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Determination of bank rockfish age and growth: a comparison of traditional and computer-aided techniques

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DETERMINATION OF BANK ROCKFISH AGE AND GROWTH: A COMPARISON OF TRADITIONAL AND COMPUTER-AIDED TECHNIQUES

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ABSTRACT

DETERMINATION OF BANK ROCKFISH AGE AND GROWTH: A COMPARISON OF TRADITIONAL AND COMPUTER-AIDED TECHNIQUES

by Aaron Everet King

This study was performed to determine the variation and reliability among and between traditional methods of otolith ageing, and a new computer-aided technique designed for this project using the rockfish, *Sebastes rufus*. As expected, break-and-burn and thin-sectioning traditional ageing methods produced the greatest similarity and counts, the traditional ageing method using whole otoliths produced the fewest counts. The generated von Bertalanffy growth curve indicated a slower growth rate than previous studies. This study also indicated a faster growth rate for females than males. The computer-aided method tended to undercount the number of bands when compared to a manual count. The computer-aided method was also markedly faster in producing multiple counts and produced less variability between counts. However, since the computer-aided method required thin-sectioning of otoliths, the overall time to produce counts was greater for the computer-aided method than traditional methods.

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INTRODUCTION

Traditional methods of otolith age determination, such as thin-sectioning and break-and-burn, are time consuming and subjective, have low between-reader and between-sample precision, and in some cases have been shown to be erroneous, often with serious consequences (Beamish 1979a, Cailliet et al. 1986, Bradford 1991). Other methods of band elucidation, such as staining (Albrechtsen 1968, Bouain and Siau 1988), and more objective approaches to band counting, have been developed (Casselman 1983), including methods for computer-aided image analysis of presumed annual rings in otoliths (Cook and Lord 1978, Small and Hirschorn 1985a and b, Frie 1982 and 1985, Neal 1987, Troadec 1991), daily growth rings in larval fish otoliths (Troadec 1991, Laidig and Pearson 1992), and scale circuli (Szedlmayer et al. 1991). These have been successful mainly for shorter-lived species such as salmonids, but have yet to be successful for longer-lived species such as rockfishes (Sebastes: Scorpaenidae). Only a few studies (e.g., Troadec 1991, Laidig and Pearson 1992) have attempted to address variability of the ring size and non-linear growth.

Many of the 63 species of rockfishes found in the northeastern Pacific (American Fisheries Society 1982) constitute an important resource to commercial and recreational fisheries (Lenarz 1986). The genus is characterized as having many long-lived species, some attaining confirmed ages in excess of 60 years (Bennett et al. 1982, Campana et al. 1990). This presents unique challenges with respect to management of species within the group.

One such species, the bank rockfish (Sebastes rufus), is distributed from Guadalupe Island, Baja California, to the Mad River in northern California

(Miller and Lea 1972) , although it does occur in Oregon landings. Recently, Escheverria (1987) and Love et al. (1990) included bank rockfish in their studies of rockfish reproduction, but age-specific information was limited due to the difficulties with age determination. Thus, information on age composition and growth of this species, vital for its management, is lacking.

The major objectives of this study were to: 1) Compare inter- and intra-method variability among the three most common traditional otolith preparation and reading methods (whole, thin-sectioned and break-and-burn) on bank rockfish otoliths; 2) Compare inter- and intra-reader variability among three readers using the three traditional ageing techniques; 3) Compare the count variability between male and female fish otoliths; 4) Determine age and growth parameters for bank rockfish; and 5) Evaluate the precision of the computer-aided ageing system relative to counts made by manually reading the otoliths.

It was expected that the computer would help standardize and speed the evaluation of otolith age information. Therefore, replicate measurements of age were expected to be more precise using the computer-aided ageing method than using the manual ageing method.

METHODS AND MATERIALS

Sources and Traditional Analysis of Bank Rockfish Otoliths

Bank rockfish otoliths have been collected from central and northern California commercial landings since 1977, and were made available to this project by the National Marine Fisheries Service (NMFS) and the California Department of Fish and Game (CDFG). Approximately 8,000 bank rockfish were sampled from commercial landings from 1977 through 1988 as part of an on-going cooperative groundfish sampling program between NMFS and CDFG. Samples were collected at ports from Avila to Eureka, California.

To choose one of the traditional methods for use in evaluating the computer-aided technique, comparisons were made among the traditional ageing methods (whole, break-and-burn, and sectioned). For this, 60 otolith sets from the 1986 catch were selected from each of three size classes: small (less than 350 mm total length), medium (350 to 450 mm total length), and large (more than 450 mm total length). These were further separated into two groups of 31 males and 29 females (Figure 1). One otolith from each otolith set was used for reading whole, and then broken-and-burned for another reading (after Chilton and Beamish 1982). The other otolith was used for a thin-sectioned reading. The thin-sectioned otoliths were placed on microscope slides and ground successively with 800 and 1200 grit sandpaper, until they were thin enough to allow light to pass through them (approximately 0.1 mm). Each of the three otolith preparations were blindly read thrice by three readers.

Several methods were used to evaluate the discrepancies between counts. In each case, the median count was used. One method used was average percent error (APE) (Beamish and Fournier 1981):

$$APE = \left[\frac{1}{N} \sum_{j=1}^{R} \left(\frac{1}{R} \sum_{i=1}^{R} \left(\frac{|X_{ij}-X_j|}{X_j}\right)\right)\right] 100$$

Where:

N = Fish Aged

R = Number of times each fish aged

X_{ij} = ith age determination of the jth fish

X_j = Average age calculated for the jth fish

Discrepancies were graphically displayed by plotting the relative number of band counts by which the paired readers or techniques differed (Cailliet et al. 1990, and Tanaka et al. 1990 for details). In addition, band counts for each method and reader were plotted against each other to evaluate the similarity of counts using different techniques.

Comparisons were made: 1) Among and between each method's counts; 2) Among and between each reader's counts; and 3) Between male and female counts.

Computer-Aided Readings

The computer-aided system developed for this study left decisions regarding both the initial computer hardware set-up of system parameters, and the final decision on each identified mark to the reader. The hardware used was an Apple Macintosh II with a microscope, video camera, video monitor, and frame grabber (Figure 2). The Macintosh system was chosen because of the inherent ease with which one can deal with graphics and images. For a complete description of the computer hardware set-up and software algorithm used, see "Bony Parts: An Image Analysis Program" (Brittnacher and Botsford 1991).

As viewed in cross-section, bank rockfish otoliths could be seen to grow along two separate axes. Due to the relative regularity of band deposition, only the region located just anterior to the sulcus was utilized for band count analysis in this study. The computer-aided system was not able to read the center of the otolith section (because of a widening of the bands). This section, which averaged 12.70 bands (SD=4.00) for males and 12.71 bands (SD=4.05) for females in the computer-aided mass reading that was performed (see below), was read manually.

Samples to be read were placed on the microscope stage and all adjustments to focus and location made by viewing the image in the video monitor. When the operator was satisfied with the image, the Macintosh was instructed to grab a frame from the video camera and display the image on the Macintosh screen. The operator then selected an oblong, rectangularly shaped region running transverse to the parallel, periodic bands that were to be counted. Within the rectangle, the light level was then scanned along a preset number of parallel lines that ran perpendicular to the bands (Figure 3).

The first step in computer processing was to average these parallel lines across the width of the rectangle, with respect to the amount of light passing through the image. If the width of the rectangle was increased, the dark and light bands did not line up (i.e., the bands were not parallel), and the computer incurred a type of phase, or registration error. The next step in computer processing was to use a matched filter to further reduce noise by filtering the one-dimensional signal that results from the averageing. This method was based on the idea that the best way to detect a signal in white noise was to correlate the noise-plus-signal with a "known signal." The known signal was derived from the shape of a "typical" annual mark on the otolith taken from approximately the middle of the rectangle. This typical annual mark was defined by the operator during the preprocessing stage, and implemented by the computer through numerical convolution. When the known signal and the averaged signal matched, the signal was considered detected. This filtering was followed by a peak or valley detector that identified the bands.

The result viewed by the operator on the screen was a hash mark indicating each point the system identified as a band, and a count of how many occur within the region chosen (Figure 4). The program then allowed the operator to change any of the decisions for the final count. However, for this study, the counts given by the computer were unaltered to allow an unbiased comparison with the manual counts. Information from any readings could be automatically or manually placed into an editable test window to produce a report of the results.

A total of 922 males and 976 females were aged using the computer-aided method. To derive this subsample, each of the years' sample inventories for each year from 1978 to 1987 were randomly sampled to obtain between 140 and 360 samples, depending upon the size of the year's catch (Figure 5). Each of these subsamples was checked using the Kolmogorov-Smirnov Goodness-of-Fit Test to determine if they represented the distribution of the entire year's sample. Each subsample was found to represent the entire year's sample within 95% confidence intervals.

Using Average Percent Error (APE) as the analytical tool, comparisons were made among three computer-aided counts for each 25 mm total length size class. In addition, von Bertalanffy age and growth parameters, L , K and

t_0, were calculated for each sex. These parameters were calculated using FISHPARM (Prager et al. 1987), a software using Marquardt's (1963) algorithm for non-linear, least squares parameter estimation (see Cailliet et al. 1990 for further discussion of this technique). The resulting von Bertalanffy growth functions and curves were then qualitatively compared with those produced in other studies (Nichol 1984, Watters et al. 1993).

Evaluation of the Computer-Aided Readings

Otoliths from 40 male and 44 female bank rockfish were selected from the 1982 catch from a range of size classes (Figure 6). These otoliths were thin-sectioned in a manner similar to the method used in the traditional and computer-aided ageing methods noted above, and placed into the computer-aided system under 14X magnification.

