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Age, growth, and maturity of cabezon, Scorpaenichthys marmoratus, in California

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AGE, GROWTH, AND MATURITY OF CABEZON,
SCORPAENICHTHYS MARMORATUS, IN CALIFORNIA

A Thesis

Presented to

The Faculty of Moss Landing Marine Laboratories

and the Department of Marine Sciences

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Joanna Marie Grebel

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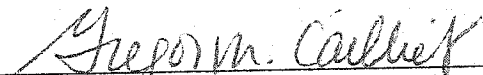
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ABSTRACT

AGE, GROWTH, AND MATURITY OF CABEZON, SCORPAENICHTHYS MARMORATUS, IN CALIFORNIA

by Joanna M. Grebel

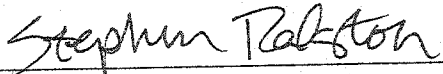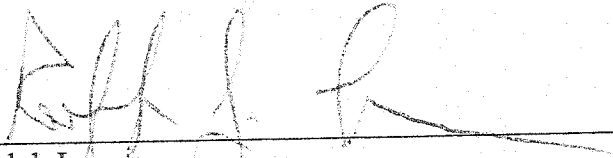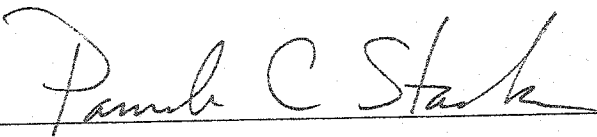The age, growth, and maturity of cabezon, *Scorpaenichthys marmoratus*, were studied from July 2000 – July 2001 in California. Although multiple structures were examined as potential ageing structures, ages were estimated from sectioned otoliths ($n = 641$). Growth was statistically compared between sexes and geographic locations. Length and age at 50 % maturity was modeled for both sexes. Females attained a larger size and grew slower ($L_\infty = 647.2$ mm TL, $k = 0.17$) than males ($L_\infty = 440.7$ mm TL, $k = 0.35$). Growth was rapid through age 4 for males and age 6 for females. The oldest male was 13 years old; the oldest female, 14 years. Length and age at maturity was estimated for males (length, $n = 129$; age, $n = 132$) and females (length, $n = 406$; age, $n = 373$), with males maturing at 297 mm (1.9 yrs) and females at 337 mm (2.3 yrs).

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INTRODUCTION

The cabezon, *Scorpaenichthys marmoratus*, is the largest member of the family Cottidae, which contains over 300 species worldwide (Nelson 1984; O'Connell 1953). Cabezon can attain a length of 990 mm total length and mass of 6.8 kg. Cabezon occur from central Baja California to Sitka, Alaska, and from intertidal to 76 m depths (Eschmeyer et al., 1983). They are demersal, solitary, and usually associated with reefs, boulders, kelp beds, and eelgrass (Lauth, 1988).

Two papers have been published to date on cabezon life history. Estimates of age, growth, and reproduction in California (O'Connell, 1953) and Washington (Lauth 1987, 1988) are based on small sample sizes (age/growth, n = 202; reproduction, n = 70). There are no quantified maturity estimates to date, although O'Connell (1953) suggested that males mature one year earlier than females. Age, growth, and reproductive parameters can vary with latitude; therefore, it is advantageous that they be examined throughout a range to characterize site-specific differences.

Cabezon are caught recreationally and commercially throughout California. Because of their close proximity to shore and ability to survive capture, cabezon are heavily targeted by the live-fish fishery in California. Started in the late 1980's, the live-fish fishery targets inshore species that can be held alive, i.e. rockfishes (*Sebastes* spp.), California halibut (*Paralichthys californicus*), California sheephead (*Semicossyphus pulcher*), and cabezon (Marx, 2000). Small boats, skiffs, and kayaks are used to set hooks and traps in water less than 30 m deep to target attractive "plate sized" fishes (about 1 kg). The fishery started quickly and was difficult to monitor due to the mobility

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of the fishermen, with fish being transported to restaurants immediately after being landed. Many targeted fishes suffer from lack of proper management, due in part to inadequate biological data such as basic life history traits. Although size and catch limits have been implemented, many are based on little, if any, scientific data (Starr et al., 2002).

Since 1995, annual cabezon live-fish fishery landings in California have averaged 108.97 metric tons (California Department of Fish and Game). From 1980 to 2002, sport fishery catches averaged 88.3 metric tons in California. In 2001 and 2002, even with time and area closures, the allowable catch of cabezon in California was exceeded and the fishery closed statewide before the end of the year. This is an indication that the fishery is overcapitalized (Starr et al., 2002).

Because of concerns about potential overharvest, particularly of small individuals by the live-fish fishery, cabezon have been chosen as one of 19 finfish species for management under the California Department of Fish and Game Nearshore Fishery Management Plan. Interim commercial regulations increased the minimum size limit from 305 mm (established before 1990) to 356 mm in 2000 (Leet et al., 2001). The size limit was further increased to 381 mm in 2001 (Starr et al., 2002) to protect immature individuals from capture in fishing. Additional management based on accurate life history information is needed to prevent overfishing and maintain cabezon populations.

This investigation was designed to re-evaluate age and growth estimates of cabezon in California and provides first estimates of maturity. Specific objectives of this study were to: 1) assess use of several calcified structures for determining cabezon age;

2) validate periodicity of increment formation in calcified structures; and 3) describe age and growth parameters of cabezon in comparison to published studies; 4) determine length and age at maturity of cabezon; and 5) determine if any site specific differences exist in age, growth, or reproductive parameters of cabezon in California.

MATERIALS AND METHODS

Cabezon specimens (n = 680) were collected from fishes landed in the commercial live-fish fishery and recreational spearfishing tournaments in California. Archived otoliths collected from 1996 to 2002 were obtained from California Department of Fish and Game, Morro Bay. Sex, total length (TL) to nearest millimeter, weight to nearest 0.1 kg, were recorded for most samples (Fig. 1). Some fish had been eviscerated prior to sampling; therefore, sex, weight, and length data were not always available. When available, gonads were assessed for maturity, removed, and weighed to the nearest 0.1 g.

Multiple Structures

Five calcified structures were evaluated for usefulness as ageing structures. Sagittal otoliths, pectoral fins, dorsal fin rays, dorsal spines, and vertebrae were removed from a variety of fish. For the purpose of this study the terms ring and annulus describe the growth patterns found in the various structures. The term ring is a concentric zone, band, or mark that describes the depositional patterns associated with either winter (opaque) or summer (translucent) growth zones (Brennan and Cailliet, 1989; Chilton and Beamish, 1982). Annulus refers to a one set of translucent and opaque ring pairs in which the deposition of both represents a yearly event.

Pectoral Fin Rays

Pectoral fin rays (n = 25) were processed following Chilton and Beamish (1982) and transverse thin sections (0.7 mm) were removed for preliminary examination. Growth rings in pectoral fin ray sections were difficult to interpret. Internal re-absorption of the vascularized core was also problematic with cabezon pectoral fin rays. Because of the re-

absorption of core material, difficulty in interpreting growth rings, and time required for preparation, it was determined that pectoral fins were not suitable structures for age determination

Sagittal Otoliths

Sagittal otoliths were removed from each specimen, air-dried, and individual otoliths were weighed to the nearest 0.001 g. Preliminary examination of whole otoliths revealed difficulty in interpreting growth rings. Although previous studies of cabezon age and growth (Lauth, 1987; O'Connell, 1953) used whole otoliths to estimate ages, growth rings were difficult to interpret in this study. Transverse thin sections (0.5 mm wide) were removed from otoliths for preliminary examination. In most cases, rings that were present on the otolith edge in transverse thin sections were not visible in whole otoliths. Based on this inability to see all rings in whole otoliths, transverse thin sections were chosen for this study.

A paired t-test was conducted on otolith masses (n = 107) to determine if any statistical difference existed between mean masses of left and right otoliths (Zar, 1999). Since no difference was detected (n = 107, $p < .05$) the right otolith was used for age estimation.

Other Structures

Dorsal fin rays, dorsal spines, and vertebrae were assessed for their usefulness as alternate ageing structures to otoliths. The first eight dorsal fin rays were removed, cleaned of extraneous tissue, and air-dried. Third, fourth, and fifth dorsal spines were removed, with condostyle intact, cleaned of extraneous tissue, and air-dried. Five

vertebrae, posterior to the skull, were removed, cleaned, and air-dried. Specimens (n = 37) that had all ageing structures removed were examined for multiple structure analysis.

All ageing structures were embedded in fiberglass resin and sectioned using a Buehler low–speed Isomet saw. Transverse sections (0.5 mm wide) were removed from the otolith nucleus and vertebral centrum. Sections (0.7 mm wide) were removed 2.0 mm above the base of the condostyle on dorsal fin rays and dorsal spines. Sections were attached to microscope slides using clear Cytoseal. Otolith sections were examined under reflected light, on a dark background. Dorsal fin ray, dorsal spine, and vertebral sections were examined under transmitted light (Chilton and Beamish, 1982). All thin sections were brushed with a thin layer of mineral oil to elucidate increments.

The relationship between size of structure (otolith width, dorsal fin ray width, dorsal spine diameter, vertebral diameter) and total length was determined by linear regression analysis (Brennan and Cailliet, 1989; Zar, 1999). Otoliths, dorsal fin rays, and dorsal spines were measured to the nearest 0.1 mm across a pre-selected axis using an ocular micrometer. The diameter of whole vertebrae was measured to the nearest millimeter on the proximal surface using calipers (Fig. 2). Because dorsal spines sections and vertebrae are not perfectly symmetrical, two measurements were taken through the center of each structure (at 90 degrees of each other) and averaged.

Age Determination

Age assessment of calcified structures involves interpretation of annuli based on their optical qualities (Casselman, 1987). When viewed with reflected light, translucent rings appear dark and opaque rings appear light. These rings can be associated with annual

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marks (when validated), and it is these rings that are counted to estimate age. For the purpose of this study, ages were estimated based on the number of opaque and translucent ring pairs counted in each structure.

All ageing structures were read solely by the author using the previously described criteria, and edge type (opaque or translucent) noted. Ages were estimated a minimum of three times and without knowledge of sex, length, date, or location of capture.

Size-at-age data were examined from this study and O'Connell (1953). Females and males were plotted separately and presented as means with confidence intervals.

