NOAA Technical Memorandum NMFS-AFSC-172

Growth and Mortality of Rockfishes (Scorpaenidae) From Alaska Waters

by
P. W. Malecha, D. H. Hanselman, and J. Heifetz

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center

June 2007

NOAA Technical Memorandum NMFS

The National Marine Fisheries Service's Alaska Fisheries Science Center uses the NOAA Technical Memorandum series to issue informal scientific and technical publications when complete formal review and editorial processing are not appropriate or feasible. Documents within this series reflect sound professional work and may be referenced in the formal scientific and technical literature.

The NMFS-AFSC Technical Memorandum series of the Alaska Fisheries Science Center continues the NMFS-F/NWC series established in 1970 by the Northwest Fisheries Center. The NMFS-NWFSC series is currently used by the Northwest Fisheries Science Center.

This document should be cited as follows:

Malecha, P. W., D. H. Hanselman, and J. Heifetz. 2007. Growth and mortality of rockfishes(Scorpaenidae) from Alaska waters. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-172, 61 p.

NOAA Technical Memorandum NMFS-AFSC-172

Growth and Mortality of Rockfishes (Scorpaenidae) From Alaska Waters

by

P. W. Malecha, D. H. Hanselman, and J. Heifetz

Auke Bay Laboratories
Alaska Fisheries Science Center
17109 Lena Loop Road
Juneau AK 99801-8626
www.afsc.noaa.gov

U.S. DEPARTMENT OF COMMERCE
Carlos M. Gutierrez, Secretary
National Oceanic and Atmospheric Administration
Vice Admiral Conrad C. Lautenbacher, Jr., U.S. Navy (ret.), Under Secretary and Administrator
National Marine Fisheries Service
William T. Hogarth, Assistant Administrator for Fisheries

June 2007

This document is available to the public through:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

www.ntis.gov

Notice to Users of this Document

ABSTRACT

Growth and mortality were estimated for seven rockfish species of the genus *Sebastes* found in the Gulf of Alaska, Bering Sea, and Aleutian Islands region. When data allowed, von Bertalanffy growth parameters were compared between various collection locations and years. Significant differences in growth were detected for most species between locations and years. Most notable was a longitudinal trend for increasing length-at-age among Pacific ocean perch (*S. alutus)*. Mortality rates estimated from life history parameters were similar to previously published estimates. Among samples of *S. alutus* and northern rockfish (*S. polyspinis)*, mortality rates in the Gulf of Alaska were greater than in the Aleutian Islands region.

CONTENTS

INTRODUCTION

Rockfish (genus *Sebastes*) are an important component of the commercial catch in the Gulf of Alaska (GOA), Bering Sea (BS), and Aleutian Islands (AI) region. In 2006, about 40,000 metric tons (t) of rockfish were caught off the coast of Alaska in the GOA, BS, and AI combined (NMFS 2007). Pacific ocean perch (*Sebastes alutus*) make up most of the rockfish landings in these areas followed by other species such as northern rockfish (*S. polyspinis*), dusky rockfish (*S. variabilis*), rougheye rockfish (*S. aleutianus*), and shortraker rockfish (*S. borealis*).

Generally, *Sebastes* species of the North Pacific Ocean are susceptible to over-harvest because they grow slowly and tend to aggregate in large schools. Due to their aggregating nature, especially when associated with specific habitat types, rockfish can be harvested in great numbers and because of their slow growth they tend to have relatively late ages-at-maturity and low annual production. For these reasons, accurate stock assessments of these species are essential. Harvest rates for most rockfish managed by the North Pacific Fishery Management Council (NPFMC) are based on spawning biomass per recruit analyses, which require accurate estimates of life-history parameters, such as growth rate, mortality, and age of maturity (Heifetz et al. 1999, Quinn and Deriso 1999, Hanselman et al. 2005).

Previous studies have demonstrated that growth parameters of *Sebastes* species can vary with latitude. Widow rockfish (*S. entomelas*) (Pearson and Hightower 1990), yellowtail rockfish (*S. flavidus*) (Fraidenburg 1980), chilipepper (*S. goodei*), and bocaccio (*S. paucispinis*) (Wilkins 1980) had greater lengths-at-age with increasing latitude. Boehlert

(1980) found a similar relationship for splitnose rockfish (*S. diploproa*) but did not find a significant difference for length-at-age of canary rockfish (*S. pinniger*) relative to latitude.

Growth rate, compared between individuals of the same age, also varies temporally. Boehlert et al. (1989) found significant differences in growth for *S. pinniger* and *S. diploproa* and Pearson and Hightower (1990) found differences in *S. entomelas* growth among years. However, they cautioned that these differences could be the result of ageing error (Boehlert et al. 1989) or a sampling artifact due to changes in the spatial distribution of the stocks (Pearson and Hightower 1990).

Natural mortality estimates are a fundamental aspect of most stock-assessment procedures. Rockfish natural mortality rates have been estimated by Archibald et al. (1981), Chilton and Beamish (1982), Nelson and Quinn (1987), and McDermott (1994). However, except for McDermott (1994), most studies have focused on the waters off the coast of British Columbia and within the GOA. Currently, there is limited information about the natural mortality rates of *Sebastes* species in the BS and AI region.

Our objective is to provide basic biological data for several species of rockfish present in the GOA, BS, and AI (Table 1). Parameters of the von Bertalanffy growth equation were calculated and growth was compared between sex, years, and geographical areas. Natural mortality estimates, based on growth parameters, were determined with the Alverson and Carney (1975) and Hoenig (1983) procedures. Updated estimates of growth parameters and mortality rates may allow for more accurate stock assessments for *Sebastes* species of the GOA, BS, and AI region.

MATERIALS AND METHODS

Data

Most samples were obtained during National Marine Fisheries Service (NMFS) research surveys from 1980 through 1999. Fork length of each specimen was measured to the nearest centimeter. Ages were determined with the “break-and-burn” technique of ageing otoliths (Chilton and Beamish 1982). Ages of *S. zacentrus*, *S. variegatus*, and *S. brevispinis* specimens were determined at the Alaska Department of Fish and Game’s (ADF&G) otolith laboratory in Juneau, Alaska. Ages of *S. alutus*, *S. polyspinis*, *S. variabilis*, and *S. aleutianus* were determined by staff of the Alaska Fisheries Science Center’s Age and Growth Program in Seattle, WA. Additional analyses of *S. alutus* were based on samples collected by NMFS surveys during 2000 through 2002.

Each sample was assigned a geographic designation based upon latitude and longitude coordinates from collection records. Each sample was assigned to one of three collection regions: GOA, AI, or BS (Fig. 1). Furthermore, the GOA and AI regions were divided into subareas. The GOA region was divided into the Eastern, Central, and Western GOA areas, and the AI region into the Eastern and Western AI areas. These subareas generally correspond to NPFMC management areas.

Growth

When sample sizes were greater than 50, von Bertalanffy growth parameters were estimated by minimizing the nonlinear regression sums of squares for the 3-parameter Ludwig von Bertalanffy (LVB) growth model (von Bertalanffy 1938):

$$L_t = L_\infty (1 - e^{-K(t-t_0)}) \quad ,$$

where L_t is fork length in millimeters at age t, K or the Brody growth rate parameter, determines the rate at which the curve approaches the horizontal asymptote L_∞, the theoretical maximum length, and t_0 is the x-intercept of the curve or age at length zero. We used the SAS NLIN procedure (SAS Institute Inc. 1996) to perform nonlinear regressions on the raw data. The nonlinear regression function failed to converge when estimating LVB parameters for *S. brevispinis*. Therefore, for this species t_0 was constrained to -1.68 mm, an average value reported for other slope rockfish (Heifetz et al. 1999), a value which might be low considering results presented hereafter.

We used F-tests, suggested by Quinn and Deriso (1999), to compare LVB parameter estimates within sexes and among areas and years. The F-test compares reduced and full model data sets as follows:

$$F = \frac{RSS_y - RSS_x}{f_y - f_x} / \hat{\sigma}_x^2 \quad ,$$

where RSS_y is the residual sum of squares for the reduced model with f_y residual degrees of freedom, RSS_x is the residual sum of squares for the full model with f_x residual degrees of freedom, and the residual mean square is:

$$\hat{\sigma}_x^2 = RSS_x \;/\; f_x \quad .$$

Multiple significance tests were made on the same data set, which could lead to spurious significant relationships because the probability of making Type I errors becomes larger than α. To avoid these errors, one could use the Bonferroni correction, which reduces the probability of Type I errors by conducting each test at an error rate of α/k, where k is the number of tests. However, for this research, we did not employ the Bonferroni correction because we were mainly interested in general trends rather than statistically significant differences in growth rates related to area, sex, and temporal patterns. The Bonferonni correction would make little difference in most comparisons because the sample sizes are so large that any small difference will be highly significant. We do, however, report F-statistics and P-values for some of the comparisons in order to make preliminary evaluations of differences.

Variability in growth is further examined for *S. alutus* since it is the most data-rich species. Growth is modeled in relation to spatiotemporal data including latitude, longitude, depth, and year, and residuals are examined across each data type. We present some graphical evidence of spatial structure in the data. We also present the best fitting nonlinear growth model that includes these data.

Mortality

We used the methods of Alverson and Carney (1975) and Hoenig (1983) to estimate total instantaneous natural mortality (M) rates. The method of Alverson and Carney (1975) uses the equation:

$$M = \frac{3\kappa}{\exp(t^{*}\kappa) - 1} \quad ,$$

where t^* is the age at which an unfished cohort reaches its greatest biomass, or critical age. Alverson and Carney suggest that $t^* \approx 0.38t_m$, where t_m is the maximum observed age. We estimated M with a t^* of 0.38 as Alverson and Carney suggest, and with a t^* of 0.25, which is appropriate when $M \approx K$.

Hoenig (1983) found an inverse relationship between longevity and mortality. Following this logic, M can be estimated by rearranging the exponential law of population decline into the following formula:

$$M = -\ln(0.01) / t_m \quad ,$$

assuming 0.01 is the proportion of the population that survives to the maximum age, t_m. Other authors have proposed a higher number surviving to t_m (Shepherd and Breen 1992). We estimated M using both 0.01 and 0.05 as the proportion surviving to t_m.

RESULTS

Growth

Of all species sampled, *S. alutus* was the most prevalent (19,292 observations). Therefore, we were able to complete a more thorough analysis and calculate a complete set of growth parameters for the species. *Sebastes alutus* specimens were collected from 14 separate years and from each geographic area. Other species were not as well represented in both the number of specimens and in years and locations of collection. The least-represented species were *S. variegatus* (100 observations) and *S. aleutianus* (215 observations); ages for both species were available for one year and from limited geographic distributions.

When sample sizes allowed, F-tests were used to compare growth parameters among various combinations of location, year, and sex. Table 2 provides between-sex F-test results for each species of rockfish for all years and areas combined. Significant differences in growth parameters were detected for every species except *S. aleutianus*. Likewise, for every species, except *S. aleutianus*, females grew to greater maximum lengths. The differences between the sexes or lack thereof, are apparent in Figures 2-5.

Sebastes alutus

Sebastes alutus samples were collected from a diverse mix of locations and years. Therefore, both spatial and temporal comparisons of growth parameters could be made. Estimated growth parameters are presented in Table 3. Results from comparisons made between regions for all years combined are listed in Table 4. Significant differences were found for each between-region comparison within sex. Figures 2a and 2b display average length-at-age and predicted length-at-age for GOA and AI *S. alutus*.

Similar comparisons are presented in Table 5, where growth parameters are compared among areas within sex for all years combined. Except for the comparisons between Central GOA and Western GOA males and females, every between-area comparison was significant. The differences are evident in Figures 2c and 2d, where growth curves plotted by area suggest a longitudinal gradient in growth. It is apparent, for both sexes that growth rate and maximum length decreases as degree of westward longitude increases. For example, L_∞ for males in the Eastern GOA was estimated at 412.7 mm, while for Western Aleutian males, L_∞ was estimated at 381.8 mm. The longitudinal gradient is less obvious for females but nonetheless is still apparent.

To determine if differences in growth between areas could be detected within a single year, growth parameters were compared between areas within years and sex. It is intuitive that areas that are distant from one another are more likely to have significantly different growth parameters than areas close to one another. In this study, within-year comparisons could only be made between areas that are adjacent or within the same region because surveys did not sample distant areas in the same year. Despite the proximity of the areas, 20 of 24 comparisons among males yielded significant ($P < 0.01$) differences while 16 of 24 comparisons among females were significant. The between-area results were inconsistent since comparisons made in some years were highly significant while not significant in other years. These differences may be the result of sampling differences or due to the high power of the statistical test.

Temporal changes in growth were detected for both sexes of *S. alutus*. Growth parameters were compared among years within area and sex. Of the 73 comparisons among males, 57 were significant ($P < 0.01$), while among females, 59 of 73 comparisons were significant. All between-year comparisons involving samples from the BS were significantly different. Ninety percent of male and female comparisons involving samples from the AI were significantly different, whereas in the GOA, 67.5% of the comparisons of males were significant while 72.5% of the comparisons of females were significantly different. Of the significant between-year differences detected, no apparent patterns could be discerned.

Additional analysis for *S. alutus* confirmed the longitudinal variability in growth parameters for both sexes. This analysis added in data from 2000-2002 from the AI and GOA, but the BS Slope survey data was removed (n~100) since it is much different latitudinally when in the same longitude. Because females and males have a large difference in growth as shown above, they were separated for these analyses. In Figures 3-4, parameter estimates with 95% confidence intervals show there was a distinct pattern for both males and females in estimates of the LVB model. The most distinct difference is in the longitudinal group that includes the Eastern GOA. The maximum size (L_∞) was much higher there than the next five longitude groups and the Brody shape parameter (K) is considerably lower. The x-intercept of the curve (t_0) was the least well defined parameter for both females and males across all longitude groups. The groups from -138º W longitude through -167º W longitude shared similar growth parameters with a much smaller maximum length and much higher shape parameter. The group that contained -170º W longitude appeared to have parameters similar to the group that contained the Eastern GOA. The group west of this region generally had lower maximum lengths and lower growth rates.

In Figures 5-6, male and female *S. alutus* were compared geographically across longitudes by showing the percent of maximum residual of the growth parameters from the pooled *S. alutus* growth model. Males and females showed very similar residual patterns from west to east. The eastern-most group and the group containing -170º W longitude had the only consistent positive residual for L_∞. The residuals for K and t_0 were negative for the eastern-most group and everything west of the -167º W longitude for both sexes, and positive for everything in between, indicating a strong pattern for these growth parameters. Residual plots for growth across latitude, year, and depth were less dramatic.

