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## GROWTH OF SABLEFISH IN SOUTHEASTERN ALASKA


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ABSTRACT

Sablefish length-at-age data from Southeastern Alaska waters are used to estimate parameters of growth models and are compared to sablefish growth in other areas. Sablefish otoliths were collected from four sites in Southeastern Alaska and aged with surface reading techniques. An allometric growth model was fit to log-transformed lengths-at-age using least squares regression. An investigation of the effects of the logarithmic transformation showed that the assumptions required for least squares procedures were satisfied by the log-transformed data. Comparison of sablefish growth at three Southeastern Alaska sites showed statistically significant variation among sites for both males and females. The differences in rate of growth among sites within Southeastern Alaska, while statistically significant, were not great in magnitude. Growth at Southeastern Alaska sites was significantly slower than at northern British Columbia sites where otoliths had been aged with "break-and-burn" techniques. Growth of sablefish in Southeastern Alaska determined from otolith aging was also slower than that determined from following length frequency modes in the same areas. The differences in growth rate are hypothesized to be due to the reading of extra annuli with the surface reading technique. Growth rates calculated from ages read by either technique are much lower than previously published values. Double reading of sablefish otoliths using both techniques is necessary to determine whether the differences in growth rate are due to differences in aging technique or to actual regional variation in growth rate.

## INTRODUCTION

A well-defined relationship among age, length, and weight is a prerequisite for accurately determining optimal yield and for understanding the life history strategy of the Gulf of Alaska sablefish population. Early attempts to determine maximum sustained yields for Gulf of Alaska sablefish (Low et al. 1976; Low and Wespestad 1979; Anon. 1978) were based on stock production models which require no explicit formulation of growth. The fit of these models to the available catch and effort data was poor since the data represented an aggregation of growth, mortality, recruitment, and harvest processes and encompassed wide temporal and spatial variation in catch rates, harvests, and effort, with unknown amounts of migration among areas. More accurate prediction of optimal yield requires explicit formulations of growth, mortality, recruitment, and harvest processes and the temporal, spatial, and age structure of the population. Recent sablefish modeling efforts (Terry and Balsiger 1981, Funk 1983) have included explicit growth submodels, but have been hampered by a lack of available data from the Gulf of Alaska area for estimating the parameters of the growth models.

Early studies of sablefish growth in British Columbia (Kennedy and Pletcher 1968), Oregon (Pruter 1954), and the Bering Sea (Sasaki et al. 1975) indicated that sablefish were a relatively fast-growing and short-lived species. Recently Beamish and Chilton (1982) reported a considerably different impression of sablefish growth using the "break-and-burn" otolith reading technique. They describe a species with very rapid initial growth, but very slow growth upon reaching maturity, with many members of the population surviving to very old ages. These newer slower growth rates have a profound impact on the yield that can be obtained from sablefish stocks on a sustained basis. They also suggest a life history strategy radically different from that described in earlier studies.

This paper describes sablefish growth from Southeastern Alaska waters and compares the growth pattern to published values from other areas. Unfortunately the methods of age determination have varied widely among sablefish growth studies so that observed differences in growth among areas could be attributed to differences in aging techniques as well as actual differences in growth. Preliminary results of this study of growth of sablefish in Southeastern Alaska were previously reported in Bracken (1981).

## LITERATURE REVIEW

The earliest aging work on sablefish was published by Bell and Gharrett (1945). They determined ages from a small sample of sablefish using scale reading techniques and reported that fish from 40 to 70 cm in length were only 2 to 4 years old.

Pruter (1954) aged sablefish captured off of the Oregon coast from scales and described growth as relatively fast and showing only a slight tendency for the rate of growth to decrease with age up to age 7. No fish were aged older than age 13 using the scale reading technique, although fish exceeding 80 cm were aged.

Female growth was reported to exceed that of males after age 3. Kennedy and Pletcher (1968) collected sablefish samples from trawls for age analysis from inlets east of Queen Charlotte Sound and from outer British Columbia coastal areas in the Gulf of Alaska. Ages were determined from both scales and otoliths. Otolith ages were determined from both surface reading and "in some cases after cutting, polishing, and burning to accentuate the pattern". Ages read from scales agree with ages from otoliths for about two-thirds of the fish younger than 3 years. For older fish, agreement between scale-read and otolith-read ages was poor and scales were found to give older ages than otoliths in most cases. Sex-specific average lengths at age were reported only for data pooled from all sites and only for ages up to 6. Ages up to 11 are reported, but sexes cannot be segregated in the published tables. Growth occurs at a rapid rate and does not approach a limiting value.

Sasaki et al. (1975, in Low et al. 1976) describe growth of sablefish in the Bering Sea from a sample taken in 1966. Both sexes were pooled together for fitting von Bertalanffy growth models. Sasaki et al. (1975) observed that growth of young sablefish was markedly different than that of older fish. They found that fitting two von Bertalanffy curves to the data, one for fish younger than age 3.3 years and one for fish older than 3.3 years described the data much better than fitting a single curve. A single von Bertalanffy model did not describe the relatively sharp transition from rapid growth at young ages to the slower, asymptotic growth at older ages.

Information on the growth of very young sablefish is sparse. Heyamoto (1962) examined scales of young sablefish 12-30 cm long finding that the first scale annulus was present in December of the first year. He speculated that the first scale annulus had begun to form at a length range of 21-23 cm, approximately 6 months after hatching.

Beamish and Chilton (1982) studied sablefish growth in British Columbia using the "break-and-burn" otolith reading technique first reported by Christensen (1964). In this technique, sablefish otoliths are fractured dorsoventrally through the nucleus and burned briefly. Annual rings are then more easily seen due to the darkening of a membrane of organic material during oxidation (Dannevig 1956). Like early researchers, Beamish and Chilton report very rapid initial growth. However, initial growth rates are somewhat higher and much older ages are obtained with the "break-and-burn" method. Ages over 20 are common and ages over 40 are observed. Thus, the rate of growth of older fish is much slower than that determined by other methods.

## METHODS

### Study Sites and Collection Techniques

Otolith samples were collected from four sites in Southeastern Alaska for age determination (Figure 1). Commercial conical pot fishing gear, described in Bracken (1981), was used to capture sablefish at the Behm Canal site. At Chatham Strait site A and Chatham Strait site B rectangular pots were used, as described in Zenger (1981). The length of sablefish captured at these sites

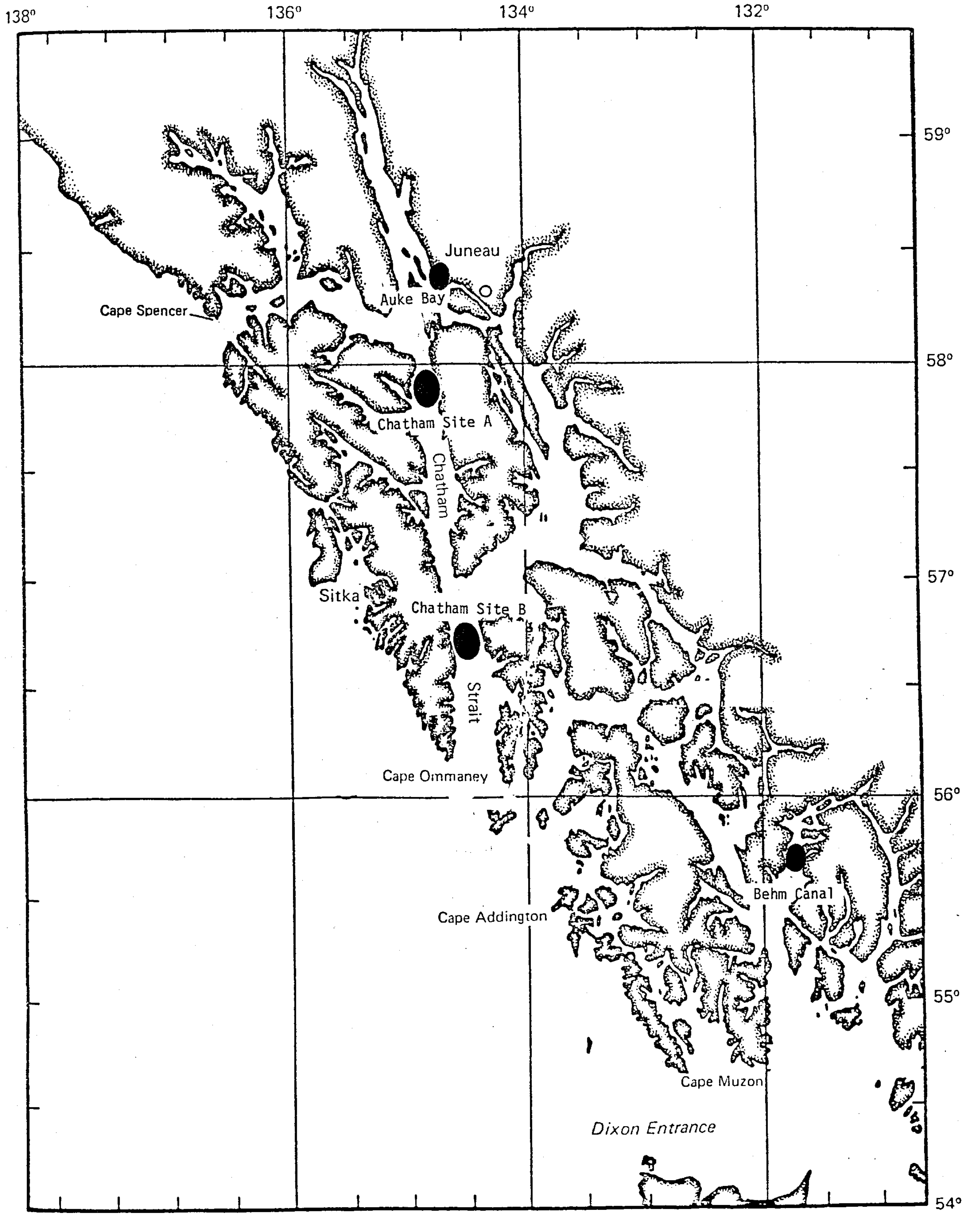


Figure 1. Sablefish otolith collection sites in Southeastern Alaska.

ranged from 40 to 80 cm. Systematic subsampling procedures were used to select fish for age determination so that the age distribution of the sample would be representative of the age distribution in the pot gear catch at each site. Hook and line gear was used to capture a sample of juvenile sablefish at the Auke Bay site. Sablefish captured in this sample ranged in length from 22 to 40 cm. The number of otoliths collected at each site and collection dates are given in Table 1. Left and right otoliths were collected from specimens captured at Auke Bay and Chatham Strait site A. Left otoliths only were taken at the Behm Canal site and Chatham Strait site B. Otoliths were pooled by 1 cm length intervals by sex and preserved in 30% ethanol for later age determination. Ages were determined at the Washington Department of Fisheries Aging Laboratory using surface reading techniques. All otoliths were read by the same reader.

Sablefish length-at-age data from northern British Columbia waters were also examined and compared to the data from Southeastern Alaska. The methods used to collect these data are described in Beamish and Chilton (1982). Data from the sample sites described as "west coast of the Queen Charlotte Islands" and "inlets east of Queen Charlotte Sound" in Beamish and Chilton (1982) are pooled and are referred to as "northern British Columbia". These samples are pooled together to approximate the spatial variation in sablefish growth in all northern British Columbia waters. Beamish and Chilton (1982) describe the otolith "break-and-burn" technique used to determine ages of these specimens.

## Growth Models

A number of different growth models were fit to the length-at-age data. Two criteria were used in evaluating various growth models. The first criterion was that the model describe the data well. The growth models considered are all empirical, since no specific underlying mechanisms for physiological growth are postulated. The second criterion was that the model should allow straightforward quantitative comparison of different data sets.

The von Bertalanffy growth model (Table 2) is widely used in fisheries biology. The three parameters $(t_0, L_\infty, K)$ describe a species which has deterministic growth, reaching a maximum length at asymptote $L_\infty$. The rate of growth is assumed to be maximum at the age at which length is theoretically zero (at $t_0$, usually a negative number) and to gradually decrease with age. The parameter $K$ describes the rate at which length approaches the asymptote $L_\infty$. The von Bertalanffy model describes the growth of long-lived slow-growing species quite well and has been previously applied to sablefish (Beamish and Chilton 1982, Low et al. 1976). However, statistical comparison of von Bertalanffy model fits to different data sets is cumbersome because three parameters are involved. Allen (1976) suggests a method which reduces the number of parameters of the von Bertalanffy model to two and linearizes the model, but this method requires prior estimates of one of the parameters which can not be obtained in a statistically rigorous fashion. Gallucci and Quinn (1979) discuss an alternate parameterization of the von Bertalanffy model based on the dependence of $K$ and $L_\infty$, but the comparison requires some restrictive assumptions concerning the third parameter. Kappenman (1981) utilized the predictive sample reuse technique of Geisser and Eddy (1979) to compare growth curves. This technique bypasses the comparisons of individual parameters. Separate fits of an arbitrary model to each of the data sets are compared to the fit of the model to pooled data from all the data sets. While this technique appears promising it is worthwhile to first consider some simpler two-parameter models.

Table 1. Number of sablefish otoliths collected for age determination from Southeastern Alaska sample sites and dates of sampling.

| Location | Date | Males | Females |
|---|---|---|---|
| Auke Bay[1] | August 1981 | 60 | 66 |
| Behm Canal[2] | June 1981 | 20 | 103 |
| Chatham Strait Site A[1] | May 1981 | 82 | 234 |
| Chatham Strait Site B[2] | May 1981 | 116 | 179 |
| Total | | 278 | 582 |

[1] Includes both left and right otoliths.

[2] Left otoliths only.

Table 2. Growth models fit to sablefish length-at-age data.

| | |
|---|---|
| von Bertalanffy model: | $L(t) = L_\infty [1 - e^{-K(t-t_0)}]$ |
| Allometric model: | $L(t) = at^b$ |
| Log-transformed allometric model: | $\log [L(t)] = \log(a) + b[\log(t)]$ |
| Exponential model: | $L(t) = ae^{bt}$ |

where: $t$ = age

$L(t)$ = length at age $t$

The allometric model (Table 2) is a two-parameter model which is frequently applied to biological growth problems, often to describe relative growth of various body dimensions. The allometric model can be linearized by a logarithmic transformation which simplifies parameter estimation. However, the logarithmic transformation alters the underlying distribution of the data so that the assumptions required for statistical inference using least square procedures need to be carefully examined, as discussed by Zar (1968). Statistical comparison of a linear, log-transformed allometric model fit to different data sets can be accomplished using standard analysis of covariance (ANCOVA) techniques.

Other two-parameter models such as an exponential and a second degree polynomial were also considered. However, in most cases the fit of the allometric model was substantially better. For these reasons, the allometric model will be considered the most appropriate choice from the class of two-parameter models.

### Parameter Estimation

A modified Levenberg-Marquardt algorithm[1] was used to estimate parameters of non-linear growth models. The iterative solution of this algorithm was terminated when residual sums of squares on two successive iterations differed by less than 0.00001%.

Standard linear least squares regression procedures were used to estimate parameters of the log-transformed allometric model. In order to use these methods, a number of assumptions are required. The first assumption is that the independent variable (age) has no measurement error. This means that repeated readings of the same otoliths are assumed to always result in the same age. The second assumption is that the residual lengths at age be normally distributed. The effect of a logarithmic transformation on the length-at-age distributions was investigated by using tests for skewness and kurtosis and a Kolmogorov-Smirnov test for overall departure from normality. The third assumption is that the variance of lengths at each age is constant. The validity of this assumption was investigated by graphically examining trends in the distributions of lengths at each age.