Precision Analysis

Error in age estimates was calculated using average percent error (APE; Beamish and Fournier, 1981):

$$100\% \times \frac{1}{R}\sum_{i=1}^{R} \frac{|X_{ij} - X_j|}{X_j}$$

where R is the number of times each fish is aged, X_{ij} is the ith age determination of the jth fish, X_j is the average age calculated for the jth fish. Coefficient of variation (CV, Chang, 1982) was calculated:

$$100\% \times \frac{\sqrt{\sum\limits_{i=1}^{R} \dfrac{(X_{ij} - X_j)^2}{R-1}}}{X_j}$$

where R is the number of times each fish is aged, X_{ij} is the *i*th age determination of the *j*th fish, X_j is the average age calculated for the *j*th fish. Index of precision (D; Chang, 1982):

$$\frac{CV}{\sqrt{R}}$$

where CV is coefficient of variation and R is number of times a fish is aged. Variability of APE and D was examined by plotting the range and mean of error for each age class.

An age frequency table was used to examine pairwise comparisons of age estimates from multiple reads by a single reader of cabezon otoliths. Age frequency tables highlight major differences between sets of age determinations. Differences are indicated by a distribution of age estimates that differ from a slope of one (Campana et al,. 1995).

Age bias plots are sensitive to both linear and non-linear biases. The use of an age bias plot, age frequency table, and CV provides a powerful comparison of matched pairs of age determinations (Campana et al., 1995). They were, therefore, examined to determine consistency of age estimations by a single reader.

Verification

The "confirmation of numerical interpretation" (Wilson et al., 1983) or determination of precision was examined by comparing the variability of estimated ages between hard parts from the same fish (n = 37; Brennan and Cailliet, 1989; Hill et al., 1989). Comparisons of age estimations in analogous structures can provide corroborative

evidence that growth in each hard part resulted from similar growth stimuli (Hill et al., 1989). Direct comparisons of age estimates from corresponding hard parts (otoliths, dorsal fin rays, dorsal spines, and vertebrae) were modeled with linear regression, and the slopes of these regressions were tested to see if they differed significantly from unity (Hill et al., 1989; Zar 1999).

Validation

Periodicity of increment formation was validated by edge analysis in otoliths. Edge analysis tracks seasonality of growth deposition by edge type (Beckman and Wilson, 1995). Timing of increment formation was determined by recording the "visual appearance" of the otolith margin (i.e., opaque or translucent) and expressing it as a percentage of the monthly sample. Ideally, all age classes should be validated throughout the lifetime of a fish, with a minimum of two complete cycles needed for examination to increase the rigor of this technique (Campana, 2001). Sufficient monthly samples were not available for each age class for successive years. Samples from several years, locations, and ages were combined. Inter-annual variability in otolith growth parameters was assumed negligible (Horn, 2002).

A chi-square contingency table was used to statistically test the periodicity of ring formation (Zar, 1999). A uniform distribution (i.e., expected distribution) used in chi-square analysis was created by using the observed number of samples with opaque edges and dividing them by 12 in order to evenly distribute the samples throughout each month. The expected and observed distributions were tested to see if they varied significantly.

A result of no statistical difference between the distributions would support no periodicity of ring formation.

Growth

Data on ages and lengths of males and females were fit to the von Bertalanffy growth equation (von Bertalanffy, 1938):

$$L_t = L_\infty (1 - e^{-k(t-t0)});$$

where L_t is total length (mm) of fish at any given age t (years), L_∞ is theoretical average maximum length (mm), k is the growth constant (yr^{-1}), and t_0 is theoretical age at size zero (yr). Parameters (L_∞, k, and t_0) were estimated for each sex using Iterative Growth modeling with Optimal Results (IGOR), a program developed in MATLAB® ,which uses nonlinear parameter estimation (Cope, 2000).

Due to the non-linear formulation of the von Bertalanffy growth function, a general linear model of covariance could not be used. A non-linear function was, therefore, used to compare growth curves between locations and sexes. Analysis of Residual Sum of Squares (ARSS; Chen et al., 1992; Haddon, 2001) compares the outcome of the hypothesis that all curves are coincident (i.e., each data set is effectively a sample from the same population) with the null hypothesis that all data sets are from independent populations (Haddon, 2001). Although von Bertalanffy parameters (L_∞, k, and t_0) can affect growth curves and be compared individually using a likelihood ratio, ARSS was chosen because it simply determines whether two or more curves are

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different, without examining which von Bertalanffy parameter is causing the statistical difference.

O'Connell's (1953) growth parameters were re-calculated from original age and length data using IGOR. Original calculations used a Ford-Walford plot, a linear fitting technique, which provides a less precise estimate of growth. Recalculation of those data in IGOR should provide more realistic von Bertlanffy growth curve parameters.

Maturity

Reproductive maturity of gonads was determined by macroscopic examination. Using reproductive maturity stages modified from Nikolsky (1963), Holden and Raitt (1974), and Cailliet et al. (1986), sexual maturity of males and females were recorded as immature (gonads small, transparent in color) or mature (sexual products in the beginning stages of development or completely developed). Length at maturity was estimated by calculating the proportion of mature individuals in 20 mm size intervals for each sex. Age at maturity was estimated by calculating the proportion of mature individuals in each age class for each sex. Calculations assumed equal weight of sample sizes although sample sizes may have been unequal. Length and age at maturity was determined for males and females by fitting a logistic model:

$$P_x = 1 / (1 + e^{(a*x+b)});$$

where P_x is proportion of fish mature at total length (mm) or age (yrs), a is theoretical size at age zero, x is the growth constant, and b is age (yrs). The inflection point in the curve (-a/b) was the calculated length or age at 50 % maturity.

RESULTS

Multiple Structure Analysis

A positive linear statistical relationship was found between fish length and diameter of structures (Fig. 3), thus demonstrating that each structure increased proportionally in size as the fish grew. This supports the use of otoliths, dorsal fin rays, dorsal spines, and vertebrae as potential ageing structures.

Overall, otoliths could be somewhat challenging to interpret, but provided consistent age estimates (Table 1). Estimation of age from otoliths was difficult at times. Rapid growth in young individuals produced many checks (i.e. false rings). In older individuals, growth rings near the otolith edge were faint, could not be seen along all axes, and improper processing (oblique cuts) had the potential to destroy growth zones.

Although growth zone patterns in dorsal fin rays were consistent and easy to interpret, they underestimated ages of older individuals compared to otoliths (Fig. 4). Average percent error, CV, and D (Table 1) were not as low as expected on the basis of their apparent ease of interpretation.

Spines were very difficult to interpret due to the presence of numerous undecipherable growth rings. It was difficult to determine which rings represented annual growth. Average percent error, CV, and D (Table 1) were lower than expected based on the difficulty of interpreting this structure, but confidence in age estimates was low. Higher than expected precision values were probably a result of repeated examination of the structure. Overall they provided the least precise or consistent age estimates.

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Vertebrae were easy to interpret and produced more precise age estimates (Table 1). Although vertebrae provided the most consistent age estimates, otoliths were chosen as the primary ageing structure because of availability of additional samples from archived collections and to allow comparison of results with previous cabezon work (Lauth 1987; O'Connell, 1953).

Growth curves comparison of otoliths (n= 54) and vertebrae (n = 49) revealed no statistical difference (F = 0.541; df = 97, p > .05). This reveals that ages otoliths and vertebrae provided similar age estimates and supports the use of either as a viable ageing structures.

Age Estimation

Ages were estimated from transverse otolith sections for 618 individuals (379 female, 239 male). The maximum age based on otoliths was 13 (males) and 14 years old (females).

Size-at-age data for individual sexes of cabezon were different between this study and O'Connell (1953; Fig. 5). The mean total lengths and 95 % confidence intervals overlapped for few ages.

Precision Analysis

Comparison of APE and D revealed greater error in younger individuals, which decreased with increasing age. Individuals estimated 2 to 5 years old had the largest relative error and least relative precision in age estimates (Fig. 6). Younger individuals grew fast and had large opaque zones with numerous checks, which were sometimes difficult to differentiate from true annuli. Poor otolith composition hindered the

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interpretation of growth increments around the entirety of the structure. Growth slowed at approximately 5 years old and annual growth increments became easier to interpret with fewer checks. Individuals aged 6 years and older displayed less error and more precision due to slower growth and more regularly spaced increments.

Age bias plots (Fig. 7) revealed all three individual reads were fairly consistent with no systematic over- or underestimation of age. Although cabezon do not live long, their otoliths are challenging to interpret. Age estimates of younger individuals have more variability, indicating that they were more difficult to read than older individuals. Precision plots revealed that 87.0 % of age estimates were within +/- 1 year; 96.3 % were within +/- 2 years (Fig. 8).

Age frequency table (Table 2) revealed no apparent bias in age determinations. Variability existed in age estimates for all age classes. All pair-wise comparisons of age estimates were consistent among examinations, with read 1 and read 3 displaying slightly more agreement between age estimates.

Verification

No statistical difference was observed between the slopes of the regression lines for otoliths and dorsal spines or otoliths and vertebrae ($p > .05$). The slopes of these regressions, therefore, were not statistically difference from the 1:1 line of agreement. A statistical difference was observed between otoliths and dorsal fin rays ($p < .05$; Fig. 4).

Validation

Determination of edge type on the otolith margin was difficult at times. It was especially challenging in older fish, which had narrow growth increments. Sometimes an age was

assigned to an individual even though its marginal state could not be determined. When this occurred, data were used in growth parameter calculations, but not edge analysis (Horn, 2002).

Edge analysis revealed that one pair of opaque and translucent growth increments were formed annually. A chi-square contingency table revealed that there was a statistical difference between the observed distribution and a uniform distribution of opaque edge formation throughout the year ($p > .05$). This demonstrates that there is a difference between opaque and translucent edge formation and that the two edge types do not form in the same proportions for each month. Although opaque edges were found throughout the year, they primarily formed from June to August (Fig. 9). The presence of a large portion of opaque edges in October through November may have resulted from improper sample processing or from oceanographic events. The low portion of opaque edges in September was a result of small sample size.