For a comparison of computer-aided versus manual band counts, two images were utilized from each otolith. One image was of the entire otolith with the region from which the readings would be made, a rectangular box, defined within the image. The other image was the rectangular box by itself, extracted from the image of the entire otolith (Figure 3).

Three computer-aided and two manual blind counts were made of the number of bands within the rectangular box. One of these manual counts (referred to here as the "full reading") utilized the entire otolith image so that the reader could follow lines outside of the rectangular box. This allowed the reader to make subjective determinations as to whether or not a band was valid, just as otoliths are traditionally read manually after being broken-and-burned or thin-sectioned (Chilton and Beamish 1982). The other manual count (referred to here as the "box reading") required that the count be made solely from the information gleaned from within the rectangular box, thereby restricting the reader to the same information available to the computer.

Using graphs, Average Percent Error (APE), precision histograms and regressions as the analytical tools, comparisons were made: 1) among the three computer-aided readings, 2) between the full and box readings, 3) between the full readings and the median of the three computer-aided readings, and 4) between the box reading and the median of the three computer-aided readings.

Since the readings were of a section and not the entire otolith, and the intent was to analyze just the computer reading, it was not possible to compare the results of the computer readings to any outside reference, such as total length. As explained above, the central part of the otoliths that were read manually were of varying widths.

RESULTS

Traditional Analysis of Bank Rockfish Otoliths

The break-and-burn method consistently produced the lowest APEs, and therefore the greatest precision among and between the three readers' counts (Table 1). APEs of break-and-burn readings ranged between 7.3 and 11.8, while for whole readings it was from 11.6 to 14.8 and for sectioned readings it was from 10.7 to 14.6. For whole and thin-sectioned readings, the results were mixed among each reader's counts. However, thin-sectioned counts provided greater precision between the three readers' counts than did the whole readings.

Generally comparing the reading methods' APEs to one another, whole vs. thin-sectioned counts were least similar due to higher overall APEs, while thin-sectioned vs. break-and-burn counts produced the greatest similarity due to lower overall APEs (Table 2).

As expected, the thin-sectioned otolith readings produced the highest overall counts per otolith for each reader for both males and females (Figure 7a and b). Whole otolith readings generally produced the fewest counts, while the break-and-burn method generally produced intermediate counts.

Comparisons between reading methods using precision histograms (Figure 8) indicated that whole and thin-sectioned counts were least similar, while thin sectioned and break-and-burn counts were most similar. Discrepancies between whole and either section or break-and-burn indicated that whole otoliths produced the lowest counts. Sections tended to produce the highest counts and discrepancies between this technique and break-and-burn were still quite high.

Reader 2 produced the highest overall precision within each reading method (Table 1). Reader 1, however, produced the highest precision between all three reading methods for both males and females (APE = 0.160 and 0.167), while reader 3 produced the lowest precision both among each method's readings, and between the three reading methods (APE = 0.281 and 0.306).

Generally, when the three readers' counts were compared to one another (Table 3), reader 1 and reader 2's counts were least similar to one another, while reader 1 vs. reader 3, and reader 2 vs. reader 3, were more similar to one another, though mixed.

With regard to reader variability, reader 2 generally produced the highest overall counts per otolith for each method. Reader 3 produced the lowest overall counts per otolith for the whole readings, and reader 1 produced the lowest overall counts per otolith for the sectioned method.

In general, female otolith counts consistently produced regressions with higher R^2 values for each reader and method than did males (Figure 7a and b). With the exception of reader 1's whole otolith count, all the female logarithmic curves for each count generally had a greater equation slope than the corresponding male logarithmic curve. No overall difference between male and female counts could be discerned.

Computer-Aided Readings

For both sexes, the mean APE decreased with increasing size class (Table 4a and b). For males, the range was from 7.4% to 2.7%. For females, mean APE values ranged from 4.8% for smaller bank rockfish, to approximately 3.0% for the largest ones. Overall, the male and female APEs were similar and compared favorably to those presented in Table 2, with males and females averageing 3.9% and 4.0%, respectively.

Based on data derived from these age determinations, von Bertalanffy growth equations indicate that females grow larger than males, but at a slightly slower rate (Figure 12a and b). The growth of the bank rockfish, as determined by FISHPARM, is best described by the equations:

Males -

$$L_t = 438.1 \{1 - e^{\{-0.07257[t-0]\}}$$

Females -

$$L_t = 500.7 \{1 - e^{\{-0.0544[t-0]\}}$$

Manual vs. Computer-Aided Readings

The three computer readings had a relatively low APE of 3.6% for males and 4.2% for females (Table 5). In the case of both males and females, the box readings more closely paralleled the full readings (APE = 3.6% and 4.4% respectively), than did the median of the computer readings (APE = 6.3% and 8.2%, respectively). The box count compared to the median computer count had a male and female APE of 3.9% and 4.8%, respectively.

Comparisons indicated that the computer-aided technique worked well with either box subsections of an otolith or with full otoliths. The full versus box/manual and box/manual versus box/computer APEs were lower (range 3.6 to 4.8) than the full manual versus box/computer APEs (range 6.3 to 8.2).

Likewise, the precision histograms (Figure 13) indicate that discrepancies were low and varied little within computer age determinations, but were higher and more variable between computer and manual age estimations. The within computer counts for both male and female bank rockfish had similar means, modes, and distributions. Within box and computer counts generally produced fewer discrepancies than the manual counts. Whether the comparison was made within the box subsection or between manual versus computer-aided counts, discrepancies ranged from 0 to 7 years. It was surprising that the full otolith readings did not show larger discrepancies than those within a box, whether by computer or manual operation.

Indeed, the regression analysis indicated that all three techniques produced essentially similar results (Figures 9-11). All readings, except the comparison between box and computer readings for males, produced slopes that were not significantly different from one. In both males and females, the median computer readings had a tendency to be less than either the full or the box readings, while the full reading had a tendency to be greater than the box reading. However, statistically speaking, the full, box/manual, and box/computer combination comparisons in general produced similar results.

DISCUSSION

It has become common in recent years to age most species of Scorpaenid fishes (and other long-lived fishes) by the otolith break-and-burn and thin-sectioning methods. A landmark study by Beamish (1979a) indicated that whole otolith readings may be unreliable after only about the first 15-to-20 years of the fish's life for some species, but still reliable for other species. This is attributed to the fact that the bands that formed after a certain age are formed along a different axis than those formed early in life. The early age bands form most rapidly along the dorso-ventral axis, while the older age bands form most rapidly along the proximal edge in the distal-proximal axis. In fact, by thin-sectioning or breaking-and-burning, rather than reading otoliths whole, it could be seen that some rockfish species may be 80 to 140 years old (Chilton and Beamish 1982). However, with only a few exceptions (Leaman and Nagtegaal 1987, Bennett et al. 1982, Campana et al. 1990), few of these species have had these estimated ages validated.

Traditional Ageing Method Comparison

On the average, the various traditional methods resulted in counts that were widely different from one another, as found in other species (Beamish 1979b), particularly other rockfish ageing studies (Chilton and Beamish 1982). As expected, whole otolith readings tended to produce the lowest counts per total length for both males and females as evidenced by their regression curves. When viewed as a whole otolith, only those bands which are formed early in life can be readily discerned. Since thin-sectioned otolith counts produced higher overall counts per otolith, this method could be assumed the most reliable of the three methods for elucidating and detecting bands. However, other studies have found the break-and-burn method helps eliminate "checking," thereby highlighting only the "true annuli" (Chilton and Beamish 1982).

If this is true, it would explain why each reader had the least trouble reproducing their counts when the break-and-burn method was used for reading. However, it is still possible that the break-and-burn method not only helps eliminate checking, but is also faulty in highlighting all "true annuli" (some checks in break-and-burn readings tend to resemble true annuli).

As discussed above, it may be assumed that bands formed past the first 15 to 20 years in life cannot be discerned in whole otolith readings. This assumption is reflected in the fact that the thin-sectioned and the break-and-burn counts are more similar to one another than either are to whole otolith counts due to the greater number of bands that can be detected in these reading methods.

While reader 2 produced the highest overall counts per otolith, and the greatest precision within each reading method, it cannot be assumed from that information that those counts are the most accurate. Reader 2's greater precision does, however, indicate a more rigid approach to applying a set criterion for distinguishing a band.

The greater slopes of the logarithmic curves for the female counts indicate a higher growth rate for female bank rockfish than males. The one exception to this tendency, reader 1's whole otolith counts, can be discounted since it has been shown that those readings are unreliable for older fish.

<u>Computer-Aided Readings</u>

No data were collected concerning the time required to produce counts on these three reading methods. However, in general, the thin-sectioning method was more time-consuming than break-and-burn preparations, while whole readings required no preparation time. Thin-sectioning of samples, along with polishing to elucidate the bands, provided a flat surface which was more conducive to computer-aided image analysis. Experiments with other methods for elucidation (such as staining and "baking" of the otoliths) of the bands were undertaken, but none produced the flat surface and band resolution required for the computer-aided method.

The ability to produce similar consecutive readings with the computer-aided system is a definite advantage over manual readings. However, the inability of the computer-aided system to utilize a more rapid means of otolith preparation than thin-sectioning (such as break-and-burn), limits its usefulness for large scale otolith readings.

A lack of fish less than 300 mm total length limited the ability to generate a von Bertalanffy growth curve that is accurate for fish less than that length. However, for the fish that were available, results indicated that bank rockfish males can reach a maximum size of 601 mm total length, and females can reach 722 mm total length. This size would place it slightly larger than its previously recorded length of 511 mm total length (Miller and Lea 1972).

