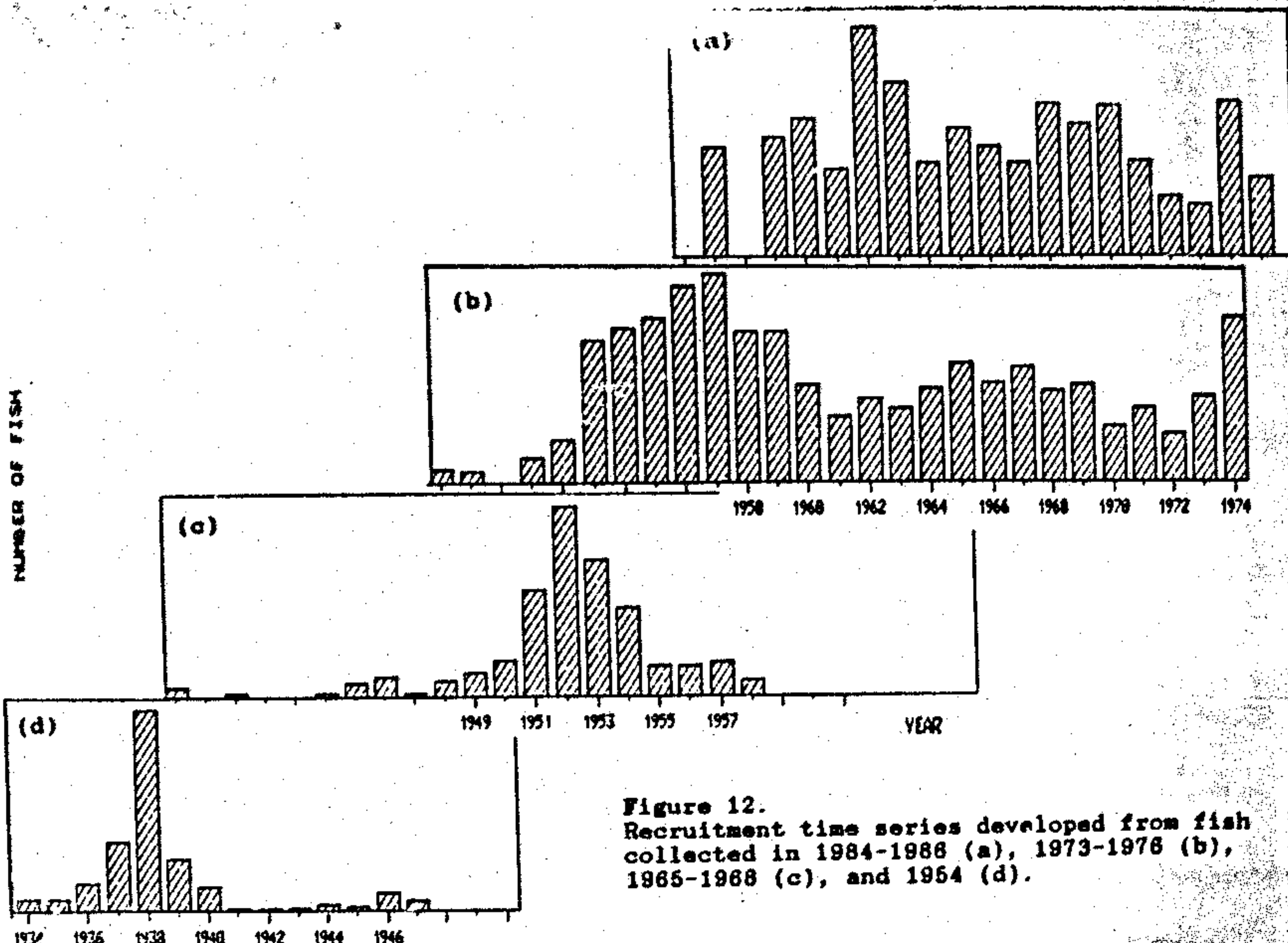



Figure 12.
Recruitment time series developed from fish collected in 1984-1986 (a), 1973-1976 (b), 1965-1968 (c), and 1954 (d).

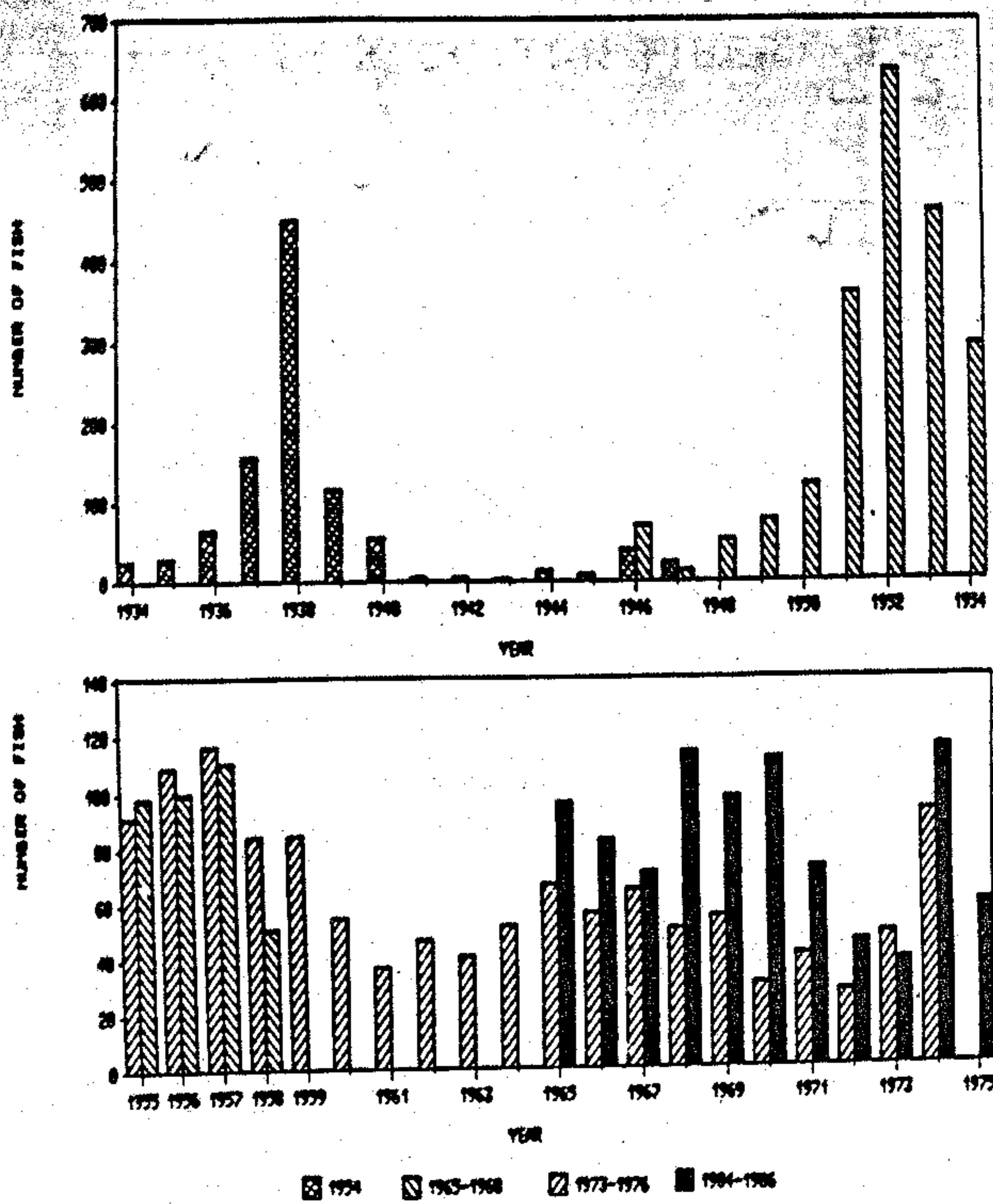



Figure 13. Recruitment time series from fish captured in 1954, 1965-1968, 1973-1976, and 1984-1986 plotted on the same axis. Note change of scale on y-axis between graphs.

generated from different sized samples collected in a variety of ways.