Growth

Females attained a larger size and grew slower ($L_\infty = 647.2$ mm, $k = 0.17$) than males ($L_\infty = 440.7$ mm, $k = 0.35$; Fig. 10). Growth appeared to be rapid through age 4 for males and age 6 for females. The oldest male was 13 years old; the oldest female, 14 years.

Analysis of the residual sum of squares revealed that growth curves were statistically significant between sexes ($F = 54.43$; $df = 356$; $p < .001$). This supports using two separate growth models to describe cabezon growth in California as opposed to a combined sex curve.

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Growth of males and females in northern and central California was significantly different (male, F = 10.97; df = 224; p < .001; female, F = 62.74; df = 316; p < .001). This should support the use of site-specific growth curves. Factors such as unequal sample sizes, overlapping confidence intervals in growth parameters, and differences in calculated expected lengths were examined when evaluating the biological relevance of the statistics. Although the statistical difference did exist, it was not deemed to be biologically important. Growth curves were, therefore, combined among locations.

Maturity Estimates

Length at maturity was calculated for 20 mm size intervals for each sex. Length at maturity was estimated for 535 individuals (406 females; 129 males). Length at 50 % maturity was greater for females (337 mm) than males (297 mm; Fig. 101Both sexes reached 100 % maturity by 475 mm.

Age at maturity was estimated by examining the proportion of mature individuals in each age class for each sex. Age at maturity was estimated for 505 individuals (373 females; 132 males). Age at 50 % maturity was greater for females (2.3 yr) than males (1.8 yr; Fig. 12). Both reached 100 % maturity by age 7.

DISCUSSION

Although more than 300 species of cottids exist worldwide, little is known about their life history. The few existing studies on cottid life history characteristics reveal relatively short lifespans and rapid growth (Daniels, 1987; Mgaya et al., 1995). Although many taxa show a correlation across species between depth and longevity (Cailliet et al, 2001), cottids apparently do not. There appears to be no trend of increased longevity with depth (Table 4).

The cabezon is the largest and only commercially important cottid in California. It has been fished heavily (commercially and recreationally) since the early 1990's, and catch quotas have been exceeded yearly since 2001. With such heavy fishing pressure, there is a need to re-evaluate their life history characteristics to assure that the best available information is available to fishery managers for successful management of the cabezon fishery.

Size frequencies (TL mm) of cabezon sampled for this study were similar to the size frequencies presented by O'Connell (1953), with the exception of individuals less than 280 mm TL, which were only available in this study. Although cabezon are reported to reach a maximum total length of 990 mm (Eschmeyer et al., 1983; Miller and Lea, 1972), specimens larger than 720 mm are uncommon in California and were not available for this study.

Multiple Structures

Although many age and growth studies have used otoliths as primary ageing structures, there are some species for which they do not provide the best age estimates because of

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small size or failure to accurately track periodicity of growth. Structures such as dorsal fin rays, dorsal and anal spines, pectoral fin rays and vertebrae have all been used successfully to estimate ages of fishes (Brennan and Cailliet, 1989; Chilton and Beamish, 1982; Hill et al., 1989; Labelle et al., 1993).

The positive relationship between total length and size characteristics of each structure supported their use for age estimation. It should be noted that this is not definitive for determining the overall acceptability for a structure over another. The most important component is overall accuracy and reproducibility of annulus counts within a particular structure.

Growth rings observed in otoliths were sometimes not well defined, as in older individuals, or difficult to differentiate from false annuli in younger individuals. Although difficulty was experienced with otoliths, a great effort was made to use this structure because it could allow a comparison of these results to previous cabezon research to determine if growth parameters had changed. Any differences observed in growth parameters could be an indication as to the status of the population. An increase in growth parameters could indicate a stressed population that is moving towards to fast growth, early reproduction, and low survivorship.

Although dorsal fin rays were not an appropriate ageing structure for this study, they should not be eliminated from future cabezon age and growth studies. Dorsal fin rays have been used successfully as a non-lethal ageing structure for commercially important fishes such as lingcod (Chilton and Beamish, 1982; McFarlane and King, 2001). Use of a non-lethal ageing structure for cabezon is important because it allows

scientists to obtain valuable biological information from fishermen without decreasing the value of their catch. With further investigation, dorsal fin rays may be a viable non-lethal ageing structure for cabezon.

Difficulties in interpreting growth rings in dorsal spine sections included variability in spacing between successive rings, no distinct differentiation between rings, and inability to determine the first year of growth. From initial examinations it was thought that dorsal spines would be a promising ageing structure because those samples examined had easily interpretable rings. Unfortunately, the number of samples that exhibited this pattern was few. In general, it was difficult to differentiate the optical properties of growth rings (i.e., opaque or translucent) in the majority of the samples. Dorsal spines tended to exhibit "gray areas" where the rings had optical properties that were a mix of opaque and translucent. Because of the uncertainty in age estimates and the error associated with ageing this structure, it was determined that they should not be examined further for this study.

Vertebral sections appeared to be the simplest and most consistently reliable structure for age estimation of cabezon in California. Compared to other calcified structures, vertebrae took longer to collect and process, but were easier to interpret. The number of growth rings appeared to increase with the size of the fish, and differentiation between opaque and translucent rings was distinct. Interpretation of the first annual mark could be challenging sometimes and could be a cause of variability in age estimates. There was high level of agreement among reads and vertebral sections ranked above all structures for this criterion.

Age Determination

This study suggests that ages obtained from whole otoliths underestimate cabezon ages in older individuals. In young fish, ages estimated from whole otoliths (O'Connell, 1953) were similar to those obtained from sections, but as the fish got older, the estimates became more dissimilar. Females aged 3 and 4 years old by O'Connell (1953) were estimated between 4 and 14 years in this study. One individual (595 mm), aged 4 years old by O'Connell (1953), would have been estimated at 14.7 years old based on von Bertalanffy growth parameters in this study. Another female (632 mm), aged 10 years old by O'Connell (1953) would have been estimated at 20.7 years old. Results from this study suggest that whole otoliths underestimate ages, especially in older individuals.

Comparison of size-at-age data between this study and O'Connell (1953) also support underestimation of cabezon ages. At any given age, the mean size in this study is smaller and, therefore, at any given size age estimation based on this study would be older. This difference in age estimation is probably due to the difference in ageing structures (i.e., whole versus sectioned otoliths) and the interpretation of fine rings on the otolith edge.

Precision Analysis

Past research suggests that cabezon otoliths are difficult to interpret. O'Connell's (1953) discarded 36% (59 individuals) of his otoliths because he considered them unreadable. Burge and Schultz (1973) also found cabezon otoliths difficult to interpret, especially those older than 5 years old. The difficulties in interpreting cabezon otoliths may explain why ageing error is high for such a short-lived species.

O'Connell (1953) reported high agreement among his age estimates. Out of 105 individuals, all age estimates agreed for 44 individuals; a difference of 1 year was observed in 61 individuals. Fifty-seven percent of the individuals examined in O'Connell were aged 5 years or less, 74% were aged 6 or less. The apparent high precision in ageing could have been resulted from examining a greater proportion of younger individuals. Discrepancies in age estimates of younger individuals in sectioned otoliths provide greater estimates of variability than in older individuals, which result in a larger APE, CV, and D for younger individuals.

The greatest error observed in this study was among individuals aged 5 years or less. Younger individuals possessed numerous false annuli that could be difficult to differentiate from true annuli. Comparing these results to those of O'Connell (1953) suggest that whole otoliths of young fish may be easier to interpret than thin sections because they lack false annuli that may only be visible in cross section. Comparing ages estimated from O'Connell (1953) to this study reveals that ages were fairly similar in younger individuals, thus supporting the use of whole otoliths to age young individuals.

Verification

Verification confirms the consistency (i.e., repeatability or precision) of a numerical interpretation (Wilson et al., 1983). Age estimations in cabezon were partially verified when comparing analogous features in the otoliths and vertebrae. The application of comparing linear regressions between hardparts provided corroborative evidence of similar age determinations. In general, there was good agreement in age estimates between corresponding otoliths and vertebrae. This provided evidence that the growth

features in each hard part that were counted for age estimation resulted from similar growth stimuli.

Verification of ages using multiple structures corroborates the trend seen in validation by edge analysis. The high level of inter-reader agreement for annulus counts of vertebrae and otoliths provided good evidence of similar age determinations. If the periodicity of growth ring deposition been different among the structures, age estimates obtained from each structure could have been double or half of the other, depending on annual or bi-annual growth ring deposition. No such differences were observed, thereby supporting similar growth ring deposition among all structures.

Validation

Validation of age estimates is essential in age and growth studies (Beamish and McFarland, 1983). Validation of otoliths proved difficult, as all age classes were not sampled throughout a year. Other ageing structures could not be used in age validation because a limited number of samples were available from summer months only. Since few samples were available, there was no way to examine edge type without bias.

Although edge analysis is the least preferred age validation method (Campana, 2001), it was the only one available for this study. Other validation methods such as marginal increment analysis and marginal increment ratio were not performed because the edge type of sectioned otoliths could be difficult to determine. The outer increments were thin and measurements were not possible. Previous research (Lauth, 1987; O'Connell, 1953) suggests cabezon do not live very long, therefore, more rigorous validation methods such radiochemical dating are not possible.

Future age validation studies of cabezon are underway. National Marine Fisheries Service tagged approximately 20 cabezon near Santa Cruz, California in January 2002. All individuals were injected with oxytetracycline and released. To date there have been no tag returns. Cabezon were also tagged and released near Fort Bragg, California. Tag return data will be examined to further examine growth and age validation. Growth curves based on individual tag returns will be fit using a von Bertalanffy growth curve and compared to growth calculations in this study.

Data from this study suggest the formation of one opaque and one translucent growth ring annually, with a greater proportion of opaque rings present from June to December (Fig. 2). The formation of opaque increments in June could correspond with upwelling of nutrient rich waters to California in early summer (Leet et al., 2001). The presence of late forming opaque growth ring may be due to warmer waters, which normally occur in California during late summer or early fall.

Growth

Our estimates of L_∞ are less than those recalculated values from O'Connell (1953; Table 3). Small individuals (less than 200 mm), which are necessary to anchor the growth curve and obtain realistic k values, were lacking in O'Connell (1953). Theoretical average maximum length (L_∞) was smaller for both sexes compared with O'Connell (1953). In this study, a calculated L_∞ value of 647 mm is suggested for females and 440.7 mm for males. Both values are smaller than the largest individuals in this study. Since L_∞, is affected by the number of individuals in a size class, larger sample sizes of smaller individuals, combined with a lack of large individuals of both

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sexes, decreased L_∞ values in this study. Although L_∞ is smaller than the maximum size for cabezon (990 mm; Eschmeyer et al., 1983), this suggests that larger individuals were under represented in this study.