The von Bertalanffy growth parameters generated in this study were compared to the growth parameters for bank rockfish generated by Watters et al. (1993) and Nichol (1984) (Table 6). While the Nichol study did not originally generate von Bertalanffy growth parameters, estimates of L and T_0 were graphically determined from the data given in the Nichol's study, and k estimated from the resultant figures. All three studies produced von Bertalanffy growth curves that were similar (Figures 14a and b). For both males and females, the Watters study generated the greatest L . For females, the Nichol study and this study produced L that were nearly identical, while for males, the Nichol study's L was between the other two. The Nichol study produced the largest k, while this study produced the smallest k. Therefore, the von Bertalanffy curve for this study indicates a slower growth rate than the other two studies, with the Nichol study indicating the fastest growth rate.

Manual vs. Computer-Aided Readings

In the box readings, the manual reader was unable to follow the bands outside a small confined area. This seems to have had the effect of lowering the number of bands assigned to a particular otolith when the full reading was used as an assumed "accurate reading." A possible explanation is that when an otolith has been polished such that light can pass through, there are places where the bands appear discontinuous. Upon closer examination, these generally appeared to be artifacts of the polishing method, and not necessarily "checks," since the bands could be seen to resume a short distance later.

The computer-aided method has a tendency to even further under-count the bands within an area than does the manual box reading. This can only be attributed to a failure of the program to properly observe some bands. The computer readings in this subsample were unaltered by the operator, since the intended result was to observe the difference between a manual reading and an unbiased computer simulation of the reading. If this had been a routine reading, the computer operator would have had a chance to scan the computer's results, and alter its readings accordingly. In this case, the operator would have had the tendency to add bands to the readings rather than discard bands as being unqualified "checks."

In general, if this system is to provide more precise and accurate information than traditional ageing methods, the necessary grinding and polishing techniques need improvement. Specifically, improved band elucidation techniques and methods to increase the computer's ability to read the bands found close to the nucleus are needed. If better methods could be found to do this, population models that using age and growth information could be made more accurate and robust through greater sample sizes.

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	Reader 1	Reader 2	Reader 3
Whole Readings			
Females	14.1	13.1	13.7
Males	11.6	14.8	12.6
Sectioned Readings			
Females	14.6	12.1	12.8
Males	12.5	10.7	14.2
B&B Readings			
Females	10.6	7.3	8.5
Males	9.8	9.6	11.8

Table 1. APE values of sex-specific band counts among three readings by each of three readers for the three traditional ageing preparation techniques (whole, sectioned, and break-and-burn). For most categories, there were 31 males and 29 females aged, with exceptions occurring as the result of disagreement about sample readability.

	Sectioned Readings		B&B Readings	
	Females	Males	Females	Males
Whole Readings				
Females				
Reader 1	19.4		12.4	
Reader 2	19.1		12.3	
Reader 3	35.2		23.3	
Males				
Reader 1		14.5		11.4
Reader 2		20.9		16.0
Reader 3		36.8		22.9
Sectioned Readings				
Females				
Reader 1			10.6	
Reader 2			12.7	
Reader 3			16.3	
Males				
Reader 1				14.4
Reader 2				11.9
Reader 3				15.7

Table 2. Matrix of reader- and sex-specific APEs derived from counts comparing the three traditional ageing preparation techniques. Sample sizes as in Table 1.

	Reader 2 Females	Reader 2 Males	Reader 3 Females	Reader 3 Males
Reader 1				
Females				
Whole Reading	16.3		16.3	
Sectioned Reading	16.3		12.8	
B&B Reading	13.4		8.8	
Males				
Whole Reading		24.7		11.3
Sectioned Reading		14.7		12.9
B&B Reading		16.0		9.9
Reader 2				
Females				
Whole Reading			10.1	
Sectioned Reading			9.8	
B&B Reading			9.9	
Males				
Whole Reading				17.3
Sectioned Reading				..9.8
B&B Reading				11.2

Table 3. Matrix of sex- and technique-specific APEs derived from counts comparing the three readers. Sample size as in Table 1.

A)

Size Range	# of Individ.	Mean APE	Stan. Dev.
< 325	14	4.8	2.09
326-350	45	4.6	2.34
351-375	92	4.1	2.66
376-400	148	4.5	2.19
401-425	167	4.2	2.53
426-450	171	4.0	2.34
451-475	161	3.8	2.40
476-500	112	3.5	2.15
501-525	46	3.0	1.70
> 526	20	3.1	1.68
All Specimens =	976	4.0	2.36

B)

Size Range	# of Individ.	Mean APE	Stan. Dev.
< 325	6	7.4	8.05
326-350	53	4.4	2.75
351-375	159	4.2	2.41
376-400	215	4.4	2.47
401-425	251	3.8	1.99
426-450	153	3.5	2.25
451-475	60	2.7	1.56
> 476	23	3.1	1.81
All Specimens =	921	3.9	2.38

Table 4. Means and standard deviations of APEs resulting from 3 computer-aided readings of each otolith over all samples available within each size class. A) is for females, while B) is for males, resulting in a total sample of 1897 otolith sections.

	Females	Males
<u>Within</u>		
Computer Readings APE	4.2	3.6
<u>Between</u>		
Full/Manual vs. Box/Manual APE	4.4	3.6
Full/Manual vs. Box/Computer APE	8.2	6.3
Box/Manual vs. Box/Computer APE	4.8	3.9

Table 5. Summary of APEs of computer-aided (always in box) versus manual (either in box or full, i.e. using the full otolith section) estimates of ages.

	L	K	T_0	n
Females				
Watters	594	0.0390	-6.96	86
Nichol	495	0.1735	1.88	153
This Study	500.7	0.0544	0.00	976
Males				
Watters	488	0.0482	-8.37	81
Nichol	459	0.1997	2.32	146
This Study	438.1	0.0730	0.00	921

Table 6. Von Bertallanffy growth parameters generated by Watters (1993), and those growth parameters generated in this study by computer-aided readings of bank rockfish otoliths for (a) Females and (b) Males. The Nichol (1984) study did not originally generate von Bertallanffy growth parameters. However, estimates of L and T_0 were graphically determined from the data given in the Nichol's study, and k estimated from the resultant figures.

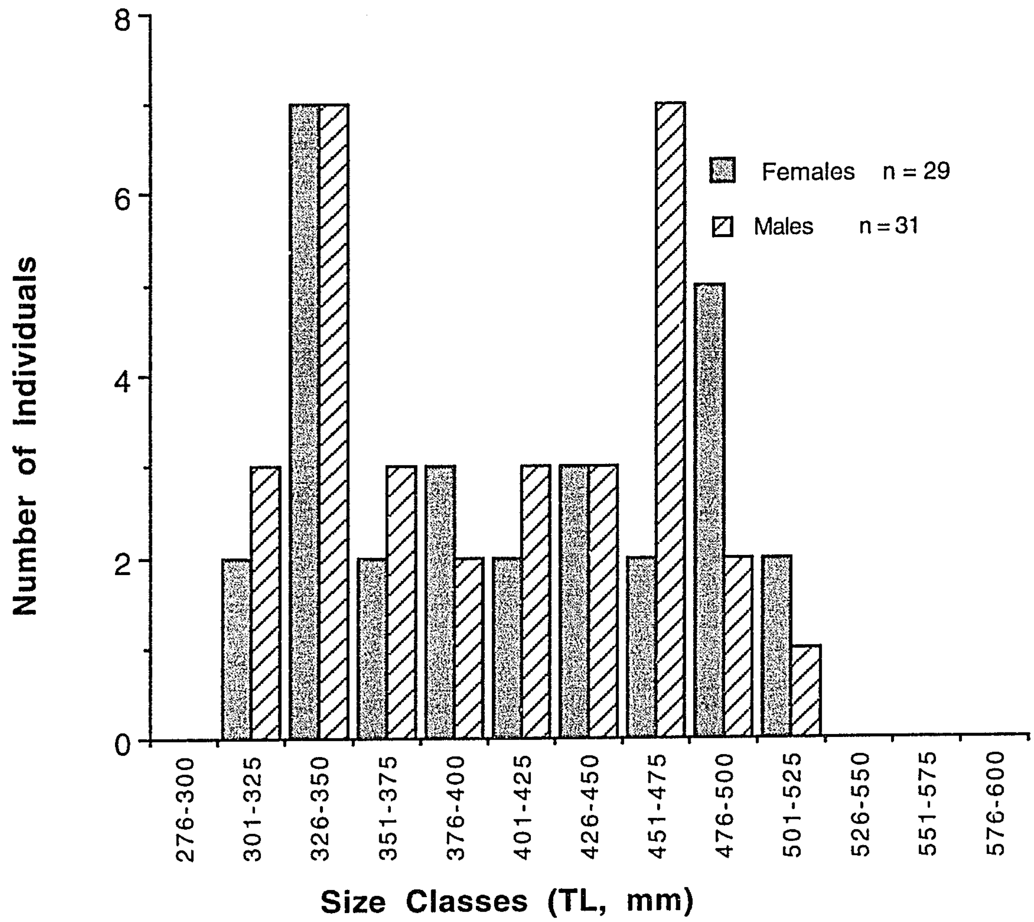

Figure 1. Size-frequency histograms of bank rockfish from which otoliths were used for comparisons of readers, preparation techniques, and ages (Tables 1-3). Intervals were arbitrarily set at 25 mm Total Length.