## RESULTS

### Growth Model Fitting

Statistical inferences from least squares procedures usually require residual deviations from predicted observations to be normally distributed. However, residual deviations cannot be examined without making an *a priori* choice of a

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[1] Subroutine ZXSSQ from the International Mathematical and Statistical Library (IMSL), IMSL, Inc., 7500 Bellaire Blvd., Houston, TX 77036-5085.

specific model and many models were initially considered. Therefore the distribution of deviations from the mean length at each age is examined as an approximation to the distribution of residuals from a specific model. Data from all sites in Southeastern Alaska are combined for each sex for this examination. The distribution of deviations from mean length at age is then examined for departures from normality for both untransformed and log-transformed observations.

Figure 2a depicts frequencies of untransformed lengths at each age for male sablefish from Southeastern Alaska waters. Several of the distributions of lengths at each age show tendencies toward positive skewness since there are a few large deviations in the positive direction from the mean and many observations with small deviations from the mean in the negative direction. Figure 2b depicts the distribution obtained when the distributions of lengths at each age are superimposed, scaling each distribution to a standard mean of zero. This distribution is skewed in the positive direction, although not significantly (test of third moment) and is slightly platykurtic since there are too few observations in the tail of the distribution and near the mean and too many in intermediate regions. The kurtosis is not significantly non-normal (test of fourth moment) and a Kolmogorov-Smirnov test of overall departures from normality is also non-significant. When these data are log-transformed (Figures 3a and 3b), positive skewness is eliminated. The log-transformation causes the Kurtosis to become marginally significantly non-normal since there are too few observations in the tail of the distribution and near the mean and too many in intermediate regions. However, the Kolmogorov-Smirnov test of overall departures from normality is still non-significant.

Female sablefish lengths at age from Southeastern Alaska waters display similar behavior. Untransformed length-at-age observations have slight positive skewness (Figures 4a and 4b) but there are no significant departures from normality. The log-transformed observations (Figures 5a and 5b) show some significant departures from normality due to the leptokurtic effect of the log transformation in concentrating observations near the mean. The effect of the log transformation on kurtosis is the opposite of that for male sablefish, however.

Appendix I describes the untransformed and log-transformed observations for male and female sablefish at each of the 3 sites where large fish were sampled and for the data from the northern British Columbia sites. The results of the normality tests are summarized in Table 3. These results indicate that untransformed and log-transformed length-at-age observations satisfy the normal distribution of residuals assumption about equally well. No radical departures from normality are evident in either case. Given the simplicity of fitting the log-transformed version of the allometric model, the log-transformed model will be used instead of the untransformed model.

There are too few observations of larger fish in the Southeastern Alaska growth data to determine whether the variance of the length-at-age observations increases with age. More observations of older ages are available in the northern British Columbia data (Appendix I) and these data do display a tendency for the variance of lengths at age to increase with age. The logarithmic transformation stabilizes this variance trend.

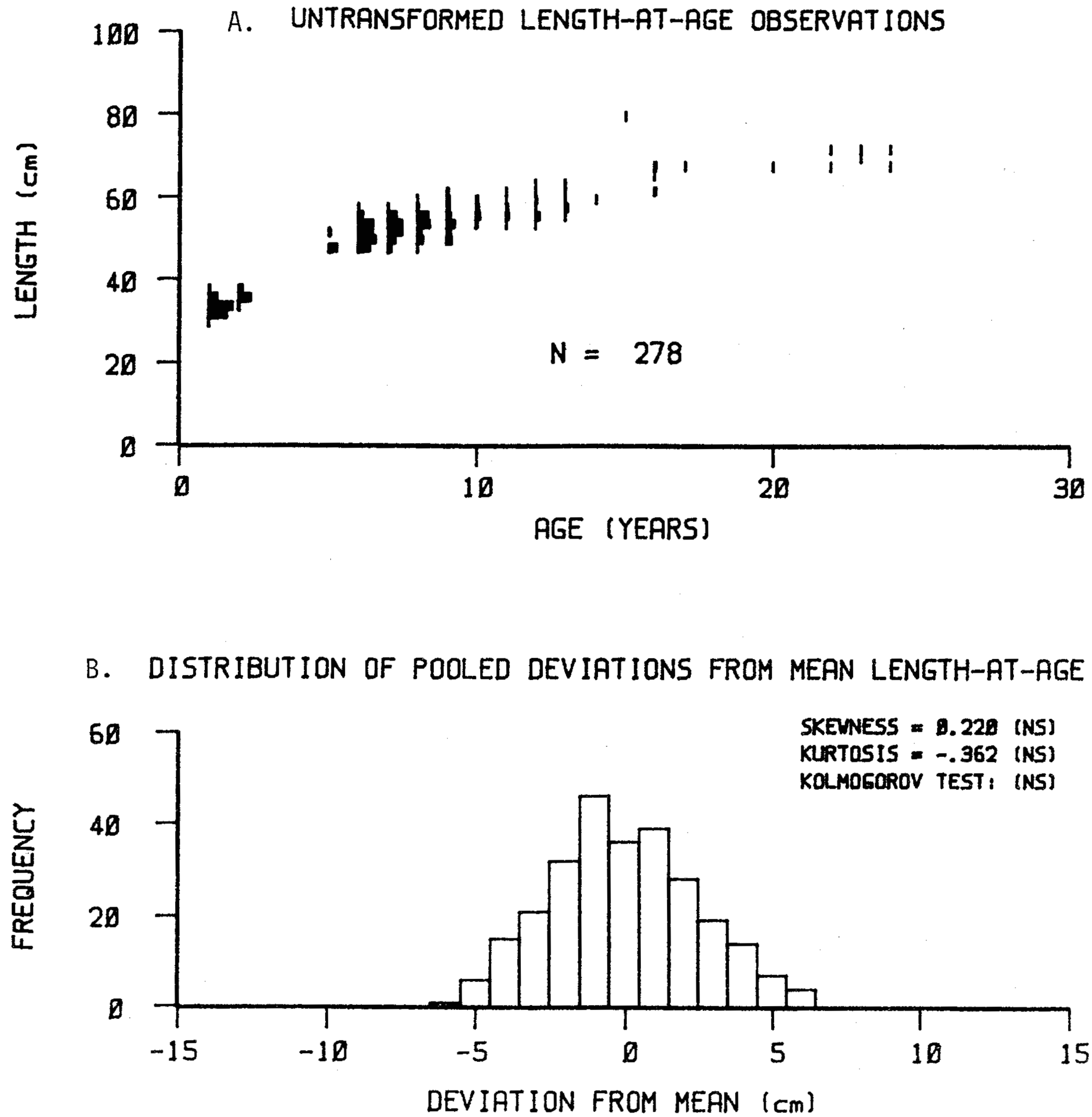



Figure 2a, 2b. Distribution of untransformed lengths-at-age for male sablefish from all sites in Southeastern Alaska.

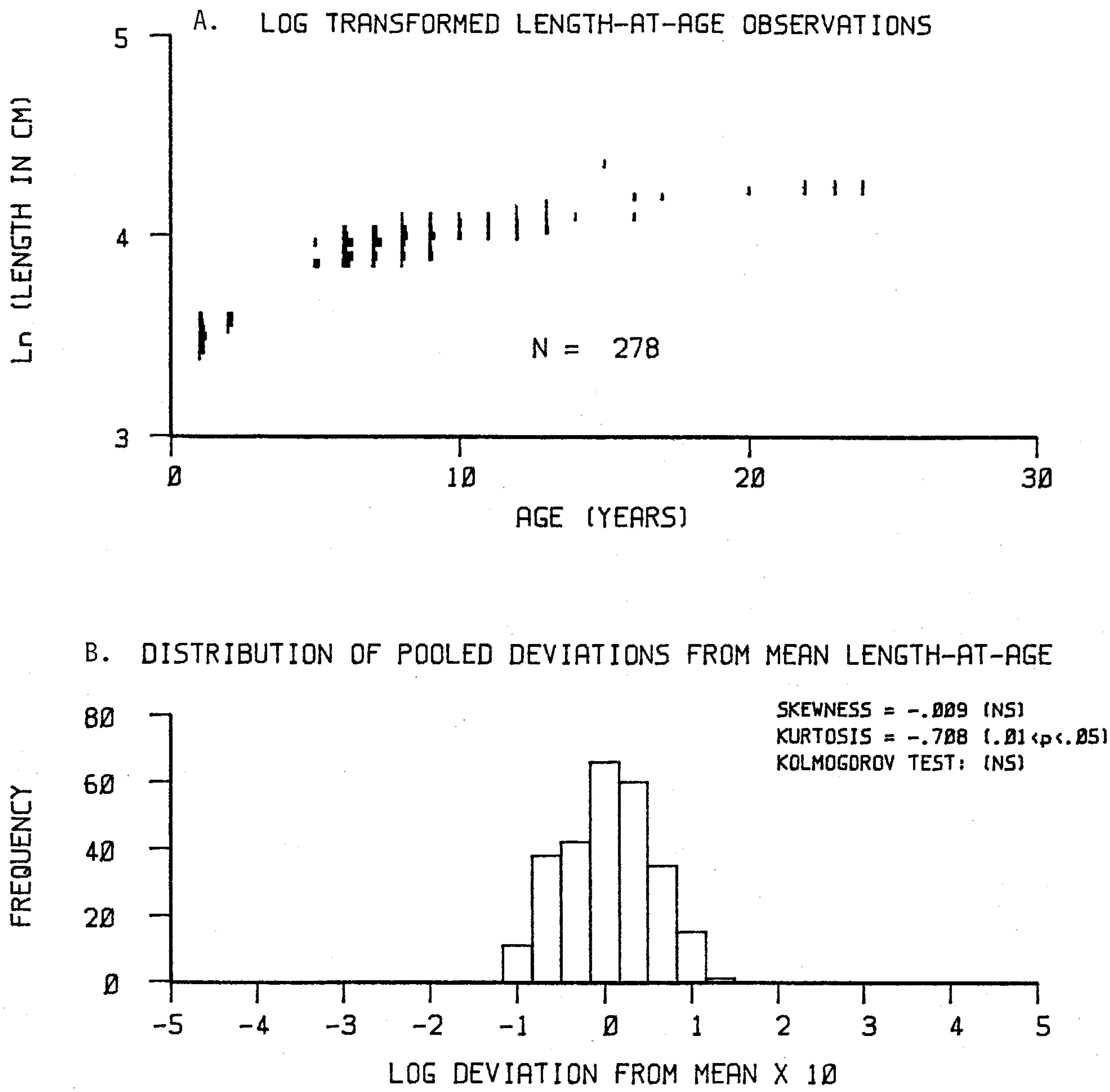



Figure 3a, 3b. Distribution of log-tranformed lengths-at-age for male sablefish from all sites in Southeastern Alaska.

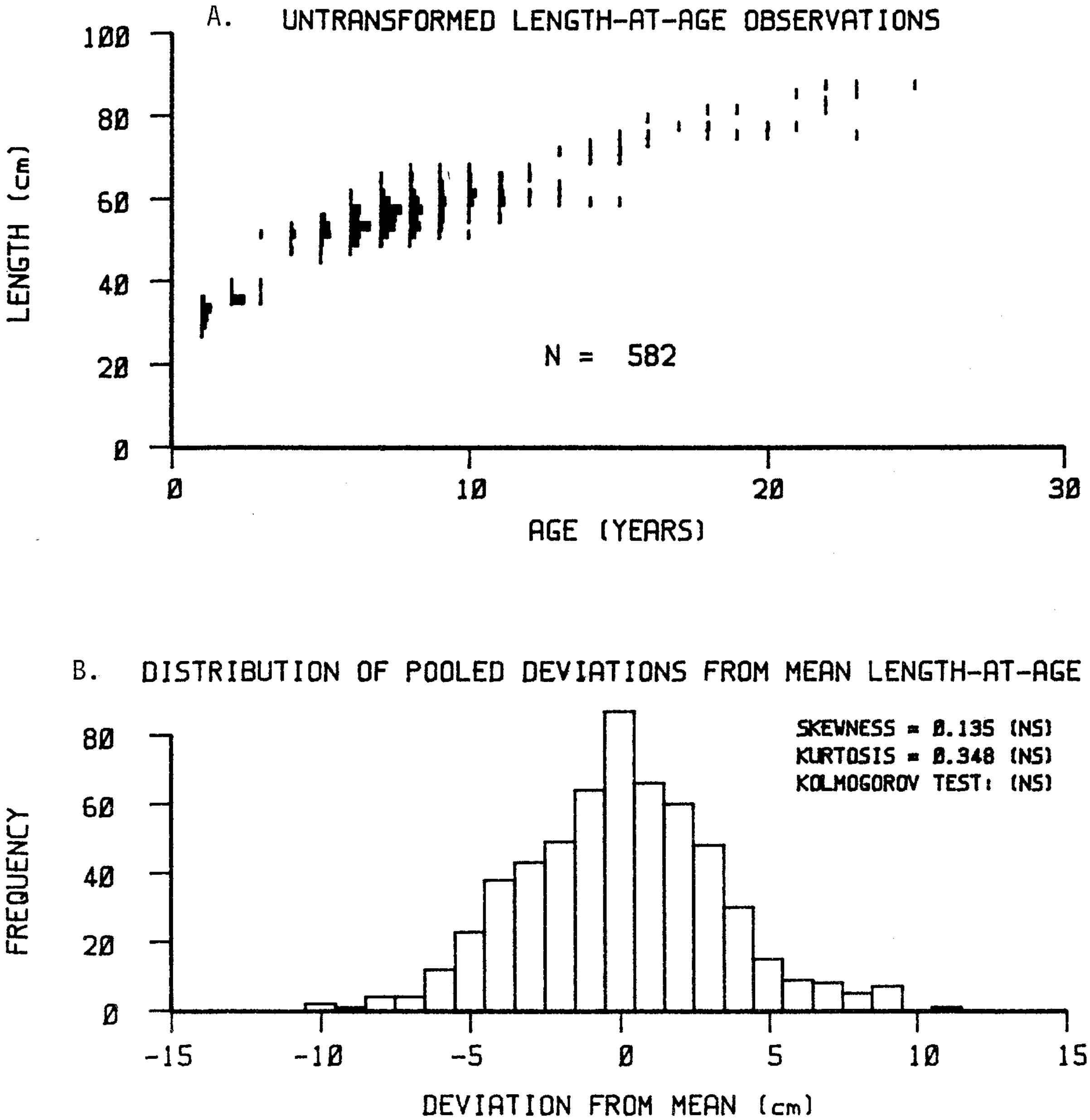



Figure 4a, 4b. Distribution of untransformed lengths-at-age for female sablefish from all sites in Southeastern Alaska.