Relative year class strengths estimated from two samples for years with overlapping recruitment estimates were not consistent. This is demonstrated by a wide range of ratios of the older recruitments to the newer recruitment estimates for each set of overlapping years (table 5).

The long time series developed from weighting the four recruitment series with the geometric means of these ratios and averaging overlapping estimates showed much higher recruitment in the late 1930's and early 1950's than any year since (figure 14).

3.5. SIZE DISTRIBUTIONS

When the size distributions of fish captured in 1954, 1965-66, 1973-74 and 1984 are compared, the 1954 distribution had a large fraction of large fish and a distinct peak near 60 inches, which reflects the large year classes of 1938 (figure 15). The other three distributions from fish captured after the opening of the sport fishery have smaller fractions of larger fish.

When assigned ages are plotted against total length for the 216 fish aged with good agreement in 1986, all of the fish 8 years and older included in the sample were over 101.6 cm total length and were vulnerable to capture (figure 16). From Pycha's (1954) and our two 1986 samples it appears that most fish enter the fishery by age 8 or 9 (table 6).

Table 5. Ratios of older recruitment estimates to newer recruitment estimates from fish collected in different samples, and geometric means of these ratios calculated for sets of overlapping estimates.

| Samples | Year | Recruitment Estimates older | newer | older:newer | Geometric Mean |
|---|---|---|---|---|---|
| 1954 & | 1946 | 39 | 69 | .57 | |
| 1965-1968 | 1947 | 23 | 12 | 1.94 | 1.04 |
| 1965-1968 & | 1955 | 98 | 91 | 1.07 | |
| 1973-1976 | 1956 | 99 | 109 | .91 | |
| | 1957 | 111 | 116 | .95 | |
| | 1958 | 51 | 84 | .61 | .87 |
| 1973-1976 & | 1965 | 66 | 95 | .70 | |
| 1984-1986 | 1966 | 56 | 81 | .68 | |
| | 1967 | 64 | 70 | .92 | |
| | 1968 | 50 | 112 | .45 | |
| | 1969 | 54 | 96 | .56 | |
| | 1970 | 30 | 110 | .27 | |
| | 1971 | 41 | 71 | .57 | |
| | 1972 | 27 | 45 | .60 | |
| | 1973 | 46 | 38 | 1.24 | |
| | 1974 | 91 | 114 | .80 | .72 |