When nested models were compared using Akaike Information Criterion, the best predictive model of *S. alutus* growth was found to be

$$L_a = \left[L_\infty + a(SEX-1) + b(LON)\right](1-e^{-K(AGE-t_0)}) + c(DEPTH) \ ,$$

where L_a is length (mm) at age (years), L_∞ is average maximum length, *SEX -1* uses sex as an indicator variable where 1 is male (no effect) and 2 is female (effect), *LON* is longitude of each specimen, K is the shape parameter of the growth curve, *AGE* is age of each specimen in years, t_0 is the x-intercept of the curve, and *DEPTH* is the depth where the specimen was caught in meters.

Parameter estimates listed in Table 6 imply that length is affected positively when specimens are female: positively by longitude and negatively by depth. The depth result parameter is significant, but negative, which is surprising because larger fish are usually found deeper. This result is probably due to the high correlation in some of the parameters (Table 6).

Sebastes polyspinis

Samples of *S. polyspinis* were collected in nine separate years and from every area except the Bering Sea. LVB parameters are presented in Table 7. Significant differences in growth were detected between locations and between years. In Table 8, F-test results are listed from comparisons of growth between regions within sex for all years combined. For both sexes, significant differences in growth were detected between collections made in the GOA and collections made in the AI. L_∞ estimates for male and female *S. polyspinis* were greater in the GOA than the AI (Figs. 7a and 7b).

Comparisons in growth between areas within sex also revealed significant differences when data from all years were combined (Table 9). For both males and females, all between-area comparisons were significantly different. Figures 7c and 7d show predicted length-at-age for males and females from each area. Within each sex, L_∞ was greatest in the Western GOA, dropped off among samples collected in areas adjacent to the Western GOA (Central GOA and Eastern AI) and was lowest in the Western AI. The differences between L_∞ for

Western GOA and Western AI collections were dramatic. The differences were 65.1 mm and 70.9 mm for males and females, respectively. Within-year comparisons of growth between areas were also mostly significant ($P < 0.01$).

Significant ($P < 0.01$) differences in growth between years within area and sex were found among collections made in each area. These differences were not entirely systematic. However, between-year differences were more prevalent among collections more separated in time. For example, 22 of the 24 between-year comparisons where collections occurred at least 6 years apart were significant. Only 21 of 34 comparisons were significantly different when collections were separated by less than 6 years.

Sebastes variabilis

Sebastes variabilis samples were collected in five separate years and in three separate areas. LVB parameter estimates are listed in Table 10. Figure 8a displays the all-year average and predicted length-at-age for both males and females. Because all samples were collected from the GOA, between-region comparisons could not be made. Table 11 provides F-test results for between-area growth comparisons for all years combined. For both sexes, significant differences in growth were found between samples for each between-area comparison.

Between-area comparisons were also made within years and sex. Ten of the 12 total comparisons were significant ($P < 0.01$). Results from between-year comparisons within areas were computed but had a very low sample size. Among males, 4 of 6 between-year comparisons were significant, while among females, 6 of 10 between-year comparisons were significant. Although many comparisons were significant, sample sizes were near the minimum threshold of 50.

Sebastes brevispinis

Sebastes brevispinis samples were collected in 1993, 1996, and 1999. Almost all samples were collected in the Eastern GOA area, with a few collected in the Central GOA area. For this species, the nonlinear parameter estimation procedure did not converge. Therefore, growth parameter estimates were calculated by constraining t_0 at –1.68 mm to facilitate the estimation procedure. However, variability of length-at-age, particularly among the older aged samples, continued to provide difficulty for the parameter estimation procedure. Estimated LVB parameters are shown in Table 12. This variability is evident in Figure 8b, where average and predicted length-at-age for all years combined is plotted for male and female *S. brevispinis*.

Comparisons between regions or areas are not available for *S. brevispinis* but comparisons between years within the Eastern GOA were made. Male growth in 1993 was significantly different ($P < 0.01$) from growth in 1996 and 1999. However, it should be noted that the number of samples collected in 1993 was small and that male growth parameters estimated for this year were inordinately different from those estimated for the other two collection years. Female growth parameters could not be estimated in 1993 because the estimation procedure failed to converge even though t_0 was constrained. Sample sizes were considerably larger in 1996 and 1999 but comparisons of growth between 1996 and 1999, for both sexes, were not significant.

Sebastes zacentrus

Sebastes zacentrus samples were collected in 1996 and 1999. Almost all samples were collected in the Eastern GOA, but a small percentage was collected in the Central GOA. Sexual dimorphism is well distinguished in this species and is apparent in Figure 8c. Estimated LVB parameters are listed in Table 13.

Because of the paucity of data, between-region and between-area comparisons could not be made for this species. However, comparisons between 1996 and 1999 were made for Eastern GOA males and females. Results were mixed for these tests, as growth was different between-years in females but not different in males.

Sebastes aleutianus

Sebastes aleutianus samples were chiefly collected in the Central GOA area and in only one year, 1990. LVB parameter estimates are listed in Table 14. This was the only species that no difference in growth was detected between the sexes. Average and predicted length-at-age are virtually indistinguishable between males and females (Fig. 8d). In this study, sample sizes were small, thus detecting differences between the sexes was unlikely.

Sebastes variegatus

A small sample of *S. variegatus* was aged from a 1999 collection from both the Eastern and Central GOA areas. The number of females sampled was slightly less than 50, the minimum sample size. However, female growth parameters were estimated regardless in order to make a comparison between males and females. LVB estimates are shown in Table 15. In Figure 9a, average and predicted length-at-age are plotted for both males and females.

Mortality

Total instantaneous natural mortality was estimated using the techniques described in Alverson and Carney (1975) and Hoenig (1983). In Table 16, sample size, maximum age and mortality estimates are given for each *Sebastes* species for all areas combined and by region and area. For the Alverson-Carney method, an assumption is made as to the age, t^*, at which an unfished cohort reaches its greatest biomass. Alverson and Carney suggest using a t^* value of 0.38 times t_m. Others have suggested using 0.25 times t_m to come up with t^*. In Table 16, mortality is estimated with both t^* values. In the Hoenig method, an assumption is made as to what proportion of the population survives to t_m. Hoenig assumed a proportion of 0.01 but other authors have proposed a higher proportion. In Table 16, natural mortality is estimated using 0.01 and 0.05 as the proportion that survives to t_m. While these methods to calculate natural mortality are rough approximations, we contend that the Hoenig method is more realistic for the longer-lived species than the Alverson-Carney method due to the different shapes of the curve when maximum age is high (Figs. 10-11). We present all of the methods to illustrate the wide range of possible values for natural mortality, but point out that the Hoenig method is likely the best approximation.

Sebastes alutus

The oldest fish observed in this entire study was a female *S. alutus*. The maximum age observed among all female *S. alutus* was 98 years and among all males was 92 years. For all areas combined, estimates of M for both sexes combined ranged from 0.001 to 0.047. For all areas combined, M was nearly the same for both sexes. The areas with the highest natural mortality estimates for males and females combined were the Central and Western GOA where the maximum age was lowest.

Sebastes polyspinis

The oldest *S. polyspinis* was estimated to be 72 years of age. This age was observed in a male specimen from the Western AI. The estimates of *M* for all areas and both sexes combined were low due to this one age being used for all fish. Natural mortality for all areas was higher among females for the Alverson-Carney approach because the Brody growth parameter was lower than among males. Among areas, the highest estimated *M*, for both sexes combined, was in the Central and Western GOA, while the lowest was in the Western AI where the maximum age was highest.

Sebastes variabilis

Samples for *S. variabilis* came only from the GOA. The oldest female *S. variabilis* sampled came from the Western GOA (59 years), while the oldest male came from the Central GOA (51 years). Natural mortalities on average were higher than *S. alutus* and *polyspinis* primarily because of a lower maximum age. Between-area differences should be viewed with caution because the sample size was quite small for the Eastern GOA which yielded a Brody growth parameter (*K*) for males greater than 0.6 which is three times the average *K*.

Sebastes brevispinis

Sebastes brevispinis were collected almost exclusively in the Eastern GOA. The oldest observed *S. brevispinis* male was 75 and the oldest observed female was 65. Natural mortality for *S. brevispinis* was lower for males than females using either estimator, mainly because of the lower maximum age of females. Natural mortality estimates are higher for *S. brevispinis* using the Alverson-Carney method than other species because of a much lower K. This result is questionable because the t_0 parameter was constrained to -1.68 for convergence, which automatically creates a lower K than growth curves with a higher t_0.

Sebastes zacentrus

Sebastes zacentrus ages were collected primarily in the Eastern GOA. The oldest male *S. zacentrus* was aged at 51 years while the oldest female was aged at 58 years. Females had a lower natural mortality under the Alverson-Carney method because of lower K, while males had a lower natural mortality under Hoenig because of a higher maximum age. Natural mortality was generally higher than the previous species because of slower growth and a lower maximum age.

Sebastes aleutianus

The sample size of *S. aleutianus* was quite small and originated exclusively from the Central GOA. Among *S. aleutianus* males, the oldest observed specimen was 73 years, while the oldest observed female was 65 years. These maximum ages are extremely conservative considering that *S. aleutianus* have been independently aged in excess of 200 years (Munk 2001). Therefore, the natural mortality estimates, which are approximately the same as those for *S. alutus,* are likely much higher than expected. Females and males appeared to have similar natural mortality rates.

Sebastes variegatus

Sebastes variegatus were collected in the Central and Western GOA with a total sample size of only 100. The maximum observed age of males was 32 while that for females was 34. Among all species observed in this report, *S. variegatus* had the highest estimated values of M and the lowest maximum ages. The maximum ages and growth parameters were similar between sexes resulting in similar estimates of natural mortality.

DISCUSSION

Growth

The LVB growth parameter estimates we calculated are, for the most part, comparable to previously published values. Table 17 displays LVB growth parameter estimates from our study and other publications. Note that not all studies have used the same techniques for determining age. Therefore, comparisons among studies may not be advisable since different ageing techniques may bias parameter estimates. Nevertheless, comparisons do provide for cursory evaluations of the estimated growth parameters. The largest disparity between the current estimates and previous estimates occurred among *S. aleutianus* and *S. zacentrus.*

Our growth parameters for *S. aleutianus* are highly different from those estimated by Westrheim and Harling (1975) and Nelson and Quinn (1987). In our study, L_∞ is smaller and K is much larger. Growth parameters estimated by us for *S. zacentrus* are vastly different from Westrheim and Harling (1975) but similar to Archibald et al. (1981). Relatively small sample sizes in our study may account for the perceived differences in parameter estimates among the different studies. Westrheim and Harling (1975) used ages based on surface reading of otoliths as opposed to our study and Archibald et al. (1981) which used the break-and-burn technique. Some of the disparate results have been caused by a lower average age from surface reading.

The apparent lack of a significant difference in growth parameters between male and female *S. aleutianus* is not without precedent. Nelson and Quinn (1987) also concluded that growth among the sexes was not significantly different. However, unlike the present study, Nelson and Quinn (1987) and Westrheim and Harling (1975) estimated a higher L_∞ value for females than for males. All three studies likely have too small a sample size to be confident in the growth parameters.

Parameter estimates for *S. polyspinis* are consistent with Clausen and Heifetz (2002). However, the L_∞ estimate presented in Westrheim and Tsuyuki (1971) is substantially smaller than our estimates or in Clausen and Heifetz (2002). This small L_∞ estimate is most likely explained by the fact that Westrheim and Tsuyuki used just two collection locations and small sample sizes to obtain their parameter estimates. In fact, the authors estimated the maximum age for males and females among their samples to be 13 and 15 years, respectively. In the present study, maximum age for both sexes was estimated at 72 years. The magnitude of such a difference is likely explained by both differences in ageing techniques and sampling differences between the two studies.

Differences in parameter estimates may be the result of larger processes at work other than simple variability due to random sampling. Spatial and temporal variability may contribute to differential growth opportunities among groups of fish. It has been demonstrated that growth can vary with latitude (Fraidenburg 1980, Wilkins 1980, Boehlert

1980, Pearson and Hightower 1990) and there is also evidence that growth may vary over time (Boehlert et al. 1989, Pearson and Hightower 1990).

Spatial variation in length-at-age is dramatically illustrated in the growth parameters estimated for *S. alutus*. For both sexes, a distinct pattern of growth occurs along a longitudinal gradient. The Eastern GOA has a distinctly different pattern than the Central GOA, and the AI and BS are much different than the GOA (Fig. 2). A longitudinal gradient in L_∞ is further supported by Archibald et al. (1981), who estimated an even higher L_∞ for *S. alutus* in British Columbia.

Between-area differences in *S. polyspinis* growth parameters are likely the result of spatial differences in growth. For this species, L_∞ was greatest in the Western GOA, dropped off in areas immediately adjacent, and dropped further in the Western AI (Fig. 3). This relationship may indicate that growth, or at least $L_{\infty,}$ is for some reason maximized in the Western GOA. This might be a result of this being the center of their optimum habitat, or the center of the distribution of their optimum prey species. Under this scenario, one would expect further reductions in L_∞ as distance from the Western GOA increases. Clausen and Heifetz (2002) also examined spatial differences in growth of *S. polyspinis*. They found that in the GOA, fish of both sexes grow faster when young and reach a larger maximum size than do fish from the AI.

The cause of spatial variation in growth is not completely known but variation in habitat is a likely cause. Other possible causes include genetic controls, trophic interactions including interspecific competition, and anthropogenic mechanisms such as fishing pressure. For example, *S. alutus* show a much larger Brody growth parameter in the Central and

Western GOA than the rest of its distribution. Given that most fishing pressure occurs in these areas, this could be a result of a density-dependent release where the most fishing pressure occurs.

In addition to spatial variation, temporal variation in growth was also detected among several species. The combined *S. alutus* data from all areas produces what appears to be a long-term increasing trend in L_∞ (Table 3). For both sexes combined, L_∞ increases from 377.2 mm in 1980 to 424.9 mm in 1999. However, the general increasing trend of L_∞ is influenced by a sampling schedule that sampled western populations to a greater extent earlier in the time series. Samples collected during the first 4 years of the data series were from either the AI or the BS. Six of the final 10 samples were collected from the GOA. If spatial differences in growth truly exist between AI, BS and GOA *S. alutus*, this sampling schedule could appear to result in a temporal trend in growth.