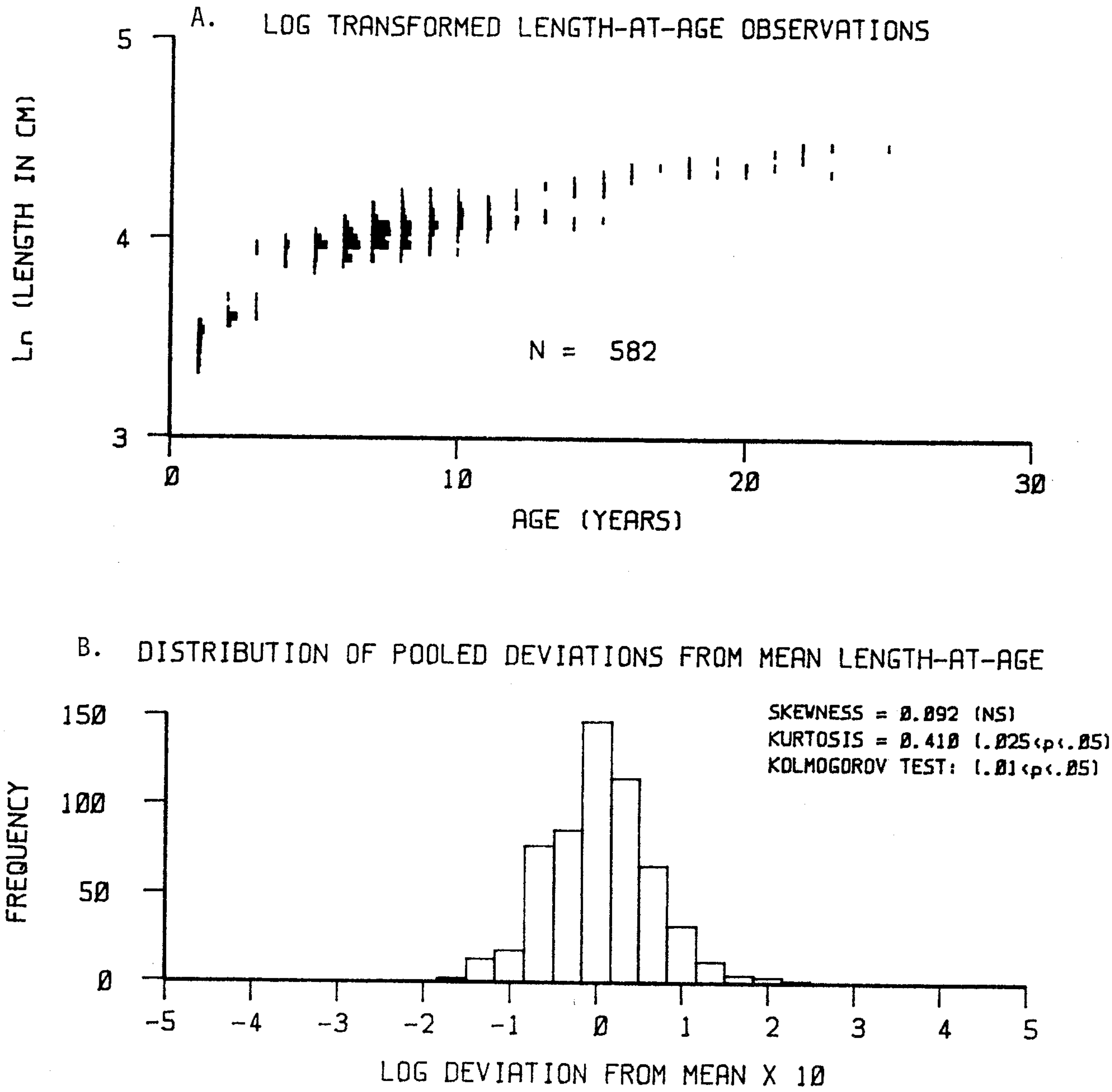



Figure 5a, 5b. Distribution of log-transformed lengths-at-age for female sablefish from all sites in Southeastern Alaska.

Table 3. Summary of results of normality tests on pooled deviations from mean lengths at age for skewness, using a test of the third moment statistic, kurtosis, using a test of the fourth moment statistic, and overall departures from normality, using a Kolmogorov-Smirnov (K-S) test.

| Site | Sex | Skewness | Kurtosis | Overall (K-S test) |
|---|---|---|---|---|
| **Untransformed Observations:** | | | | |
| All Ak. Sites | Males | ns | ns | ns |
| All Ak. Sites | Females | ns | ns | ns |
| Northern B.C. | Males | ns | ** | ns |
| Northern B.C. | Females | ** | ** | ns |
| **Log-Transformed Observations:** | | | | |
| All Ak. Sites | Males | ns | * | ns |
| All Ak. Sites | Females | ns | * | * |
| Northern B.C. | Males | ns | *** | ns |
| Northern B.C. | Females | *** | *** | * |
| Chatham-A | Males | ns | * | * |
| Chatham-A | Females | ns | ns | ns |
| Chatham-B | Males | ns | ns | ns |
| Chatham-B | Females | ns | ns | ns |
| Behm Canal | Males | ns | ns | ns |
| Behm Canal | Females | ns | ns | ns |

* p < .05

** p < .01

*** p < .005

Comparison of Growth Models:

For Southeastern Alaska male sablefish the log-transformed allometric model had a 5% lower residual sum of squares than the von Bertalanffy model (Figure 6a). The fit of the log-transformed allometric model to the Southeastern Alaska female sablefish growth data (Figure 6b) is even better in comparison to the von Bertalanffy model, with a 10% reduction in the residual sum of squares. For female sablefish length does not reach a definite asymptote within the observed ages, and the allometric model is better at describing the continued gradual growth in length with age.

Conversely, for northern British Columbia male sablefish, the von Bertalanffy model has a 21% lower residual sum of squares than the allometric model (Figure 7a). These length-at-age data describe very fast growth at early ages and reach a definite asymptote for older ages. The von Bertalanffy model is better able to describe the relatively sharp curvature of the growth data at the transition between fast and slow growth. For female sablefish from northern British Columbia (Figure 7b) this curvature is not so sharp and the von Bertalanffy model has only a 3.4% lower residual sum of squares. The increasing variance of length at age with age is clearly evident in the female sablefish growth data.

Overall the fits of the two models are not radically different with the exception of male sablefish from northern British Columbia. Given the ease with which linear models can be compared, the log-transformed allometric model was used for growth curve comparisons.

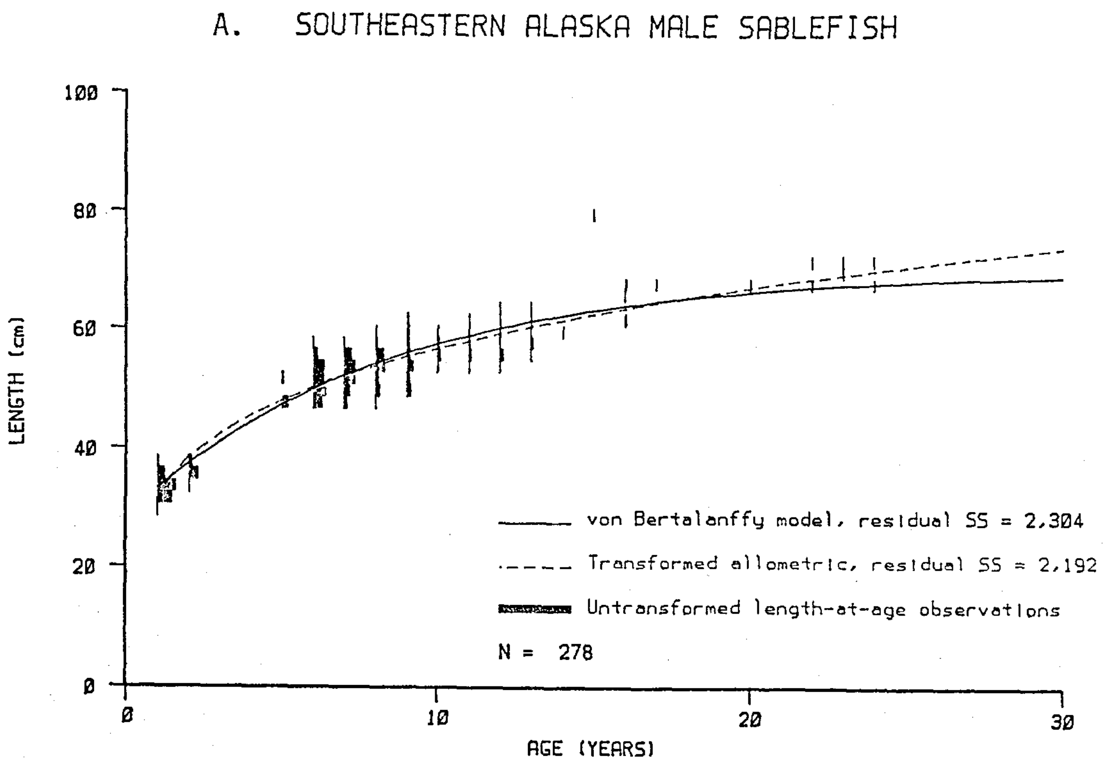
Variation in Growth Among Sites within Southeastern Alaska

Sablefish captured at Chatham Strait site A, Chatham Strait site B, and at the Behm Canal site were compared for differences in growth. The sample of sablefish from Auke Bay consisted only of smaller juveniles and could not be directly compared to samples from the other sites. Analysis of covariance (ANCOVA) techniques were used to compare growth data from the three sites using the linear log-transformed allometric model. Variances among the three sites were not found to vary for males or females, using Bartlett's test of homogeneity of variance. For male sablefish there is no significant difference in slope (parameter b of the allometric model) of log-transformed allometric models fitted independently through the growth data for male sablefish from the three sites (Figure 8). Intercepts (parameter a of the allometric model) are significantly different ($p < .005$). Growth was fastest at the Behm Canal site and slowest at Chatham Strait site A.

For female sablefish there was also no significant difference in the slopes of the three independent regressions (Figure 9). Intercepts were significantly different ($p < .005$). As for males, growth was fastest at the Behm Canal site and slowest at Chatham Strait site A.

Comparison of Southeastern Alaska and Northern British Columbia Growth Data

Growth data from all four Southeastern Alaska sample sites were pooled and compared with data pooled from the two sample sites in northern British Columbia. The amount of variability found among the sample sites in Southeastern Alaska is



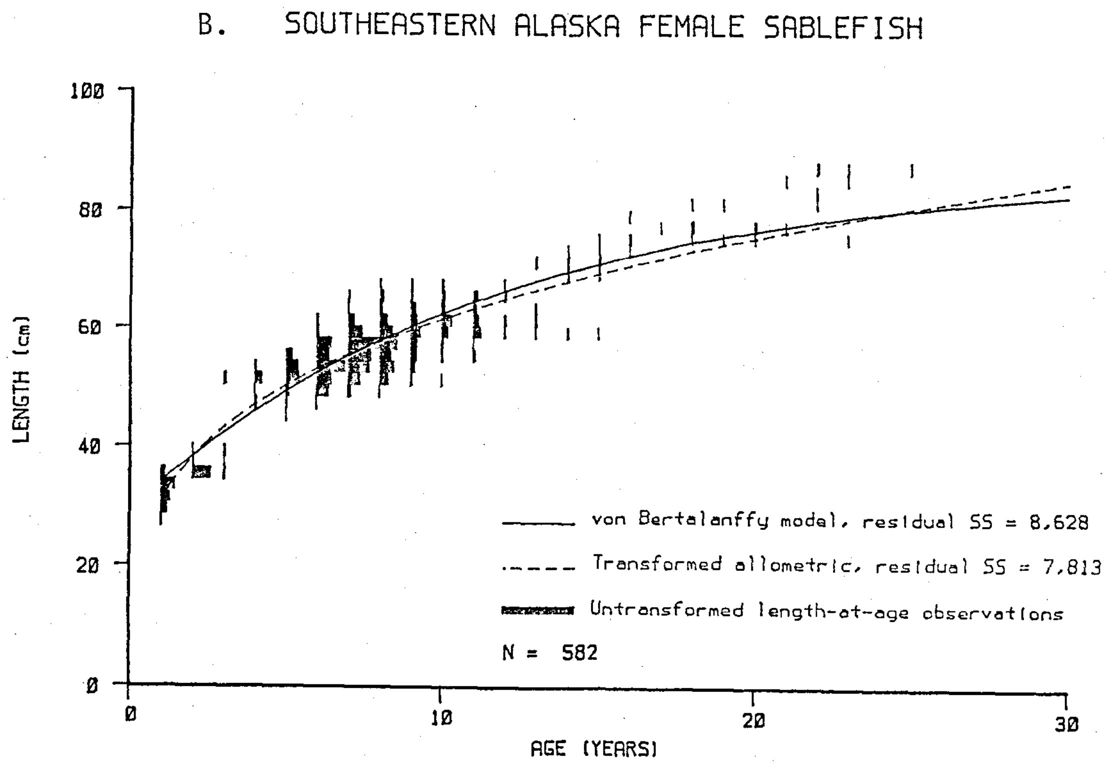




Figure 6a, 6b. Comparison of the fit of the von Bertalanffy growth model and the log-transformed allometric model to Southeastern Alaska male and female sablefish length-at-age observations.