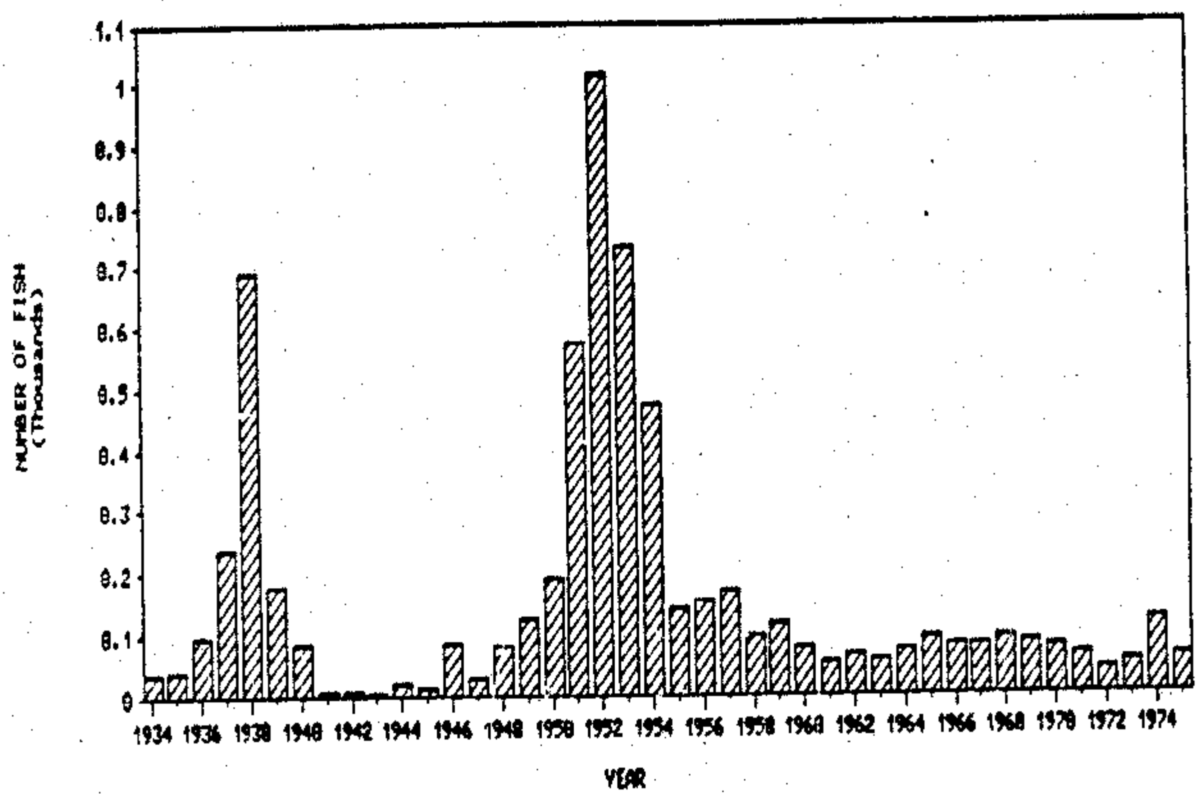



**Figure 14.** Recruitment time series developed from four weighted recruitment series.

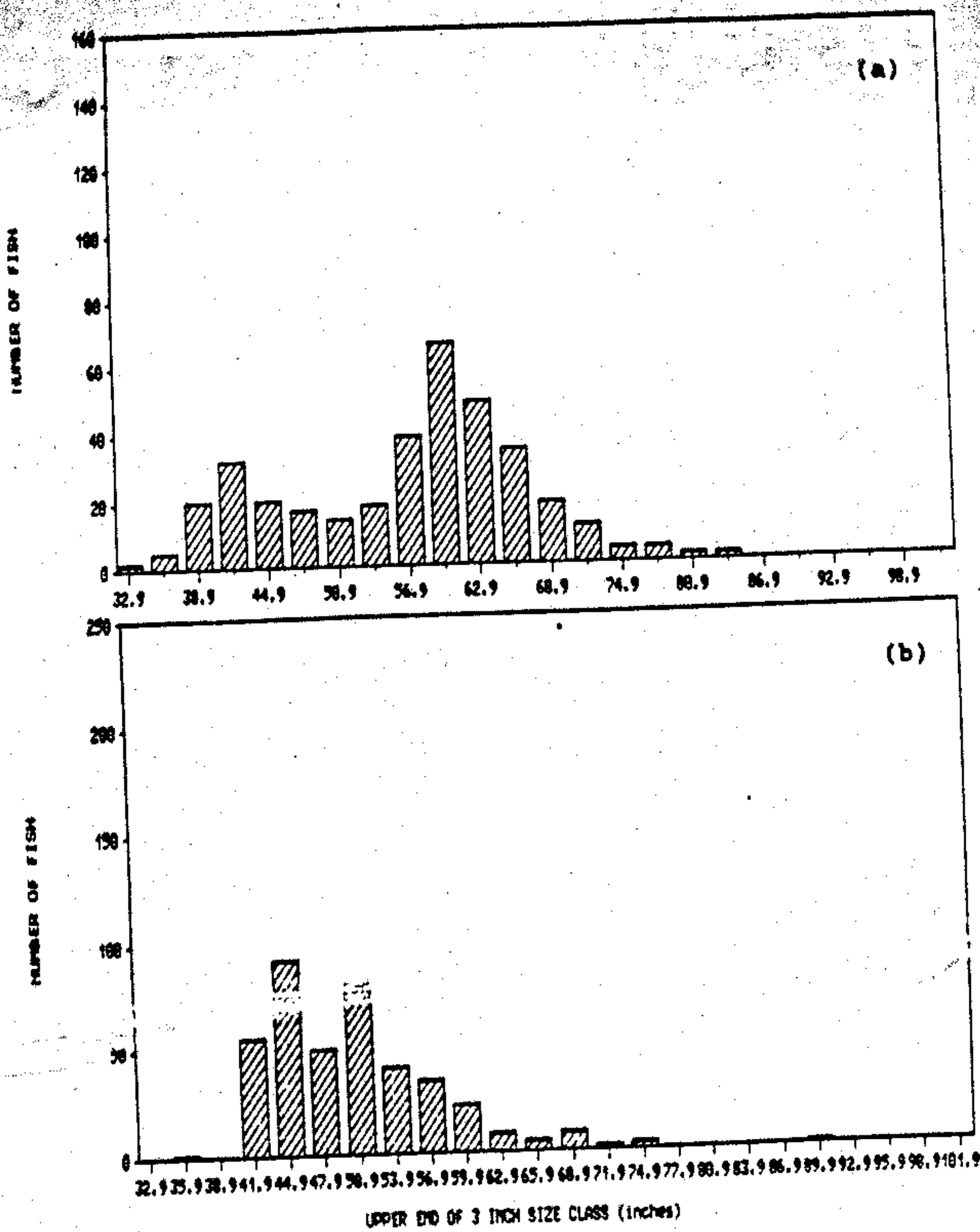
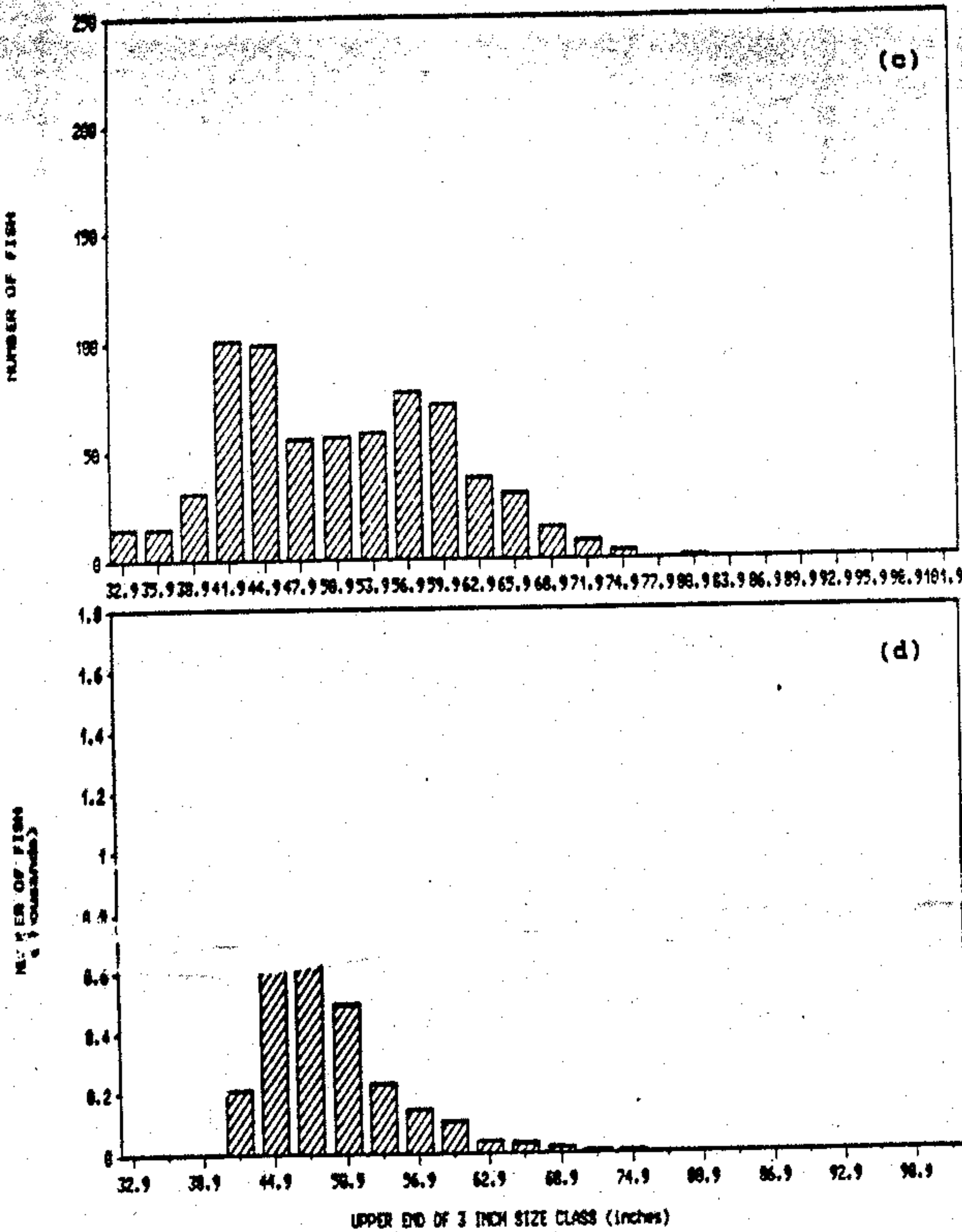



Figure 15. Size distributions of fish captured in 1954 (a), 1965-1968 (b), 1973-1976 (c), and 1984 (d).


(c)
NUMBER OF FISH
(d)
UPPER END OF 3 INCH SIZE CLASS (inches)

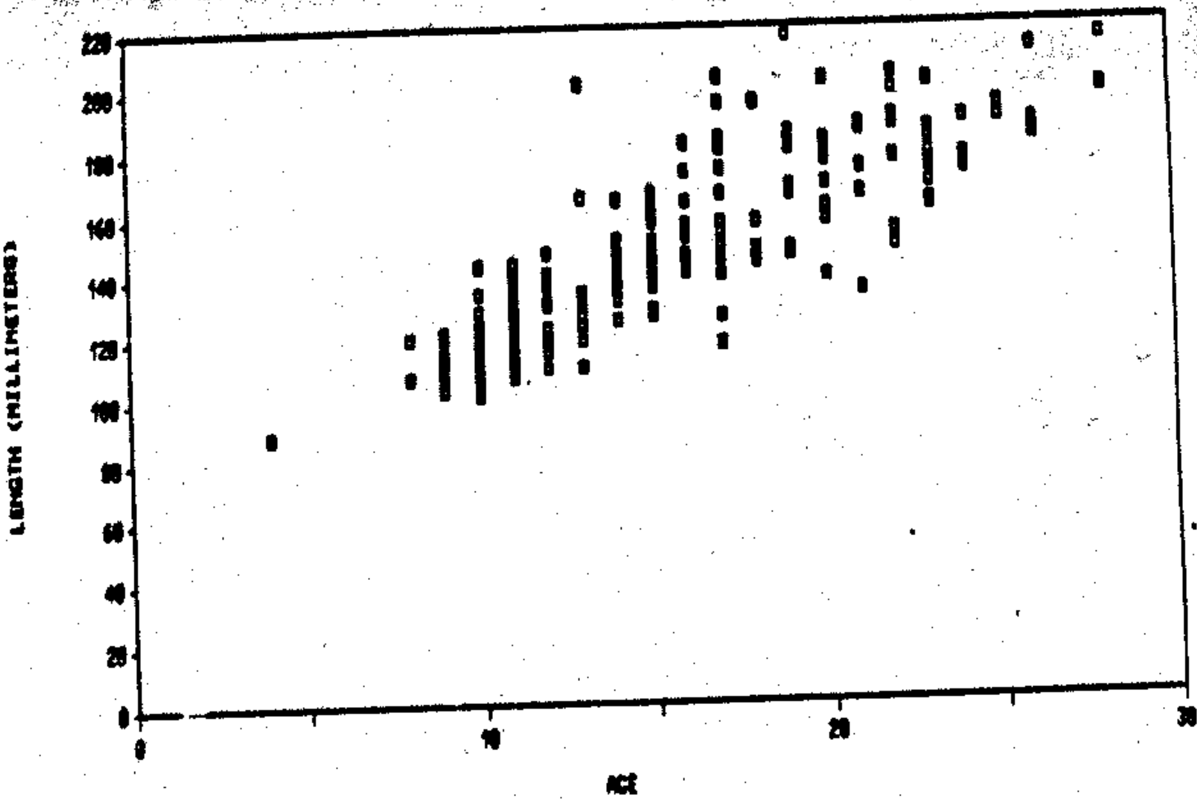



Figure 16. Age-length relationship for 216 fish aged with good agreement in 1986.