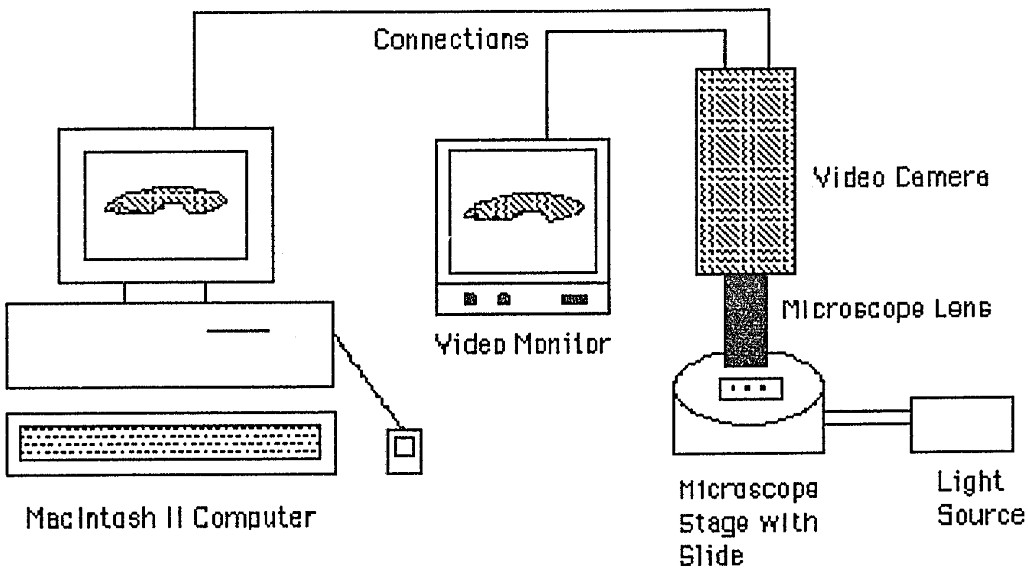

Figure 2. The hardware used was an Apple Macintosh II with a microscope, video camera, video monitor, and frame grabber. The Macintosh system was chosen because of the inherent ease with which one can deal with graphics and images.

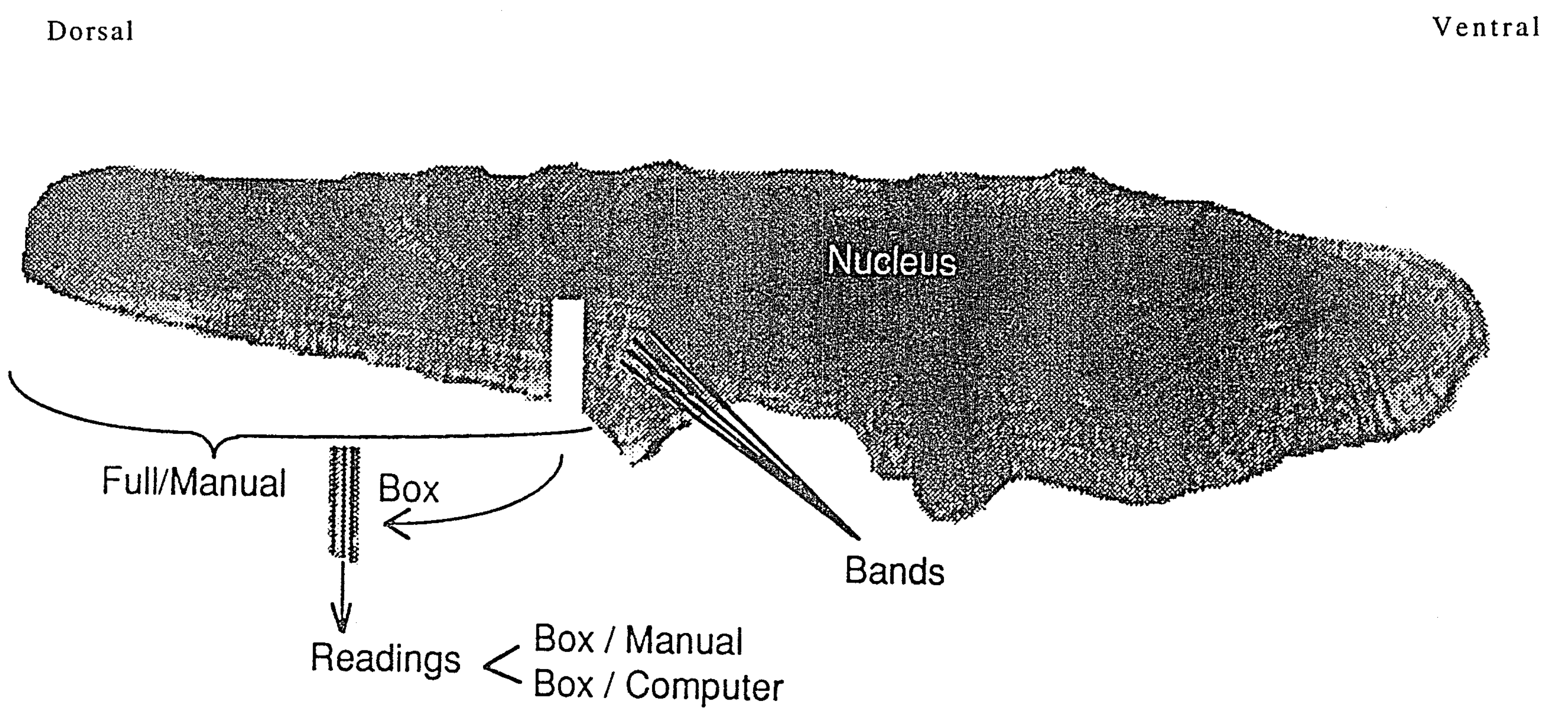

Figure 3. Diagram of bank rockfish otolith section identifying the nucleus (N), an idealized "box" across a group of bands (for "Box/Manual" or "Box/Computer" readings), and the remaining bands (which could be utilized for "Full/Manual" readings). In many cases, three segments of the box were read during "Box/Computer" readings.

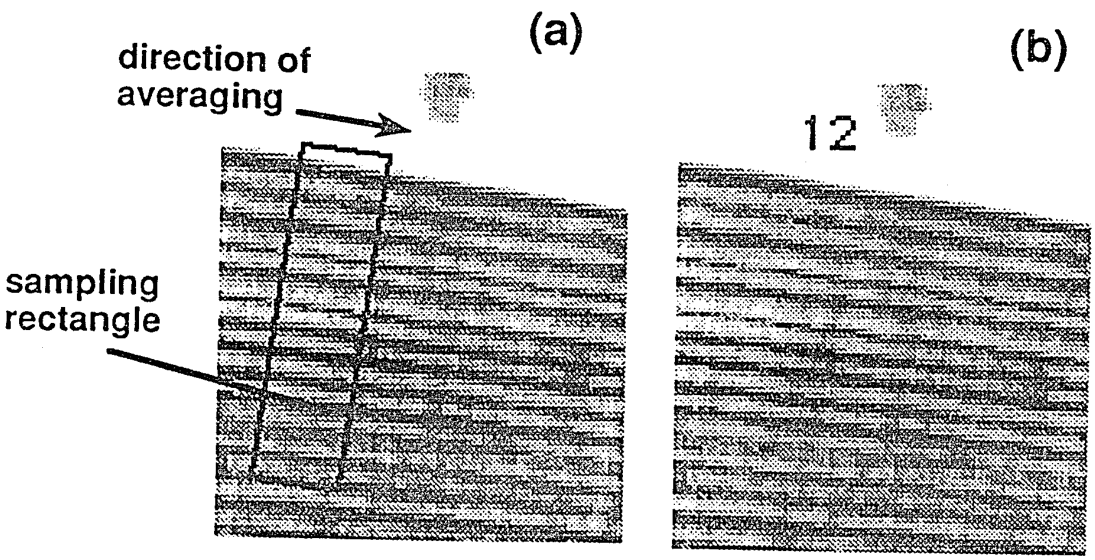

Figure 4 Image analysis process using "Boney Parts": (a) User Specified rectangle within which image is read. Position, length, width and orientation of the rectangle are specified by the user; (b) The results after averageing, filtering, and valley detection. Identified annual marks are indicated by a tic-mark for reader perusal and the total number identified in the rectangle appears at the top.