In Figure 9b, average length-at-age of 10-year-old male and female *S. alutus*, are plotted by year of collection. Average length-at-age does not increase uniformly. Instead, length-at-age increases rapidly during the first few collection years, but from 1984 onward, length-at-age consistently alternates between low and high values. This alternating pattern is a result of the collection schedule, which generally alternated between the GOA and the AI after 1984.

In Figures 9c and 9d, average length-at-age of GOA and AI 8- and 10-year-old *S. alutus* are plotted by year of collection. The plot of GOA *S. alutus* implies that length-at-age was stable during the period in which collections were made in the region. However, the plot of AI *S. alutus* displays greater variability and perhaps some indication of an increasing trend in length-at-age early in the time series. This early trend is based on just three data points (1980, 1983, and 1986) but a plot of length-at-age of BS fish reveals a similar trend. Boehlert et al. (1989) also found increasing growth rates on the west coast of North America from 1970 and into the early 1980s among *S. diploproa* and *S. pinniger*. Our F-test results support the claim for temporal variation in growth among *S. alutus* of the BS and AI. All between-year comparisons in the BS were significant and 90% of the between-year comparisons in the AI were significant compared to 70% of between-year comparisons in the GOA. One can only speculate about the cause of temporal variation in growth, but Boehlert et al. (1989) suggests that depleted stocks resulted in a density-dependent reaction to increased prey availability.

Growth of *S. polyspinis* within the GOA also differed temporally. Generally, L_∞ increased over time (Table 7). In 1984, L_∞ for both sexes combined was 375.5 mm and in 1999, L_∞ was 403.5 mm. However, in plots not presented, there was no apparent trend in average length-at-age among 7- and 9-year-old fish. Among-year comparisons of length-at-age data for other ages were not practical due to the paucity of data.

Although temporal differences in growth may occur, sampling differences are likely the cause of some of the significant differences detected between years in this study. For example, *S. alutus* were sampled from the BS in 1981 and 1982. For both sexes, growth was significantly different between years. It is unlikely, however, that in one year growth conditions could change so dramatically and length-at-age could be so different, especially given the slow nature of *S. alutus* growth. Thus, spatial differences in sampling procedures among years may result in apparent between-year differences in growth when spatial differences in growth or distribution of age classes occur within areas.

Mortality

In this study, natural mortality was estimated from life history parameters. In Table 18, mortality estimates from this and other studies are presented. Methods for determining mortality rates among the different studies are varied; nevertheless, mortality estimates from the present study are comparable to previous estimates.

Maximum age is an important component in both the Alverson-Carney and Hoenig methods for estimating M. In the Alverson-Carney method, t_m is used to approximate the critical age. The Hoenig method uses the proportion that survives to t_m in a regression equation that estimates mortality. Since these methods rely heavily on t_m, the methods are prone to overestimate mortality when small sample sizes are used. This is due to the fact that small samples are less likely to contain older individuals due to their scarcity within the population. Therefore, small samples have a tendency to produce larger estimates of M because they tend to employ smaller t_m values. This relationship may explain why the mortality estimates for *S. aleutianus* from this study are slightly higher than those previously published. In this study, only 215 individual *S. aleutianus* were aged and t_m within the sample was 73, compared with a t_m of 200+ years in Munk (2001). This small sample was likely not large enough to capture the full range of ages within the population and therefore the estimates of mortality rates were high.

Dependence on t_m may have also influenced mortality estimates for *S. alutus* and *S. polyspinis*. For these two species, there appeared to be a difference in mortality rates between regions. Mortality estimates for both species were greater within the GOA than within the AI region. However, the higher mortality rates in the GOA may be an indication of greater fishing mortality rather than an actual difference in natural mortality. This is because the methods used to determine M are dependent on t_m and do not take into account fishing mortality. Maximum ages of GOA *S. alutus* and *S. polyspinis* were lower than the maximum ages of fish from the AI. If fishing pressure varies between regions, t_m within a sample collected from a region with higher fishing pressure is likely to be lower because older individuals are more likely to be removed from the population. Therefore, in areas with greater fishing mortality, maximum age is likely to be lower and M is likely to be higher.

CONCLUSION

This research provides von Bertalanffy growth parameter and natural mortality estimates for seven *Sebastes* species of the North Pacific and Bering Sea. The estimates document life history parameters for areas and species that have sparse coverage in previously published works. Evidence for spatial variation in growth is apparent among *S. polyspinis* and evidence for spatial and temporal variation is apparent among *S. alutus*. Further analysis of spatiotemporal changes in growth and mortality should be conducted for at least these two species, and as more data becomes available for the other *Sebastes* species, these techniques could be extended to them. As stock assessment models become more complex and spatially explicit, fishery managers may wish to alter current stock assessment methods or harvest practices because of results from studies such as these.

In general, mortality estimates based on life history parameters may not provide the most accurate measurements of mortality. However, the estimates herein provide some basis for the management of stocks for which little information is known.

ACKNOWLEDGMENTS

We thank Kris Munk and the staff at the ADF&G Age Laboratory in Juneau and the numerous otolith readers at the Alaska Fisheries Science Center's Age and Growth Program in Seattle.

CITATIONS

Alverson, D. L., and M. J. Carney. 1975. A graphic review of the growth and decay of population cohorts. J. Cons. Int. Explor. Mer. 36:133-143.

Archibald, C. P., W. Shaw, and B. M. Leaman. 1981. Growth and mortality estimates of rockfishes (Scorpaenidae) from B.C. coastal waters, 1977-1979. Can. Tech. Rep. Fish. Aquat. Sci. No. 1048.

Boehlert, G. W. 1980. Size composition, age composition, and growth of canary rockfish, *Sebastes pinniger*, and splitnose rockfish, *S. diploproa*, from the 1977 rockfish survey. Mar. Fish. Rev. 42(3-4):57-63.

Boehlert, G. W., M. M. Yoklavich, and D. B. Chelton. 1989. Time series of growth in the genus *Sebastes* from the northeast Pacific Ocean. Fish. Bull., U.S. 87(4):791-806.

Chilton, D. E., and R. J. Beamish. 1982. Age determination methods for fishes studied by the groundfish program at the Pacific Biological Station. Can. Spec. Pub. Fish. Aquat. Sci. 60, 102 p.

Clausen, D. M., and J. Heifetz. 1989. Slope rockfish, p. 99-149. *In* T. K. Wilderbuer (ed.), Condition of groundfish resources of the Gulf of Alaska in 1988. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-165.

Clausen, D. M., and J. Heifetz. 2002. The northern rockfish, *Sebastes polyspinis*, in Alaska: commercial fishery, distribution, and biology. Mar. Fish. Rev. 64(4):1-27.

Fraidenburg, M. E. 1980. Yellowtail rockfish, *Sebastes flavidus*, length and age composition off California, Oregon, and Washington in 1977. Mar. Fish Rev. 42(3-4):54-56.

Gunderson, D. R. 1980. Using *r-K* selection theory to predict natural mortality. Can. J. Fish. Aquat. Sci. 37:2266-2271.

Hanselman, D., J. Heifetz, J. T. Fujioka, and J. N. Ianelli. 2005. Gulf of Alaska Pacific ocean perch, p. 525-578. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite 306, Anchorage, AK 99501.

Heifetz, J., and D. M. Clausen. 1991. Slope rockfish, p. 5-1 – 5-30. *In* Stock assessment and fishery evaluation report for the 1992 Gulf of Alaska groundfish fishery. North Pacific Fishery Management Council, 605 W. 4th Ave, Suite 306, Anchorage, AK 99501.

Heifetz, J., J. N. Ianelli, D. M. Clausen, and J. T. Fujioka. 1999. Slope rockfish, p. 6-1 – 6-49. *In* Stock assessment and fishery evaluation report for the 2000 Gulf of Alaska groundfish fishery. North Pacific Fishery Management Council, 605 W. 4th Ave, Suite 306, Anchorage, AK 99501.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull., U.S. 82:898-903.

McDermott, S. F. 1994. Reproductive biology of rougheye and shortraker rockfish, *Sebastes aleutianus* and *Sebastes borealis*. Masters Thesis, Univ. Washington. Seattle, WA. 76 p.

Munk, K. M. 2001. Maximum ages of groundfish in waters off Alaska and British Columbia and considerations of age determination. Alaska Fish. Res. Bull. 8(1):12-21.

Nelson, B. D., and T. J. Quinn. 1987. Population parameters of rougheye rockfish (*Sebastes aleutianus*), p. 209-228. *In* Proc. Int. Rockfish Symp. Univ. Alaska Sea Grant Report No. 87-2.

NMFS (National Marine Fisheries Service). 2007. Historical catch statistics. NMFS Alaska Region, Sustainable Fisheries Division. Available: *www.fakr.noaa.gov/sustainable fisheries/catchstats.htm* (April 2007).

Pearson, D. E., and J. E. Hightower. 1990. Spatial and temporal variability in growth of widow rockfish (*Sebastes entomelas*). U.S. Dep. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-167, 43 p.

Quinn, T. J. II, and R. B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press. New York.

SAS Institute Inc. 1996. SAS/STAT guide for personal computers, Proprietary Software Release 6.11. SAS Institute Inc., Cary, North Carolina.

Shepherd, S. A., and P. A. Breen. 1992. Mortality in abalone: its estimation, variability, and causes, p. 276-304. *In* S. A. Shepherd, M. J. Tegner, and S. A. Guzman del Proo, (eds.), Abalone of the world: Biology, fisheries, and culture. Fishing News Books, Cambridge, UK.

von Bertalanffy, L. 1938. A quantitative theory of organic growth. Hum. Biol. 10:181-213.

Westrheim, S. J., and W. R. Harling. 1975. Age-length relationships for 26 scorpaenids in the northeast Pacific Ocean. Fish. Mar. Serv., Res. Dev. Dir. Tech. Rep. 565, 12 p.

Westrheim S. J., and H. Tsuyuki. 1971. Taxonomy, distribution, and biology of the northern rockfish, *Sebastes polyspinis*. J. Fish. Res. Bd. Can. 30:235-247.

Wilkins, M. E. 1980. Size composition, age composition, and growth of chilipepper, *S. goodei*, and bocaccio, *S. paucispinis*, from the 1977 rockfish survey. Mar. Fish. Rev. 42(3-4):48-53.

Table 1.--List of rockfish species for which growth and mortality was estimated in order of sample size.

Scientific Name	Common Name
Sebastes alutus	Pacific ocean perch
Sebastes polyspinis	Northern rockfish
Sebastes variabilis	Dusky rockfish
Sebastes brevispinis	Silvergray rockfish
Sebastes zacentrus	Sharpchin rockfish
Sebastes aleutianus	Rougheye rockfish
Sebastes variegatus	Harlequin rockfish

Table 2.--F-statistics and probabilities from tests comparing von Bertalanffy growth parameters between sexes of seven species of the genus *Sebastes*. All years and areas combined.

Species	F-statistic	P-value
S. alutus	311.6	1.5 E-197
S. polyspinis	22.9	1.1 E-14
S. variabilis	14.7	1.8 E-9
S. brevispinis	23.5	1.4 E-14
S. zacentrus	56.8	1.0 E-30
S. variegatus	6.4	5.4 E-4
S. aleutianus	1.0	0.38

Table 3.--Estimated von Bertalanffy parameters for Pacific ocean perch (*Sebastes alutus*) by geographic area, year of collection, and sex. Asterisks indicate parameter was not estimated due to paucity of data.

		Females				Males				Sexes Combined			
Area	Year	L_∞	K	t_0	N	L_∞	K	t_0	N	L_∞	K	t_0	N
All Areas	All	413.8	0.175	-0.58	9486	392.1	0.190	-0.62	9806	403.3	0.181	-0.62	19292
	1980	391.1	0.144	-1.40	435	350.6	0.223	-0.02	455	377.2	0.167	-0.76	890
	1981	412.2	0.117	-2.22	649	384.4	0.132	-2.36	676	398.5	0.125	-2.25	1325
	1982	418.1	0.139	-1.46	224	386.2	0.173	-1.32	260	403.0	0.151	-1.60	484
	1983	403.1	0.145	-1.46	1210	379.1	0.168	-1.15	1283	391.5	0.154	-1.35	2493
	1984	423.2	0.186	-0.65	1103	406.4	0.202	-0.62	1308	412.2	0.198	-0.60	2411
	1986	412.4	0.170	-0.76	931	387.5	0.190	-0.64	929	401.6	0.175	-0.77	1860
	1987	422.5	0.193	-0.30	869	401.3	0.212	-0.32	911	411.2	0.203	-0.31	1780
	1990	419.2	0.182	-0.57	890	397.8	0.207	-0.40	874	410.1	0.190	-0.55	1764
	1991	415.8	0.164	-0.53	529	394.6	0.161	-1.6	593	404.5	0.163	-0.86	1122
	1993	430.2	0.169	-0.60	773	409.8	0.176	-0.81	710	421.8	0.170	-0.75	1483
	1994	434.4	0.134	-1.23	422	402.2	0.155	-1.06	419	419.2	0.142	-1.18	841
	1996	445.7	0.150	-1.23	377	402.2	0.199	-0.69	341	427.5	0.165	-1.09	718
	1997	445.6	0.137	-0.81	612	411.1	0.152	-0.93	547	431.5	0.141	-0.91	1159
	1999	440.0	0.149	-0.89	462	413.0	0.170	-0.68	500	424.9	0.161	-0.76	962
GOA	All	424.9	0.182	-0.47	4474	404.4	0.200	-0.45	4644	413.8	0.192	-0.45	9118
	1984	423.2	0.186	-0.65	1103	406.4	0.202	-0.62	1308	412.2	0.198	-0.60	2411
	1987	422.5	0.193	-0.30	869	401.3	0.212	-0.32	911	411.2	0.203	-0.31	1780
	1990	419.2	0.182	-0.57	890	397.8	0.207	-0.40	874	410.1	0.190	-0.55	1764
	1993	430.2	0.169	-0.60	773	409.8	0.176	-0.81	710	421.8	0.170	-0.75	1483
	1996	445.7	0.150	-1.23	377	402.2	0.200	-0.69	341	427.5	0.165	-1.09	718
	1999	440.0	0.149	-0.89	462	413.0	0.170	-0.68	500	424.9	0.161	-0.76	962
AI	All	410.0	0.161	-0.69	4087	384.5	0.177	-0.76	4170	398.7	0.166	-0.78	8257
	1980	391.1	0.144	-1.40	435	350.6	0.223	-0.02	455	377.2	0.167	-0.76	890
	1983	403.1	0.145	-1.46	1210	379.1	0.168	-1.15	1283	391.5	0.154	-1.35	2493
	1986	412.4	0.170	-0.76	931	387.5	0.190	-0.64	929	401.6	0.175	-0.77	1860
	1991	414.1	0.165	-0.43	477	392.2	0.159	-1.24	537	402.6	0.162	-0.88	1014
	1994	434.4	0.134	-1.23	422	402.2	0.155	-1.06	419	419.2	0.142	-1.18	841
	1997	445.6	0.137	-0.81	612	411.1	0.152	-0.93	547	431.5	0.141	-0.91	1159
BS	All	413.5	0.129	-1.74	925	385.4	0.152	-1.60	992	399.6	0.140	-1.66	1917
	1981	412.2	0.117	-2.22	649	384.4	0.132	-2.36	676	398.5	0.125	-2.25	1325
	1982	418.1	0.139	-1.46	224	386.2	0.173	-1.32	260	403.0	0.151	-1.60	484
	1991	413.9	0.200	-1.05	52	399.3	0.202	-0.58	56	406.7	0.194	-1.07	108
Eastern GOA	All	431.7	0.173	-0.41	2481	412.7	0.180	-0.60	2493	421.8	0.177	-0.50	4974
	1984	452.9	0.115	-3.96	534	431.6	0.090	-8.31	670	435.7	0.104	-6.14	1204
	1987	423.6	0.196	-0.13	483	403.3	0.212	-0.13	465	414.9	0.200	-0.19	948
	1990	423.3	0.169	-0.70	486	398.8	0.188	-0.81	471	413.5	0.172	-0.88	957
	1993	428.4	0.178	-0.06	491	406.8	0.185	-0.22	420	420.2	0.178	-0.19	911
	1996	458.6	0.138	-1.25	196	411.3	0.169	-1.17	158	442.0	0.143	-1.39	354
	1999	443.6	0.141	-1.00	291	420.5	0.155	-0.95	309	431.8	0.148	-0.98	600