Size composition of both sexes was smaller overall in this study compared with O'Connell (1953). The largest female in study measured 690 mm (14 years); the largest male was 518 mm (10 years). The largest female in O'Connell (1953) study was 720 mm (13 years) and the largest male, 559 mm TL (9 years). The absence of large male individuals in this study may be a result of heavy fishing, especially since the onset of the live fish fishery. Male cabezon are nest guarders and would be more susceptible to capture during spawning season. Heavy fishing pressure could have selectively removed larger individuals of both sexes since O'Connell's (1953) original research.

Comparison of growth curves from O'Connell and this study were statistically and significantly different between females (F = 33.53, df = 443, p < .001) and males (F = 28.39, df = 268, p < .001), suggesting that ages obtained from whole otoliths are different from transverse thin sections. Statistical differences may have resulted from unequal sample sizes (this study, n = 641; O'Connell, n= 105), with a smaller size composition in this study. An abundance of food and different oceanographic regimes may have promoted rapid growth in cabezon, such that the 595 mm female that was estimated at 4 years old by O'Connell (1953) could have in fact been that young. More than likely, heavy fishing pressure since the 1990's reduced maximum total length, forcing fish to mature at a smaller size because they have to put energy into reproduction instead of growth.

Size class inequality, overlapping confidence intervals, and differences in calculated expected lengths may have contributed to the statistical difference in site-specific growth in this study. The lack of small individuals in both NCA and SCA may have led to the statistical difference in growth. It is difficult to compare growth between locations when representative samples of the whole populations are not available. Ninety-five percent confidence intervals of von Bertalanffy growth parameters overlapped between NCA and CCA (Table 3), indicating that there was no sex-specific difference in growth between locations. Calculated expected lengths of females in southern California (SCA) were similar to NCA and CCA. If any difference were to be expected in growth curves it would have been between SCA and the rest of California due in part to Point Conception, which is a natural faunal barrier. Studies have shown differences in growth rates between individuals that live south of Point Conception and those that inhabit more northern waters (MacNair et al., 2001), therefore, any difference in growth rates would have been expected in SCA, not between NCA and CCA. A difference in growth curves (hence, growth parameters) might indicate different populations. This is probably not the case of cabezon in California; therefore, growth curves were combined for sexes.

Maturity

This study provides the first quantitative estimates of age and length at maturity of cabezon in California. Based on the results from this study the current minimum size limit of 381 mm (15 inches) is inadequate for females. This size limit would only allow 44 mm of growth before fish are recruited to the fishery. In a healthy population, such

minimum size limits would be adequate because enough fish could survive to reproduce. In California, cabezon populations are in decline (Leet et al., 2001; Starr et al., 2003). To maintain cabezon populations, a size limit of 432 mm (17 inches) would be more appropriate because it would allow females at least 98 mm of growth and reproductive potential.

Conclusions

Results from this study suggest that cabezon have a greater longevity than previously recorded. Based on the maximum reported size of 990 mm total length (Eschmeyer et al., 1983), it is probable that cabezon could attain ages of 20 years or more. An increase in the minimum size limit or implementation of an upper size limit could provide protection for cabezon.

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Table 1. Analysis of error among otoliths, dorsal fin rays, dorsal spines, and vertebrae of cabezon in California, using average percent error (APE), coefficient of variation (CV) and index of precision (D).

	n	APE	CV	D
Otolith	36	9.70	13.11	7.57
Dorsal fin ray	36	10.45	14.52	8.39
Dorsal spine	36	11.40	15.76	9.10
Vertebrae	36	5.30	3.68	2.12

Table 2. Age frequency table summarizing pairwise comparisons of age estimates between multiple reads from a single reader of cabezon otoliths.

Read 1 vs Read 2

Age (yrs) estimated by: Read 1	Read 2															Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
0	32															32
1	1	3	6	6												16
2		2	35	14	3		1									55
3		1	12	54	17	8	1									93
4		1	1	22	63	16	9	1								97
5			1	6	24	62	20	12								125
6				1	6	18	35	11	3	1						75
7			2		2	2	8	24	11	8	3					60
8						1	7	4	16	7	3	1	1			40
9						1	2	3	3	6	5	2				22
10										3	6	3				12
11												3	1	1		5
12												1		1		2
13													3	1	2	6
14																0

Read 1 vs Read 3

Age (yrs) estimated by: Read 1	Read 3															Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
0	32															32
1		6	8	2												16
2		6	39	8	2	1										56
3			13	54	18	8										93
4			2	14	71	24	2									113
5			1	11	25	56	27	5								125
6				1	7	19	38	9	1							75
7			2		2	1	16	26	11	2						60
8							3	10	19	6	2					40
9						1	1	2	8	4	6					22
10									2	3	4	2	1			12
11											2	1	2			5
12												1		1		2
13												2		3	1	6
14																0

Read 2 vs Read 3

Age (yrs) estimated by: Read 2	Read 3															Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
0	32		1													33
1		4	2		1											7
2		6	36	8	4	1										55
3		2	20	62	16	5										105
4			3	13	71	22	7									116
5				8	24	53	16	6	1							108
6			1	1	8	21	39	9	3	1						83
7					1	8	18	23	3	2						55
8							6	9	16	2						33
9							1	2	12	6	4					25
10								3	4	3	6	1				17
11									1	1	3	2	3			10
12									1		1	2	1			5
13													1	2		3
14														1	1	2

Table 3. Comparison of cabezon growth parameters in California, including 95 % confidence intervals of each estimate.

		Female	95 % CI	Males	95 % CI
O'Connell (1953)	L_∞	760		604	
	k	0.09		0.17	
	n	70		35	
O'Connell (1953)	L_∞	678.3	619.5 to 737.1	535.8	499.3 to 572.3
recalculated	k	0.23	0.15 to 0.32	0.46	0.23 to 0.68
	t_0	-1.40	-2.45 to −0.34	-0.23	-1.21 to 0.75
Present study	L_∞	647.2	601.2 to 693.3	440.7	421.4 to 460.1
	k	0.17	0.14 to 0.20	0.35	0.26 to 0.44
	t_0	-1.7	-2.18 to −1.31	-1.50	-2.13 to −0.87
	n	377		239	

Table 4 Summary of published literature on cottid age and growth, including maximum age, maximum length, maximum depth, and location of study.

Marine Species	Max. age	Max. length (mm TL)	Max. depth (m)	Location	Citation
Artedius corallinus	3	140	21	CA	Burge and Schultz, 1973
Artedius harringtoni	2	100	21	CA	Burge and Schultz, 1973
Artedius lateralis	3	140	13	CA	Burge and Schultz, 1973
Clinocottus analis	8 (M); 6 (F)	180	18	CA	Wells, 1986
Clinocottus globiceps	5	190	0	BC	Mgaya, 1995
Clinocottus recalvus	2	130	0	CA	Burge and Schultz, 1973
Gymnocanthus pistilliger	10 (M); 9 (F)	230	325	AK	Hoff, 2000
Gymnocanthus tricuspis	8 (M); 9 (F)	300	240	AK	Smith et al., 1997
Hemilepidotus hemilepidotus	7	510	275	CA	Burge and Schultz, 1973
Jordania zonope	5	150	38	CA	Burge and Schultz, 1973
Leptocottus armatus	3	460	156	CA	Burge and Schultz, 1973
Myoxocephalus brandti	8 (M); 9 (F)	300	n/a	SJ	Pachenko, 2002
Myoxocephalus geneus	1	n/a	n/a	ATL	Lazzari et al., 1989
Myoxocephalus jaok	12 (M); 15 (F)	460	550	SJ	Pachenko, 2002
Myoxocephalus octodecemspinosus	9	460	n/a	ATL	Morrow, 1951
Myoxocephalus scorpius	15	900	110	NF	Ennis, 1970
Myoxocephalus stelleri	8 (M); 9 (F)	400	n/a	SJ	Pachenko, 2002
Nautichthys oculofasciatus	2	200	110	CA	Burge and Schultz, 1973
Oligocottus maculosus	5	89	0	BC	Chadwick, 1976
Oligocottus rubellio	2	100	n/a	CA	Burge and Schultz, 1973
Oligocottus snyderi	1.5	89	0	CA	Freeman et al., 1985
Orthonopias triacis	2	100	30	CA	Burge and Schultz, 1973
Ruscarius creaseri	2	76	27	CA	Burge and Schultz, 1973
Scorpaenichthys marmoratus	13	990	76	CA	O'Connell, 1953
	6			CA	Burge and Schultz, 1973
	16 (M); 17 (F)			WA	Lauth, 1987
Triglopsis quadricornis	11	600	100	BB	Timola and Luotonen, 1986

AK = Alaska; ATL = Atlantic; BB = Bothnian Bay; BC = British Columbia; CA = California; SJ = Sea of Japan; NF = Newfoundland;