Table 6. Summary of age-length data for ages 8-10 year old fish from 1954 and 1984-1986 samples.

| Data Source | Total length | Number of fish<br>Age 8 | Age 9 | Age 10 |
|---|---|---|---|---|
| 1984-1986 | < 40" | 0 | 0 | 0 |
| | ≥ 40" | 2 | 13 | 22 |
| 1954 | < 39" | 1 | 0 | 0 |
| | ≥ 39" | 19 | 4 | 6 |
| | ≥ 42" | 15 | 2 | 5 |

Adjustments to recruitment series for fishing mortality were, therefore, applied to fish after their eighth year (see methods).

## 3.6. CORRELATION OF ESTIMATED RECRUITMENT AND FLOW:

The correlation analysis of estimated recruitment and flow during the same year, previous two years and subsequent two years from 1965 to 1975 produced the highest correlations of 0.44 and 0.36 when recruitment and flows one and two years before, respectively were correlated (table 7). None of these correlations, however, were significant. A multiple regression of recruitment with flows from the same year and previous year had a much higher correlation ($r = 0.66$) than recruitment with flows in any single year or other combination of 2 years. The resulting regression equation,

$$y = 0.40 \text{ (Flow at lag 0)} + 0.45 \text{ (Flow at lag -1)} + 87777$$

was significant at the 90 % level ($p < 10$ %), but not at the 95 % level. Recruitment, flow the same year and flow the previous year plotted along the same axis demonstrates this correlation (figure 17). Since the correlation is poor prior to about 1970 and these estimates are less reliable because these older fish were from a smaller sample, correlation of recruitment and flow of the same year and previous year from just 1970 to 1975 was performed. This resulted in an even higher correlation coefficient of 0.88, while the level of significance ($p = 10$ %) was similar.

Table 7. Correlation coefficients of recruitment and flow at various lags Recruitment estimates are from 1964-1986 recruitment time series and flow is the sum of January through June average monthly Sacramento River Delta outflow.

| Lag (years) | Correlation coefficient | Level of significance |
|---|---|---|
| -2 | 0.36 | p < 50 % |
| -1 | 0.44 | p < 20 % |
| 0 | 0.28 | p < 50 % |
| +1 | 0.10 | p > 50 % |
| +2 | 0.30 | p < 50 % |

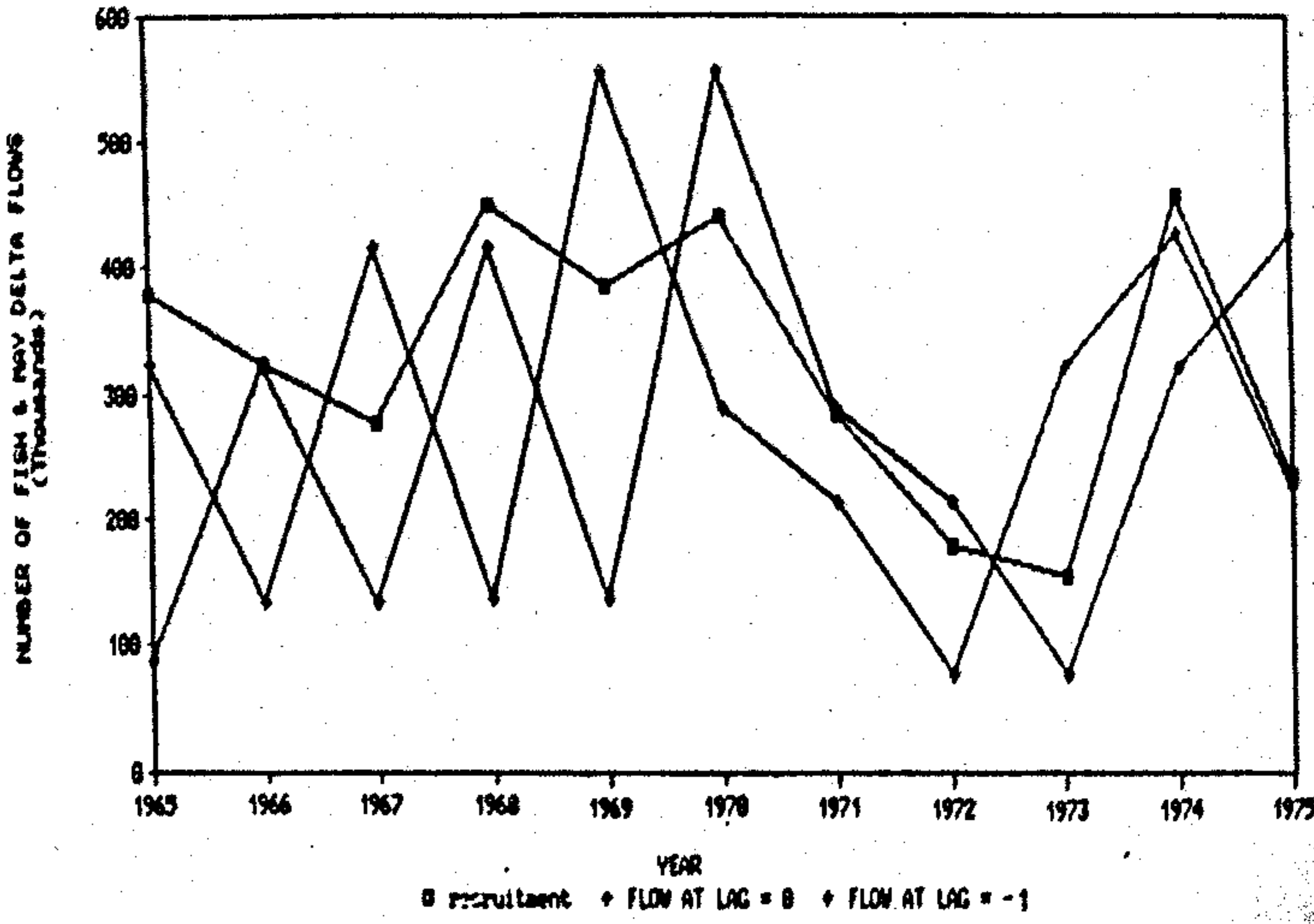



Figure 17. Sturgeon recruitment, flow the same year and flow the previous year plotted on the same axis.

# 4. DISCUSSION

The weak positive correlation of sturgeon recruitment and flow the same year and previous year suggests a possible dependency of recruitment on flow. Determination of whether this reflects a true causal influence requires examination of the sampling and ageing procedures used to generate estimates of past recruitment. If individual mortality rates are not time-varying, an accurately aged random sample of the population will reflect past recruitment. The following discussion first addresses errors in age determinations and the randomness of samples, then examines the relationship of recruitment with flow, and finally suggests how this relationship could be further studied.

## 4.1.1. AGEING AGREEMENT BETWEEN PAIRS OF READERS:

Much of the increase in pairwise agreement of assigned ages from 1985 to 1986 may be due to the replacement of reader A who assigned consistently higher ages than readers B and C. Also, aging criteria were incorporated for the second round of aging. Finally, eight fish were omitted from the 1986 reading because the sections did not include the first annual annulus, and twenty-four new sections from fish captured in May 1986 were included.

Kohlhorst et al. (1980) compared pairwise agreement between readers for 40 fish selected randomly from fish collected by CDFG in 1965-1970. Three of five readers aged the fish both before and after aging criteria were established. These aging criteria included rules about assigning a marginal annulus and counting pairs of bands as one or two years growth. Pairwise agreement increased from 8 %, 13 %, and 33 % to 15 %, 40 %, and 40 % for pairs of readers A & B, B & C, and A & C, respectively.