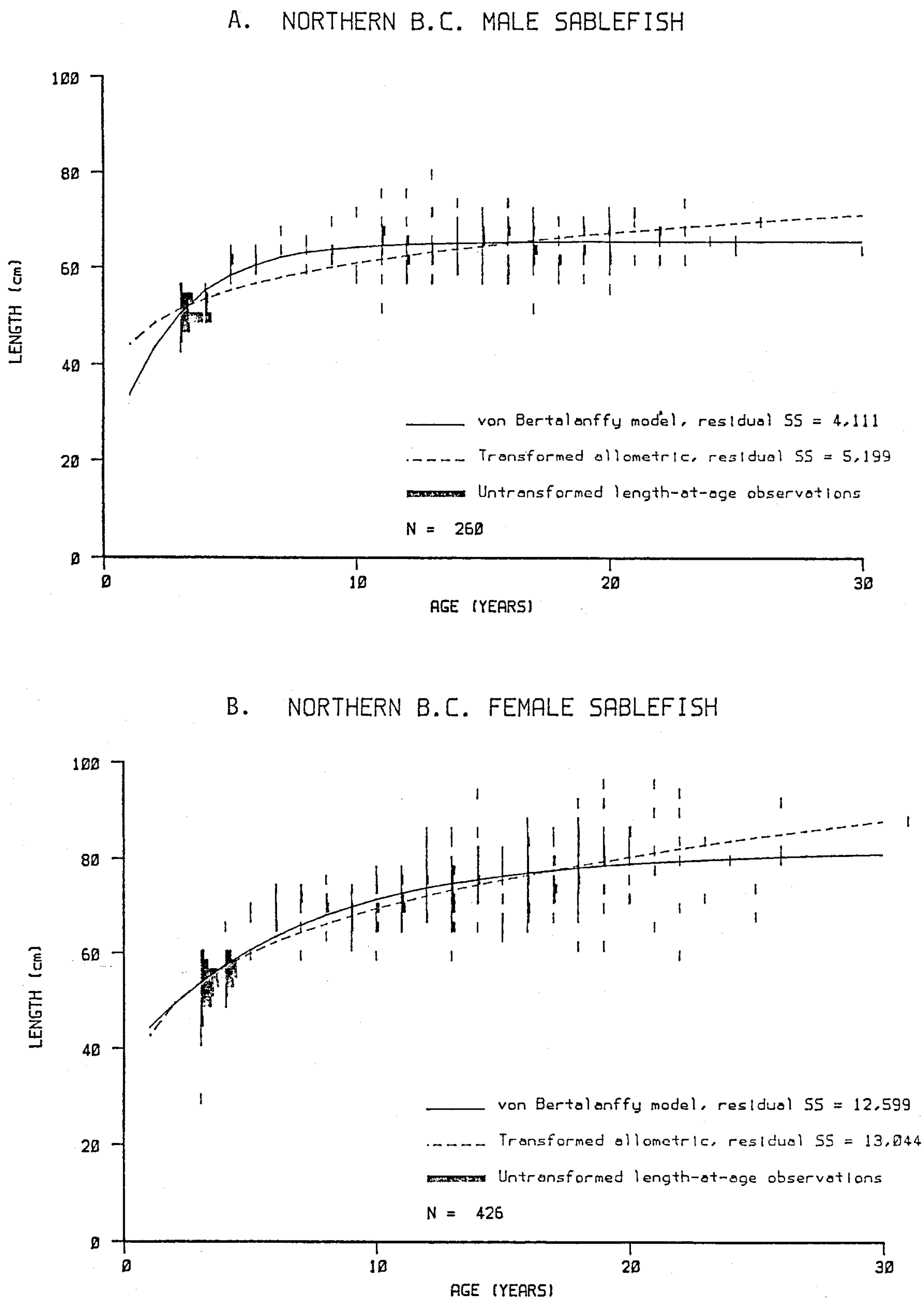
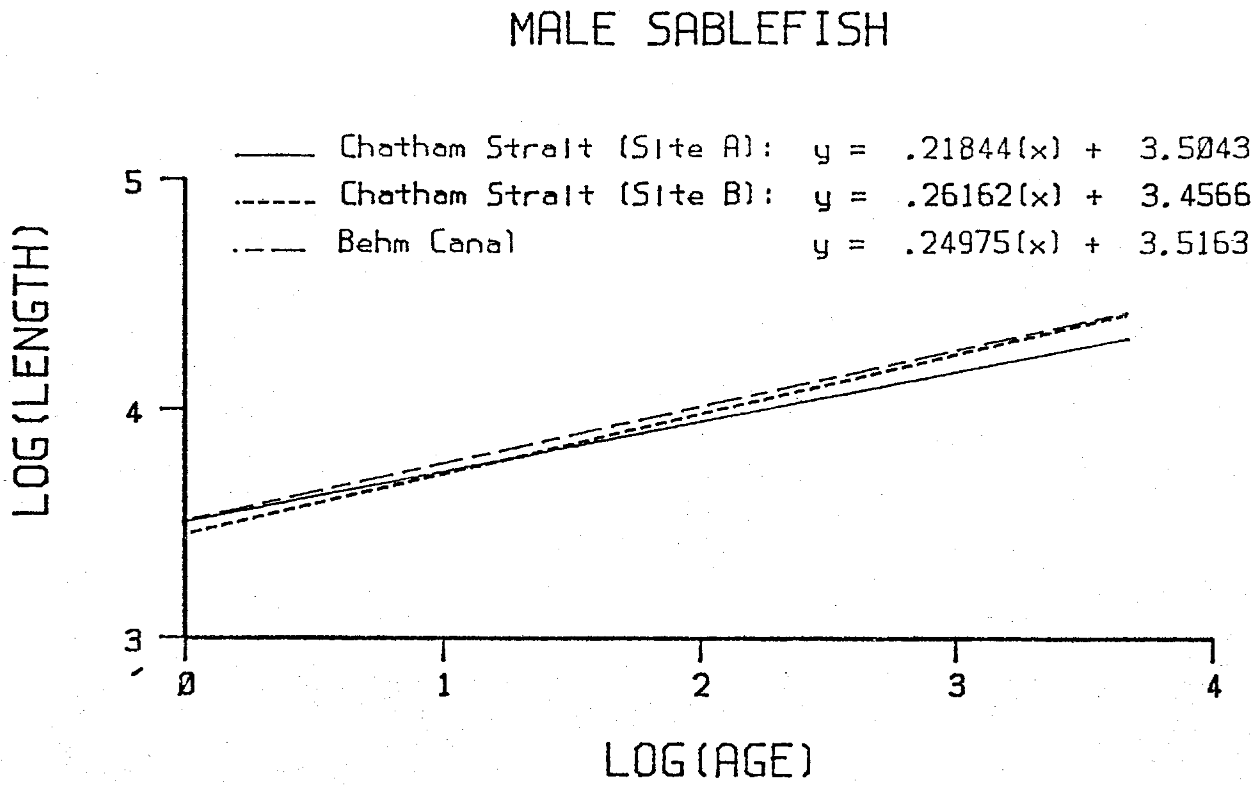


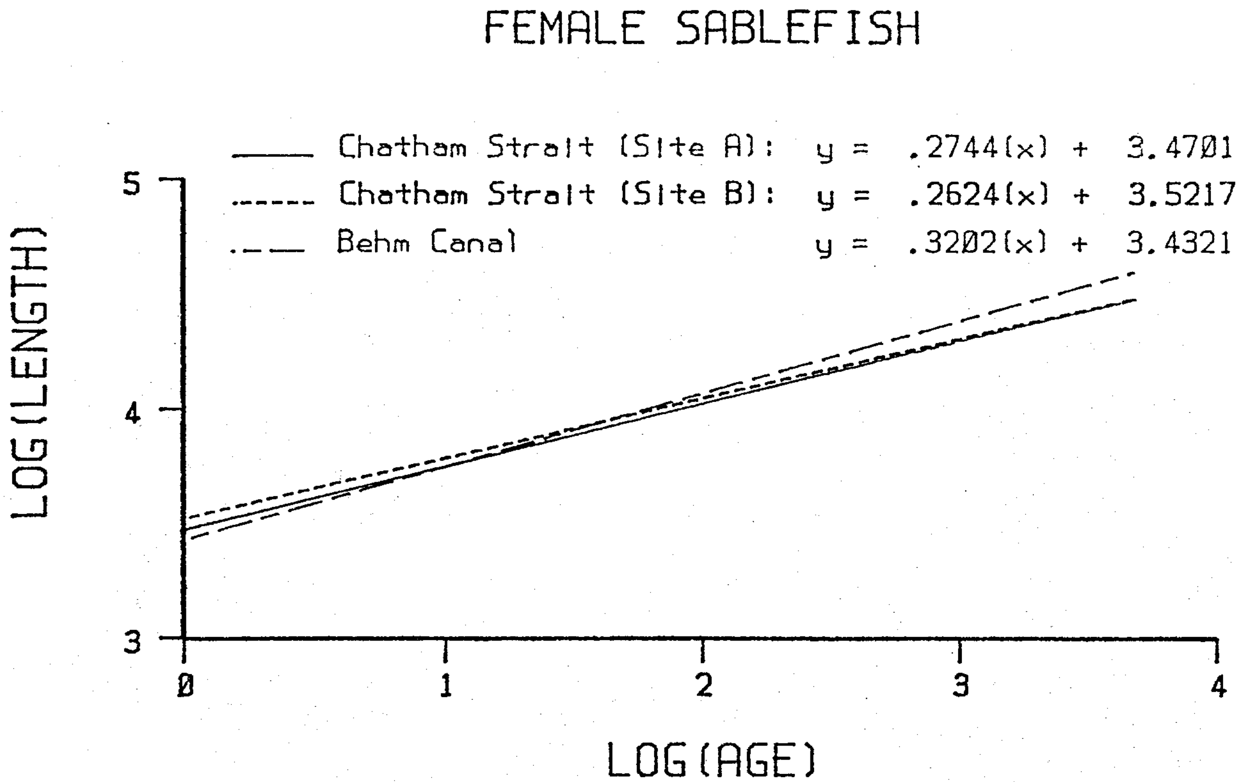

Figure 7a, 7b. Comparison of the fit of the von Bertalanffy growth model and the log-transformed allometric model to northern British Columbia male and female sablefish length-at-age observations.




ANALYSIS OF COVARIANCE

| Source of Variation | df | SS | MS | F | |
|---|---|---|---|---|---|
| ($H_o$: Equal Slopes) | | | | | |
| Among regressions: | 2 | .01008 | .005004 | 1.323 | (NS) |
| Within regressions: | 29 | .10970 | .003783 | | |
| ($H_o$: Equal Elevations) | | | | | |
| Among adjusted means: | 2 | .13426 | .06713 | 17.385 | ($p < .005$) |
| Pooled within areas: | 31 | .11970 | .00386 | | |

Figure 8. Analysis of covariance comparing male sablefish growth among sites within Southeastern Alaska.




ANALYSIS OF COVARIANCE

| Source of Variation | df | SS | MS | F | |
|---|---|---|---|---|---|
| ($H_o$: Equal Slopes) | | | | | |
| Among regressions: | 2 | .01750 | .00875 | .7889 | (NS) |
| Within regressions: | 45 | .49922 | .01109 | | |
| ($H_o$: Equal Elevations) | | | | | |
| Among adjusted means: | 2 | .23236 | .11618 | 10.567 | ($p < .005$) |
| Pooled within areas: | 47 | .51672 | .01099 | | |

Figure 9. Analysis of covariance comparing female sablefish growth among sites within Southeastern Alaska.

assumed to approximate the magnitude of the variance component among all areas within Southeastern Alaska. Similarly, the pooled data from the two sites in northern British Columbia are assumed to represent the variance component among all sites within northern British Columbia. Variances between the two areas were not found to differ significantly for males or females, using an F ratio test for homogeneity of variance. Slopes of the log-transformed allometric model fitted through the growth data from each area were very different ($p < .001$) for both males (Figure 10) and females (Figure 11).

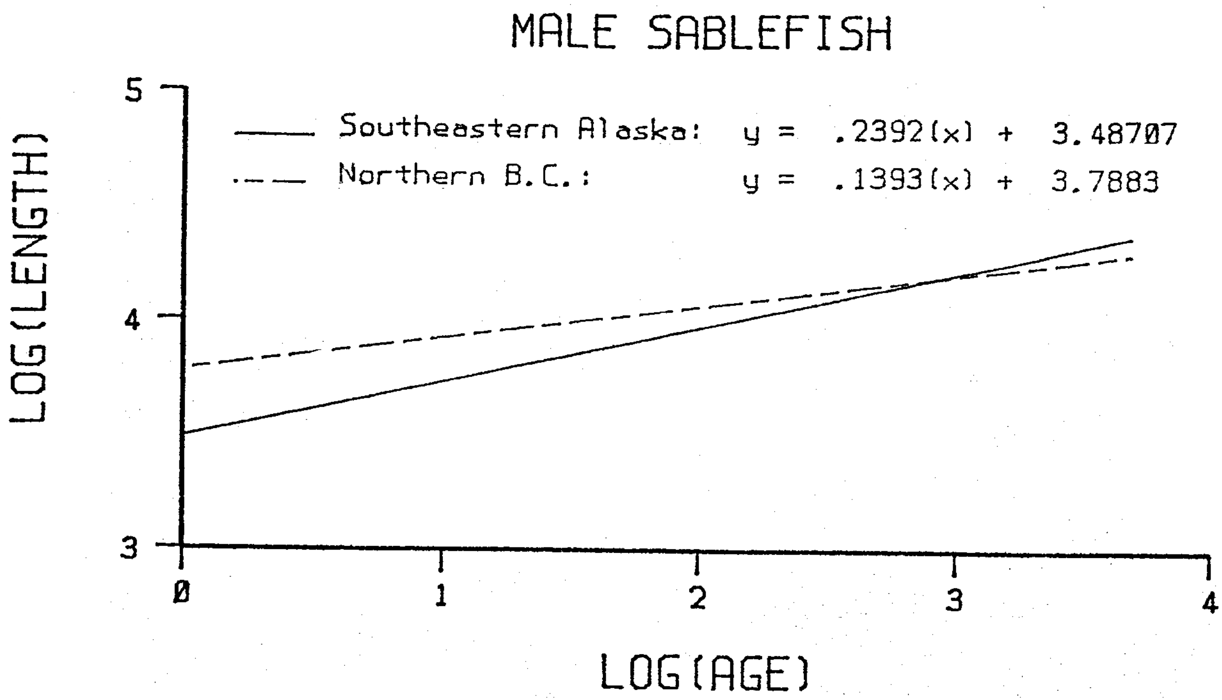
The untransformed length-at-age data and fitted models are shown for males and females in Figure 12. The Southeastern Alaska data clearly describe much slower growth at early ages. The differences between the growth curves for the two areas decrease with age. The Southeastern Alaska lengths lag behind the British Columbia lengths by two to three years of growth. The northern British Columbia data describe a species with very rapid initial growth and relatively little growth beyond age six or seven.

## Growth from Length-Frequency Modes

Length frequencies were taken from six samples of sablefish captured with pot gear at the Behm Canal site from June 1979 to March 1983 (Figure 13). The June and August 1979 samples were taken from shallow water in the Behm Canal area and consist only of juvenile sablefish. The marked mode evident in these distributions represents the strong 1977 year class. The length-frequency distributions of samples from December 1979 to March 1983 were taken from deeper water in the Behm Canal area. The modes of these distributions may approximately represent the 1977 year class but are affected by contributions from other year classes and are probably somewhat too large. If these modes are assumed to represent the average lengths at age of the 1977 year class and compared to the lengths at age determined from the surface-aged otoliths from the Behm Canal site in June of 1979, a considerable discrepancy results. Growth rates determined from surface-read otoliths underestimate the lengths at age by about one to two years growth, even at early ages (Figure 14). These discrepancies could be due either to abnormally fast growth by the 1977 year class or to over-aging of otoliths in the surface reading technique.

# DISCUSSION

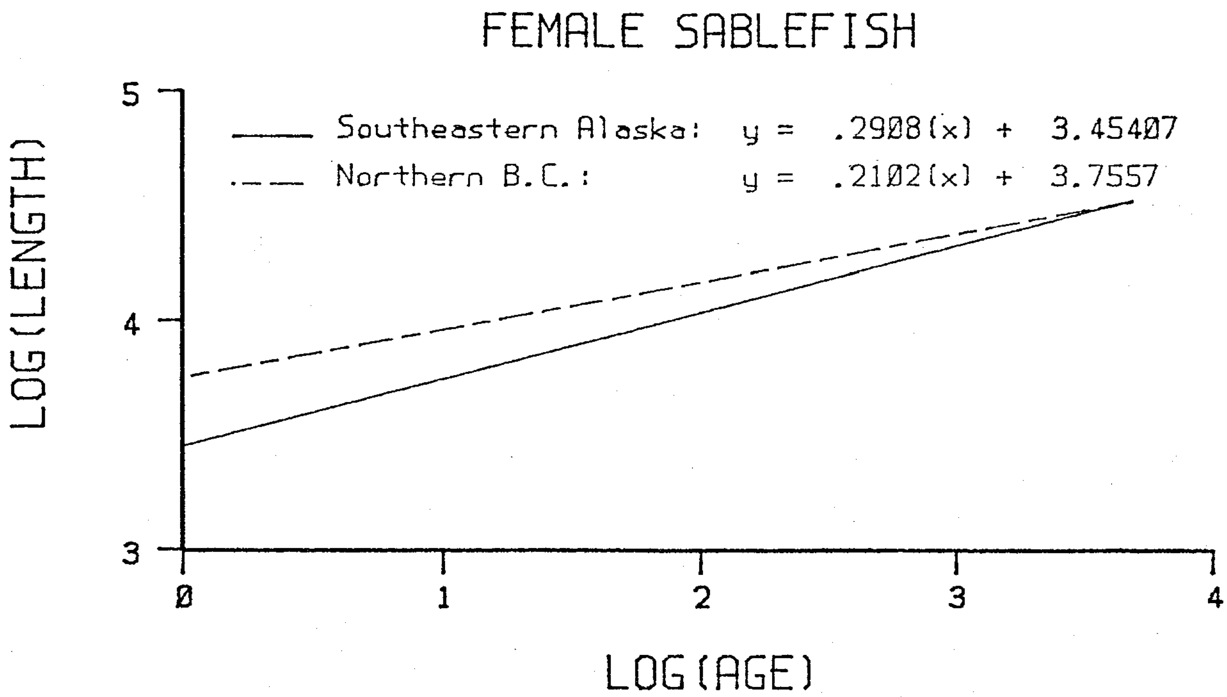
Sablefish growth in both northern British Columbia and Southeastern Alaska is characterized by an initial period of fast growth, followed by slower asymptotic growth. The change in the rate of growth appears to be rather abrupt and coincides with the approximate age of sexual maturity. This relatively rapid transition from fast to slow growth is probably indicative of fundamental changes in physiology and behavior associated with the onset of sexual maturity. A change in rate of growth at sexual maturity is well established in other species and separate growth curves are often fit to data before and after the age of sexual maturity (e.g., Somerton 1979). For sablefish, Low et al. (1976) obtained better fits of the von Bertalanffy model by partitioning sablefish length-at-age data into two size groups, although the size categories did not correspond to the age of sexual maturity. However a single growth expression is often desirable for simplicity in modeling applications, even though the fit may be less precise.