Table 3. -- Cont.

		Females				Males				Sexes Combined			
Area	Year	L_∞	K	t_0	N	L_∞	K	t_0	N	L_∞	K	t_0	N
Central GOA	All	416.2	0.204	-0.239	1412	396.7	0.227	-0.142	1541	405.3	0.217	-0.18	2953
	1984	410.6	0.211	-0.27	493	389.8	0.254	0.10	547	398.8	0.232	-0.10	1040
	1987	417.1	0.215	0.11	165	401.5	0.211	-0.28	206	406.3	0.221	0.02	371
	1990	415.1	0.199	-0.35	360	399.9	0.218	-0.20	359	408.3	0.206	-0.30	719
	1993	438.4	0.163	-0.85	177	416.5	0.189	-0.64	191	428.2	0.174	-0.77	368
	1996	420.3	0.213	-0.09	99	403.3	0.219	-0.20	103	411.0	0.217	-0.13	202
	1999	434.9	0.163	-0.79	118	405.8	0.195	-0.44	135	415.9	0.185	-0.50	253
Western GOA	All	413.2	0.204	-0.33	581	390.4	0.245	-0.00	610	399.7	0.228	-0.12	1191
	1984	431.6	0.101	-6.81	76	383.4	0.259	-0.35	91	389.1	0.237	-0.64	167
	1987	421.1	0.186	-0.61	221	395.0	0.235	-0.18	240	405.0	0.213	-0.36	461
	1990	*	*	*	44	*	*	*	44	411.7	0.248	0.52	88
	1993	413.7	0.213	-0.20	105	408.8	0.177	-1.15	99	408.9	0.203	-0.48	204
	1996	441.8	0.128	-2.72	82	362.7	0.348	0.56	80	399.9	0.204	-0.82	162
	1999	408.2	0.198	-0.11	53	380.1	0.236	0.19	56	393.4	0.219	0.09	109
Eastern AI	All	407.1	0.170	-0.54	2241	385.7	0.181	-0.61	2237	397.3	0.174	-0.59	4478
	1980	380.1	0.170	-1.31	238	354.8	0.233	0.18	243	369.5	0.207	-0.02	481
	1983	400.4	0.172	-0.54	774	378.8	0.190	-0.37	732	390.3	0.180	-0.45	1506
	1986	413.0	0.171	-0.68	526	393.3	0.176	-0.86	537	404.5	0.170	-0.83	1063
	1991	408.8	0.158	-0.83	216	393.3	0.150	-1.55	267	399.2	0.154	-1.22	483
	1994	441.1	0.128	-1.24	204	406.4	0.159	-0.73	206	424.8	0.140	-1.03	410
	1997	455.6	0.135	-0.71	283	415.6	0.156	-0.74	252	437.7	0.143	-0.75	535
Western AI	All	416.0	0.149	-0.90	1846	381.8	0.174	-0.94	1933	402.2	0.154	-1.07	3779
	1980	406.2	0.112	-2.29	197	342.6	0.222	-0.22	212	391.3	0.125	-2.09	409
	1983	419.8	0.104	-3.53	436	381.7	0.133	-3.13	551	397.3	0.120	-3.29	987
	1986	411.6	0.169	-0.87	405	377.9	0.233	0.24	392	397.3	0.186	-0.60	797
	1991	423.1	0.170	0.05	261	381.4	0.188	-0.52	270	412.9	0.162	-0.50	531
	1994	422.7	0.146	-1.11	218	401.1	0.137	-2.29	213	412.5	0.141	-1.62	431
	1999	438.0	0.137	-0.91	329	406.6	0.149	-1.09	295	426.2	0.139	-1.05	624

Table 4.--F-statistics and probabilities from tests comparing von Bertalanffy growth parameters of male and female Pacific ocean perch (*Sebastes alutus*) between regions for all years combined. Comparisons of male values are above the diagonal. Female values are below the diagonal in italics.

		GOA	AI	BS
GOA	F-statistic		687.3	400.3
	P-value		0	1.1 E-235
AI	F-statistic	*520.0*		9.8
	P-value	*0*		1.8 E-06
BS	F-statistic	*352.0*	*24.5*	
	P-value	*8.6 E-209*	*1.0 E-15*	

Table 5.--F-statistics and probabilities from tests comparing von Bertalanffy growth parameters of male and female Pacific ocean perch (*Sebastes alutus*) between areas for all years combined. Comparisons of male values are above the diagonal. Female values are below the diagonal in italics.

		BS	W. AI	E. AI	W. GOA	C. GOA	E. GOA
BS	F-statistic		4.5	19.3	261.1	386.3	350.1
	P-value		0.004	2.2 E-12	7.8 E-138	1.6 E-206	1.2 E-198
W. AI	F-statistic	*15.3*		6.8	145.3	293.6	317.1
	P-value	*7.4 E-10*		1.4 E-4	7.2 E-87	7.8 E-170	1.6 E-186
E. AI	F-statistic	*38.5*	*12.4*		195.9	349.7	347.8
	P-value	*2.0 E-24*	*4.7 E-8*		1.8 E-115	2.4 E-200	4.7 E-204
W. GOA	F-statistic	*222.2*	*122.4*	*134.6*		2.5	39.4
	P-value	*3.1 E-119*	*8.7 E-74*	*1.8 E-81*		0.060	5.7 E-25
C. GOA	F-statistic	*314.4*	*226.8*	*237.5*	*1.0*		62.7
	P-value	*2.2 E-171*	*1.3 E-133*	*9.9 E-141*	*0.414*		1.3 E-39
E. GOA	F-statistic	*304.3*	*237.3*	*267.0*	*20.8*	*43.3*	
	P-value	*5.7 E-175*	*1.5 E-142*	*4.6 E-160*	*2.4 E-13*	*1.7 E-27*	

Table 6.--Parameter estimates and correlation between parameters for best length prediction model for Pacific ocean perch (*Sebastes alutus*) chosen by best Akaike Information Criterion.

	Value	Std. Error	t-value
L_∞	493.055	2.7939	176.476
k	0.176458	0.001045	168.786
t_0	-0.60562	0.027213	-22.2549
a	12.7936	0.484612	26.3997
b	0.488797	0.015009	32.5669
c	-0.03397	0.003769	-9.0138

Correlation of parameter estimates:

	L_∞	k	t_0	a	b
k	-0.157				
t_0	-0.156	0.871			
a	-0.0685	-0.036	-0.0317		
b	0.926	-0.0896	-0.0913	0.0194	
c	-0.505	-0.102	0.0364	0.00575	-0.196

Table 7.--Estimated von Bertalanffy parameters for northern rockfish (*Sebastes polyspinis*) by geographic area, year of collection, and sex. Asterisks indicate parameter was not estimated due to paucity of data.

		Females				Males				Sexes Combined			
Area	Year	L_∞	K	t_0	N	L_∞	K	t_0	N	L_∞	K	t_0	N
All Areas	All	375.6	0.178	-0.31	1900	357.4	0.205	-0.04	1774	367.8	0.187	-0.25	3674
	1984	389.1	0.131	-3.10	181	346.2	0.202	-1.60	175	375.5	0.129	-4.18	356
	1986	349.1	0.106	-6.09	286	331.9	0.111	-7.15	279	342.7	0.103	-7.16	565
	1987	384.3	0.153	-1.89	262	358.8	0.200	-0.85	235	373.0	0.169	-1.51	497
	1990	399.0	0.167	-0.11	237	371.7	0.205	0.27	202	386.9	0.182	0.05	439
	1993	411.6	0.148	-0.97	181	399.7	0.173	-0.33	173	406.4	0.159	-0.67	354
	1994	326.0	0.251	1.52	214	324.5	0.213	0.49	195	325.4	0.230	1.02	409
	1996	421.2	0.157	-0.05	214	402.9	0.175	0.15	248	412.7	0.164	0.01	462
	1997	371.7	0.158	-0.44	165	330.7	0.230	0.52	134	355.0	0.180	-0.09	299
	1999	413.8	0.178	0.25	160	393.6	0.202	0.15	133	403.5	0.191	0.30	293
GOA	All	403.7	0.155	-0.72	1235	381.0	0.186	-0.25	1166	393.5	0.166	-0.55	2401
	1984	389.1	0.131	-3.10	181	346.2	0.202	-1.60	175	375.5	0.129	-4.18	356
	1987	384.3	0.153	-1.89	262	358.8	0.200	-0.85	235	373.0	0.169	-1.51	497
	1990	399.0	0.167	-0.11	237	371.7	0.205	0.27	202	386.9	0.182	0.05	439
	1993	411.6	0.148	-0.97	181	399.7	0.173	-0.33	173	406.4	0.159	-0.67	354
	1996	421.2	0.157	-0.05	214	402.9	0.175	0.15	248	412.7	0.164	0.01	462
	1999	413.8	0.178	0.25	160	393.6	0.202	0.15	133	403.5	0.191	0.30	293
AI	All	343.6	0.173	-0.49	665	324.0	0.216	0.18	608	335.3	0.187	-0.27	1273
	1986	349.1	0.106	-6.09	286	331.9	0.111	-7.25	279	342.7	0.103	-7.16	565
	1994	326.0	0.251	1.52	214	324.5	0.213	0.49	195	325.4	0.230	1.02	409
	1997	371.7	0.158	-0.44	165	330.7	0.230	0.52	134	355.0	0.180	-0.09	299
Eastern GOA	1996	*	*	*	4	*	*	*	6	*	*	*	10
Central GOA	All	400.5	0.153	-1.06	738	376.6	0.190	-0.33	701	390.2	0.166	-0.78	1439
	1984	348.6	0.285	0.89	82	338.5	0.204	-2.23	91	342.6	0.255	-0.09	173
	1987	374.5	0.168	-1.91	152	350.5	0.241	-0.18	142	365.3	0.187	-1.32	294
	1990	397.2	0.144	-1.53	141	363.3	0.226	0.30	126	378.5	0.187	-0.30	267
	1993	408.7	0.142	-1.40	72	405.6	0.157	-0.74	64	407.5	0.149	-1.05	136
	1996	419.3	0.155	-0.10	154	396.1	0.174	0.07	162	409.4	0.160	-0.08	316
	1999	411.7	0.173	-0.09	137	391.5	0.195	-0.26	116	401.5	0.185	-0.08	253
Western GOA	All	406.1	0.167	0.13	493	384.8	0.193	0.28	459	396.1	0.177	0.170	952
	1984	391.3	0.167	-0.28	99	348.0	0.247	0.20	84	377.0	0.162	-1.39	183
	1987	392.9	0.161	-0.66	110	366.1	0.181	-0.97	93	378.4	0.177	-0.60	203
	1990	409.3	0.173	0.59	96	393.4	0.164	-0.07	76	403.9	0.166	0.25	172
	1993	411.5	0.162	-0.24	109	397.3	0.192	0.35	109	404.8	0.174	0.00	218
	1996	428.6	0.157	-0.00	56	415.2	0.182	0.70	80	420.8	0.172	0.45	136
	1999	*	*	*	23	*	*	*	17	*	*	*	40

Table 7. -- Cont.

		Females				Males				Sexes Combined			
Area	Year	L_∞	K	t_0	N	L_∞	K	t_0	N	L_∞	K	t_0	N
Eastern AI	All	392.4	0.150	-0.79	201	370.2	0.184	-0.15	188	384.4	0.158	-0.66	389
	1986	392.5	0.153	-1.31	71	369.4	0.226	0.31	69	383.8	0.167	-1.17	140
	1994	361.0	0.178	-0.58	82	370.8	0.162	-0.67	86	366.1	0.169	-0.65	168
	1997	*	*	*	48	*	*	*	33	409.3	0.142	-0.45	81
Western AI	All	335.2	0.138	-1.69	464	319.7	0.149	-1.69	420	329.2	0.139	-1.86	884
	1986	335.7	0.115	-3.82	215	330.7	0.083	-9.33	210	332.8	0.102	-5.58	425
	1994	320.6	0.190	0.78	132	315.6	0.149	-0.96	109	319.5	0.163	-0.21	241
	1997	357.5	0.143	-1.18	117	326.1	0.201	-0.06	101	343.4	0.163	-0.73	218

Table 8.--F-statistics and probabilities from tests comparing von Bertalanffy growth parameters of male and female northern rockfish (*Sebastes polyspinis*) between regions for all years combined. Comparisons of male values are above the diagonal. Female values are below the diagonal in italics.