Pairwise agreement within two years was over 90 % for all three pairs of readers in 1986, but averaged only 74 % in 1985. For the 40 fish aged by readers 1, 2 and 3 in Kohlhorst et al. (1980), pairwise agreeement within two years increased from 28 %, 50 % and 78 %, to 93 %, 95 % and 98 % after aging criteria were established.

Although the use of more expicit ageing rules increased agreement between readers, the results of such aging studies may be biased due to assumptions in developing the aging criteria. The results are more consistent, but not necessarily more accurate.

The question of how many years of growth the annuli represent will be answered through field grow-out or hard part analysis. Ongoing mark-recapture studies with sturgeon injected with tetracylcline will help validate the general aging method. Preliminary results of this study indicate that our interpretation of annual annuli is valid (Brennan, 1987). Validation of any aging method, however, requires validation in all age classes in a population (Beamish and McFarlane 1983). Also, many fin ray sections have features like pairs of bands or faint rings that will require extensive mark-recapture studies to validate their interpretation.

Readers B and C did not consistently assign the same age to the same fish from one year to the next. Although each reader assigned two fairly close ages to the same fish as demonstrated by high correlation coefficients (0.96 and 0.92), the number of exact agreements was low. Some of this variation is due to the establishment of aging criteria, but much of it is probably individual variation in interpretation of annual annuli.

4.1.2. AGEING AGREEMENT AMONG THREE READERS:

Improvements in the 1986 agreements between readers may be due to several factors. First, fin rays from many fish which had relatively poor agreement in the 1985 aging had more sections (some of different thicknesses) prepared for the 1986 readings. Second, reader A, who agreed poorly with both readers B and C was replaced. Third, eight fish from the 1985 aging were omitted in 1986 because the section may not have included the first year's annulus. Fourth, readers B and C were more experienced the second time around and the new reader A had some prior experience in aging sturgeon. Finally, the aging rules established after the 1985 aging probably improved the agreement.

4.1.3. AGE DISTRIBUTION OF ERRORS IN AGE DETERMINATION:

Errors in age determination increased with age in 1985, but not in 1986. Similar variability in the age distribution of errors in age determinations was also seen by Kohlhorst et al. (1980). He divided fish in the 1965-1970 and 1973-1976 samples into 5-year age classes ages 0 to 4, 5 to 9, etc. Since the true age of these fish is unknown, some type of integer average age must have been used to assign fish to these age classes. Although residuals like those calculated in 1986 were not calculated for these fish, the percent of times that at least two out of three readers agreed on the age of the fish was calculated. This percent agreement decreased for older age classes for the 1973-1976 fish, but not for those in the 1965-1970 sample. For example, for the 1973-1976 sample, readers agreed on 72 % of fish 10 to 14 years old, but only 55 % of fish ages 15 to 19 years old and 52 % of fish aged 20 to 24 years old. For the 1965-1970 sample, readers agreed on the ages of 65 %, 56 %, and 67 % for age clasees 10 to 14, 15 to 19, and 20 to 24 years old, respectively.

For a sample of sturgeon fin ray sections, whether errors in age determination increase with age seems to be both a function of the collection of specimens which have been prepared in different ways and of the readers aging the sections. Also, it is possible that at low error rates, an increase of errors in age dterminations may not be detected.

4.1.4. EFFECTS OF ERRORS IN AGE DETERMINATIONS ON THE SHAPE OF AN AGE STRUCTURE:

Errors in age determinations affect the age structure in somewhat predictable ways. Peaks of recruitment spread out and flatten more or are lost as the errors in age determinations increase. Valleys, on the other hand, fill in. As errors in age determinations increase, major features become less distinct and age structures flatten out. It follows that errors in age determinations, if large enough, could alter the age structure enough that backcalculation of recruitment is essentially meaningless.

Assuming that errors in age determinations in 1986 are similar to those estimated, the age distribution generated from the fish which at least two out of three readers had agreed upon the ages of or the threee readers had assigned three consecutive ages reflects relative age class strengths for 8 through 15 year old fish. Fish age 16 years and older, on the other hand, were captured in such small numbers that when the assumed 1986 error rate was applied, differences in relative age class sizes were reduced. The 1986 age distribution which generated from assigned ages when at least 2 out of 3 readers agree or the readers assign 3 consecutive ages is, most likely, a slightly distorted version of the true age distribution because the error rate has already been applied. Since similar age distributions with similar relative numbers of fish in each age class were also generated by using approximately 10 % higher and lower error rates, small changes in error rates seem to have little effect on an age structure.

Pycha (1956) estimated that 1938 was an extremely good year for recruitment and 1937 and 1939 were also relatively good based on number of 17, 18 and 19 year old fish in his 1954 sample. Assuming that aging errors by Pycha are similar to those in 1986 (they were probably greater since only one reader aged the fish), all the recruitment he assumed to have occurred in 1937 and 1939, might have taken place in 1938. Additionally, moderate recruitment assumed to have taken place in 1936 and 1940 might also have been due to fish erroneously aged. Thus the late 1930's spike of recruitment noted by Pycha (1956) may have been caused by a single strong year class.

4.2. AGE DISTRIBUTIONS FROM AGEING DATA:

Including fish on which only two readers agreed or the three readers assigned three consecutive ages increased the sample size and maintained the same relative age class strengths of fish up to the age of 15 years. The increased uncertainty of the ages of a larger percent of the fish captured over the ages of about 20 years and the small sample size of these older fish limits the conclusions about relative year class strength of these older fish. Confidence in relative year class strength of fish from about 16 through 19 years old is similarly limited.

4.3. AGE DISTRIBUTIONS OF FISH CAPTURED AT DIFFERENT LOCATIONS:

Sampling in different areas in the bay and delta results in samples encompassing different age groups of fish. Relatively young age groups have been captured in Suisun and Grizzly Bays and near Candlestick Park, while older age groups have been captured in Carquinez Straits and San Pablo Bay. The oldest age groups have been captured near Tiburon. Since the sturgeon population in the bay and delta is separated into these different age groups of fish in different locations, some type of stratified sampling is needed to determine relative year class strength of the entire population. For this study, samples from all capture locations are simply combined without any weighting and the resultant age distributions are assumed to be representative of the population. This is fairly reasonable since the San Pablo Bay and Candlestick Park samples include relatively younger fish, and the Tiburon sample included older fish.

l three subsamples have peaks in the age distributions of fish near 11 and 15 years old. When the thre distributions are combined, these peaks remain. Major trends in recruitment which show up in each subsample are still apparent when the samples are simply combined.

Combining the age distributions of fish captured in different locations in the same year by CDFG in 1965-1968 and 1973-1976 also gives age distributions which show some major trends in relative year class strength. By combining data from several years, more fish from different capture locations are included and therefore more age classes are represented. Thus, major trends in year class strength should show up for groups of fish of similar ages in these relatively large samples.

Age distributions developed by combining samples including different age groups, however, may or may not show relative age class strength between different groups of fish collected in different locations. For example, in the CDFG 1973-1976 age distribution, old and young fish were captured in different areas. Since one area may have been more intensively sampled than the other, relative numbers of old and young fish can not be compared.

4.4. RECRUITMENT TIME SERIES:

Since few fish over the age of 20 years were captured in Pycha's 1954 sample, no conclusions about recruitment prior to 1934 should be drawn. Also, not much can be concluded about recruitment in the late 1940's since these fish were too young in 1954 and too old in 1965-1968 to be captured in large numbers. Pycha (1956), however, captured a relatively large number of 6 year old fish in 1954 and these are not included in the recruitment series because they were assumed to be too small to be fully vulnerable to the capture method. It is probably safe to assume that these 6 year old fish reflected a spike of recruitment in

1948 which was not as big as those of the late 1930's and early 1950's.