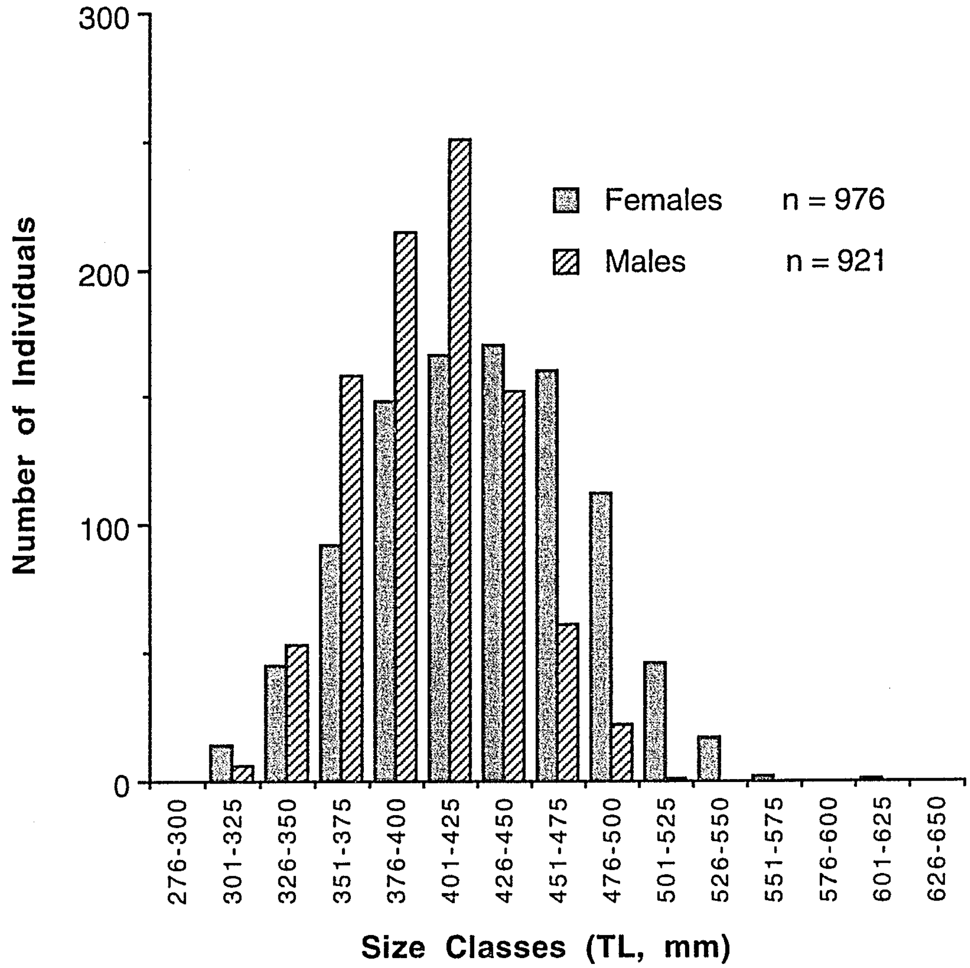

Figure 5. Size-frequency histograms of female and male bank rockfish from which otoliths were used for computer-aided APE comparisons among size intervals (Table 4). Intervals are the same as for Figure 1.

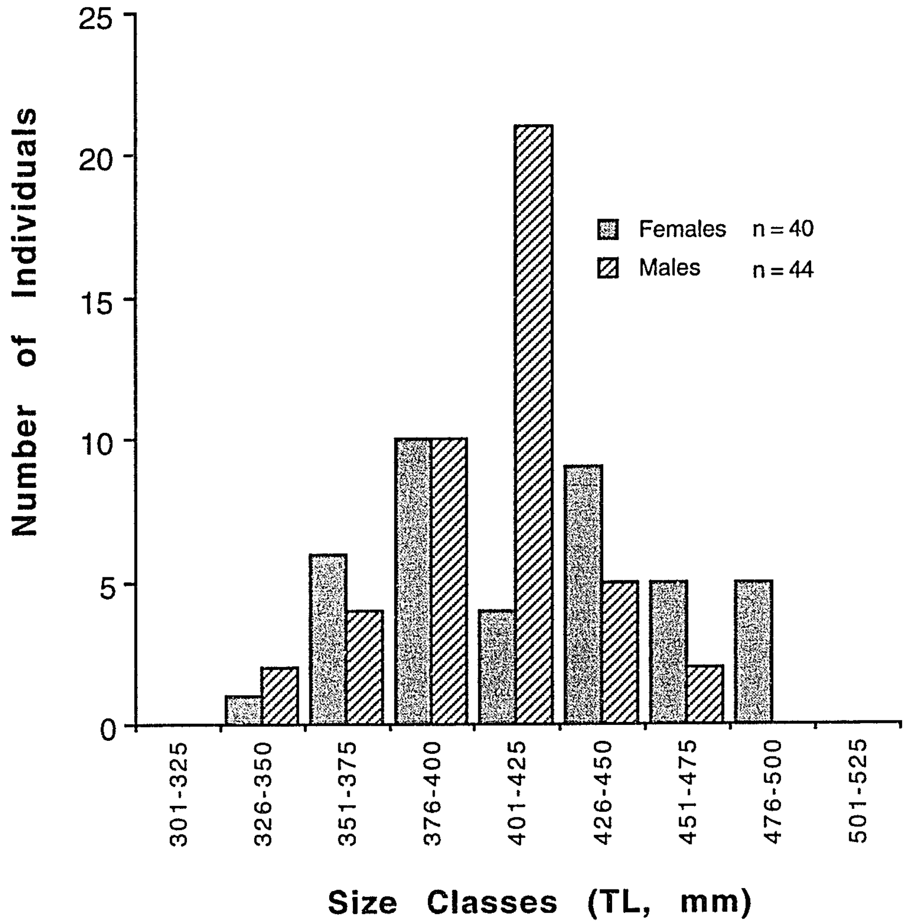

Figure 6. Size-frequency histograms of female and male bank rockfish from which otoliths were used for APE comparisons between computer-aided and manual otolith readings (Table 5). Intervals same as for Figure 1.

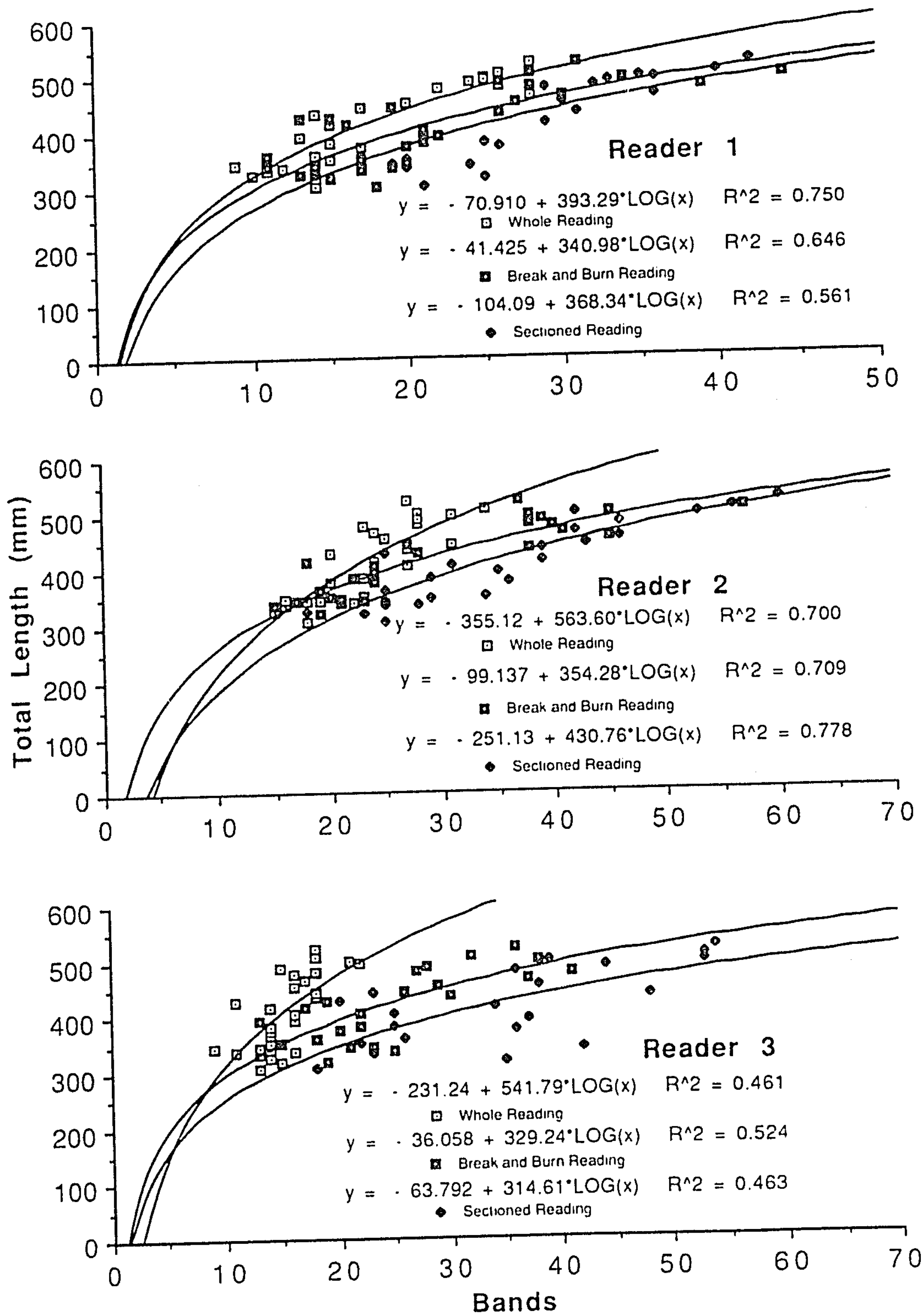

Figure 7a. Relationships between total length and median band counts (readings) of female bank rockfish comparing three traditional otolith preparation and reading techniques (section, break-and-burn, and whole). Equations and lines represent the best-fit logarithmic regressions.