## ANALYSIS OF COVARIANCE

| SOURCE OF VARIATION | DF | SS | MS | F | |
|---|---|---|---|---|---|
| ($H_0$: <u>HOMOGENOUS RESIDUAL VARIANCES</u>) | | | | | |
| DEVIATIONS FROM REGRESSION | | | | | |
| NORTHERN B.C. | 24 | .4123 | .0172 | 1.41 | (NS) |
| SOUTHEASTERN ALASKA | 17 | .2071 | .0122 | | |
| $H_0$: <u>EQUAL SLOPES</u> | | | | | |
| BETWEEN REGRESSIONS | 1 | .8821 | .8821 | 58.42 | (P<.001) |
| WITHIN REGRESSIONS | 41 | .6194 | .0151 | | |

Figure 10. Analysis of covariance comparing male sablefish growth between Southeastern Alaska sites and northern British Columbia sites.




ANALYSIS OF COVARIANCE

| SOURCE OF VARIATION | DF | SS | MS | F | |
|---|---|---|---|---|---|
| ($H_0$: HOMOGENOUS RESIDUAL VARIANCES) | | | | | |
| DEVIATIONS FROM REGRESSION | | | | | |
| SOUTHEASTERN ALASKA | 22 | .4697 | .Ø214 | 1.237 | (NS) |
| NORTHERN B.C. | 24 | .4145 | .Ø173 | | |
| ($H_0$: EQUAL SLOPES) | | | | | |
| BETWEEN REGRESSIONS | 1 | .7913 | .7913 | 41.21 | ($P<.ØØ1$) |
| WITHIN REGRESSIONS | 46 | .8842 | .Ø192 | | |

Figure 11. Analysis of covariance comparing female sablefish growth between Southeastern Alaska sites and northern British Columbia sites.

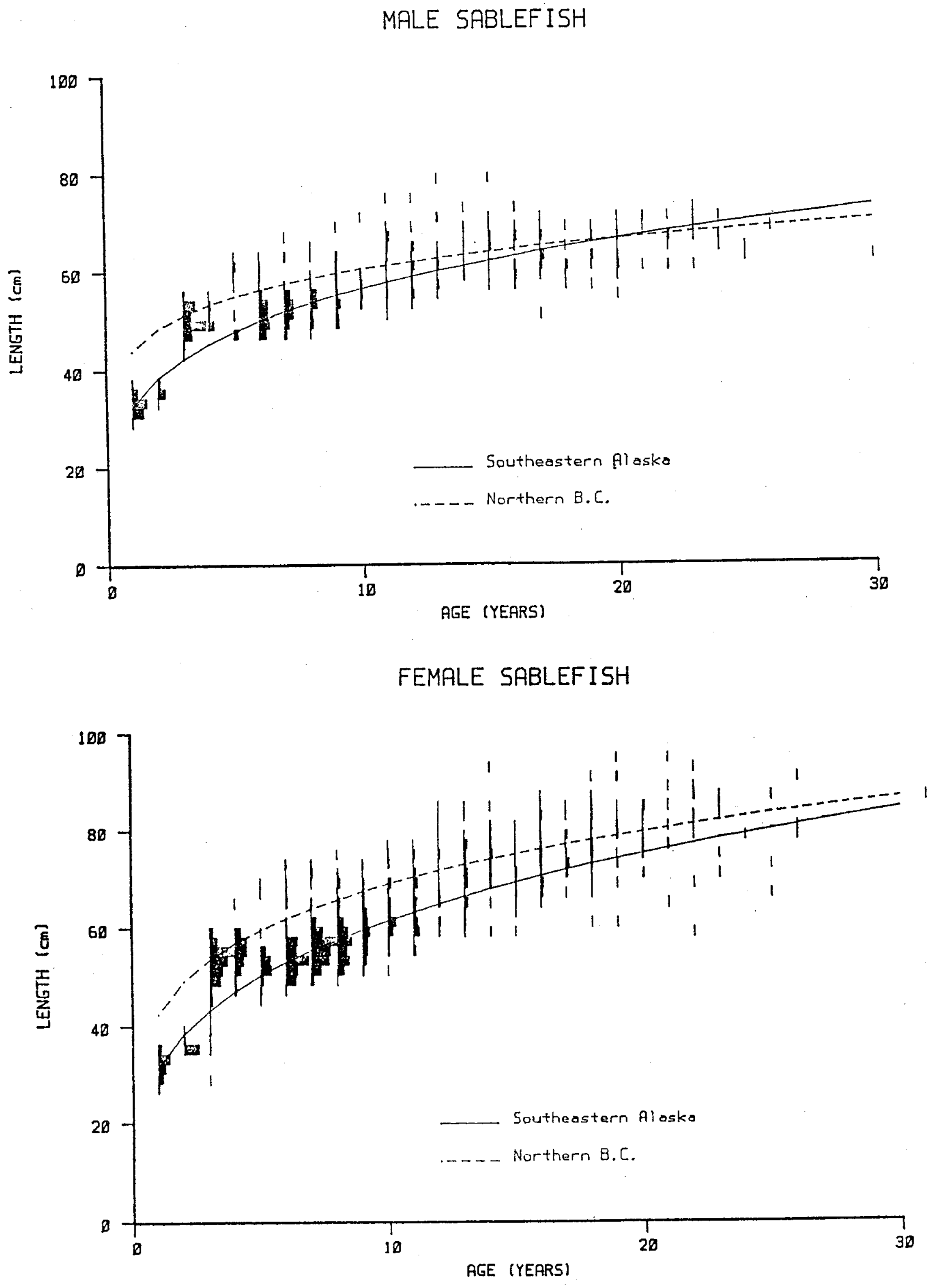



Figure 12. Comparison of length-at-age observations and fitted allometric models for northern British Columbia and Southeastern Alaska male and female sablefish.

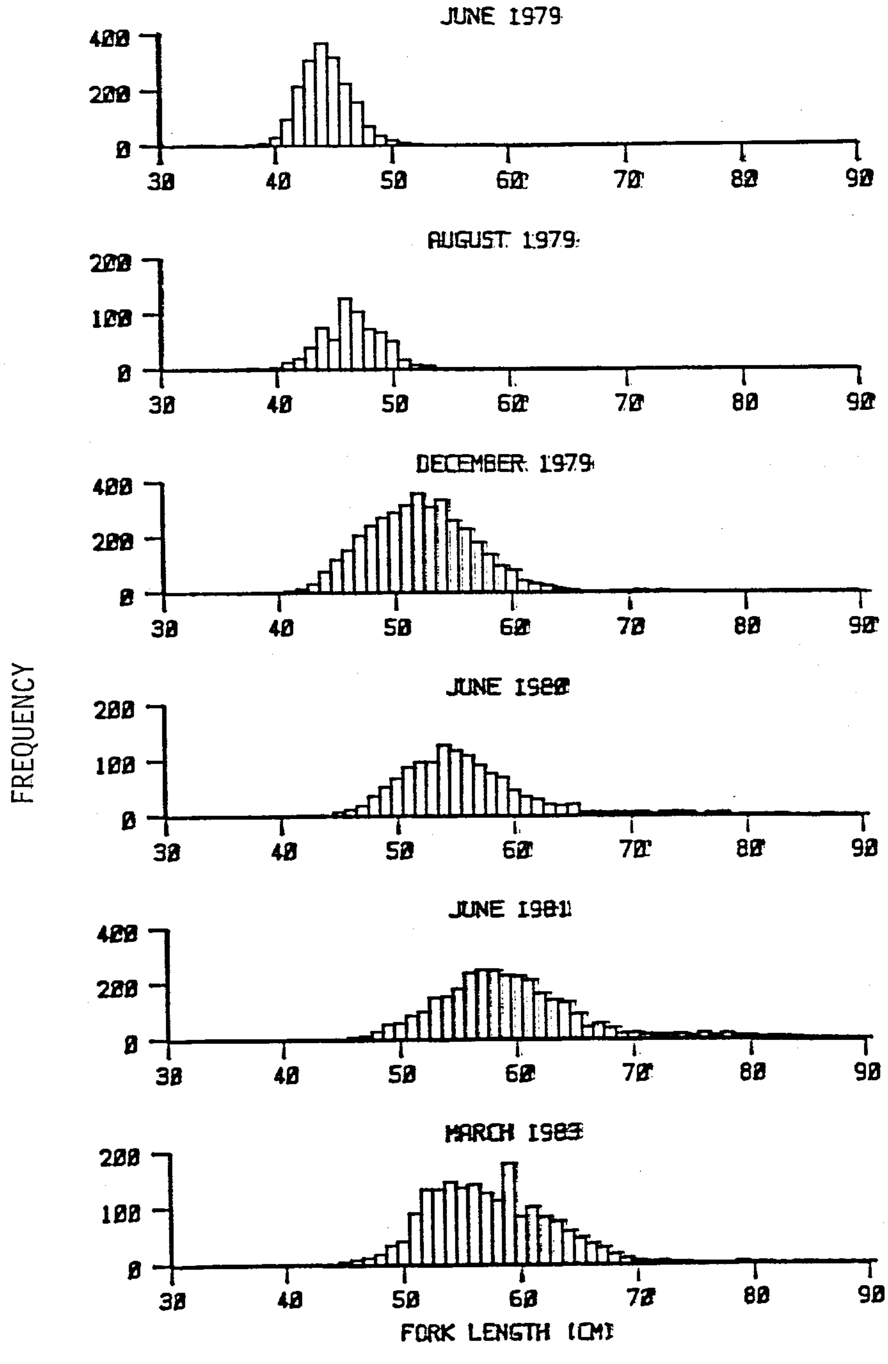



Figure 13. Length-frequency observations of sablefish collected at the Behm Canal site from June 1979 to March 1983.

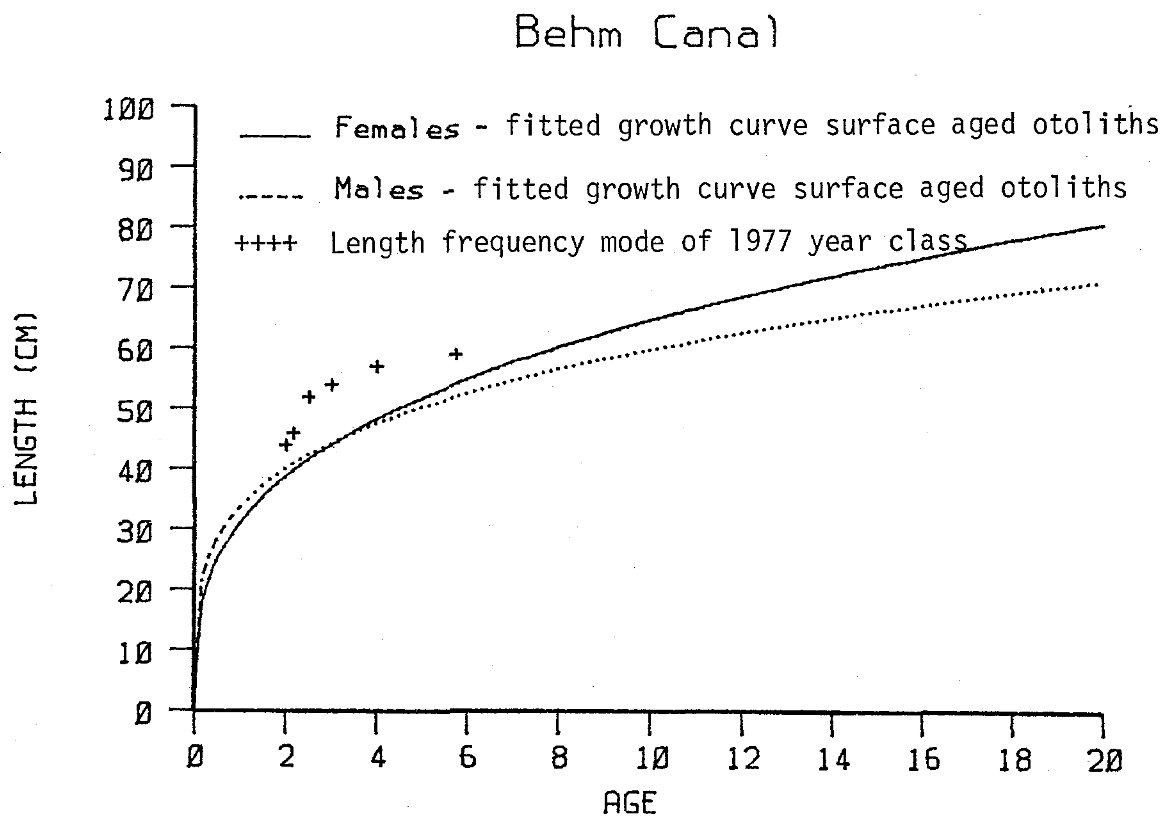



Figure 14. Comparison of sablefish growth as calculated from length-frequency modes of samples collected at the Behm Canal site from June 1979 to March 1983 with growth calculated from aging otoliths collected at the Behm Canal site in June 1981.

Initial growth rates from the Southeastern Alaska sablefish length-at-age data are slower than those obtained from the northern British Columbia data. It is not possible to determine from the length-at-age data whether the observed differences in sablefish growth between Southeastern Alaska and northern British Columbia are due to differences in aging technique or to actual differences in growth in the two areas. The fact that the differences among sites within Southeastern Alaska were relatively minor, though significant, suggests that similar relatively minor differences in growth should appear between Southeastern Alaska and northern British Columbia. The growth from length-frequency modes also indicate that surface-reading may have overestimated ages of younger fish. This is unusual since surface-read otolith ages are normally less than "break and burn" read ages (Beamish and Chilton 1983). However, the surface-read data from Southeastern Alaska also produced fewer older-aged fish than in British Columbia. This indicates that older fish may have been underaged. A review of the surface aging techniques suggests that two extra annuli could have been counted, one at the focus and one at the outer edge of the otolith. Adjusting the Southeastern Alaska ages downward by two years (Figure 15) brings the fitted growth curve much closer to the British Columbia curve than the unadjusted fitted growth curve (Figure 12). This type of error, along with underaging of older surface-aged fish is one possible explanation for the observed differences in the length-at-age data between Southeastern Alaska and northern British Columbia. The observed differences could also be due to actual differences in growth rate between the sites. The following hypotheses could be postulated for actual differences in growth rate:

1. Differences in energetics arising from different environments in spatially segregated non-migratory populations with identical genotypes (e.g., food supply, temperature).