From the four recruitment time series, given that the data weres collected in different ways, a few conclusions can

be made about past trends in recruitment. First, recruitment has been variable for the past 50 years. Second, the extreme highs and lows in recruitment of the 1930's are no longer seen. The possible single strong year class of 1938 after near depletion of the fishery may have given rise to another set of strong year classes in the early 1950's. Since the age of first spawning has been shown to be variable in sturgeon and different between the sexes and they can spawn more than once (Semakula and Larkin 1968), repeated dominant year classes produced by a previous one would not be expected to continue for more than a generation or two after the production of a large age class.

Kohlhorst (1980) claimed that 14 years is approximately the age of first spawning for female white sturgeon. Doroshov et al. (1983) spawned fish ranging from 16 to 24 years of age. Many of these fish were probably spawning for a second or third time. The variabilty in age of maturation would cause a dominant year class like the one produced in 1938 to produce offspring over a range of years. The result would be a more spread-out recruitment peak similar to the one of the early 1950's which was backalculated from the CDFG 1965-1968 samples. Fish from a wide recruitment peak like this one of the late 1950's, and fish from the 1938 age class spawning for a second time would produce offspring over an even wider number of years. Repeated dominant age classes resulting from previous dominant age classes would therefore, continue for only a few generations. This "generation effect" by which a surge of births at one time (followed by survival to reproduction) is echoed in a surge of births one generation later has been observed in many populations that have undergone disturbances. The amount of time it takes these echoing oscillations to settle back to equilibrium depends partially on the synchronicity of reproduction in a year class. A larger time range of first reproduction would result in shorter and wider echoing recruitment peaks that would be quickly damped (Keyfitz 1972).

Estimates of recruitment for the same year that were developed from age distributions of fish captured in different years were not consistent as demonstrated by variability in the ratios of the estimates. This is not surprising since the recruitment series were developed from non-random samples. Also, since fish over a range of only about ten years (ages 9 through 19) were effectively sampled, taking samples every ten years is not frequent enough to develop a continuous recruitment time series. It follows that a realistic long time series of recruitment can not be made by combining these four recruitment time series. If truly random samples collected several years apart through some type of stratified sampling were used to develop recruitment series, ratios of estimates of recruitment from two samples for the same year should be relatively constant. The long-term recruitment time series developed by weighting the four series suggest that recruitment in the late 1930's and early 1950's was much higher than any time since. This time series, however, was developed ignoring the fact that the three oldest recruitment series were from non-random population sampling. Thus, strong conclusions can not be drawn from this time series.

4.5. SIZE DISTRIBUTIONS:

Size distributions of sturgeon captured in 1954, 1965-1966, 1973-1974 and 1984 demonstrate the effects of angling on a population. The earliest distribution of fish captured the same year the fishery was opened has a large fraction of large catchable fish, partly due to the 1938 year class. Subsequent fishing pressure and fewer large year classes, however, shifted the size distribution so that there are relatively few large catchable fish. Currently most fish caught by anglers have just entered the fishery, and few anglers catch large fish. The implication of this shaped size distribution is that only a small percent of the population lives long enough to reproduce. Since fecundity in sturgeon is so high that the eggs from a single female can number in the millions, this small fraction of old fish in the population probably does not limit year class size. This is further supported by the increased abundance of sturgeon during the thirty years that this shape size distribution has existed.

4.6. CORRELATION OF ESTIMATED RECRUITMENT AND FLOW:

Weak, yet positive correlations of recruitment and spring and early summer outlfow suggest that flow might be important in determining year class size. Long-term correlations were not feasible due to past non-random samples of the population. The highest, but non-significant, correlation was observed for recruitment and combined flows from the same year and previous year. Possible mechanisms could include pre-spawning adult food supply and juvenile food supply and available habitat.

This correlation increased from 0.66 to 0.88 when only six years (1970-1975) were included in the analysis. This could be due to one of two factors: (1) recruitment and flow might not be strongly correlated and the higher correlation for a shorter time period is just chance, or (2) our recruitment estimates for fish over the age of 15 years at the time of capture are not accurate. The relatively small sample size of these older fish and limited accuracy of recruitment estimates discussed previously support this second possibility.

To understand the relationship of sturgeon recruitment and flow would require extensive population sampling. This sampling would need to be stratified by area so as to include all ages of fish. The total numbers of fish in each area would also need to be known to properly weight the samples when they are combined. Catch per unit effort, size of each area and distribution of fish in the area could be used to estimate the number of fish in each aea.

Fin ray sections or other hard parts used for age determinations would need to be collected from large numbers of fish. However, collec'ion of fin rays from live fish in the manner desribed above (see methods) has been shown to cause up to 50 % mortality (Kohlhorst 1979). Killing large numbers of sturgeon to determine whether flow is important in controlling recruitment is probably not justifiable as long as the population maintains itself at current levels. Further studies on the effects of fin ray removal and development of alternate techniques for collecting hard parts while reducing mortality should be evaluated.

## 5. REFERENCES


Beamish, R. J. and G. A. McFarlane. 1983. The forgotten requirement for age validation in fisheries biology. Trans. Am Fish. Soc. 112:735-743.

Brennan, J. 1987. Age determination and verification of California white sturgeon, Acipenser transmontanus: a comparitive analysis. M.A. Thesis (in prep.), San Jose State University.

Chadwick, H. K. 1959. California sturgeon tagging sturgeon CFG 45(4):297-301.

Cuanang, A. 1984. San Francisco Bay Sturgeon. Angler Publications. Oakland, Ca. 89 pp.

Doroshov, S. I., Clark, W. H., Lutes, P. B., Swallow, R. L., Beer, K. E., McGuire, A. B. and M. D. Cochran. 1983. Artificial propagation of the white sturgeon, Acipenser transmontanus Richardson. Aquaculture 32:93-104.

Hogg, R. V. and E. A. Tannis. 1983. Probability and Statistical Inference (second edition). Macmillan Publishing Co , Inc. New York. 533 pp.

Keyfitz, N. 1972. Population waves. pp. 1-38 in T. N. E. Greville (ed.) Population Dynamics. Academic Press, New York, N.Y.

Kohlhorst, D. W. 1979. Effect of first pectoral fin ray removal on survival and estimated harvest rate of white sturgeon in the Sacramento-San Joaquin estuary. CFG 65(3): 173-177.

Kohlhorst, D. W. 1980. Recent trends in the white sturgeon population in California's Sacramento-San Joaquin estuary. CFG 66(4):210-219.

Kohlhorst, D. W., Miller, L. W. and J. J. Orsi. 1980. Age and growth of white sturgeon collected in the Sacramento-San Joaquin estuary, California: 1965-1970 and 1973-1976. CFG 66(2):83-95.

Miller, L. W. Personal communication.

Miller, L. W. 1972. White sturgeon population characteristics in the Sacramento-San Jaoquin estuary as measured by tagging. CFG 58(2):94-101.

Pycha, R. L. 1956. Progress report on white sturgeon studies. CFG 42(1):23-56.

Semakula, S. N., and P. A. Larkin. 1968. Age, growth, food, and yield of the white sturgeon (Acipenser transmontanus) of the Fraser River, British Columbia. J. Fish. Res. Bd. of Canada 25(12):2589-2602.

Stevens, D. E. and D. W. Miller. 1983. Effects of river flow on abundance of young chinook salmon, American Shad, longfin smelt and delta smelt in the Sacramento-San Joaquin River system. North American J. Fish. Management 3:425-437.

Stevens, D. E., Kohlhorst, D. W., Miller, L. W. and D. W. Kelley. 1985. The decline of striped bass in the Sacramento-San Joaquin Estuary. Trans. Am. Fish. Soc. 114(1):12-30.