		GOA	AI
GOA	F-statistic		308.3
	P-value		5.4 E-161
AI	F-statistic	*318.7*	
	P-value	*1.7 E-167*	

Table 9.--F-statistics and probabilities from tests comparing von Bertalanffy growth parameters of male and female northern rockfish (*Sebastes polyspinis*) between areas for all years combined. Comparisons of male values are above the diagonal. Female values are below the diagonal in italics.

		W. AI	E. AI	W. GOA	C. GOA
W. AI	F-statistic		139.2	360.8	407.2
	P-value		1.6 E-68	2.4 E-152	1.4 E-178
E. AI	F-statistic	*121.7*		11.0	8.4
	P-value	*9.6 E-63*		4.7 E-7	1.7 E-5
W. GOA	F-statistic	*361.2*	*14.4*		5.6
	P-value	*1.5 E-156*	*4.4 E-9*		8.4 E-4
C. GOA	F-statistic	*376.9*	*9.6*	*9.5*	
	P-value	*2.8 E-172*	*3.2 E-6*	*3.4 E-6*	

Table 10.--Estimated von Bertalanffy parameters for dusky rockfish (*Sebastes variabilis*) by geographic area, year of collection, and sex. Asterisks indicate parameter was not estimated due to paucity of data. NC denotes parameter was estimated but non-linear parameter estimation procedure failed to converge.

		Females				Males				Sexes Combined			
Area	Year	L_∞	K	t_0	N	L_∞	K	t_0	N	L_∞	K	t_0	N
GOA	All	469.5	0.235	1.23	987	455.4	0.253	1.28	910	463.1	0.242	1.24	1897
	1984	485.6	0.138	-2.18	86	488.5	0.127	-2.62	75	486.6	0.132	-2.42	161
	1987	479.5	0.163	-2.05	164	462.6	0.164	-3.01	163	473.1	0.162	-2.39	327
	1990	490.0	0.195	1.07	77	459.4	0.238	1.73	68	475.0	0.213	1.35	145
	1993	456.8	0.251	1.28	328	451.1	0.242	1.05	284	454.3	0.246	1.17	612
	1996	480.1	0.232	1.39	332	458.0	0.273	1.49	320	469.8	0.248	1.40	652
Eastern GOA	All	469.0	0.130	-9.37	159	443.7	0.668	5.48	142	454.9	0.220	-2.81	301
	1990	*	*	*	23	*	*	*	14	*	*	*	37
	1993	463.4	0.131	-11.36	55	NC	NC	NC	50	NC	NC	NC	105
	1996	472.3	0.169	-4.06	81	446.7	0.656	5.64	78	457.2	0.322	1.82	159
Central GOA	All	478.7	0.222	1.07	534	465.7	0.231	1.01	510	473.4	0.224	1.01	1044
	1984	*	*	*	35	*	*	*	34	418.7	0.443	2.87	69
	1987	444.7	0.261	-0.31	107	512.7	0.077	-10.09	109	459.2	0.169	-3.11	216
	1990	*	*	*	33	*	*	*	34	460.7	0.294	3.06	67
	1993	478.0	0.218	1.06	170	474.7	0.208	0.81	146	476.9	0.213	0.93	316
	1996	492.6	0.217	1.29	189	469.6	0.253	1.36	187	484.3	0.226	1.22	376
Western GOA	All	463.5	0.229	1.17	294	451.6	0.263	1.76	258	458.9	0.238	1.35	552
	1984	488.0	0.156	-0.59	51	*	*	*	41	489.5	0.147	-1.04	92
	1987	484.0	0.189	0.11	57	452.3	0.316	2.39	54	470.9	0.213	0.40	111
	1990	*	*	*	21	*	*	*	20	*	*	*	41
	1993	426.6	0.295	1.43	103	430.1	0.281	1.41	88	428.0	0.289	1.42	191
	1996	479.3	0.207	0.99	62	460.0	0.270	2.38	55	473.0	0.216	1.17	117

Table 11.--F-statistics and probabilities from tests comparing von Bertalanffy growth parameters of male and female dusky rockfish (*Sebastes variabilis*) between areas for all years combined. Comparisons of male values are above the diagonal. Female values are below the diagonal in italics.

		W. GOA	C. GOA	E. GOA
W. GOA	F-statistic		14.0	8.8
	P-value		6.4 E-9	1.1 E-5
C. GOA	F-statistic	*12.4*		11.1
	P-value	*6.4 E-9*		4.1 E-7
E. GOA	F-statistic	*9.0*	*8.1*	
	P-value	*8.3 E-6*	*2.8 E-5*	

Table 12.--Estimated von Bertalanffy parameters for silvergray rockfish (*Sebastes brevispinis*) by geographic area, year of collection, and sex. Note that t_0 was constrained at –1.68 to facilitate convergence of the parameter estimation procedure. Asterisks indicate parameter was not estimated due to paucity of data. NC denotes parameter was estimated but non-linear parameter estimation procedure failed to converge.

		Females				Males				Sexes Combined			
Area	Year	L_∞	K	t_0	N	L_∞	K	t_0	N	L_∞	K	t_0	N
GOA	All	622.5	0.093	-1.68	421	571.4	0.110	-1.68	423	598.0	0.100	-1.68	844
	1993	NC	NC	NC	67	465.7	0.328	-1.68	65	478.3	0.422	-1.68	132
	1996	652.7	0.080	-1.68	173	583.7	0.101	-1.68	191	620.3	0.088	-1.68	364
	1999	653.8	0.080	-1.68	181	594.8	0.098	-1.68	167	623.7	0.088	-1.68	348
Eastern GOA	All	619.1	0.095	-1.68	401	570.1	0.110	-1.68	403	595.4	0.101	-1.68	804
	1993	NC	NC	-1.68	67	465.7	0.328	-1.68	65	478.3	0.422	-1.68	132
	1996	652.7	0.080	-1.68	173	583.7	0.001	-1.68	191	620.3	0.088	-1.68	364
	1999	648.3	0.082	-1.68	161	593.4	0.097	-1.68	147	619.3	0.090	-1.68	308
Central GOA	1999	*	*	*	20	*	*	*	20	*	*	*	40

Table 13.--Estimated von Bertalanffy parameters for sharpchin rockfish (*Sebastes zacentrus*) by geographic area, year of collection, and sex. Asterisks indicate parameter was not estimated due to paucity of data.

		Females				Males				Sexes Combined			
Area	Year	L_∞	K	t_0	N	L_∞	K	t_0	N	L_∞	K	t_0	N
GOA	All	350.2	0.122	-0.75	245	284.4	0.167	-0.48	172	326.4	0.131	-0.81	417
	1996	347.7	0.112	-2.43	131	287.0	0.137	-2.54	76	323.8	0.118	-2.69	207
	1999	359.8	0.111	-0.63	114	285.1	0.169	-0.32	96	336.4	0.116	-0.97	210
Eastern GOA	All	348.8	0.118	-1.06	235	281.0	0.172	-0.46	162	324.4	0.129	-1.00	397
	1996	347.7	0.112	-2.43	131	287.0	0.137	-2.54	76	323.8	0.118	-2.69	207
	1999	358.4	0.102	-1.34	104	277.2	0.178	-0.29	86	333.8	0.109	-1.50	190
Central GOA	1999	*	*	*	10	*	*	*	10	*	*	*	20

Table 14.--Estimated von Bertalanffy parameters for rougheye rockfish (*Sebastes aleutianus*) by geographic area, year of collection, and sex. Asterisks indicate parameter was not estimated due to paucity of data.

		Females				Males				Sexes Combined			
Area	Year	L_∞	K	t_0	N	L_∞	K	t_0	N	L_∞	K	t_0	N
GOA	1990	495.7	0.100	0.18	114	497.9	0.119	1.14	101	496.3	0.108	0.63	215
Eastern GOA	1990	*	*	*	0	*	*	*	2	*	*	*	2
Central GOA	1990	496.7	0.099	0.18	109	497.7	0.120	1.20	99	496.8	0.109	0.67	208
Western GOA	1990	*	*	*	5	*	*	*	0	*	*	*	5

Table 15.--Estimated von Bertalanffy parameters for harlequin rockfish (*Sebastes variegatus*) by geographic area, year of collection, and sex. Asterisks indicate parameter was not estimated due to paucity of data.

		Females				Males				Sexes Combined			
Area	Year	L_∞	K	t_0	N	L_∞	K	t_0	N	L_∞	K	t_0	N
GOA	1999	323.2	0.110	-3.26	45	306.0	0.091	-4.76	55	315.1	0.099	-3.86	100
Eastern GOA	1999	*	*	*	15	*	*	*	22	300.2	0.069	-8.79	37
Central GOA	1999	*	*	*	30	*	*	*	33	320.8	0.128	-1.54	63

Table 16.--Mortality estimates calculated by area and sex for several rockfish species of the genus *Sebastes*. Mortality was estimated by the methods suggested in Alverson and Carney (1975) and Hoenig (1983). N is the number of observations; t_m is the maximum observed age in a sample. The critical age was calculated at 0.38 ($t^*_{(0.38)}$) and 0.25 ($t^*_{(0.25)}$) times t_m. Alverson-Carney (A-C) estimates of M were calculated with both t^* values. Hoenig's estimate (Hoe) was calculated with different values (0.01 and 0.05) for the proportion that survives to t_m. Subscripts in the column headings indicate the values used for the estimates of M.

Species	Sex	N	t_m	$t^*_{(0.38)}$	$t^*_{(0.25)}$	A-C$_{(0.38)}$	A-C$_{(0.25)}$	Hoe$_{(0.01)}$	Hoe$_{(0.05)}$
S. alutus									
All Areas	Combined	19292	98	37	25	0.001	0.007	0.047	0.031
	male	9806	92	35	23	0.001	0.007	0.050	0.033
	female	9486	98	37	25	0.001	0.007	0.047	0.031
GOA	Combined	9118	84	32	21	0.001	0.010	0.055	0.036
	male	4644	84	32	21	0.001	0.009	0.055	0.036
	female	4474	78	30	20	0.002	0.016	0.059	0.038
AI	Combined	8257	98	37	25	0.001	0.009	0.047	0.031
	male	4170	92	35	23	0.001	0.009	0.050	0.033
	female	4087	98	37	25	0.001	0.010	0.047	0.031
Eastern GOA	Combined	4974	84	32	21	0.002	0.013	0.055	0.036
	male	2493	84	32	21	0.002	0.013	0.055	0.036
	female	2481	78	30	20	0.003	0.018	0.059	0.038
Central GOA	Combined	2953	75	29	19	0.001	0.011	0.061	0.040
	male	1541	75	29	19	0.001	0.010	0.061	0.040
	female	1412	70	27	18	0.003	0.018	0.066	0.043
Western GOA	Combined	1191	75	29	19	0.001	0.010	0.061	0.040
	male	610	75	29	19	0.001	0.008	0.061	0.040
	female	581	70	27	18	0.003	0.018	0.066	0.043
BS	Combined	1917	91	35	23	0.003	0.018	0.051	0.033
	male	992	91	35	23	0.002	0.015	0.051	0.033
	female	925	84	32	21	0.006	0.028	0.055	0.036
Eastern AI	Combined	4478	98	37	25	0.001	0.007	0.047	0.031
	male	2237	92	35	23	0.001	0.009	0.050	0.033
	female	2241	98	37	25	0.001	0.008	0.047	0.031
Western AI	Combined	3779	93	35	23	0.002	0.013	0.050	0.032
	male	1933	81	31	20	0.002	0.016	0.057	0.037
	female	1846	93	35	23	0.002	0.014	0.050	0.032
S. polyspinis									
All Areas	Combined	3674	72	27	18	0.003	0.020	0.064	0.042
	male	1774	72	27	18	0.002	0.016	0.064	0.042
	female	1900	66	25	17	0.006	0.030	0.070	0.045

Table 16.-- Cont.

Species	Sex	N	t_m	$t^*_{(0.38)}$	$t^*_{(0.25)}$	A-C$_{(0.38)}$	A-C$_{(0.25)}$	Hoe$_{(0.01)}$	Hoe$_{(0.05)}$
GOA	Combined	2401	44	17	11	0.033	0.096	0.105	0.068
	male	1166	44	17	11	0.026	0.083	0.105	0.068
	female	1235	43	16	11	0.040	0.108	0.107	0.070
AI	Combined	1273	72	27	18	0.003	0.020	0.064	0.042
	male	608	72	27	18	0.002	0.014	0.064	0.042
	female	665	66	25	17	0.007	0.032	0.070	0.045
Central GOA	Combined	1439	43	16	11	0.035	0.100	0.107	0.070
	male	701	41	16	10	0.031	0.095	0.112	0.073
	female	738	43	16	11	0.041	0.110	0.107	0.070
Western GOA	Combined	952	44	17	11	0.029	0.088	0.105	0.068
	male	459	44	17	11	0.024	0.079	0.105	0.068
	female	493	43	16	11	0.035	0.100	0.107	0.070
Eastern AI	Combined	389	54	21	14	0.019	0.064	0.085	0.055
	male	188	49	19	12	0.019	0.065	0.094	0.061
	female	201	54	21	14	0.022	0.068	0.085	0.055
Western AI	Combined	884	72	27	18	0.010	0.037	0.064	0.042
	male	420	72	27	18	0.008	0.033	0.064	0.042
	female	464	66	25	17	0.013	0.047	0.070	0.045
S. variabilis									
All Areas	Combined	1897	59	22	15	0.003	0.021	0.078	0.051
	male	910	51	19	13	0.006	0.031	0.090	0.059
	female	987	59	22	15	0.004	0.023	0.078	0.051
Eastern GOA	Combined	301	51	19	13	0.009	0.043	0.090	0.059
	male	142	51	19	13	0.000	0.000	0.090	0.059
	female	159	41	16	10	0.059	0.140	0.112	0.073
Central GOA	Combined	1044	51	19	13	0.009	0.041	0.090	0.059
	male	510	51	19	13	0.008	0.038	0.090	0.059
	female	534	35	13	9	0.037	0.111	0.132	0.086
Western GOA	Combined	552	59	22	15	0.003	0.022	0.078	0.051
	male	258	49	19	12	0.006	0.033	0.094	0.061
	female	294	59	22	15	0.004	0.024	0.078	0.051
S. aleutianus									
All Areas	Combined	215	73	28	18	0.017	0.052	0.063	0.041
	male	101	73	28	18	0.014	0.046	0.063	0.041
	female	114	65	25	16	0.028	0.074	0.071	0.046
Central GOA	Combined	208	73	28	18	0.017	0.052	0.063	0.041
	male	99	73	28	18	0.013	0.045	0.063	0.041
	female	109	65	25	16	0.028	0.074	0.071	0.046

Table 16.-- Cont.