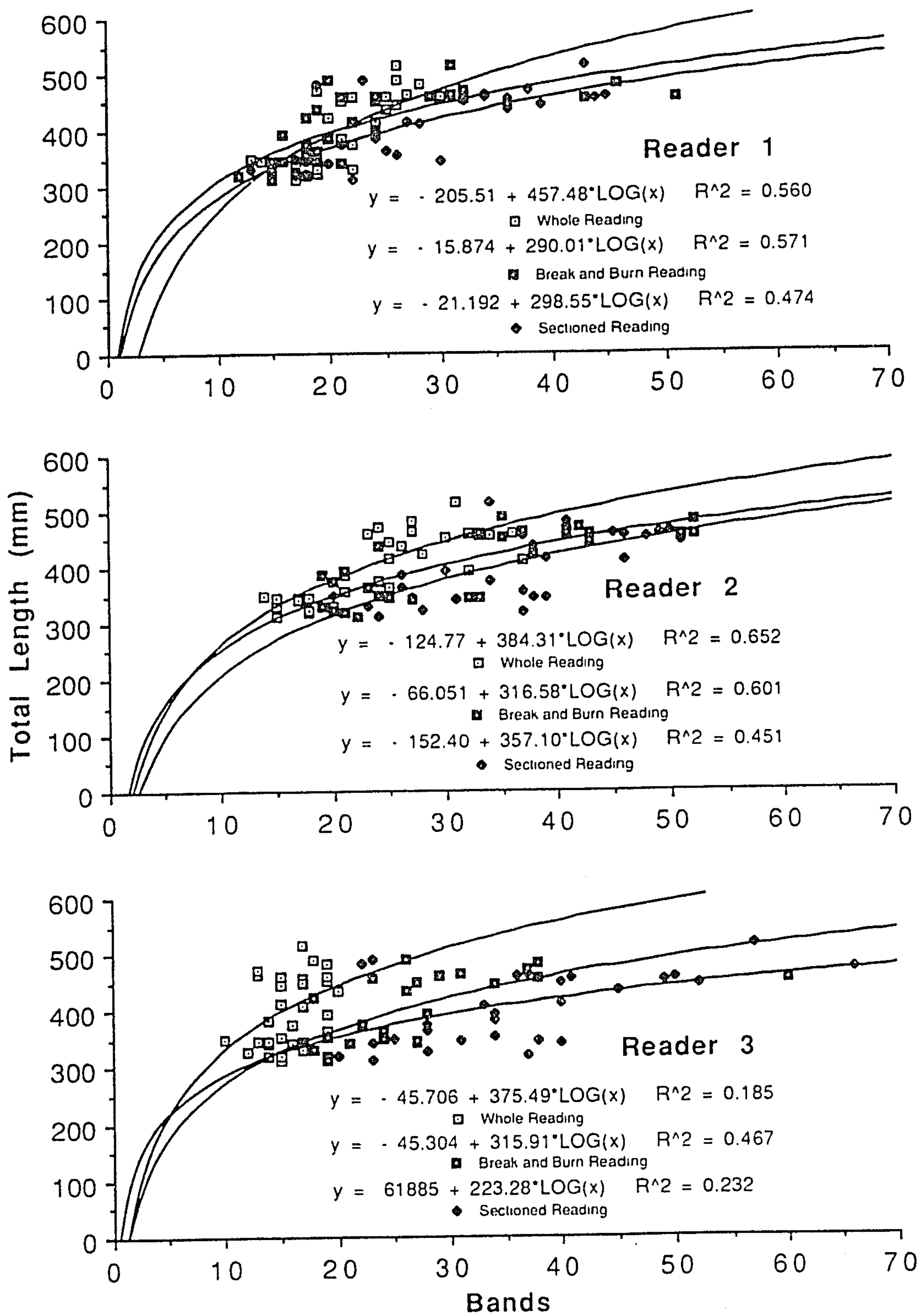

Figure 7b. Relationships between total length and median band counts (readings) of male bank rockfish comparing three traditional otolith preparation and reading techniques (section, break-and-burn, and whole). Equations and lines represent the best-fit logarithmic regressions.

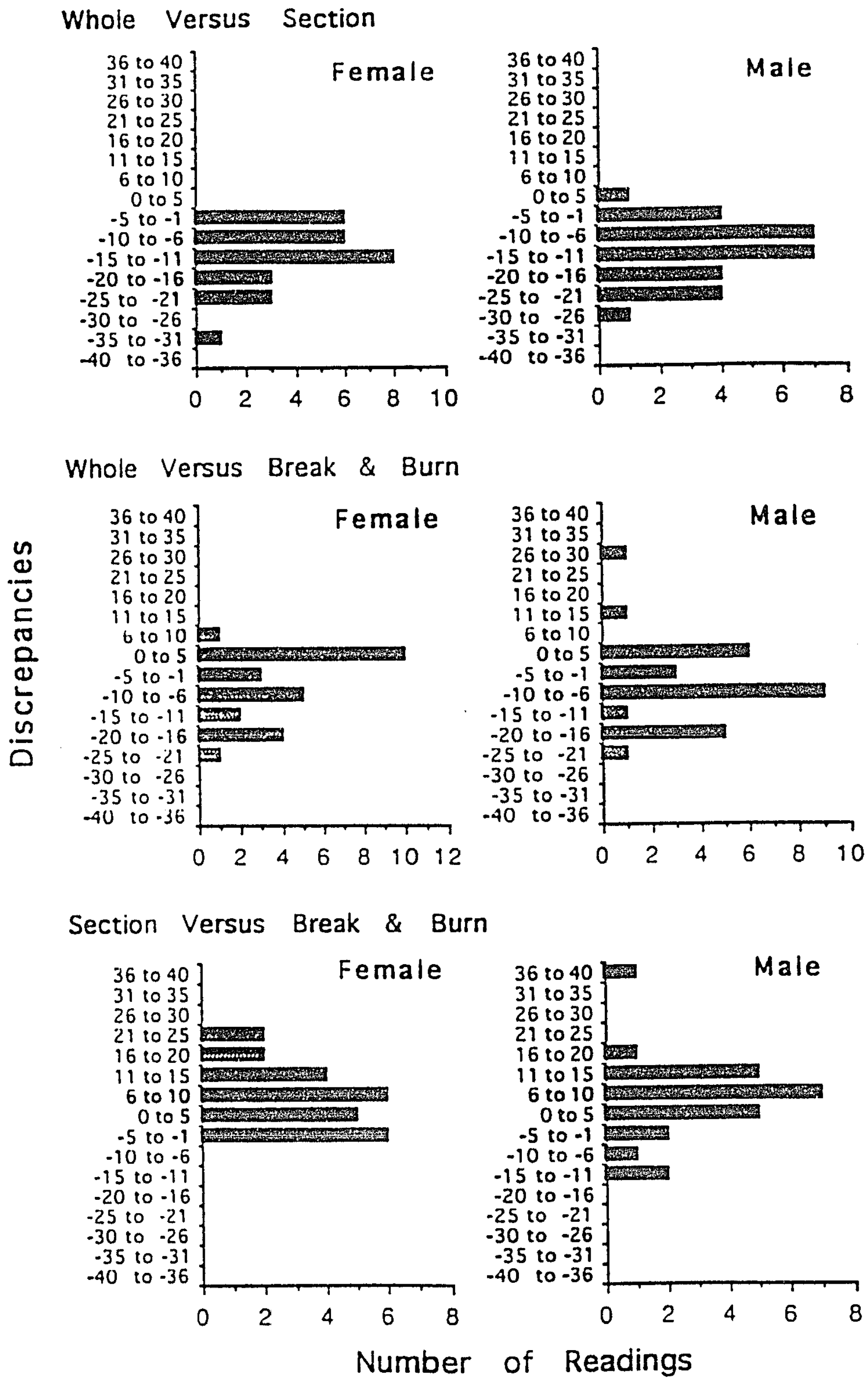

Figure 8. Band count precision histograms, comparing the readings of one reader from the three traditional ageing preparation techniques for both sexes of bank rockfish. Histograms represent the discrepancies (positive and/or negative differences) in number ("N") of paired counts.

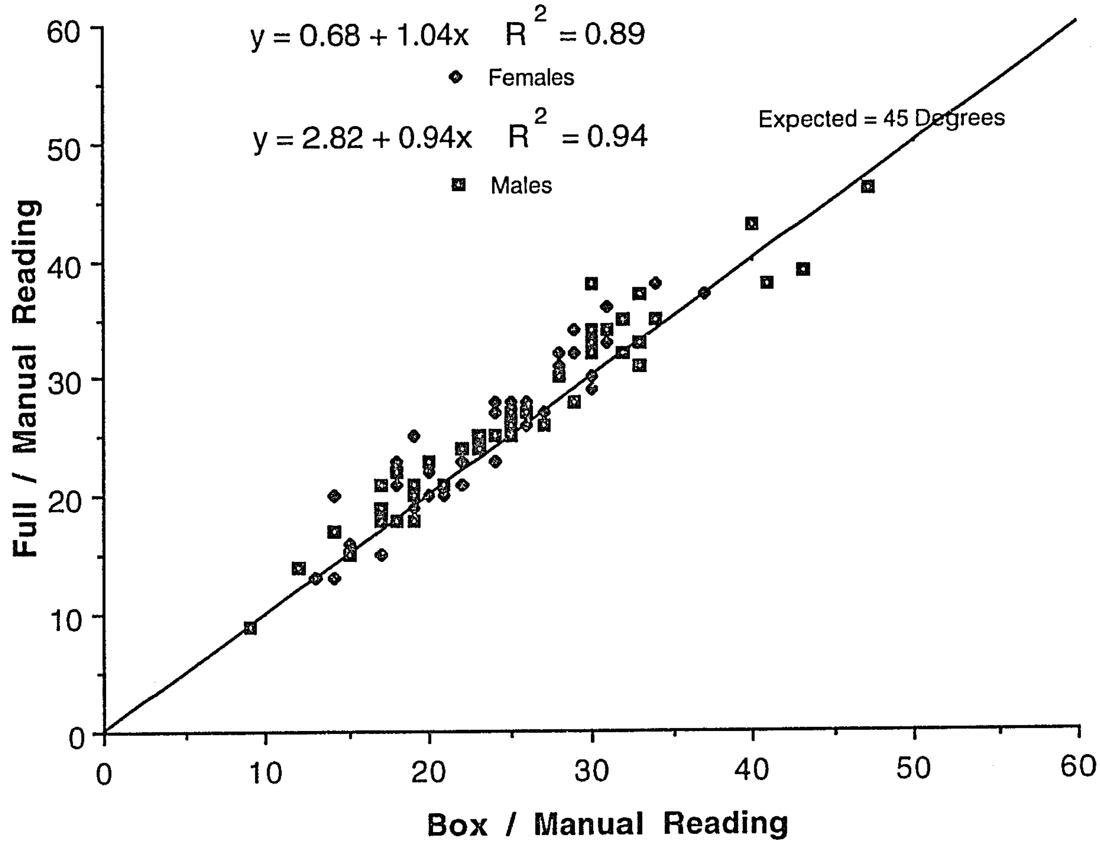

Figure 9. Plot of Full/Manual readings versus Box/Manual readings. Test of plot slope versus a slope of 1 finds no significant difference between the two slopes. However, visual comparison finds the tendency was for the Full/Manual readings to be slightly more than the Box/Manual readings.