# 6. APPENDIX

## 6.1. Calculation of estimated 1986 error rate.

The probability of any reader assigning the true age to a fish was calculated from rates of pairwise agreement in 1986 (eq. 1). The probability of any reader assigning an age either one or two years higher or lower than the true age was similarly calculated from the rates of pairwise disagreements by one or two years (eqs. 2 and 3, respectively).

$$P(0) = \frac{n(A-B=0)+n(B-C=0)+n(A-C=0)}{3N} = \frac{127+123+107}{3(244)} = 0.49 \quad (1)$$

$$P(1) = \frac{n(A-B=1)+n(B-C=1)+n(A-C=1)}{3N} = \frac{67+66+77}{3(244)} = 0.29 \quad (2)$$

$$P(2) = \frac{n(A-B=2)+n(B-C=2)+n(A-C=2)}{3N} = \frac{36+31+40}{3(244)} = 0.15 \quad (3)$$

where:

P(0) = probability that any reader assigns the true age to a fish.
P(1) = probability that any reader assigns an age to a fish that is one year higher or lower than the true age.
P(2) = probability that any reader assigns an age to a fish that is two years higher or lower than the true age.

n(A-B=0) = number of times readers A and B assigned the same age to a fish.
n(A-B=1) = number of times readers A and B assigned ages one year apart to a fish.
n(A-B=2) = number of times readers A and B assigned ages two years apart to a fish.
n(B-C= 0, 1 or 2) and n(A-C= 0, 1 or 2) are similarly calculated.

Based on these probabilities and using the rules that an age is assumed correct when at least two of three readers agree or when the three readers assign three consecutive ages the middle age is assumed correct, the probability that an assumed correct age is the true age can be estimated as follows:

P(assumed correct age is true age) =

$$
\begin{aligned}
&P(0)P(0)P(0) = (.49)(.49)(.49) = 0.118\\
+&P(1)P(0)P(0) = (.29)(.49)(.49) = 0.070\\
+&P(0)P(1)P(0) = (.49)(.29)(.49) = 0.070\\
+&P(0)P(0)P(1) = (.49)(.49)(.29) = 0.070\\
+&P(2)P(0)P(0) = (.15)(.49)(.49) = 0.036\\
+&P(0)P(2)P(0) = (.49)(.15)(.49) = 0.036\\
+&P(0)P(0)P(2) = (.49)(.49)(.15) = 0.036\\
+&P(0)P(1)P(1) = (.49)(.29)(.29) = 0.041\\
+&P(1)P(1)P(0) = (.29)(.29)(.49) = 0.041\\
+&P(0)P(1)P(1) = (.49)(.29)(.29) = 0.041\\
&\text{-----}\\
&0.56
\end{aligned}
$$

The first seven combinations of probabilities reflect cases where the age is assumed correct when at least two out of three readers agree. The last three combinations reflect cases where the three readers assign three consecutive ages.

P(assumed correct age is off from true age by one year) =

$$
\begin{aligned}
&P(1)P(1)P(1) = (.29)(.19)(.29) = 0.024\\
+&P(1)P(1)P(0) = (.29)(.29)(.49) = 0.041\\
+&P(0)P(1)P(1) = (.49)(.29)(.29) = 0.041\\
+&P(1)P(0)P(1) = (.29)(.49)(.29) = 0.041\\
+&P(1)P(1)P(2) = (.29)(.29)(.15) = 0.013\\
+&P(2)P(1)P(1) = (.15)(.29)(.29) = 0.013\\
+&P(1)P(2)P(1) = (.29)(.15)(.29) = 0.013\\
+&P(0)P(1)P(2) = (.49)(.29)(.15) = 0.021\\
+&P(0)P(2)P(1) = (.49)(.15)(.29) = 0.021\\
+&P(1)P(0)P(2) = (.29)(.49)(.15) = 0.021\\
+&P(1)P(2)P(0) = (.29)(.15)(.49) = 0.021\\
+&P(2)P(1)P(0) = (.15)(.29)(.49) = 0.021\\
+&P(2)P(0)P(1) = (.15)(.49)(.29) = 0.021\\
&\text{-----}\\
&0.31
\end{aligned}
$$

The first seven combinations of probabilities reflect cases where the age is assigned when at least two out of three readers agree. The last six combinations reflect cases where the three readers assign three consecutive ages.

Since 31 % of the ages assumed correct are one year too high or low, 16 % the fish in each age class are moved up and down one age class. The remaining 68 % in each age class are left as assigned. This may be conservative since only 56 % of the assumed correct ages of the fish were estimated to be the true ages. The remaining unexplained 12 % were included here for simplicity.

6.2. Ages assigned to each fish by each reader in 1986.

1986 STURGEON AGE DATA SET

| SAMPLE ID #: | AGE ASSIGNED BY READER A: | AGE ASSIGNED BY READER B: | AGE ASSIGNED BY READER C: |
|---|---|---|---|
| 1040 | 14 | 14 | 14 |
| 1041 | 15 | 15 | 15 |
| 1042 | 15 | 15 | 16 |
| 1043 | 15 | 15 | 15 |
| 1044 | 15 | 14 | 15 |
| 1045 | 15 | 15 | 13 |
| 1046 | 11 | 11 | 11 |
| 1047 | 19 | 21 | 16 |
| 1048 | 12 | 11 | 12 |
| 1049 | 10 | 11 | 10 |
| 1051 | 14 | 14 | 13 |
| 1052 | 9 | 9 | 9 |
| 1055 | 17 | 17 | 16 |
| 1072 | 9 | 9 | 8 |
| 1073 | 10 | 10 | 10 |
| 1074 | 10 | 10 | 10 |
| 1075 | 11 | 11 | 10 |
| 1076 | 13 | 13 | 13 |
| 1077 | 10 | 10 | 10 |
| 1078 | 9 | 9 | 9 |
| 1079 | 10 | 10 | 9 |
| 1080 | 10 | 10 | 10 |
| 1081 | 17 | 16 | 13 |
| 1082 | 10 | 10 | 9 |
| 1083 | 10 | 10 | 10 |
| 1084 | 8 | 8 | 8 |
| 1085 | 9 | 9 | 8 |
| 1086 | 13 | 12 | 11 |
| 1087 | 9 | 9 | 9 |
| 1088 | 10 | 11 | 11 |
| 1089 | 9 | 9 | 9 |
| 1090 | 9 | 9 | 8 |
| 1091 | 12 | 11 | 8 |
| 1092 | 10 | 10 | 10 |
| 1093 | 9 | 9 | 8 |
| 1094 | 9 | 9 | 7 |
| 1151 | 22 | 22 | 21 |

| | | | |
|---|---|---|---|
| 1153 | 20 | 21 | 21 |
| 1154 | 15 | 15 | 16 |
| 1155 | 19 | 20 | 18 |
| 1156 | 23 | 23 | 27 |
| 1157 | 17 | 16 | 16 |
| 1158 | 25 | 27 | 26 |
| 1159 | 17 | 17 | 16 |
| 1160 | 10 | 10 | 9 |
| 1162 | 11 | 11 | 11 |
| 1163 | 20 | 20 | 21 |
| 1165 | 20 | 19 | 18 |
| 1166 | 22 | 21 | 22 |
| 1167 | 17 | 17 | 13 |
| 1169 | 22 | 22 | 23 |
| 1170 | 14 | 14 | 14 |
| 1171 | 14 | 15 | 16 |
| 1172 | 11 | 11 | 11 |
| 1173 | 23 | 22 | 27 |
| 1174 | 20 | 21 | 18 |
| 1176 | 15 | 15 | 15 |
| 1177 | 20 | 21 | 19 |
| 1180 | 17 | 17 | 17 |
| 1182 | 21 | 20 | 18 |
| 1183 | 17 | 17 | 15 |
| 1186 | 16 | 15 | 17 |
| 1187 | 17 | 15 | 15 |
| 1188 | 10 | 8 | 8 |
| 1189 | 15 | 14 | 13 |
| 1191 | 18 | 18 | 17 |
| 1192 | 14 | 12 | 16 |
| 1193 | 11 | 10 | 9 |
| 1194 | 19 | 17 | 17 |
| 1195 | 23 | 23 | 23 |
| 1196 | 15 | 15 | 15 |
| 1197 | 21 | 20 | 20 |
| 1198 | 15 | 15 | 15 |
| 1199 | 15 | 15 | 15 |
| 1200 | 20 | 19 | 16 |
| 1201 | 19 | 21 | 24 |
| 1202 | 21 | 21 | 21 |
| 1203 | 15 | 16 | 14 |
| 1204 | 21 | 19 | 19 |
| 1205 | 22 | 21 | 18 |
| 1206 | 21 | 21 | 21 |
| 1207 | 20 | 17 | 19 |
| 1208 | 16 | 19 | 19 |
| 1209 | 19 | 20 | 20 |
| 1210 | 23 | 25 | 25 |
| 1211 | 19 | 18 | 17 |
| 1212 | 13 | 13 | 13 |
| 1214 | 22 | 22 | 22 |
| 1215 | 20 | 21 | 18 |
| 1216 | 25 | 23 | 23 |
| 1217 | 24 | 22 | 21 |
| 1218 | 27 | 26 | 28 |
| 1219 | 17 | 17 | 18 |