Species	Sex	N	t_m	$t^*_{(0.38)}$	$t^*_{(0.25)}$	A-C$_{(0.38)}$	A-C$_{(0.25)}$	Hoe$_{(0.01)}$	Hoe$_{(0.05)}$
S. brevispinis+									
All Areas	Combined	844	75	29	19	0.018	0.054	0.061	0.040
	male	423	75	29	19	0.015	0.048	0.061	0.040
	female	421	65	25	16	0.031	0.079	0.071	0.046
Eastern GOA	Combined	804	67	25	17	0.025	0.068	0.069	0.045
	male	403	67	25	17	0.021	0.062	0.069	0.045
	female	401	65	25	16	0.030	0.077	0.071	0.046
S. zacentrus									
All Areas	Combined	417	58	22	15	0.023	0.069	0.079	0.052
	male	172	51	19	13	0.020	0.068	0.090	0.059
	female	245	58	22	15	0.027	0.075	0.079	0.052
Eastern GOA	Combined	397	58	22	15	0.024	0.070	0.079	0.052
	male	162	51	19	13	0.019	0.065	0.090	0.059
	female	235	58	22	15	0.028	0.078	0.079	0.052
S. variegatus									
All Areas	Combined	100	34	13	9	0.115	0.225	0.135	0.088
	male	55	32	12	8	0.135	0.255	0.144	0.094
	female	45	34	13	9	0.105	0.213	0.135	0.088
Central GOA	Combined	63	34	13	9	0.091	0.195	0.135	0.088
	male	33	32	12	8	0.107	0.220	0.144	0.094
	female	30	34	13	9	0.095	0.201	0.135	0.088

+*S. brevispinis* von Bertalanffy parameters were estimated by constraining t_0 at -1.68 mm, the average value reported for other slope rockfish in Heifetz et al. (1999).

Table 17.--Comparison of von Bertalanffy parameters of *Sebastes* species from the present study and other published estimates. All parameters are estimates for both sexes combined.

Species	Location	t_0	K	L_∞ (mm)	Reference
S. alutus	British Columbia	-8.22	0.088	448.0	1
	British Columbia	-5.22	0.126	426.0	1
	Gulf of Alaska	-0.32	0.207	411.0	2
	Gulf of Alaska	-0.45	0.192	413.8	3
	Bering Sea	-1.66	0.140	399.6	3
	Aleutian Islands	-0.78	0.166	398.7	3
S. polyspinis	Gulf of Alaska	0.70	0.220	302.0	5[++]
	Gulf of Alaska	-1.51	0.190	356.0	2,4
	Gulf of Alaska	-0.55	0.166	393.5	3
	Aleutian Islands	-0.27	0.187	335.3	3
S. variabilis	Gulf of Alaska	1.24	0.242	463.1	3
S. brevispinis	British Columbia	-6.30[+]	0.080	585.0	1
	British Columbia	-6.30[+]	0.085	568.0	1
	Gulf of Alaska	-1.68[+]	0.100	598.0	3
S. zacentrus	British Columbia	-2.12	0.095	349.0	1
	British Columbia	-3.10	0.070	429.0	7[++]
	Gulf of Alaska	-0.81	0.131	326.4	3
S. aleutianus	British Columbia	-1.10	0.067	645.0	7[++]
	Gulf of Alaska	-4.21	0.050	547.4	6
	Gulf of Alaska	0.63	0.108	496.3	3
S. variegatus	British Columbia	-0.60	0.160	299.0	7[++]
	Gulf of Alaska	-3.86	0.099	315.1	3

1) Archibald et al. 1981; 2) Clausen and Heifetz 1989; 3) Present study; 4) Heifetz and Clausen 1991; 5) Westrheim and Tsuyuki 1971; 6) Nelson and Quinn 1987; 7) Westrheim and Harling 1975.

[+] *Sebastes brevispinis* von Bertalanffy parameters were estimated by constraining t_0 to the value given in the table.

[++] Ages were estimated from surface readings of whole otoliths.

Table 18.--Mortality rates and maximum age (t_m) for selected *Sebastes* species from the present study and other published estimates. Mortality rates determined by CC (catch curve), AC (Alverson and Carney 1975), GI (gonadal index, Gunderson 1980) and CO (combination). Combination estimates are an average value from the methods of both Alverson and Carney and Hoenig (1983), see text. All mortality estimates are instantaneous rates of natural mortality (*M*), except for catch curves, which estimate the instantaneous rate of total mortality (*Z*).

Species	Location	Mortality Rate	t_m	Method	Reference
S. alutus	British Columbia	0.02-0.08	90	CC	1,2
	Gulf of Alaska	0.025-0.032	84	CO	3
	Bering Sea	0.025-0.031	91	CO	3
	Aleutian Islands	0.021-0.028	98	CO	3
S. polyspinis	Gulf of Alaska	0.06	49	AC	4
	Gulf of Alaska	0.069-0.082	44	CO	3
	Aleutian Islands	0.030-0.060	72	CO	3
S. variabilis	Gulf of Alaska	0.038-0.096	59	CO	3
S. brevispinis	British Columbia	0.01-0.07	80	CC	1,2
	Gulf of Alaska	0.041-0.057	75	CO	3
S. zacentrus	British Columbia	0.05-0.07	45	CC	1
	Gulf of Alaska	0.056-0.059	58	CO	3
S. aleutianus	British Columbia	0.01-0.04	140	CC	1,2
	Gulf of Alaska	0.04	95	CC	5
	Various	0.030-0.039	na	GI	6
	Gulf of Alaska	0.041-0.055	73	CO	3
S. variegatus	Gulf of Alaska	0.127-0.157	34	CO	3

1) Archibald et al. 1981; 2) Chilton and Beamish 1982; 3) Present study; 4) Heifetz and Clausen 1991; 5) Nelson and Quinn 1987; 6) Mcdermott 1994.

Figure 1.--Map of the North Pacific Ocean and Bering Sea identifying the geographic designations used in the present study. The Gulf of Alaska (GOA) region is composed of the Eastern, Central, and Western GOA subareas. Likewise, the Aleutian Islands (AI) region is composed of the Eastern and Western AI subareas. Subareas generally correspond with North Pacific Fishery Management Council (NPFMC) management areas.

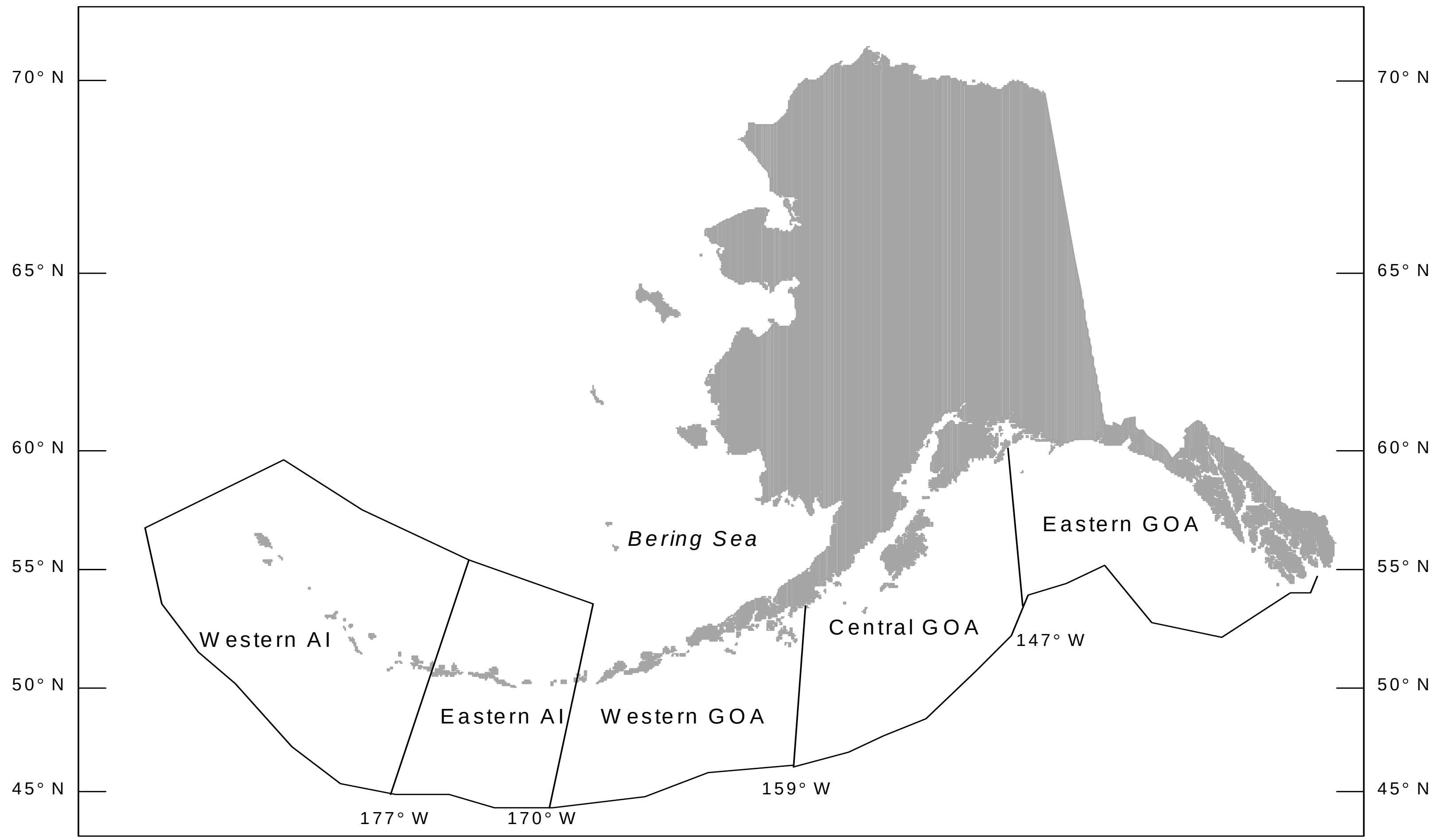


Figure 2.--a) Average and predicted length-at-age for male *Sebastes alutus* from the GOA and AI, all years combined. b) Average and predicted length-at-age for female *S. alutus* from the GOA and AI, all years combined. c) Predicted length-at-age by area for male *S. alutus*, all years combined. d) Predicted length-at-age by area for female *S. alutus*, all years combined.

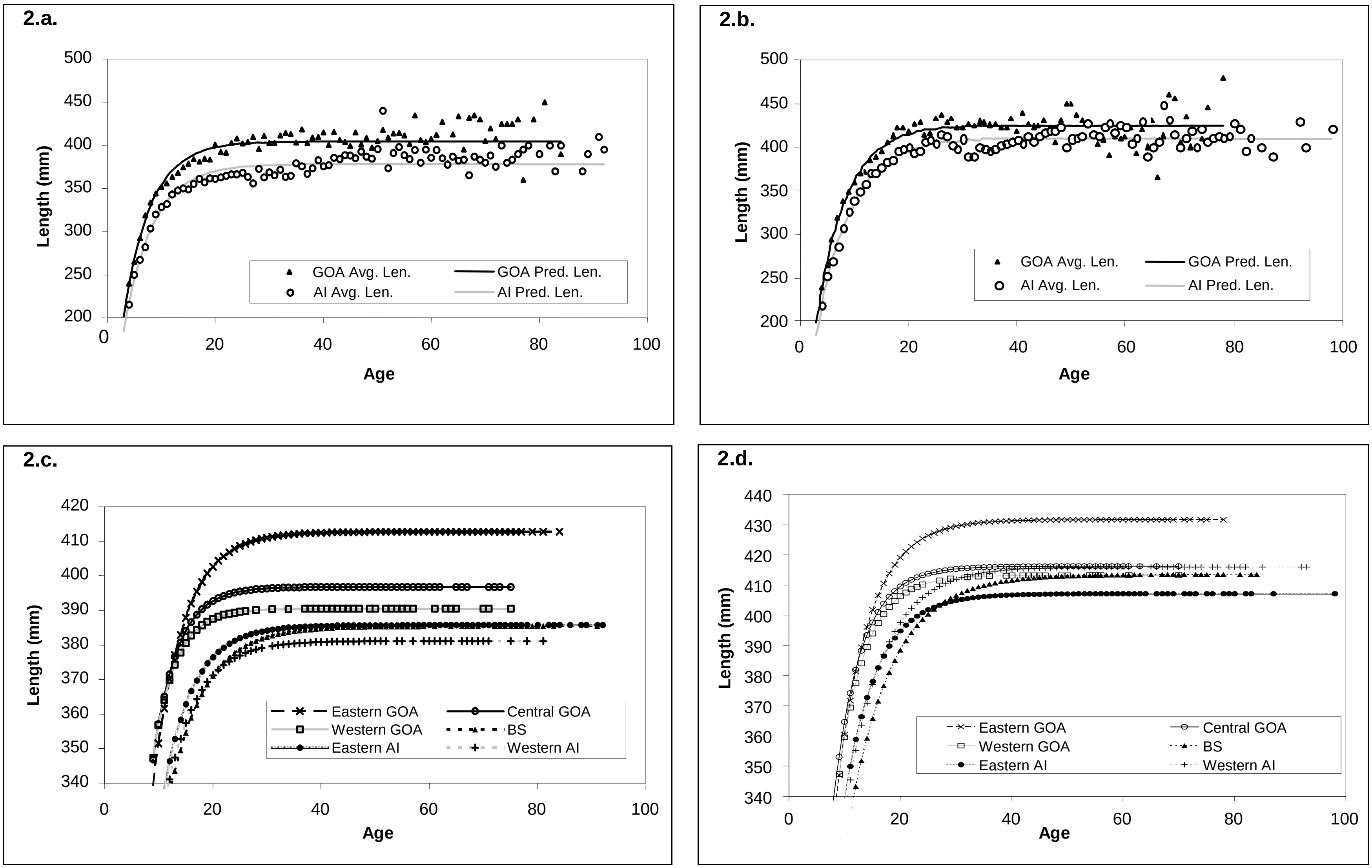


Figure 3.--LVB parameter estimates for male *Sebastes alutus* including 95% confidence intervals as binned across 10 longitudinal groups. Groups less than -180 represent values between 170º and 180º E. longitude.