2. Genetic differences in spatially or genetically isolated non-migratory populations.

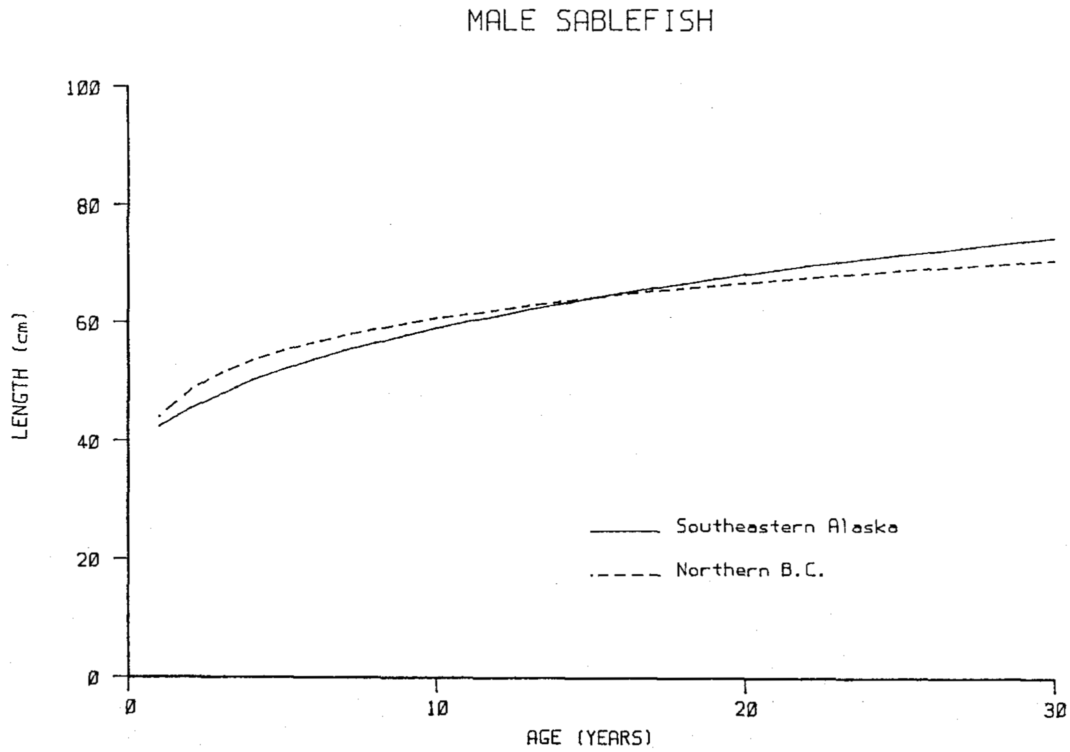
3. Energetics differences in the rearing environments of migrating populations.

4. Energetics differences in the migratory environments of migratory populations that are spatially segregated during migration.

5. Energetics differences between migratory and non-migratory populations.

6. Genetic differences between migratory and non-migratory populations.

Double reading of otoliths using both aging techniques on the same otolith is essential in order to determine whether the observed differences in length-at-age data are due to aging errors or to actual variation in the rate of growth. Comparative studies of aging methods are being conducted and results will be presented in future reports. Regardless of aging error, it can safely be concluded that early sablefish growth is more rapid and mature sablefish growth is much slower than reported in the early literature.



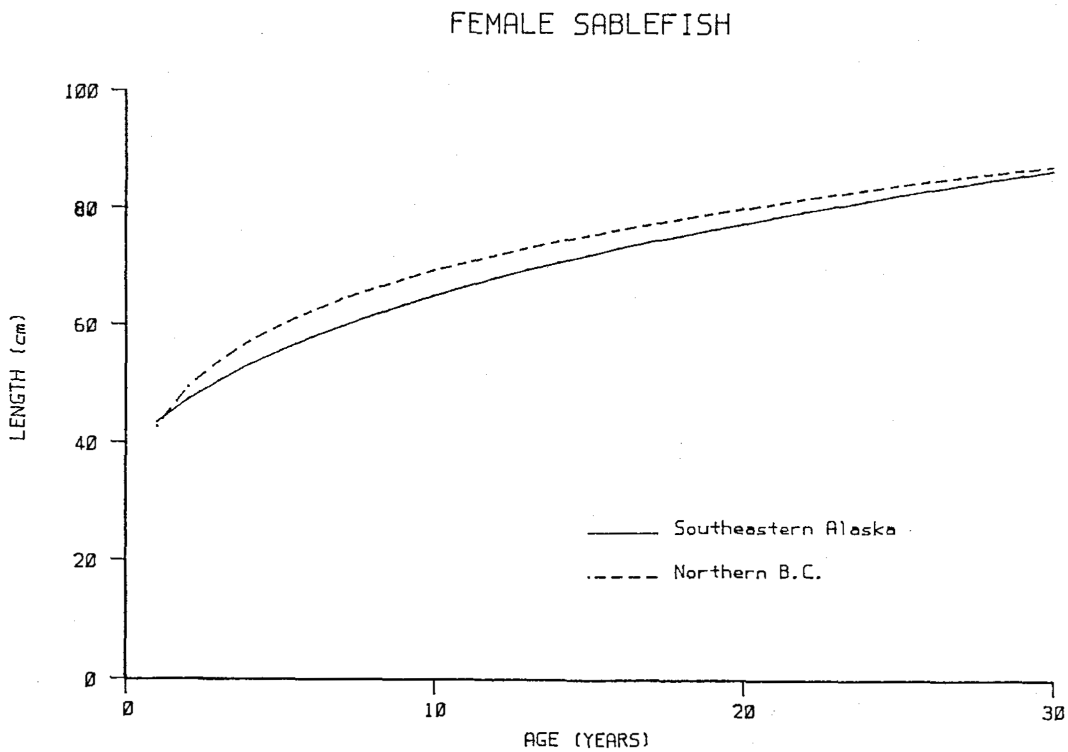




Figure 15. Comparison of fitted allometric models for male (A) and female (B) sablefish from northern British Columbia and Southeastern Alaska after adjusting for a two year aging error in the Alaskan data.

## ACKNOWLEDGMENTS

Sandy McFarlane of the Pacific Biological Station, Canada Department of Fisheries and Oceans, graciously provided sablefish growth data from northern British Columbia. Ruth Mandapat of the Washington Department of Fisheries Aging Laboratory read the Southeastern Alaska otoliths. Phil Rigby donated vessel time for capture the Auke Bay sample of juvenile sablefish.

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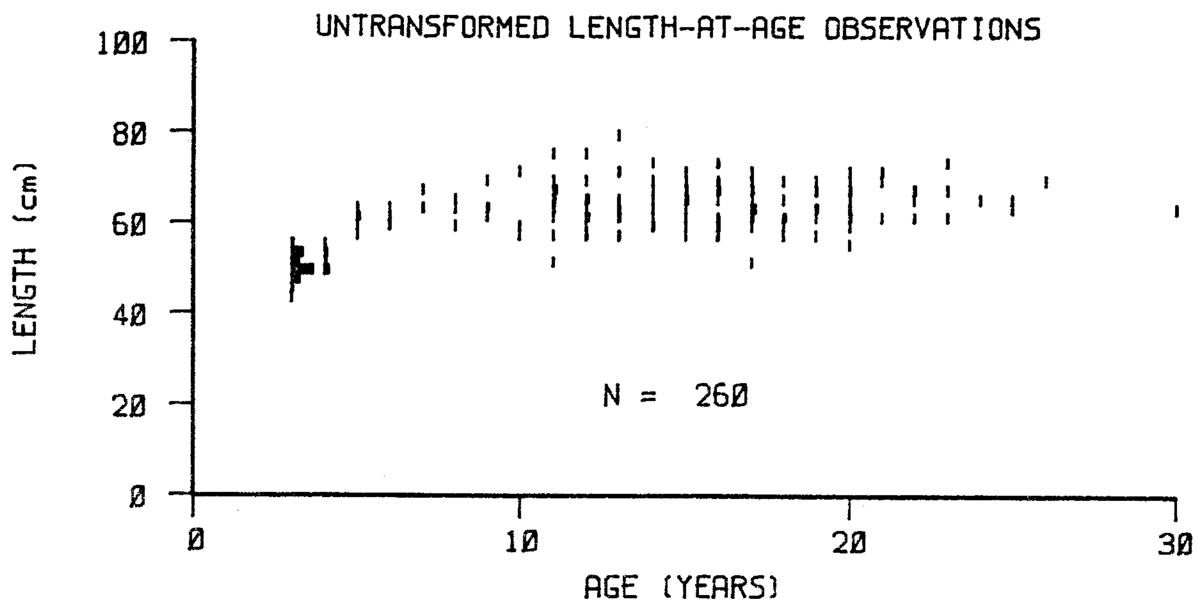
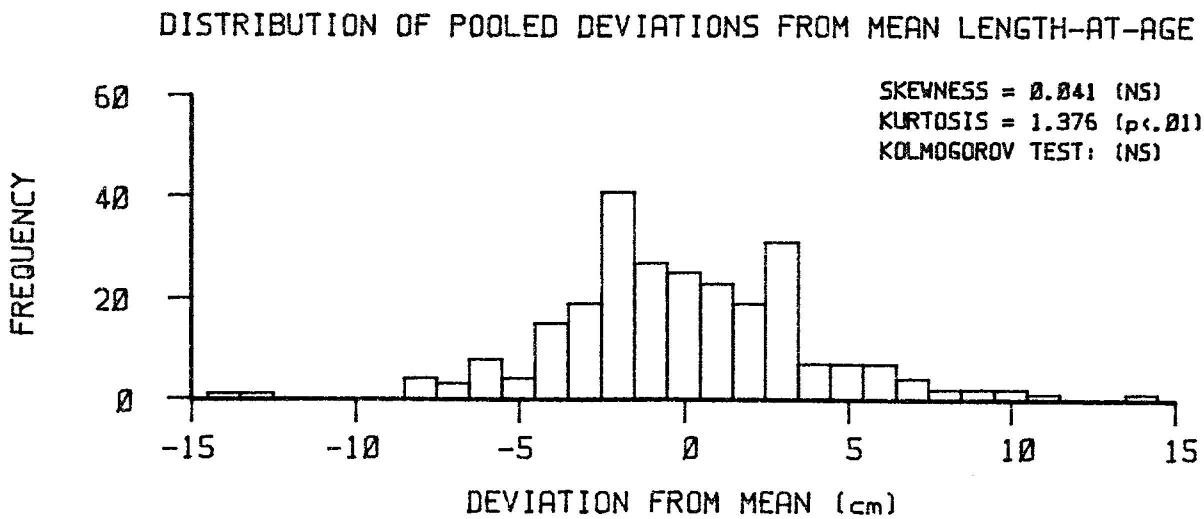
# APPENDIX I

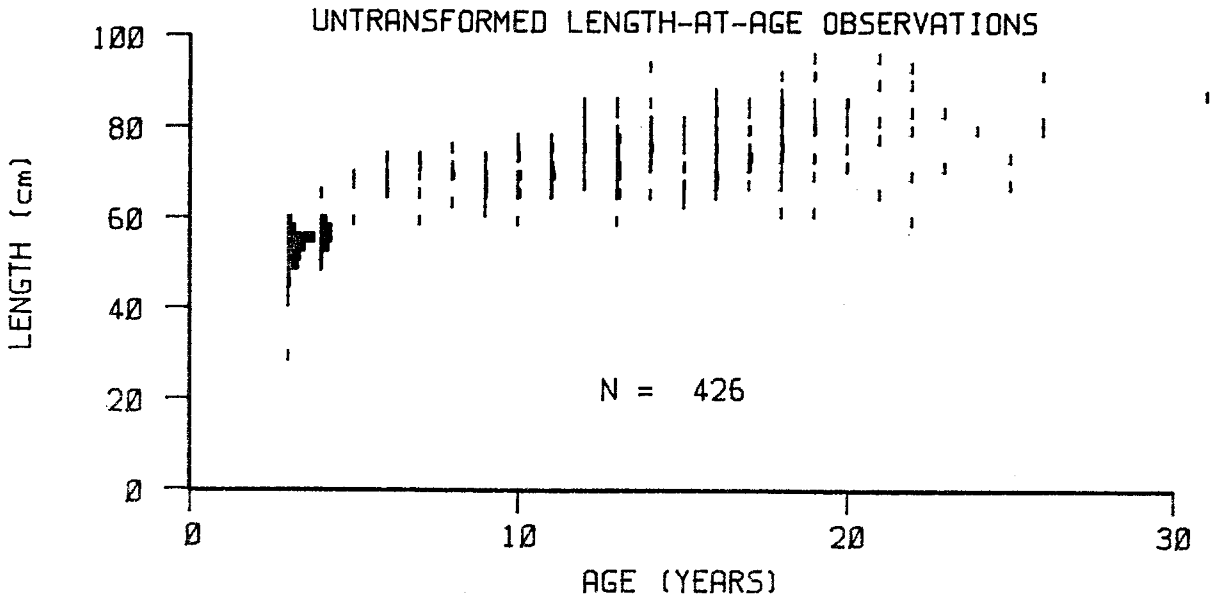
Untransformed and log-transformed length-at-age distributions for Southeastern Alaska and northern British Columbia sites.