| | | | |
|---|---|---|---|
| 1220 | 21 | 24 | 23 |
| 1221 | 11 | 11 | 11 |
| 1222 | 13 | 13 | 15 |
| 1223 | 17 | 17 | 15 |
| 1225 | 14 | 14 | 14 |
| 1226 | 26 | 26 | 25 |
| 1227 | 27 | 25 | 25 |
| 1228 | 14 | 14 | 14 |
| 1229 | 19 | 19 | 18 |
| 1230 | 25 | 26 | 26 |
| 1231 | 24 | 22 | 22 |
| 1232 | 17 | 17 | 17 |
| 1233 | 17 | 15 | 17 |
| 1234 | 21 | 20 | 22 |
| 1235 | 11 | 11 | 11 |
| 1236 | 18 | 18 | 18 |
| 1237 | 23 | 23 | 22 |
| 1238 | 26 | 25 | 24 |
| 1239 | 14 | 14 | 14 |
| 1240 | 19 | 19 | 17 |
| 1241 | 11 | 11 | 11 |
| 1243 | 22 | 22 | 23 |
| 1244 | 17 | 17 | 17 |
| 1245 | 13 | 16 | 12 |
| 1246 | 15 | 15 | 15 |
| 1247 | 23 | 25 | 23 |
| 1248 | 22 | 23 | 23 |
| 1249 | 24 | 26 | 24 |
| 1250 | 11 | 11 | 11 |
| 1251 | 16 | 14 | 14 |
| 1252 | 13 | 13 | 11 |
| 1253 | 22 | 20 | 23 |
| 1254 | 21 | 19 | 20 |
| 1255 | 10 | 9 | 10 |
| 1256 | 24 | 28 | 28 |
| 1257 | 24 | 24 | 23 |
| 1258 | 13 | 15 | 15 |
| 1259 | 26 | 28 | 25 |
| 1260 | 23 | 25 | 23 |
| 1261 | 13 | 16 | 16 |
| 1262 | 18 | 18 | 18 |
| 1263 | 15 | 15 | 18 |
| 1265 | 23 | 23 | 23 |
| 1266 | 22 | 20 | 20 |
| 1267 | 23 | 23 | 22 |
| 1270 | 11 | 13 | 11 |
| 1271 | 14 | 14 | 14 |
| 1272 | 23 | 20 | 21 |
| 1273 | 16 | 16 | 16 |
| 1274 | 11 | 11 | 11 |
| 1275 | 9 | 9 | 9 |
| 1276 | 12 | 11 | 13 |
| 1277 | 11 | 11 | 11 |
| 1278 | 13 | 13 | 13 |
| 1279 | 11 | 11 | 10 |
| 1280 | 14 | 13 | 14 |

| | | | |
|---|---|---|---|
| 1281 | 12 | 12 | 12 |
| 1282 | 11 | 10 | 11 |
| 1283 | 17 | 15 | 18 |
| 1284 | 11 | 10 | 11 |
| 1285 | 4 | 4 | 4 |
| 1286 | 17 | 17 | 17 |
| 1287 | 11 | 11 | 11 |
| 1288 | 19 | 19 | 19 |
| 1289 | 12 | 12 | 12 |
| 1290 | 20 | 20 | 17 |
| 1291 | 11 | 10 | 11 |
| 1293 | 13 | 14 | 16 |
| 1294 | 16 | 21 | 21 |
| 1295 | 12 | 11 | 11 |
| 1296 | 11 | 10 | 10 |
| 1297 | 17 | 18 | 17 |
| 1298 | 17 | 16 | 16 |
| 1299 | 13 | 12 | 14 |
| 1300 | 11 | 11 | 11 |
| 1302 | 13 | 13 | 12 |
| 1303 | 14 | 13 | 12 |
| 1304 | 10 | 10 | 10 |
| 1305 | 11 | 10 | 9 |
| 1306 | 12 | 11 | 11 |
| 1307 | 12 | 12 | 12 |
| 1308 | 18 | 16 | 19 |
| 1309 | 11 | 6 | 10 |
| 1310 | 17 | 18 | 19 |
| 1311 | 11 | 8 | 12 |
| 1312 | 16 | 13 | 17 |
| 1313 | 22 | 20 | 22 |
| 1314 | 20 | 17 | 19 |
| 1315 | 17 | 15 | 17 |
| 1316 | 12 | 12 | 12 |
| 1317 | 10 | 10 | 10 |
| 1318 | 12 | 11 | 11 |
| 1319 | 13 | 12 | 12 |
| 1320 | 10 | 10 | 10 |
| 1321 | 14 | 15 | 14 |
| 1322 | 10 | 9 | 9 |
| 1323 | 11 | 11 | 11 |
| 1324 | 11 | 10 | 10 |
| 1325 | 13 | 11 | 13 |
| 1326 | 16 | 15 | 16 |
| 1328 | 12 | 11 | 12 |
| 1329 | 11 | 10 | 11 |
| 1330 | 16 | 13 | 15 |
| 1331 | 15 | 15 | 15 |
| 1332 | 9 | 9 | 9 |
| 1333 | 10 | 10 | 10 |
| 1334 | 11 | 10 | 11 |
| 1335 | 21 | 20 | 20 |
| 1336 | 20 | 17 | 17 |
| 1337 | 17 | 18 | 17 |
| 1338 | 9 | 9 | 9 |
| 1339 | 11 | 11 | 11 |

| | | | |
|---|---|---|---|
| 1340 | 11 | 11 | 10 |
| 1341 | 15 | 14 | 14 |
| 1342 | 17 | 16 | 16 |
| 1343 | 10 | 13 | 9 |
| 1344 | 16 | 14 | 14 |
| 1345 | 15 | 17 | 21 |
| 1346 | 15 | 13 | 15 |
| 1349 | 15 | 15 | 14 |
| 1350 | 15 | 15 | 14 |
| 1351 | 24 | 24 | 20 |
| 1352 | 11 | 10 | 11 |
| 1353 | 17 | 16 | 16 |
| 1354 | 14 | 12 | 12 |
| 1355 | 11 | 11 | 10 |
| 1356 | 11 | 11 | 11 |
| 1123 | 27 | 26 | 26 |
| 1124 | 18 | 17 | 16 |
| 1125 | 23 | 23 | 21 |
| 1126 | 17 | 15 | 15 |
| 1127 | 16 | 16 | 16 |
| 1128 | 16 | 16 | 15 |
| 1129 | 12 | 11 | 11 |
| 1130 | 13 | 15 | 14 |
| 1131 | 10 | 10 | 10 |
| 1132 | 11 | 11 | 11 |
| 1133 | 15 | 15 | 14 |
| 1134 | 11 | 11 | 11 |
| 1135 | 12 | 12 | 12 |
| 1136 | 18 | 20 | 20 |
| 1137 | 15 | 15 | 15 |
| 1138 | 10 | 10 | 10 |
| 1139 | 16 | 16 | 16 |
| 1140 | 10 | 10 | 10 |
| 1141 | 19 | 19 | 17 |
| 1142 | 17 | 17 | 17 |
| 1143 | 12 | 12 | 12 |
| 1144 | 19 | 19 | 19 |
| 1145 | 11 | 11 | 11 |
| 1146 | 12 | 12 | 12 |