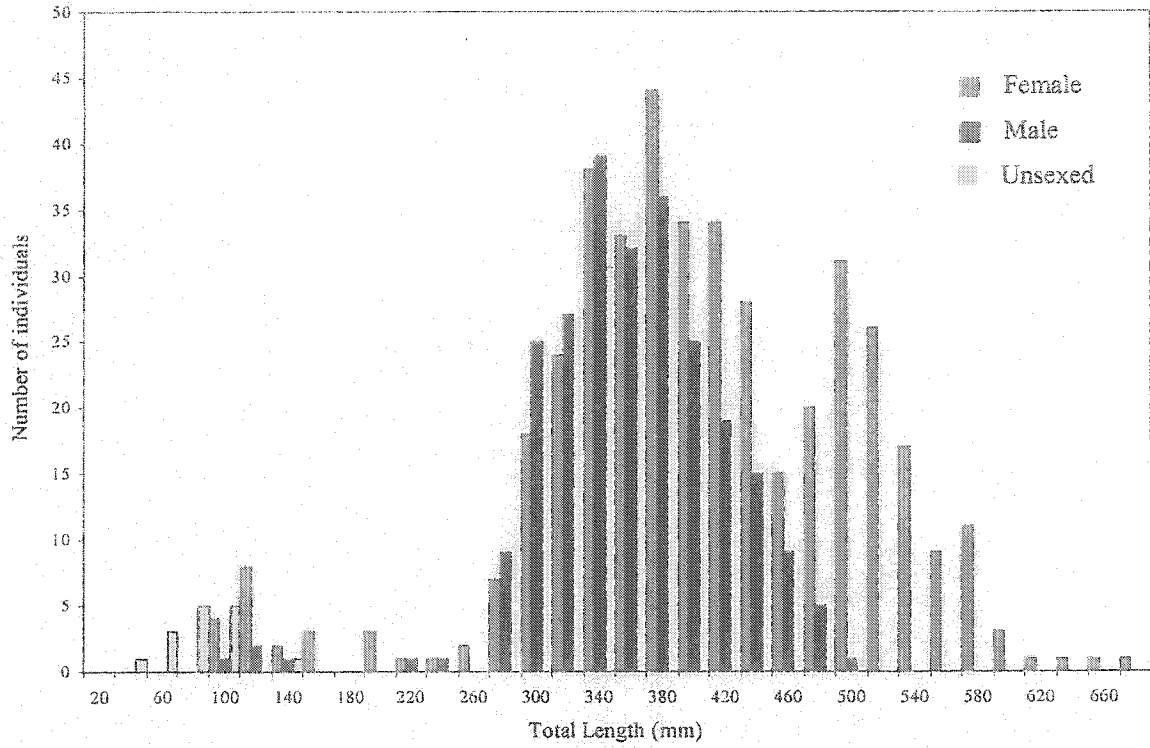SJ = Sea of Japan; WA = Washington [Length and depth information from www.fishbase.org]