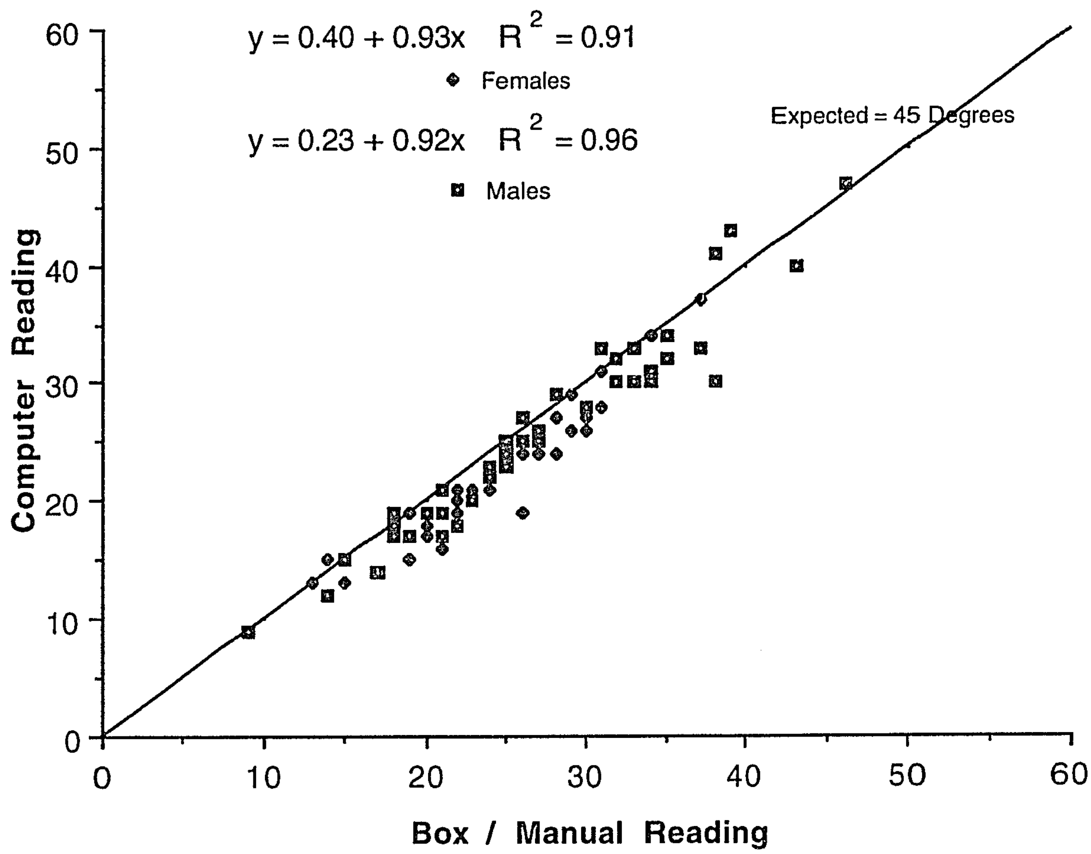

Figure 10. Plot of Computer readings versus Box/Manual readings. Test of plot slope versus a slope of 1 finds no significant difference between the two slopes for females, and a slope that has nearly no significant difference than 1 for males. However, visual comparison finds the tendency was for the Box/Manual readings to be slightly more than the Computer readings

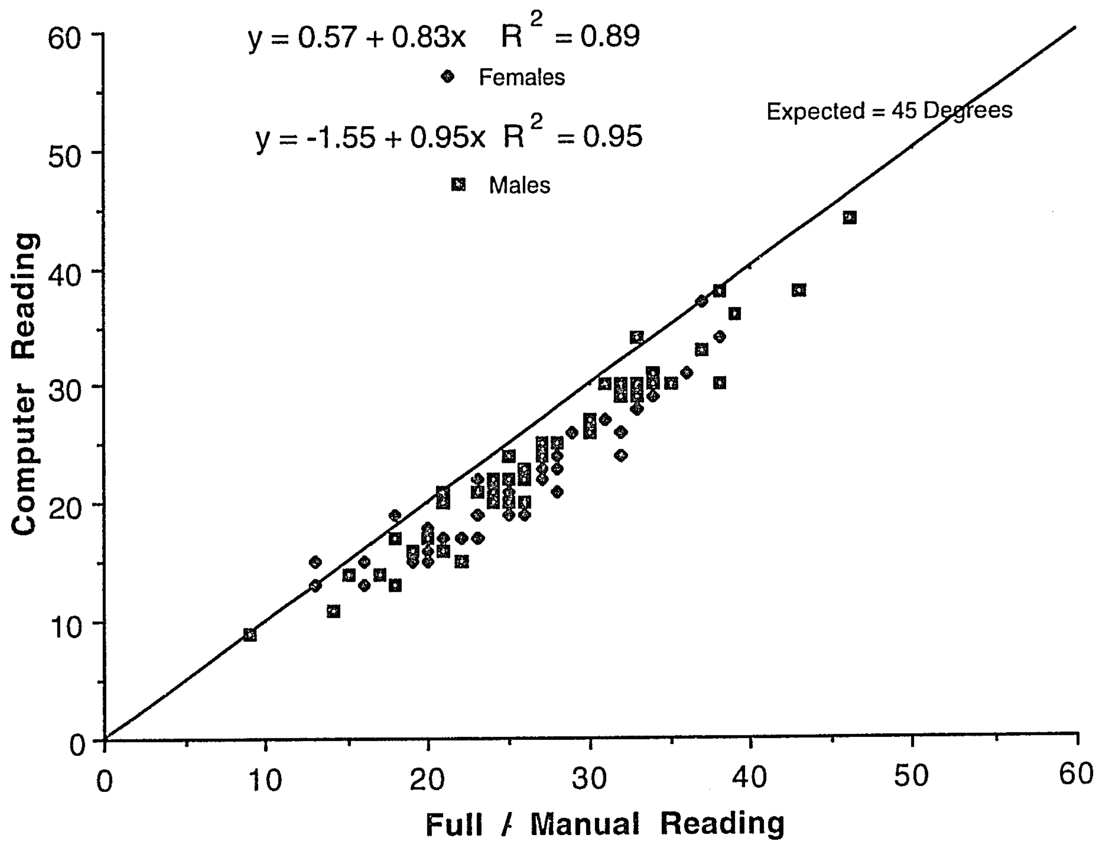

Figure 11. Plot of Computer readings versus Full/Manual readings. Test of plot slope versus a slope of 1 finds no significant difference between the two slopes. However, visual comparison finds the tendency was for the Full/Manual readings to be slightly more than the Computer readings