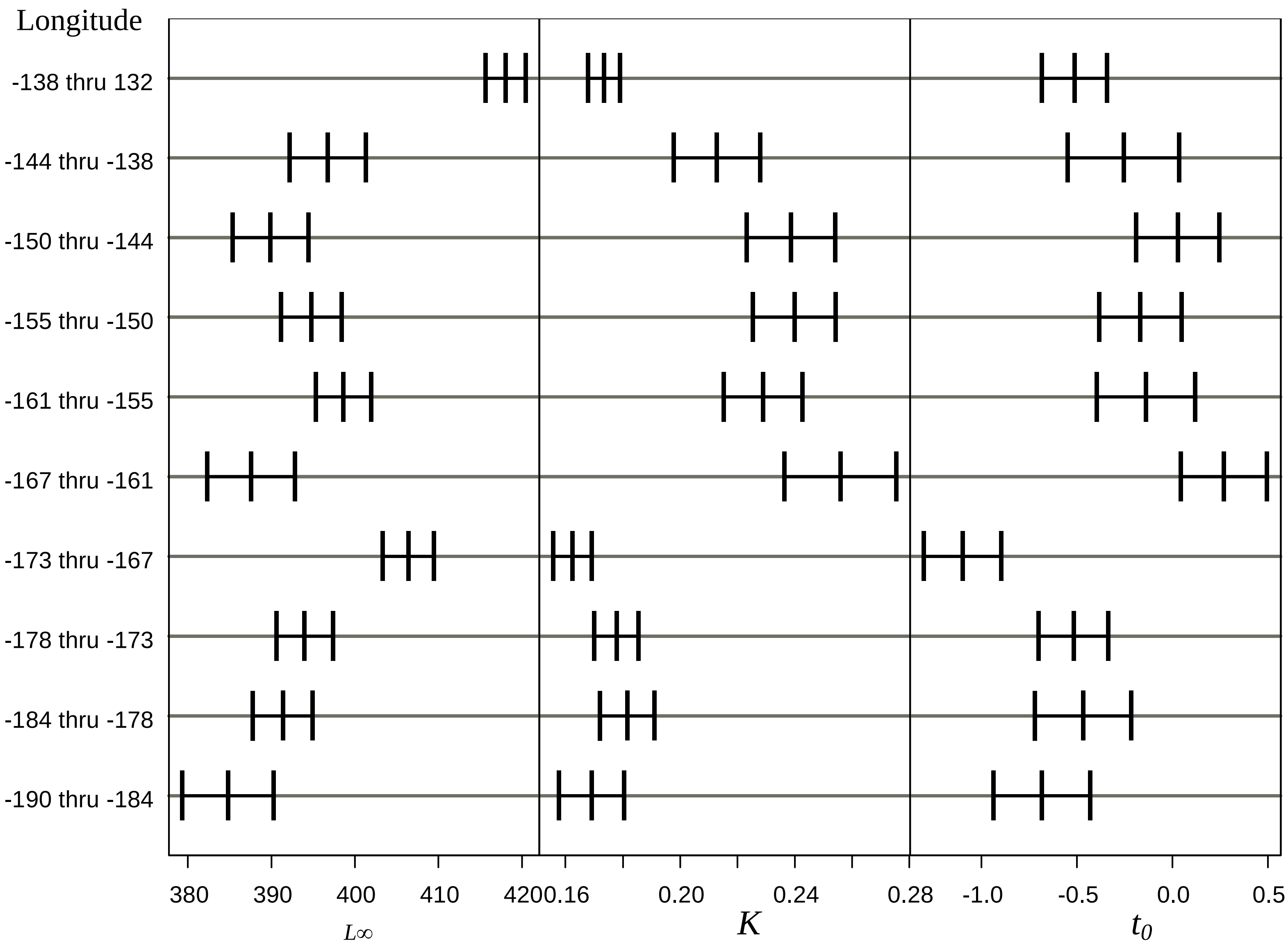


Figure 4.--LVB parameter estimates for female *Sebastes alutus* including 95% confidence intervals as binned across 10 longitudinal groups. Groups less than -180 represent values between 170º and 180º E. longitude.

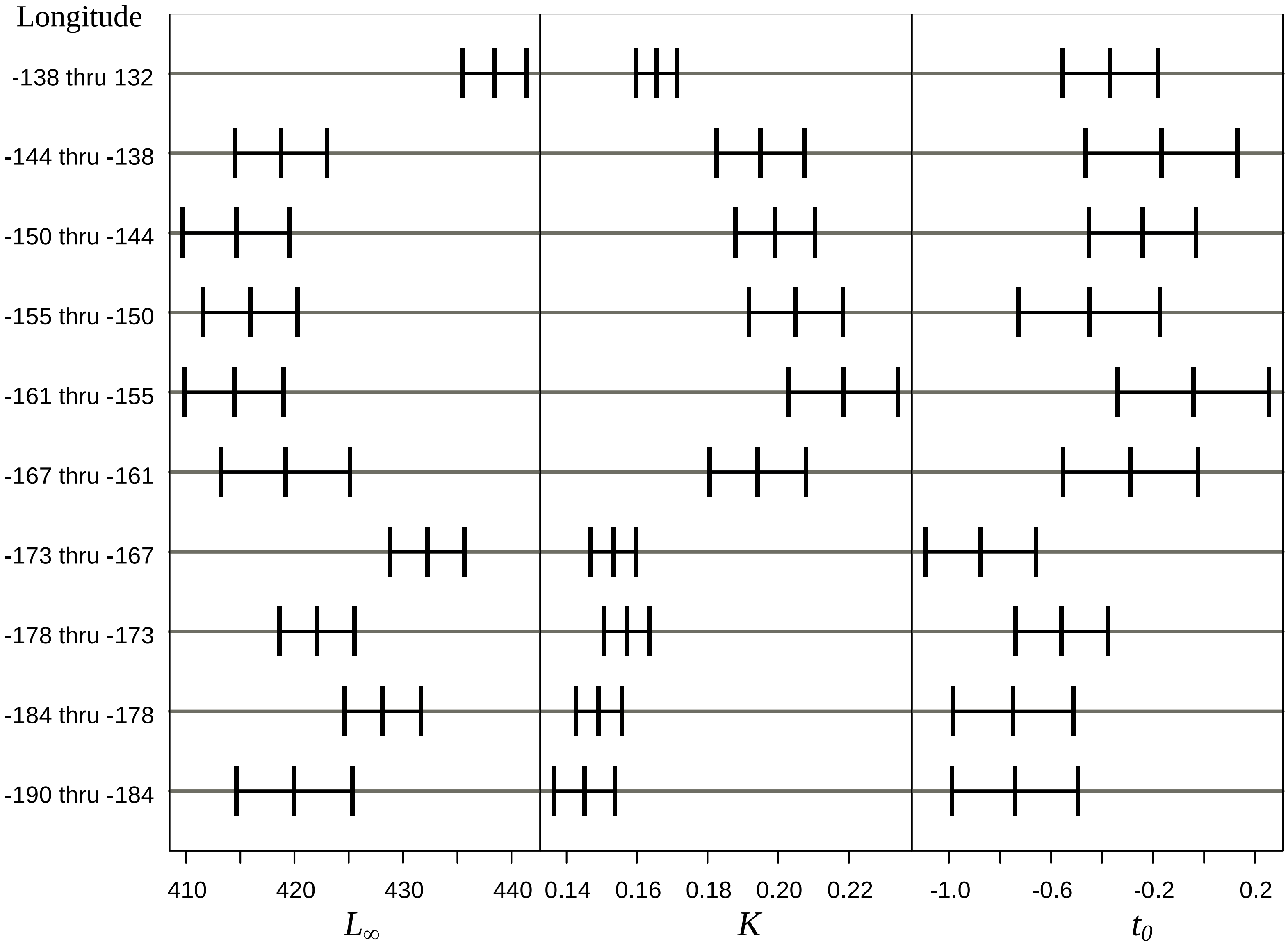


Figure 5.--Map of male growth parameter residuals from overall *Sebastes alutus* LVB growth parameters. Residuals are represented as percent of largest residual.

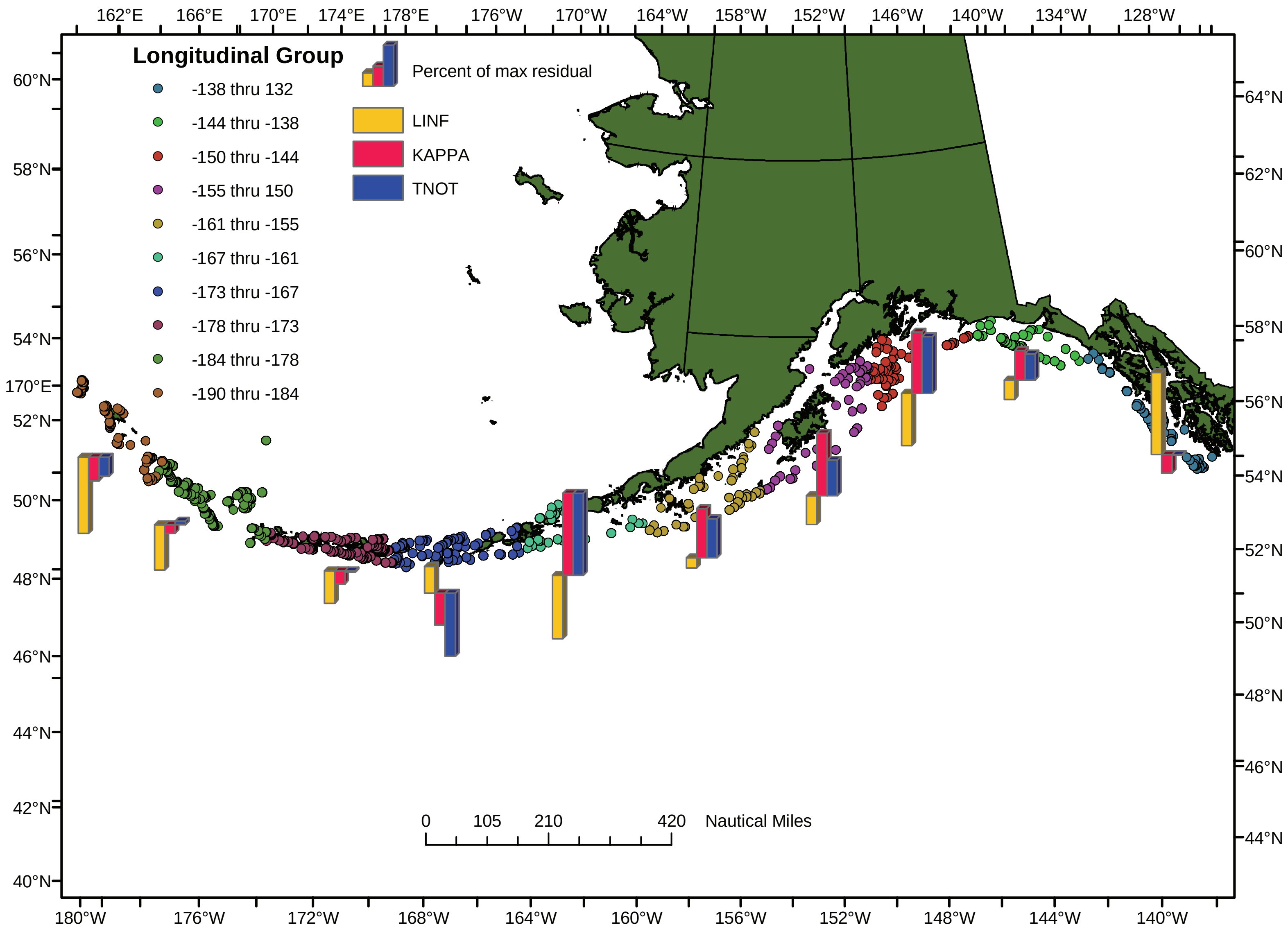


Figure 6.--Map of female growth paramater residuals from overall *Sebastes alutus* LVB growth parameters. Residuals are represented as percent of largest residual.

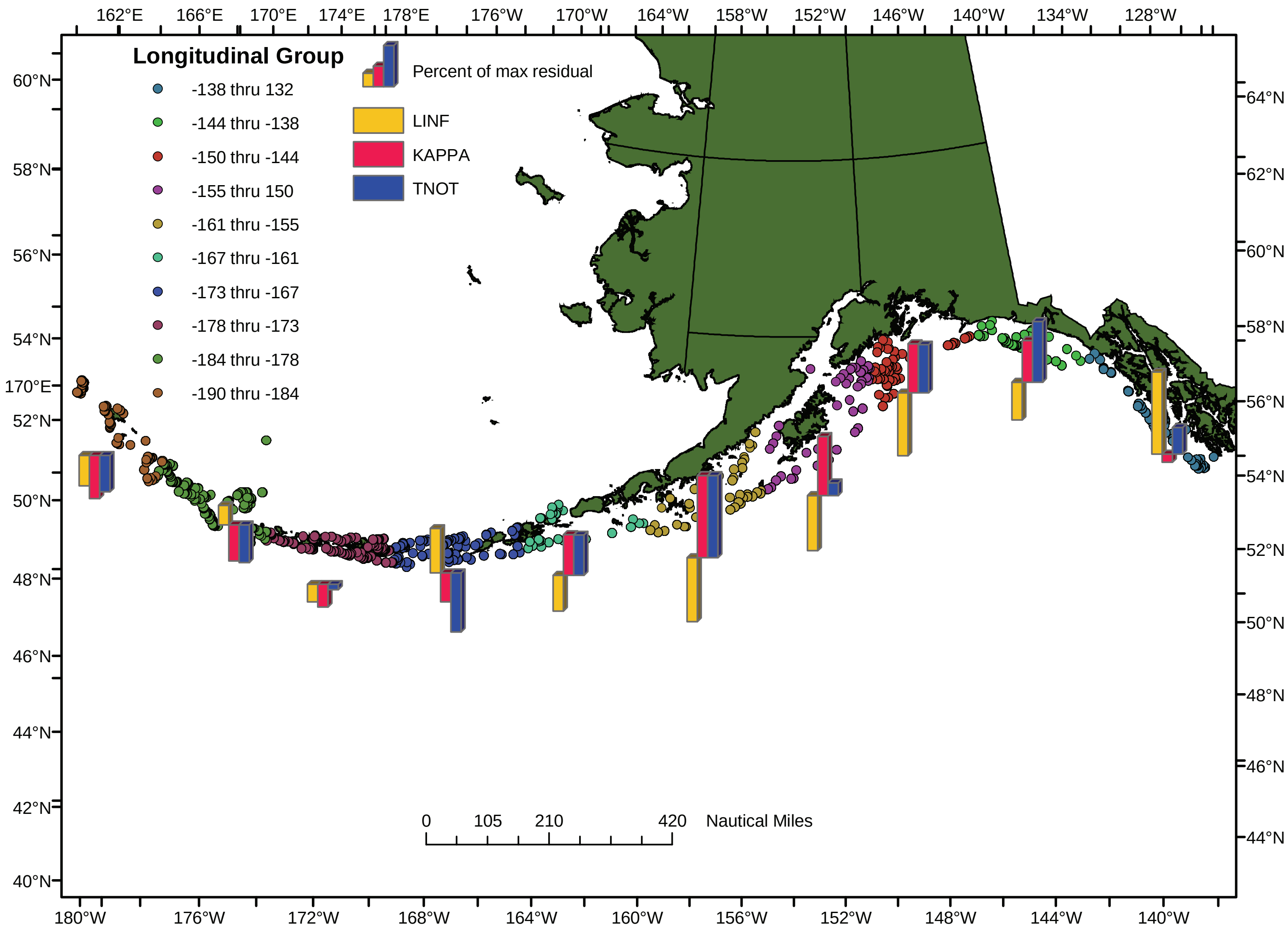


Figure 7.--a) Average and predicted length-at-age for male *Sebastes polyspinis* from the GOA and AI, all years combined. b) Average and predicted length-at-age for female *S. polyspinis* from the GOA and AI, all years combined. c) Predicted length-at-age by area for male *S. polyspinis*, all years combined. d) Predicted length-at-age by area for female *S. polyspinis*, all years combined.