# NORTHERN B.C. MALE SABLEFISH

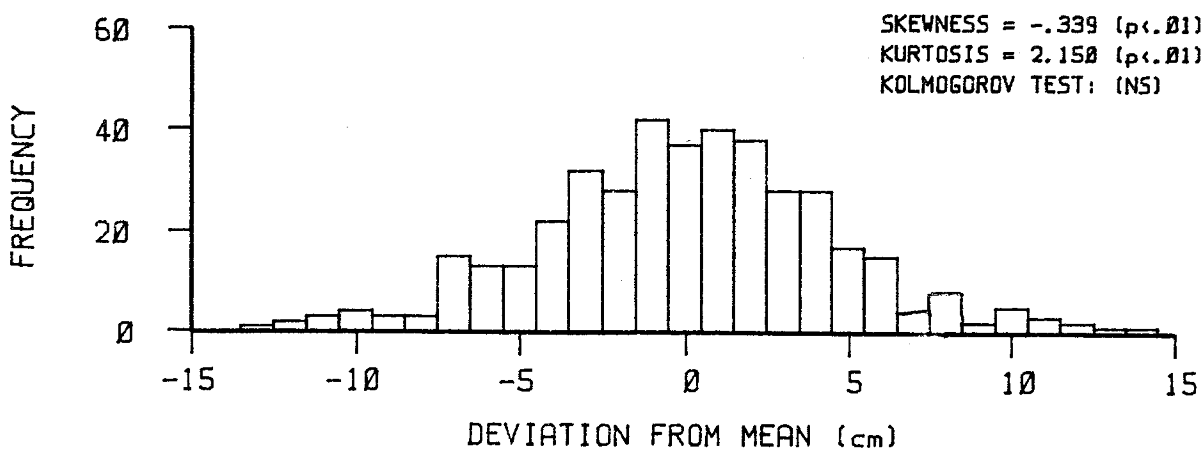


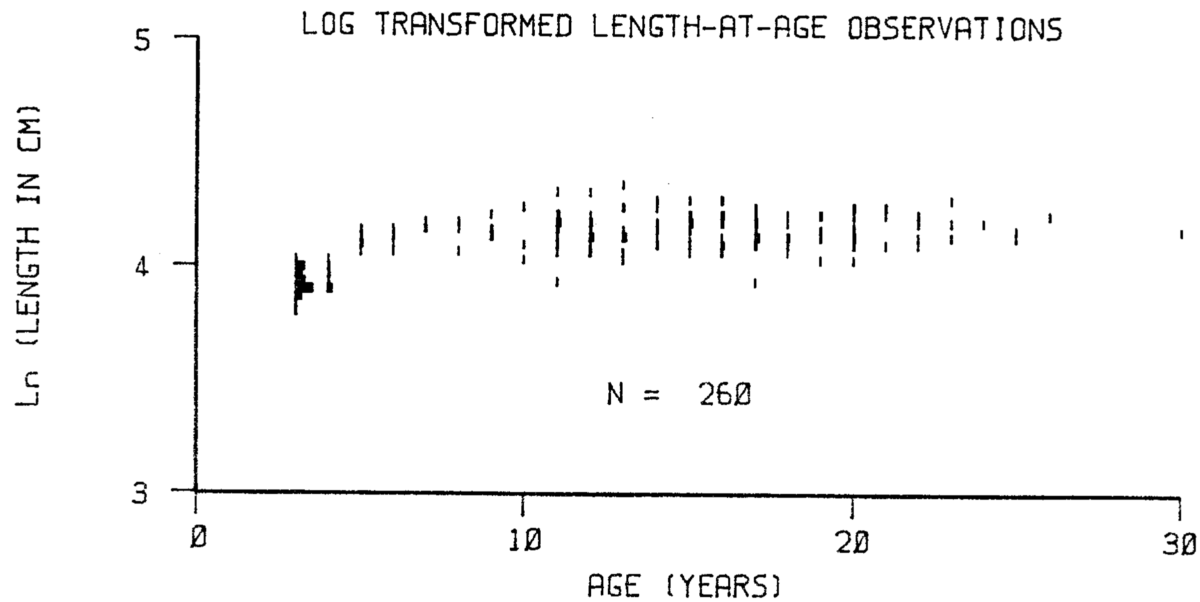
# NORTHERN B.C. FEMALE SABLEFISH

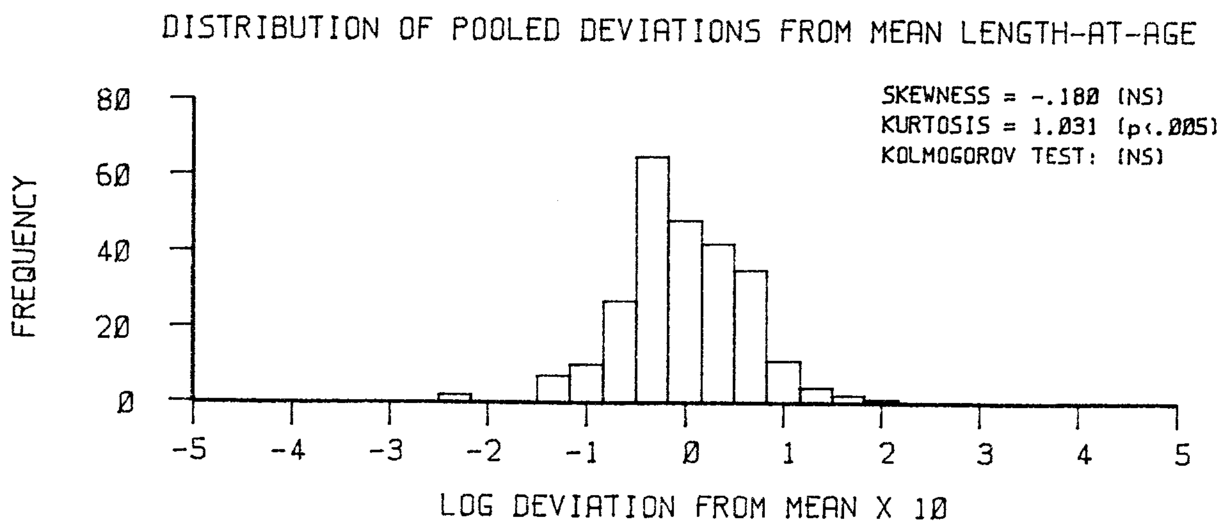


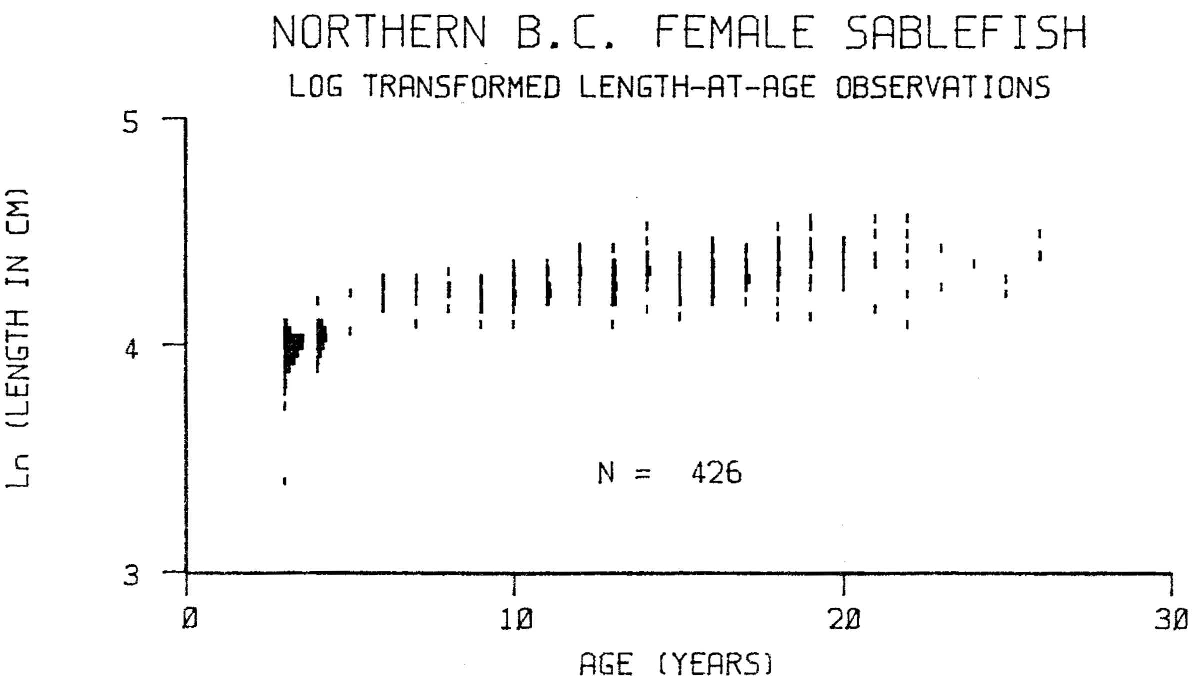

DISTRIBUTION OF POOLED DEVIATIONS FROM MEAN LENGTH-AT-AGE

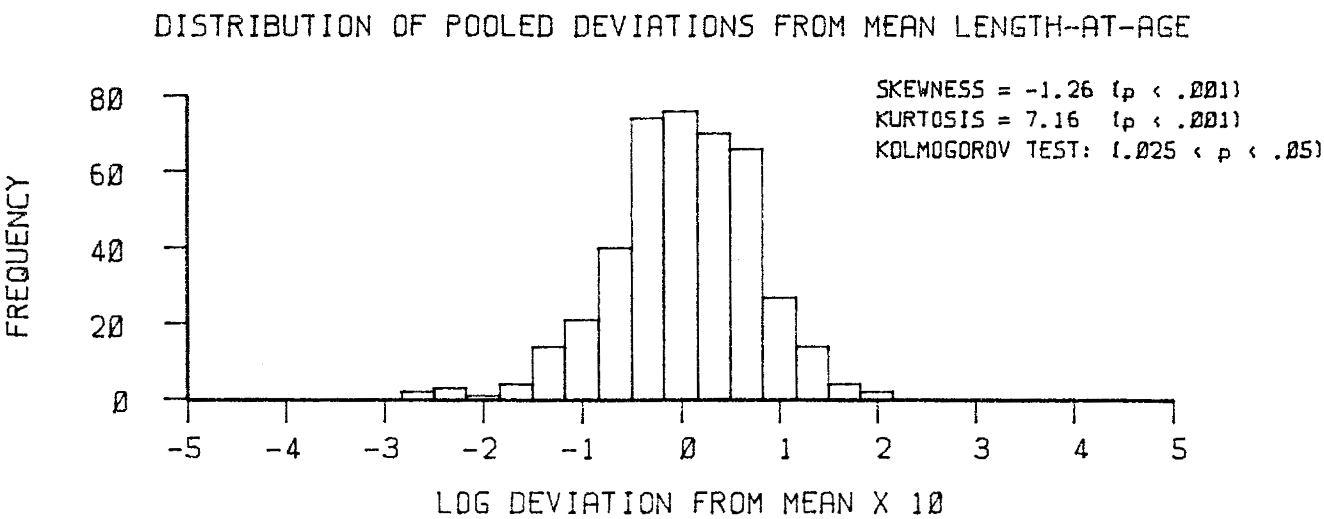


# NORTHERN B.C. MALE SABLEFISH



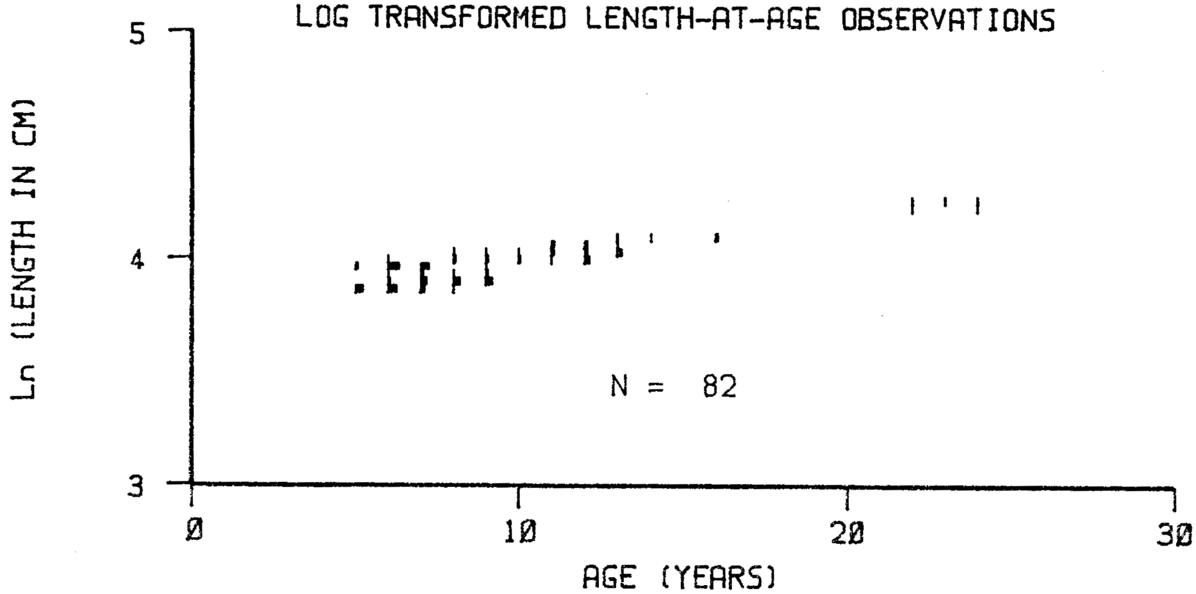




NORTHERN B.C. FEMALE SABLEFISH
LOG TRANSFORMED LENGTH-AT-AGE OBSERVATIONS
Ln (LENGTH IN CM)
5
4
3
N = 426
0
10
20
30
AGE (YEARS)

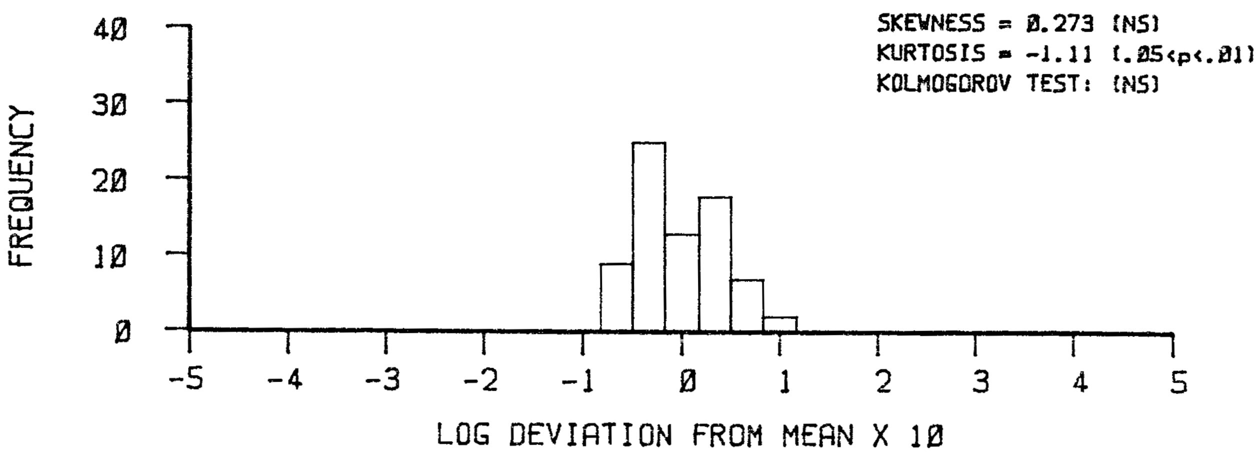

DISTRIBUTION OF POOLED DEVIATIONS FROM MEAN LENGTH-AT-AGE
SKEWNESS = -1.26 (p < .001)
KURTOSIS = 7.16 (p < .001)
KOLMOGOROV TEST: (.025 < p < .05)
FREQUENCY
80
60
40
20
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
LOG DEVIATION FROM MEAN X 10