Fig. 1 Length frequency distribution (n = 680) of cabezon collected in California from 1996 to 2002.
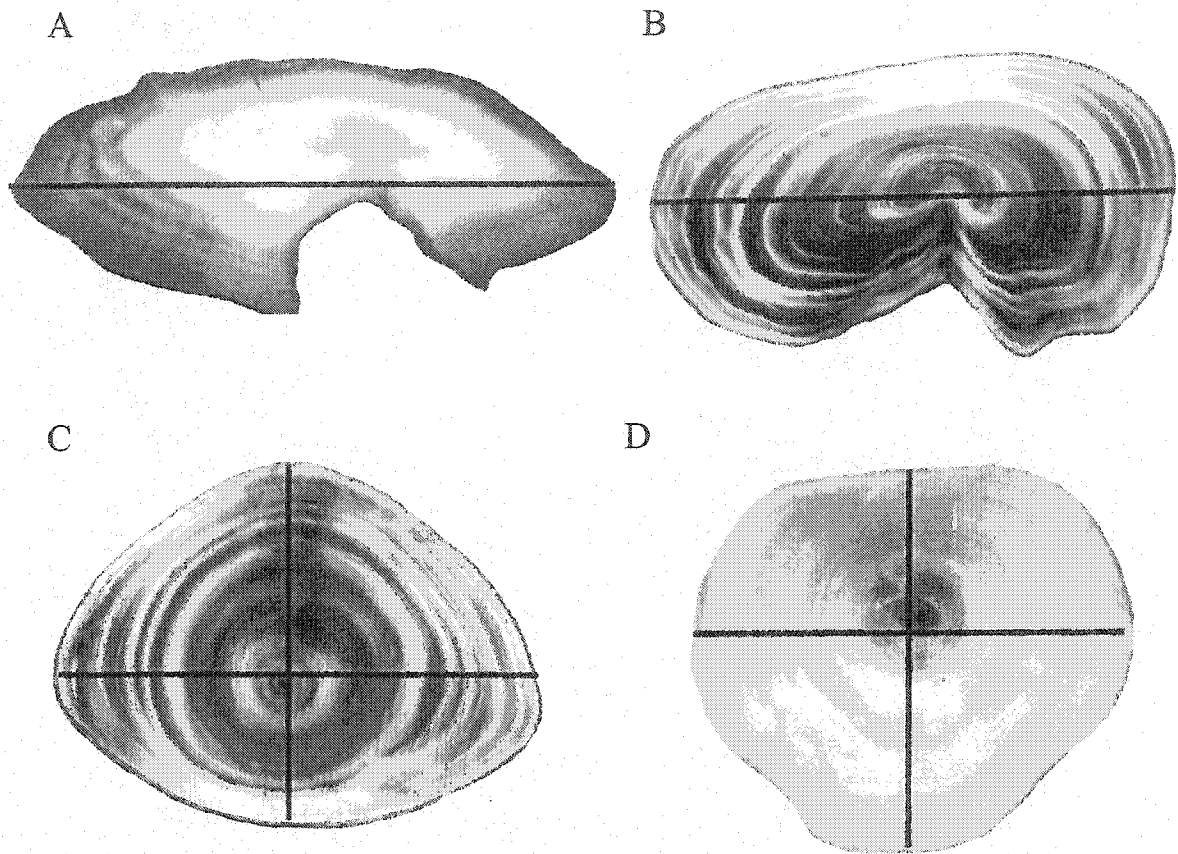
Fig. 2 Images of calcified structures of cabezon used for age estimation. Lines mark axis of measurement. (A) Otolith, (B) dorsal fin ray, (C) dorsal spine (D) vertebra.
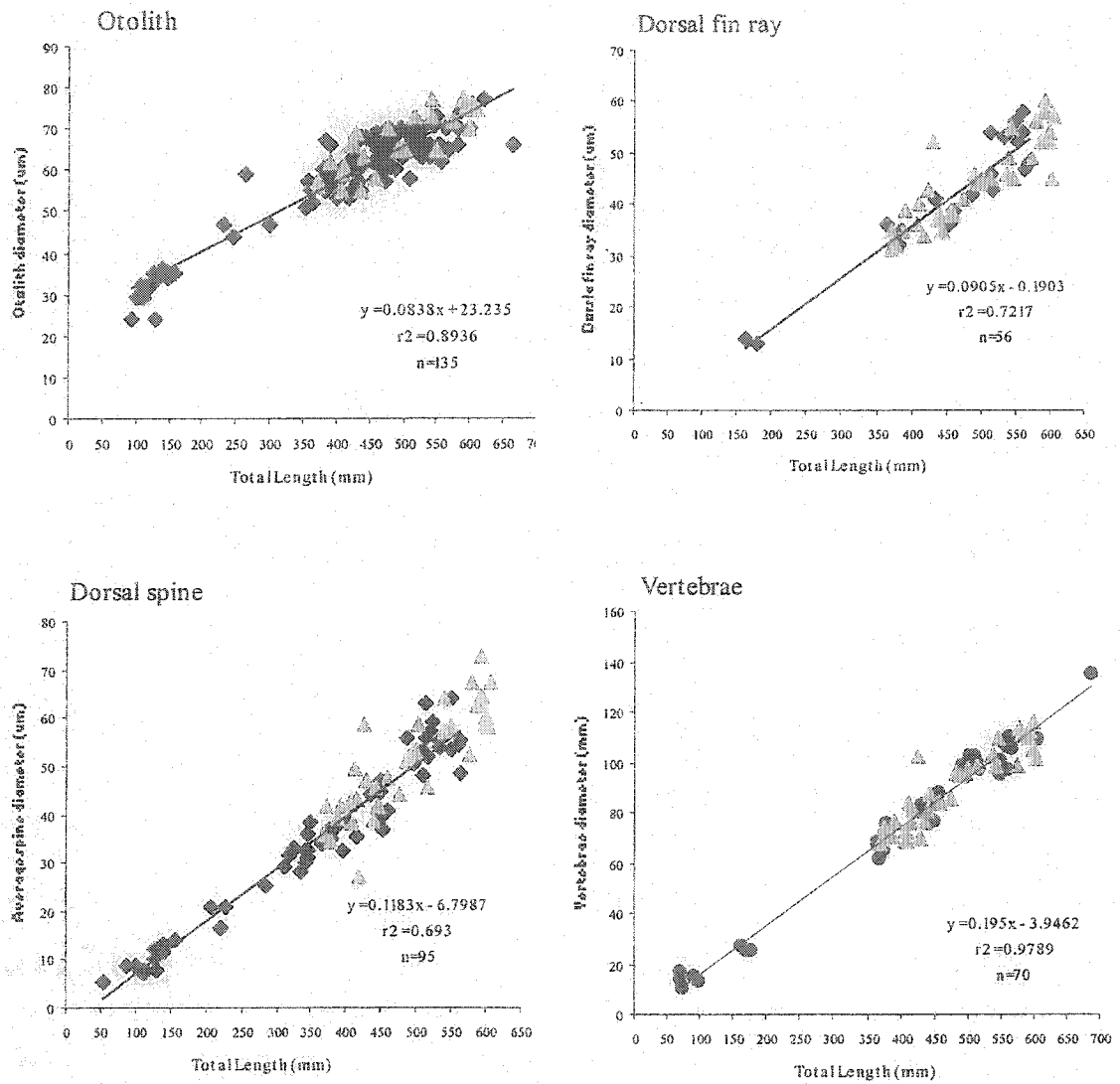
Fig. 3 Relationship between diameter of otoliths, dorsal fin rays, dorsal spines, and vertebrae, with total length of fish in the cabezon. Triangles represent those samples used in the multiple structural comparison.
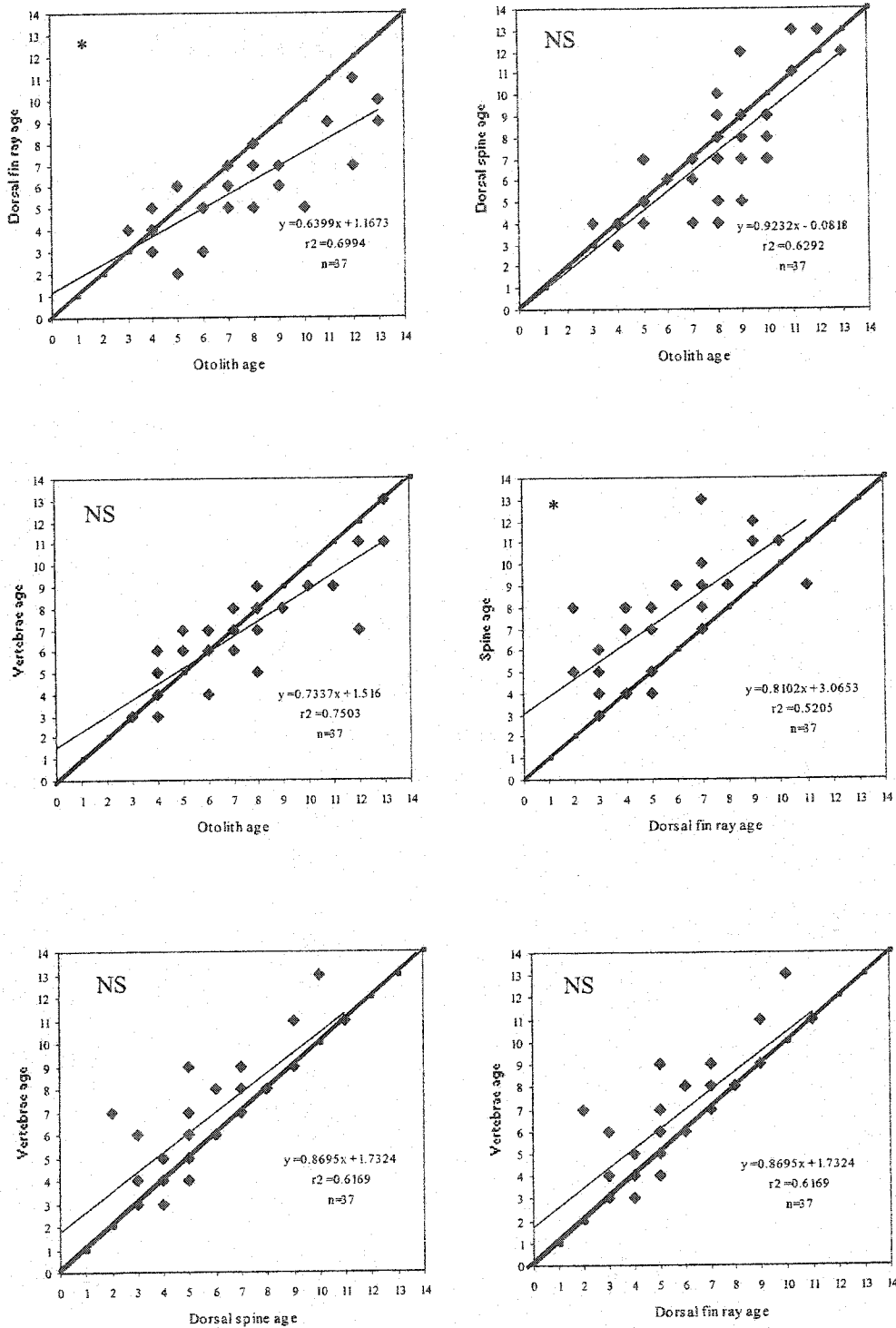
Fig. 4 Pairwise comparisons between age estimates using four calicified structures from cabezon in California (* = significant at p < 0.001; NS = not statistically significant). The thick diagonal line shows the direct correspondence of estimates, while the thin line shows the fitted regression.
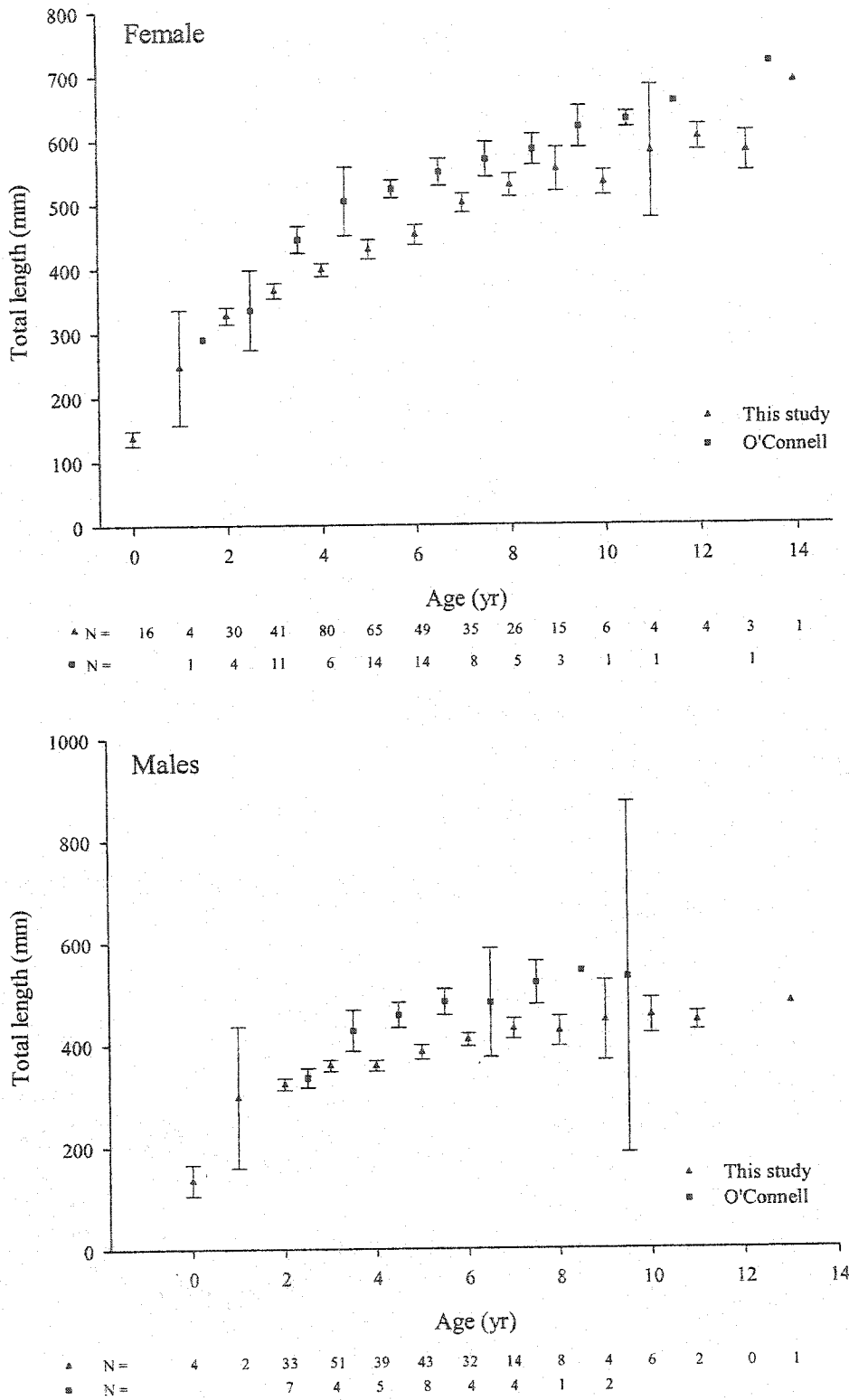
Fig. 5 Growth curves for female and male cabezon in California (this study, red triangle; O'Connell (1953) data, blue square), expressed as mean size at age estimated from otoliths. The vertical bars represent 95 % confidence intervals, and "n" is the sample size at each age for each study.
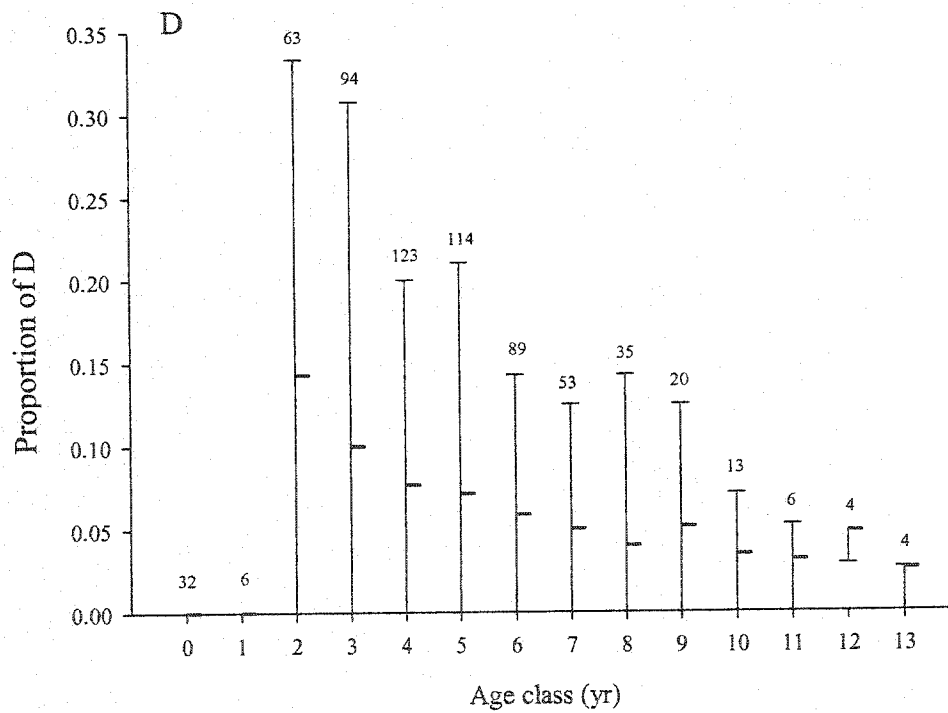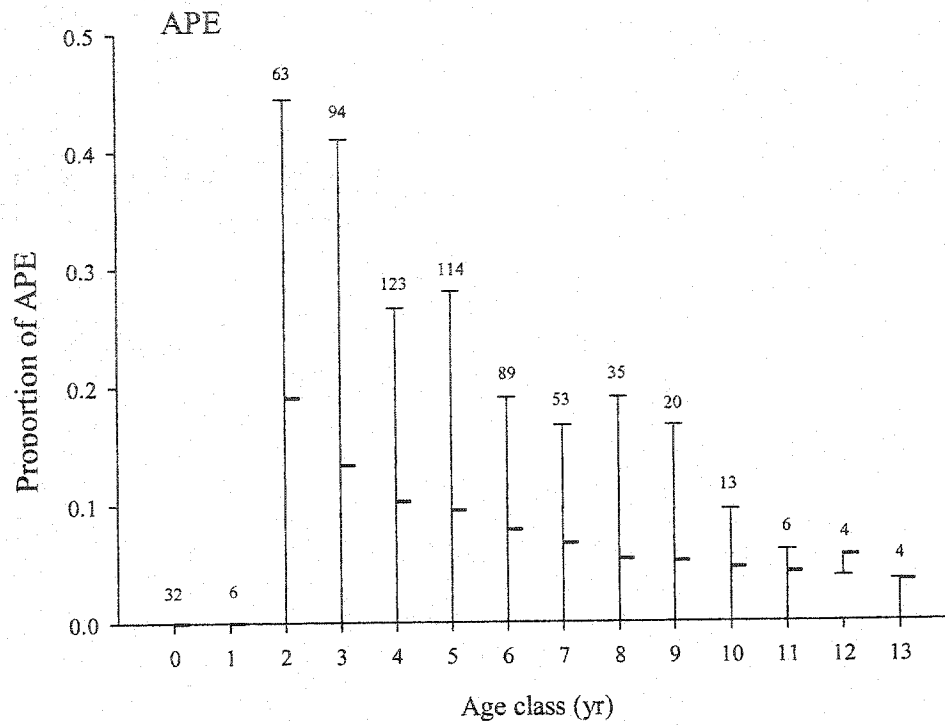
Fig. 6 Comparison of average percent error (APE) and index of precision (D) within each age class. Mean percent error is represented by black bar. All samples lie within whiskers. Age classes 0 and 1 did not contain any error.
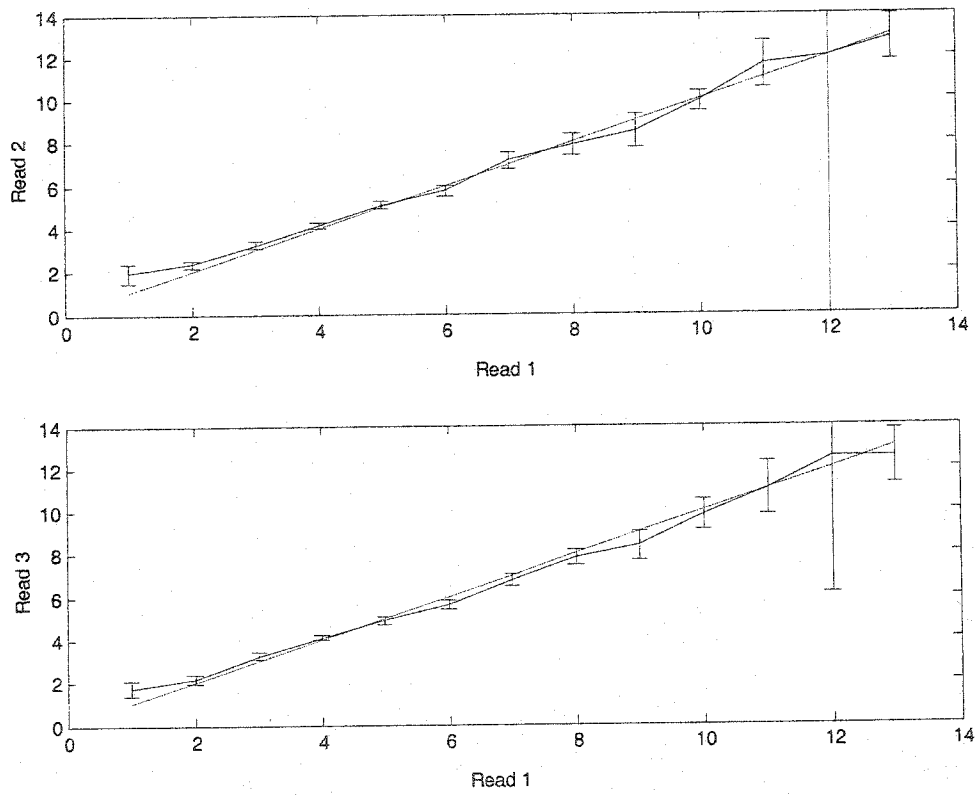
Fig. 7 Age bias plots summarizing pairwise comparisons of age estimates between three reads for cabezon sampled in California. Vertical bars represent 95 % confidence intervals of the samples.