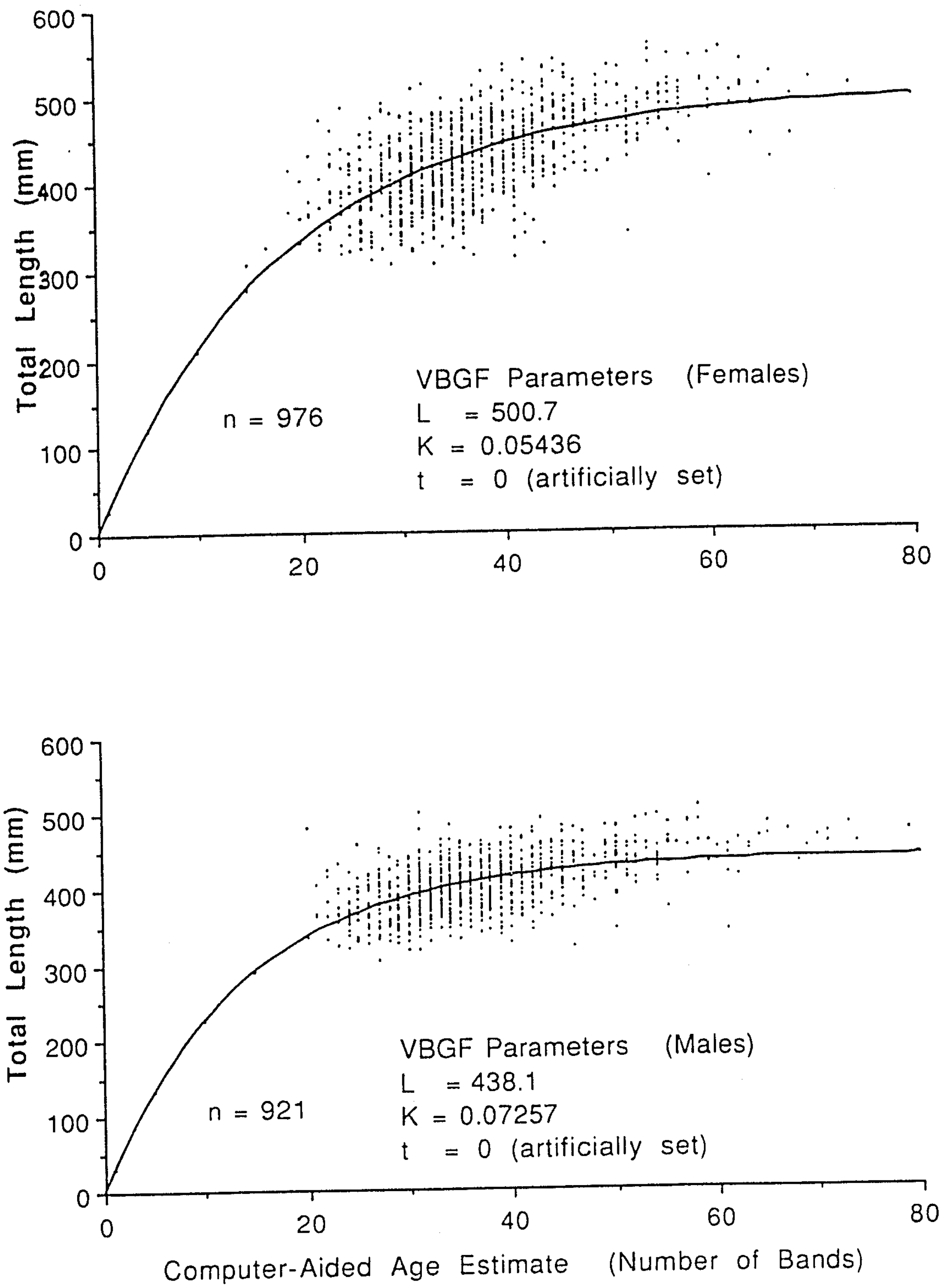

Figure 12a and b. Plot of computer-aided age estimates (number of bands in the nucleus plus the median of three computer-aided counts) against total length (TL, mm) for the 977 female and 921 male bank rockfish aged in this study. The curve and parameters L and K represent the best Von Bertalanffy fit (Prager et al. 1987) with to arbitrarily set at 0 to remedy the lack of samples under 300 mm TL (and therefore under 20 years of age).

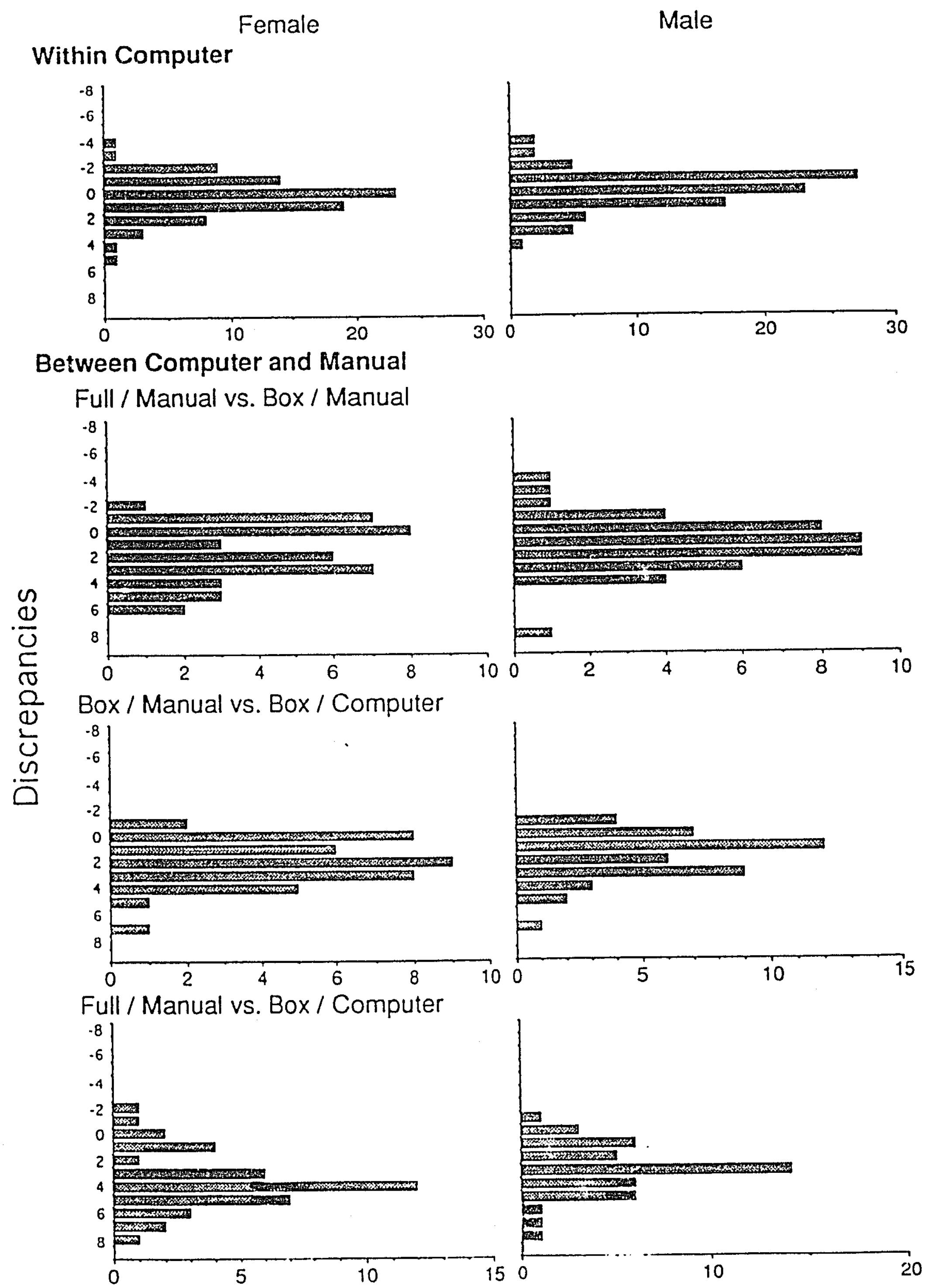

Figure 13. Band count precision histograms for both sexes within computer-aided ("Box/Computer") and between manual and computer-aided estimates of ages.

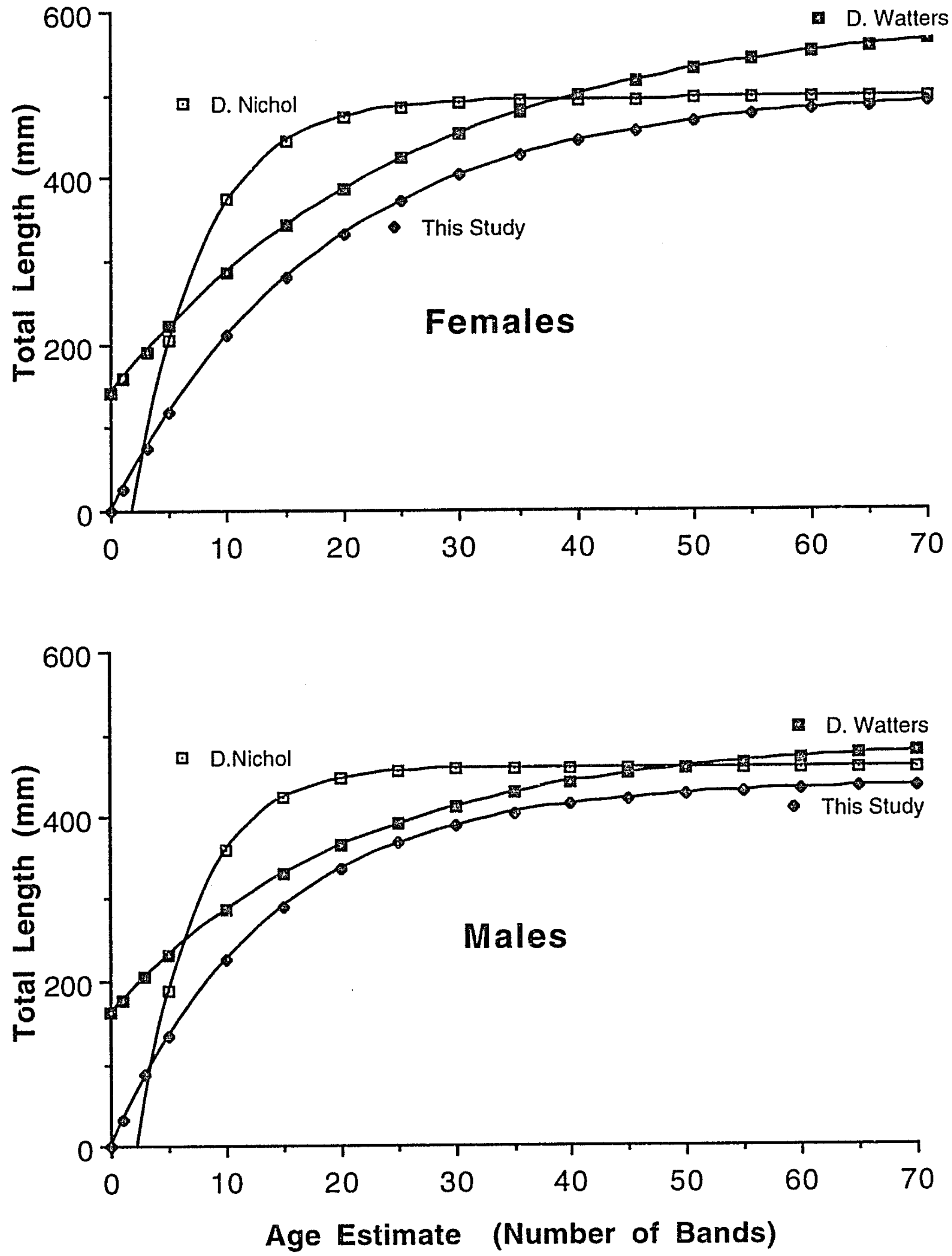

Figure 14a and b. The von Bertalanffy growth curve generated in this study as compared to the growth curve for bank rockfish generated by Watters et al. (1993) and Nichol (1984). The growth curve depicted here was determined for the Nichol study from data given in that study.