# CHATHAM STRAIT (SITE A) MALE SABLEFISH

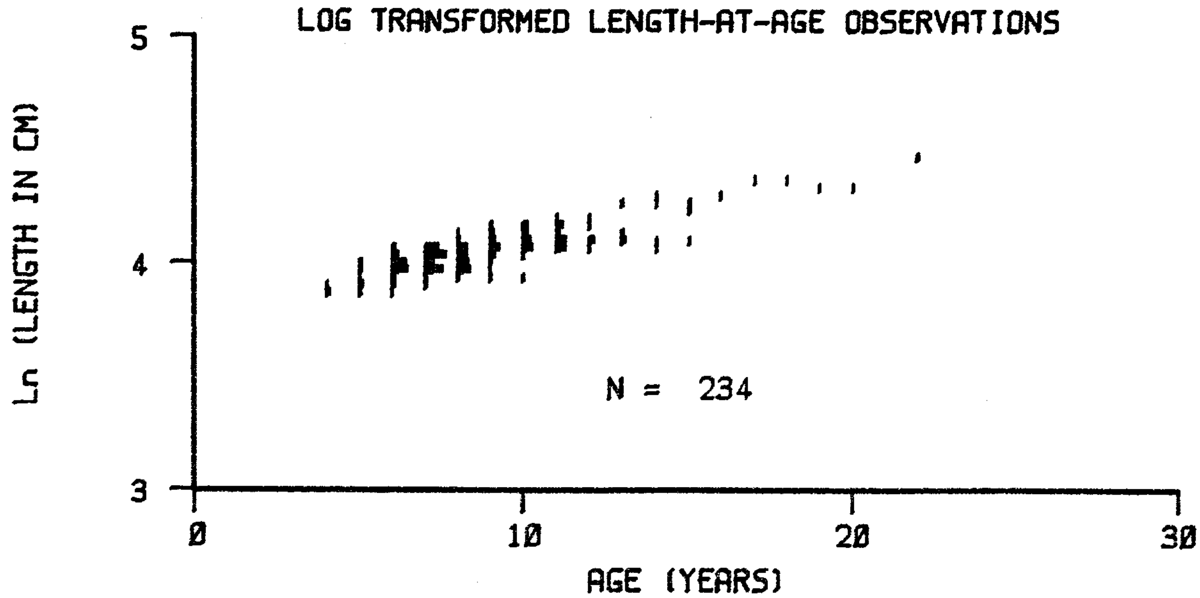
LOG TRANSFORMED LENGTH-AT-AGE OBSERVATIONS



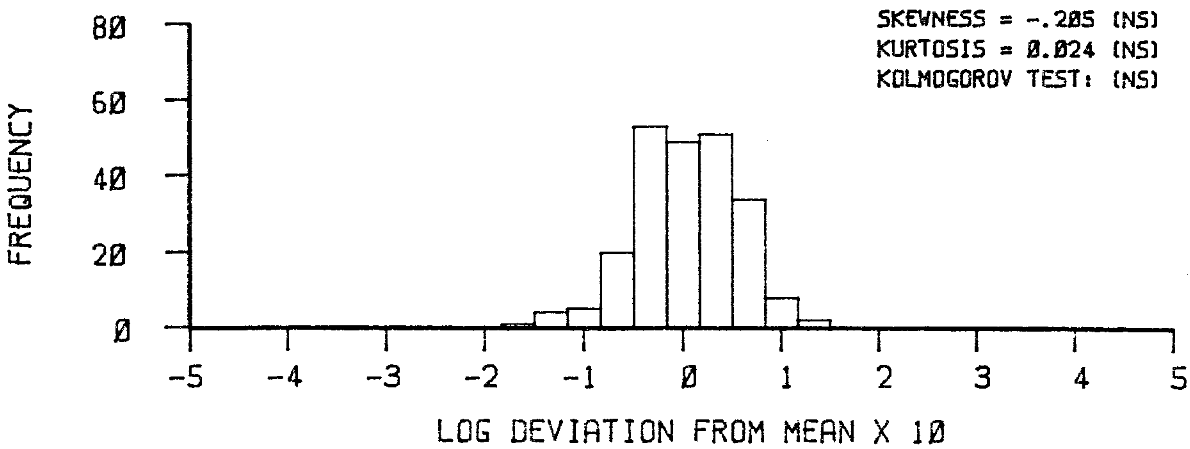

DISTRIBUTION OF POOLED DEVIATIONS FROM MEAN LENGTH-AT-AGE



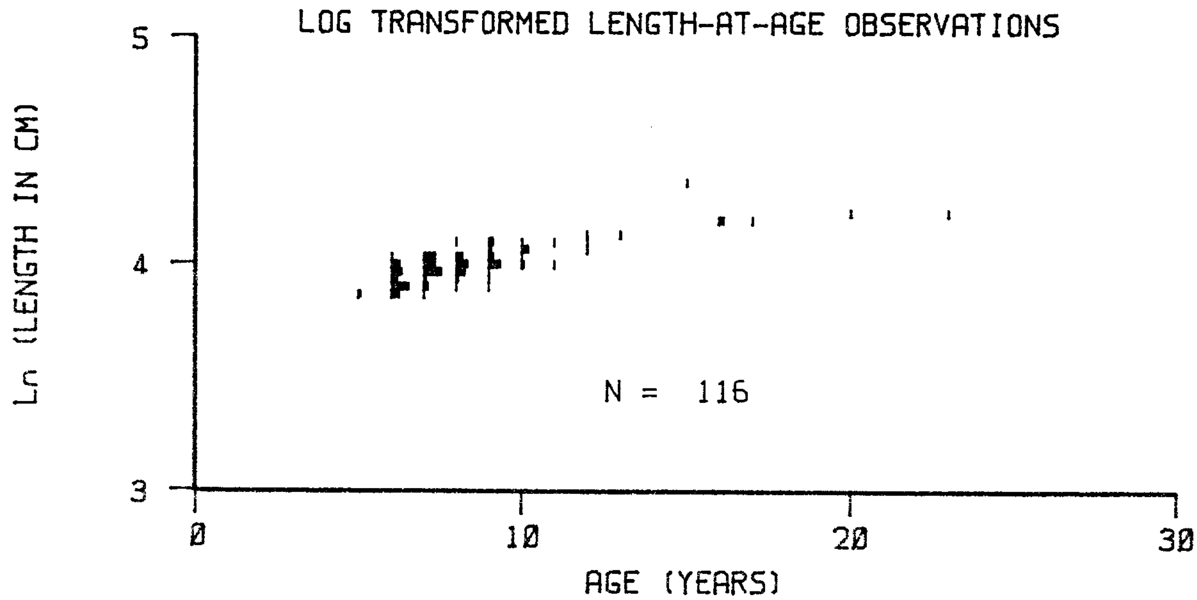
# CHATHAM STRAIT (SITE A) FEMALE SABLEFISH

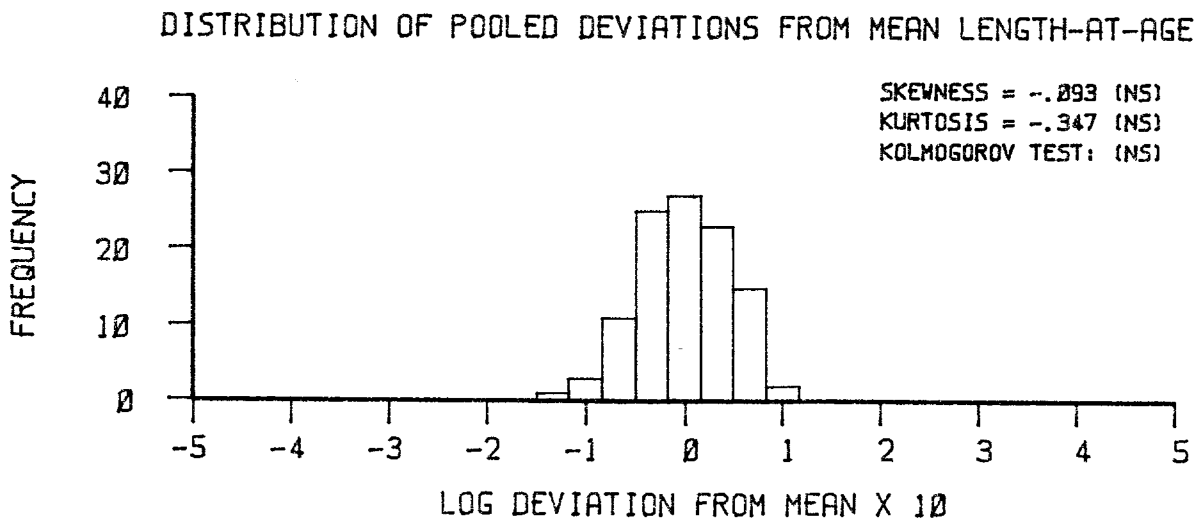



DISTRIBUTION OF POOLED DEVIATIONS FROM MEAN LENGTH-AT-AGE

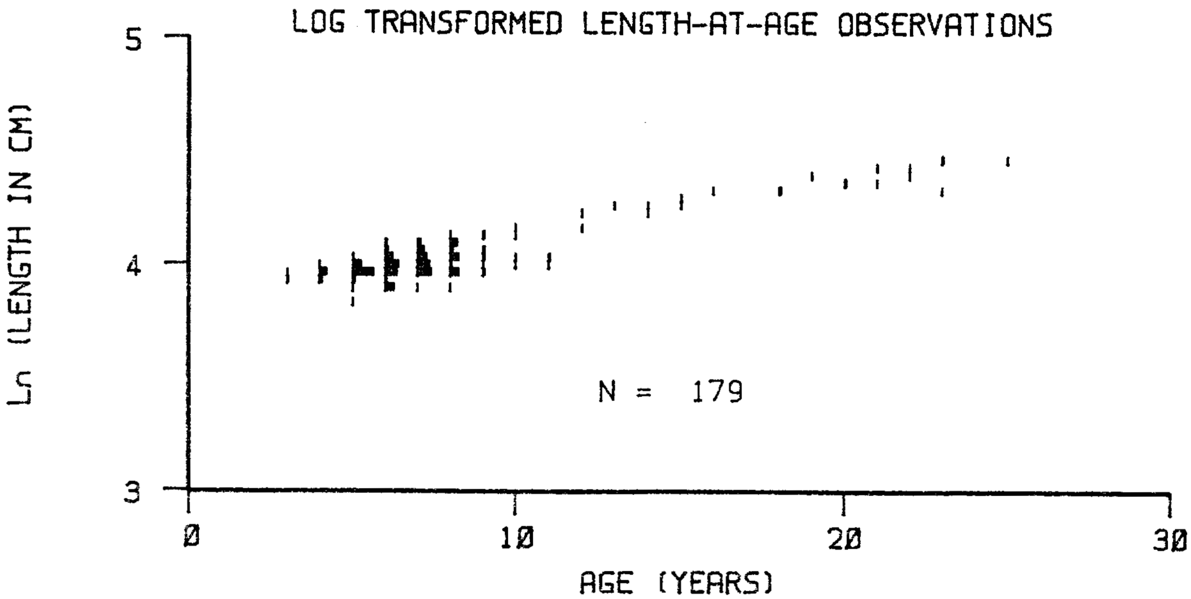


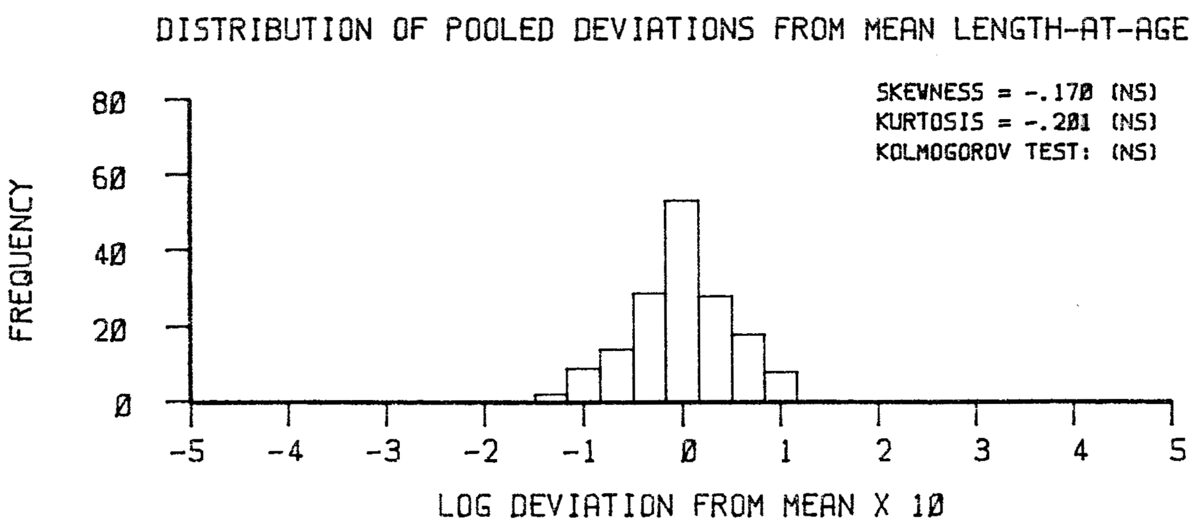
# CHATHAM STRAIT (SITE B) MALE SABLEFISH



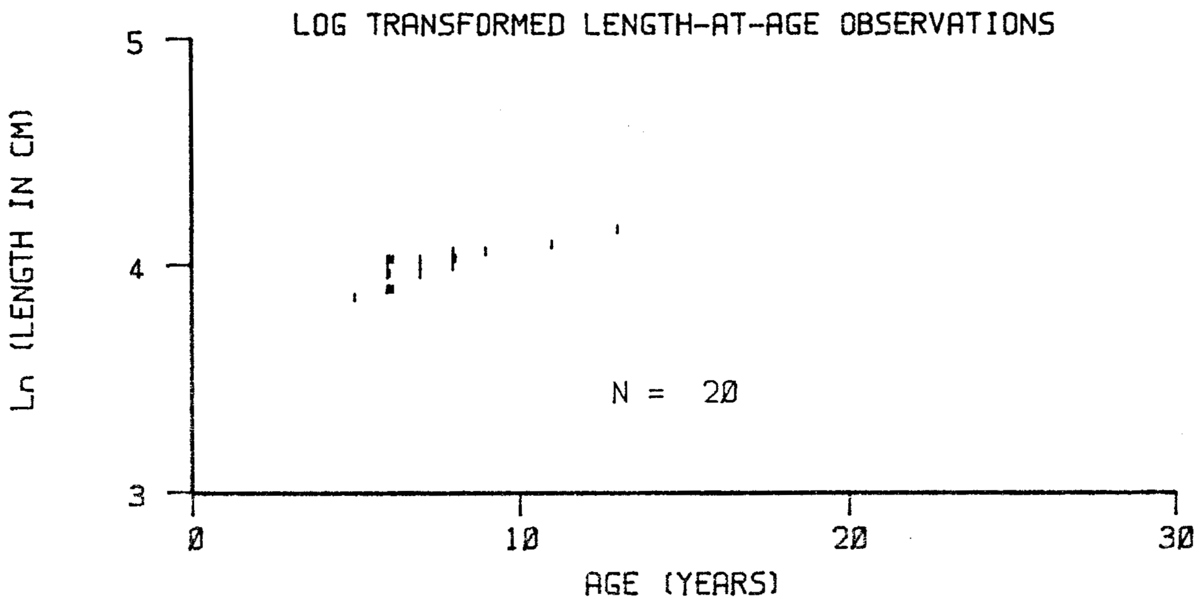



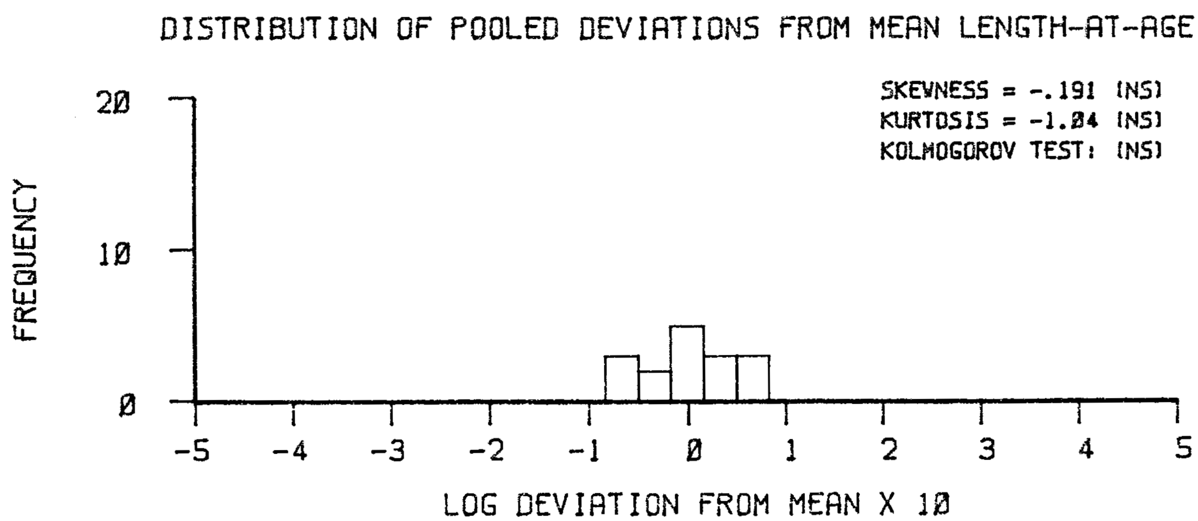
## CHATHAM STRAIT (SITE B) FEMALE SABLEFISH



# BEHM CANAL MALE SABLEFISH



# BEHM CANAL FEMALE SABLEFISH