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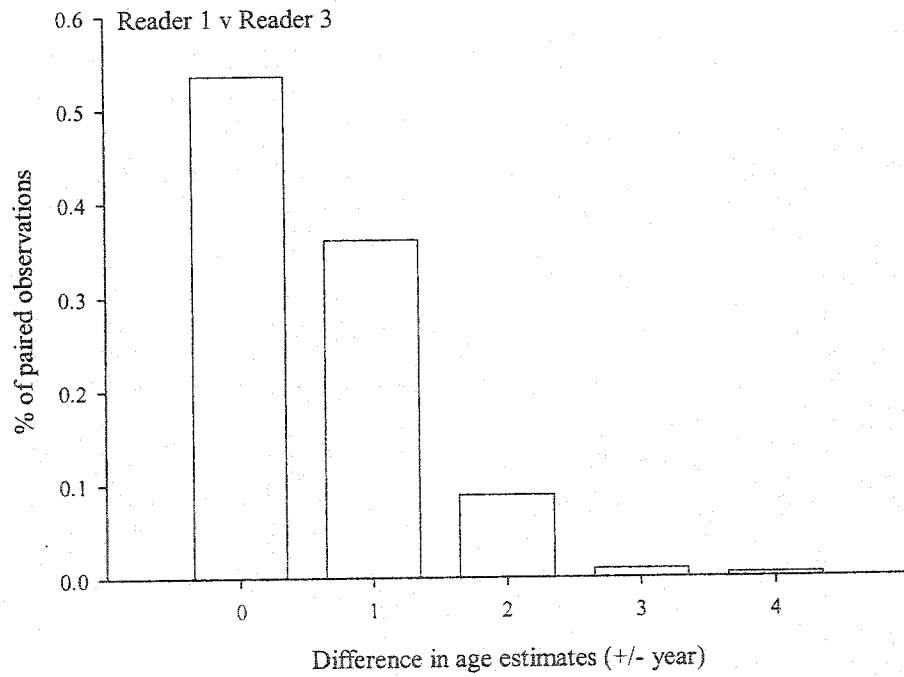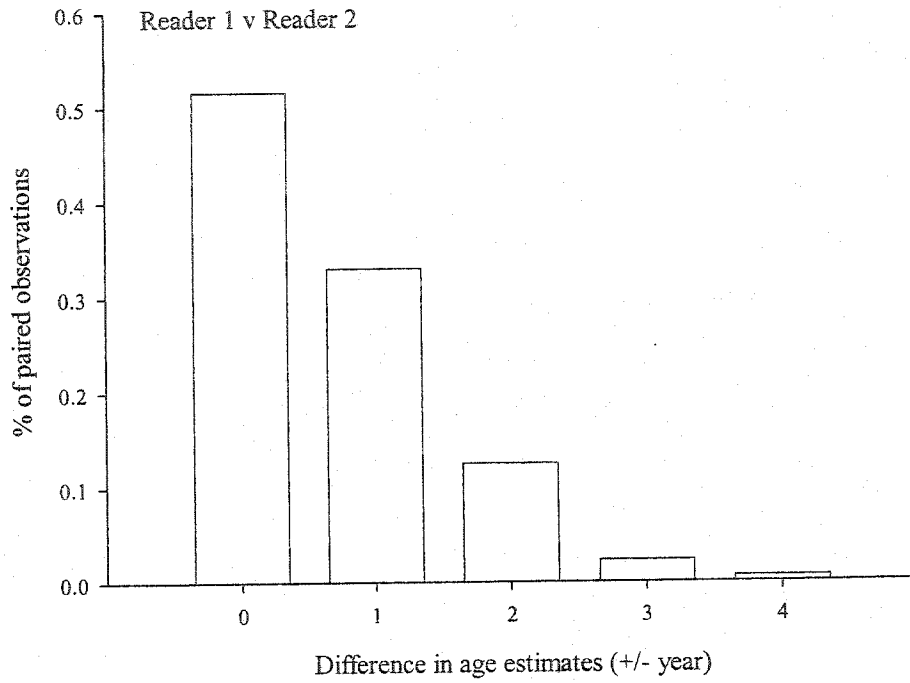
Fig. 8 Differences in otolith annulus counts by comparing three independent counts of reader 1 vs reader 2 and reader 1 vs reader 3, (0 = no differences, exact agreement).
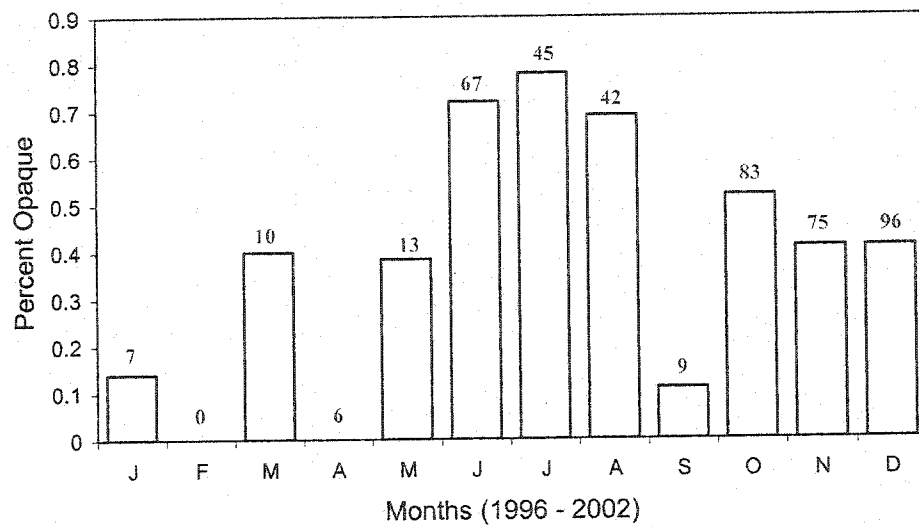
Fig. 9 Histogram of percentage of otoliths collected from 1996 to 2002 that had an opaque edge present by month of capture. All age classes are combined for analysis.
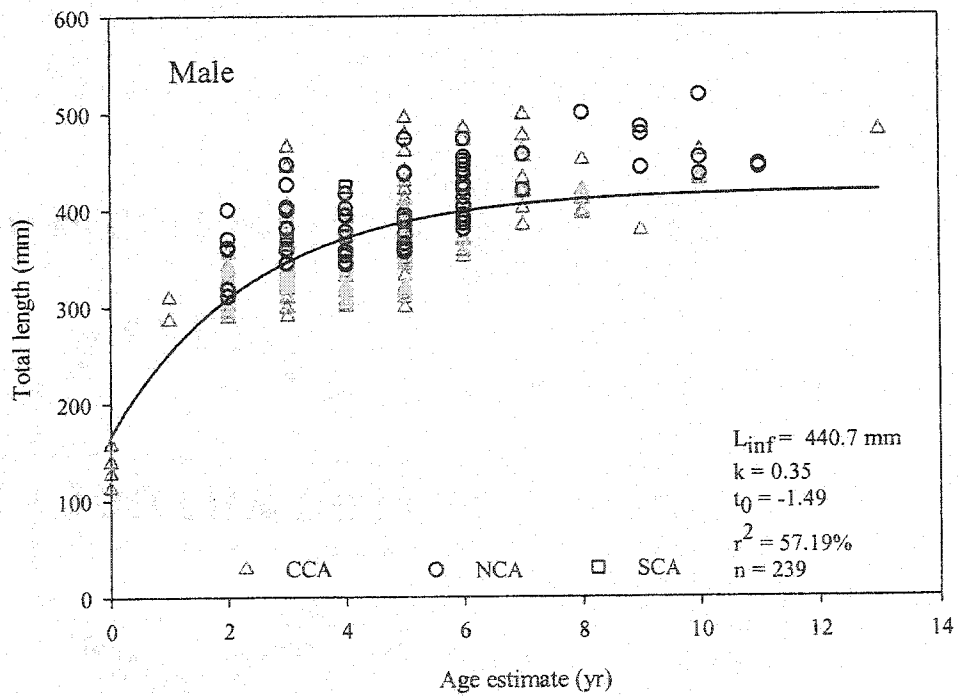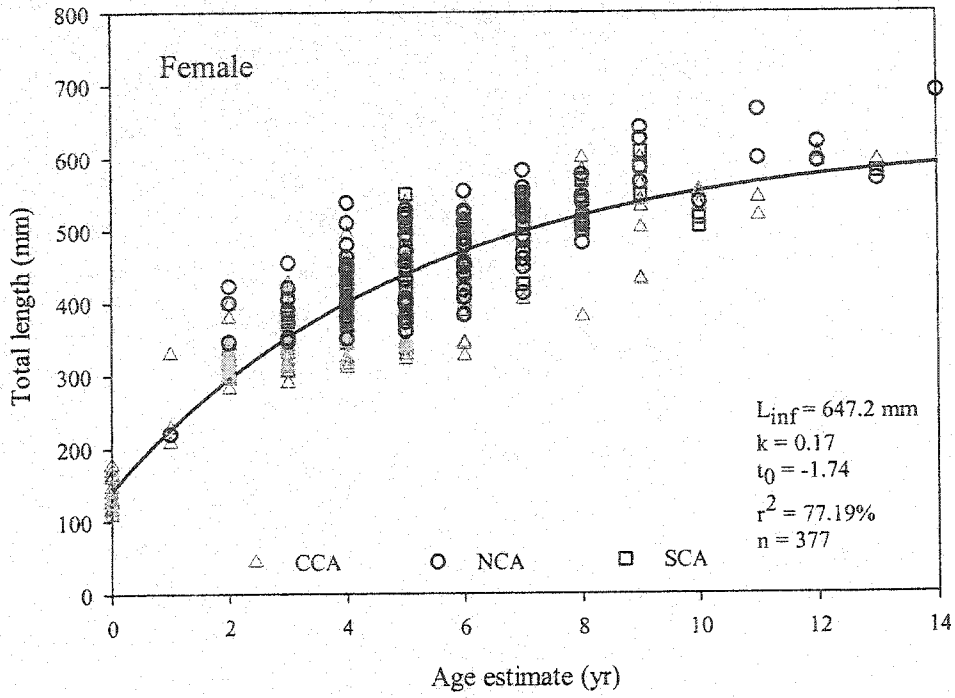
Fig. 10 von Bertalanffy growth curve estimate of female and male cabezon in California (CCA = central California; NCA = northern California; SCA = southern California).
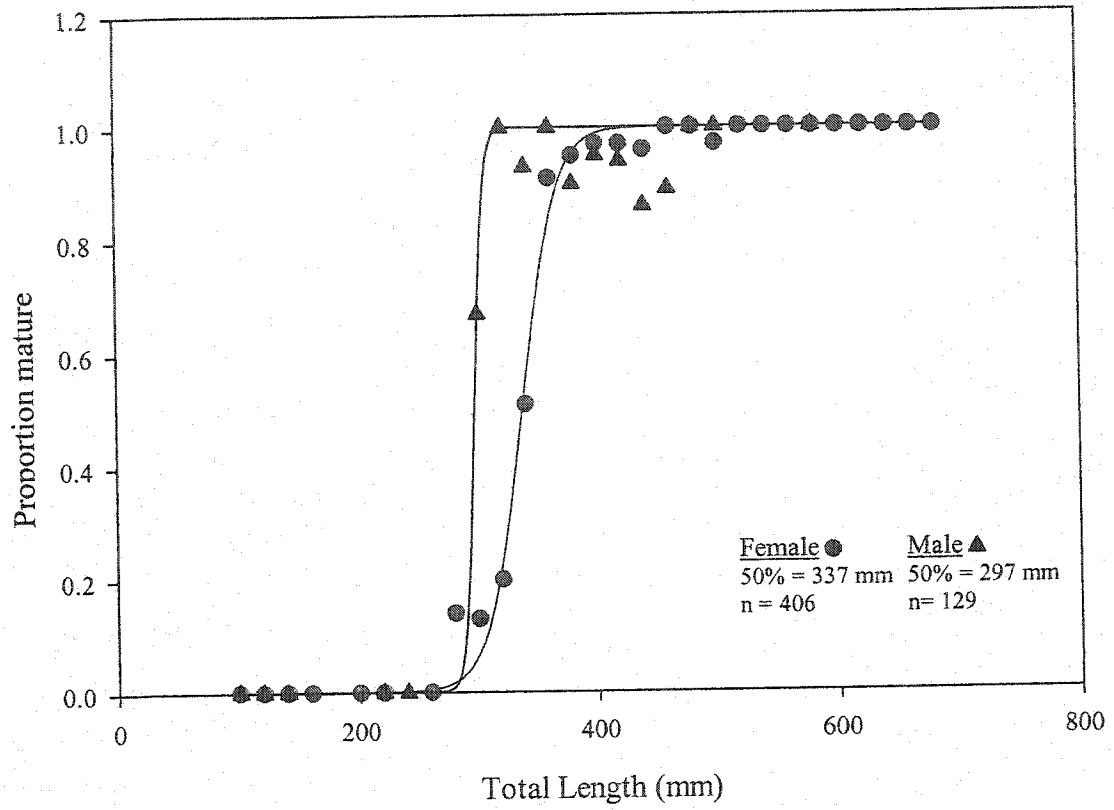
44

Fig. 11 Logistic plot of proportion mature versus length of male and female cabezon in California. Graph assumes equal weight of samples although sample sizes may be unequal.
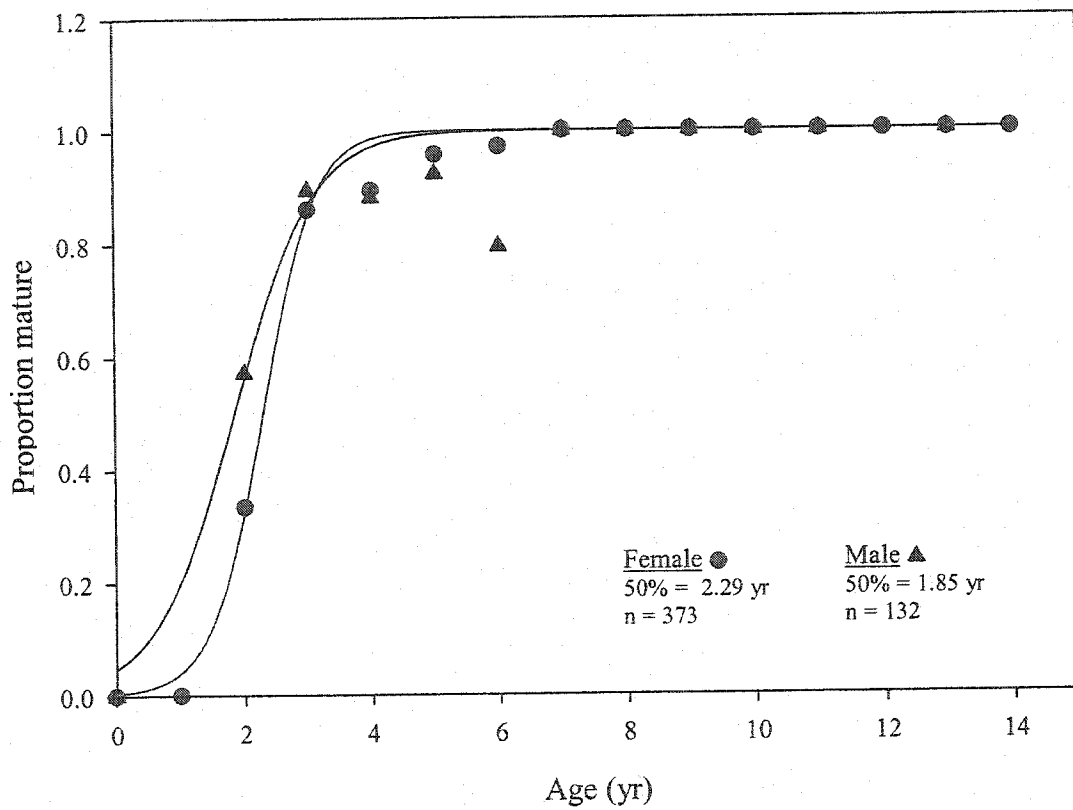
Fig. 12 Logistic plot of proportion mature versus age of male and female cabezon in California. Graph assumes equal weight of samples although sample sizes may be unequal.