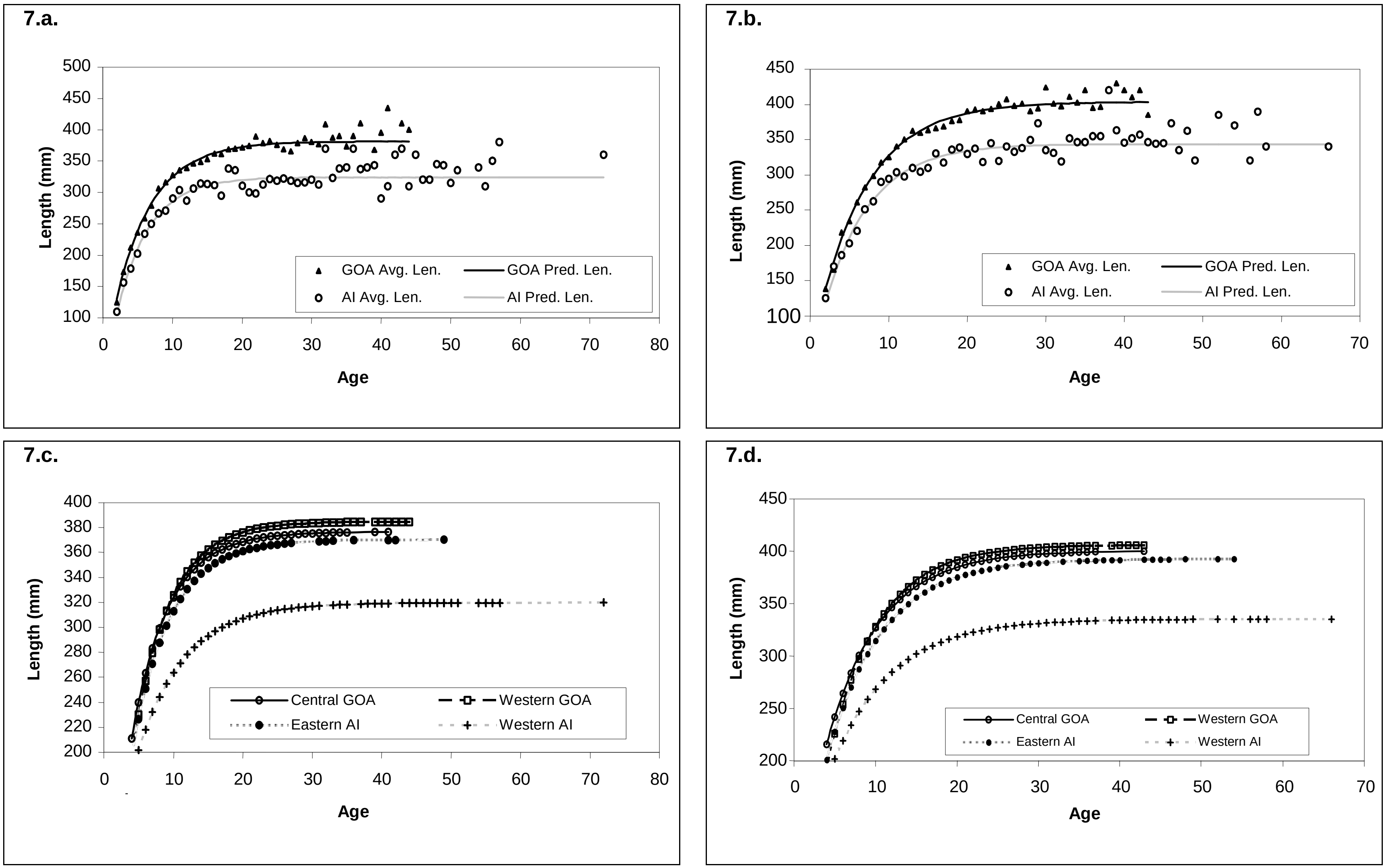


Figure 8.--a) Average and predicted length-at-age for male and female *S. variabilis*, all areas and years combined. b) Average and predicted length-at-age for male and female *S. brevispinis*, all areas and years combined. c) Average and predicted length-at-age for male and female *Sebastes zacentrus*, all areas and years combined. d) Average and predicted length-at-age for male and female *Sebastes aleutianus*, all areas and years combined.

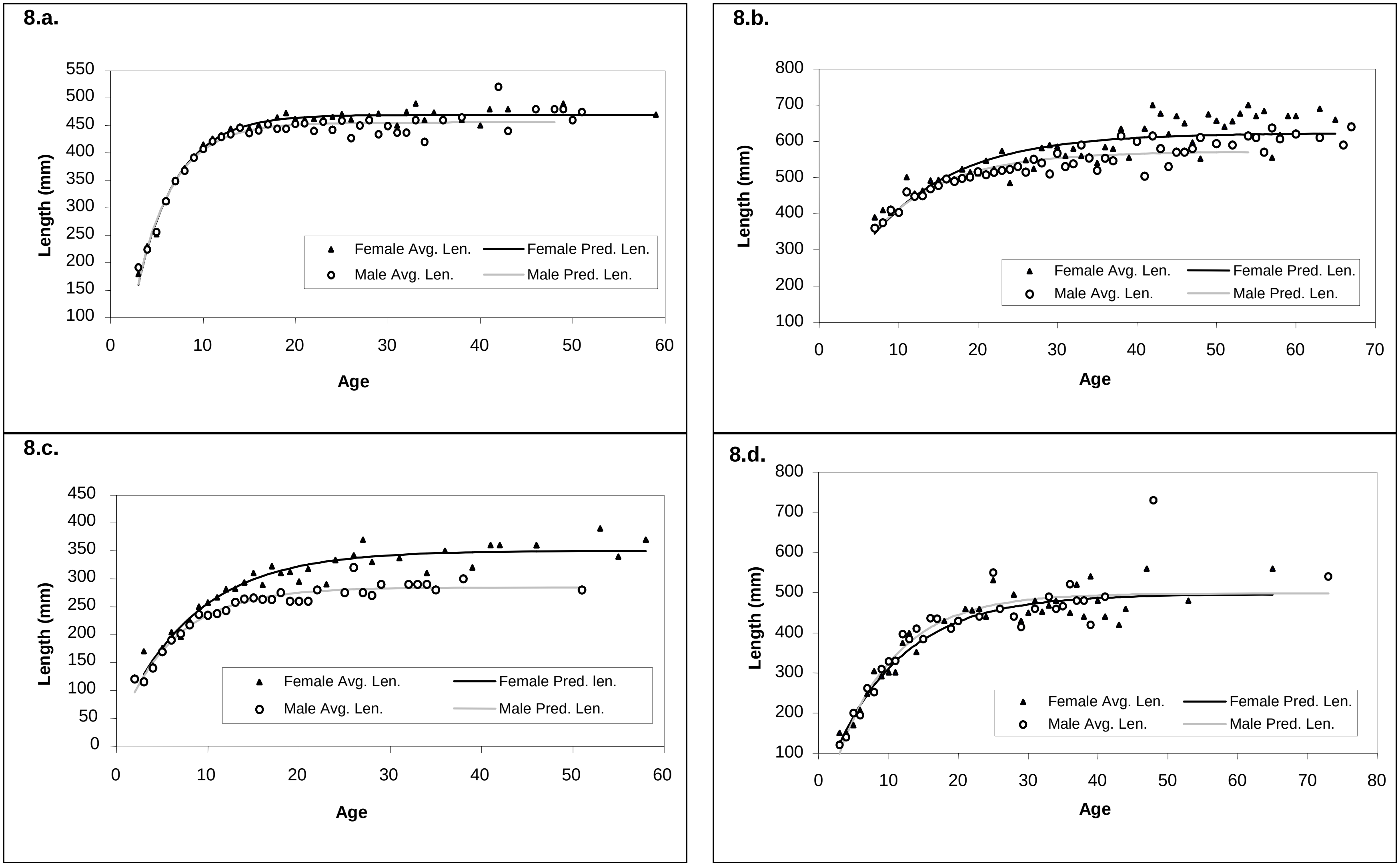


Figure 9.--a) Average and predicted length-at-age for male and female *S. variegatus*, all areas and years combined. b) Average length of 10-year-old male and female *S. alutus* by year. Area of collection designated by shape of data point. c) Average length of 8- and 10-year-old male and female *S. alutus* from the GOA by year. d) Average length of 8- and 10-year-old male and female *S. alutus* from the AI by year.

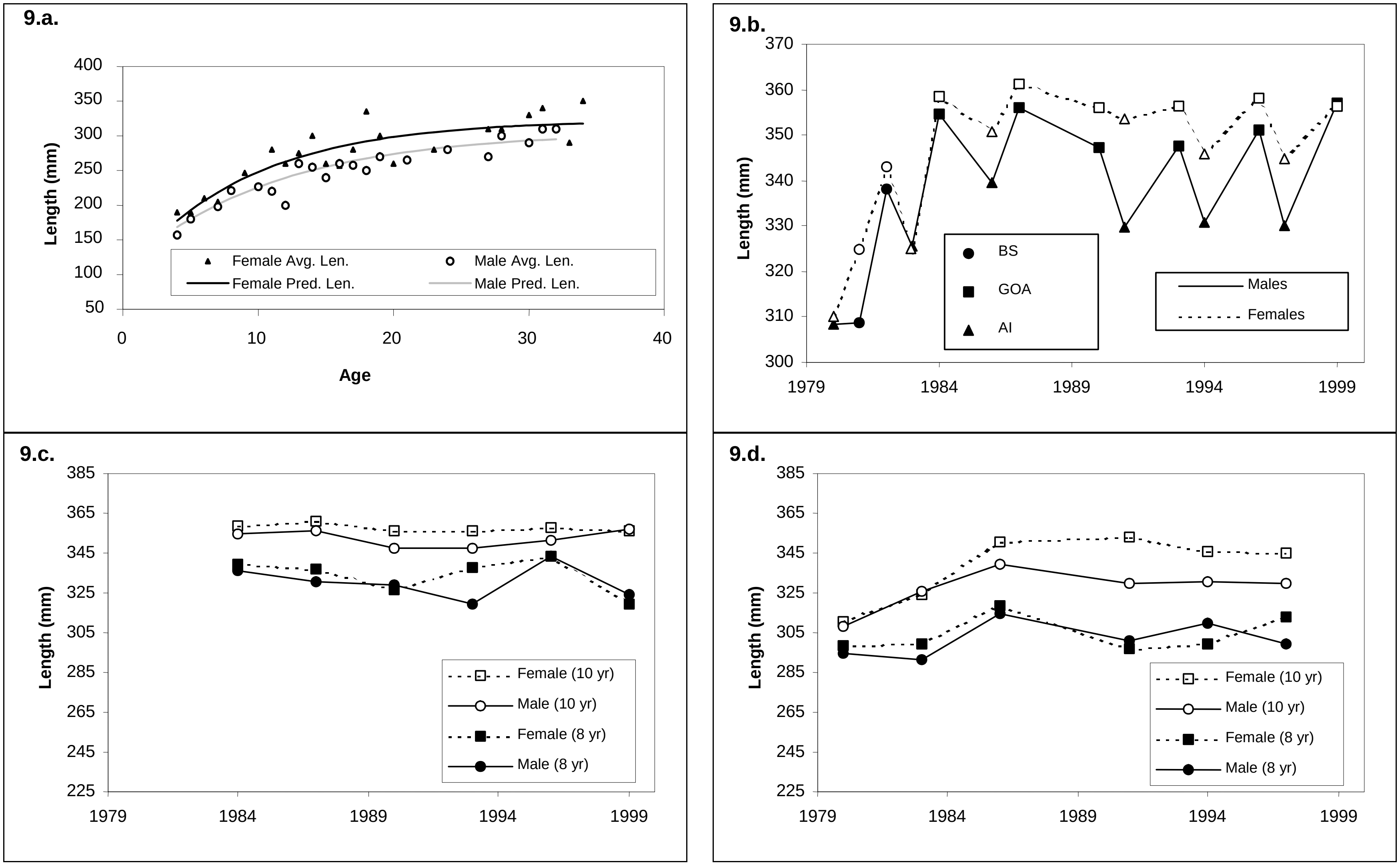


Figure 10.--Alverson-Carney natural mortality estimates as a function of maximum age and Brody's growth parameter (K). Method shown is critical age of $0.38t_m$.

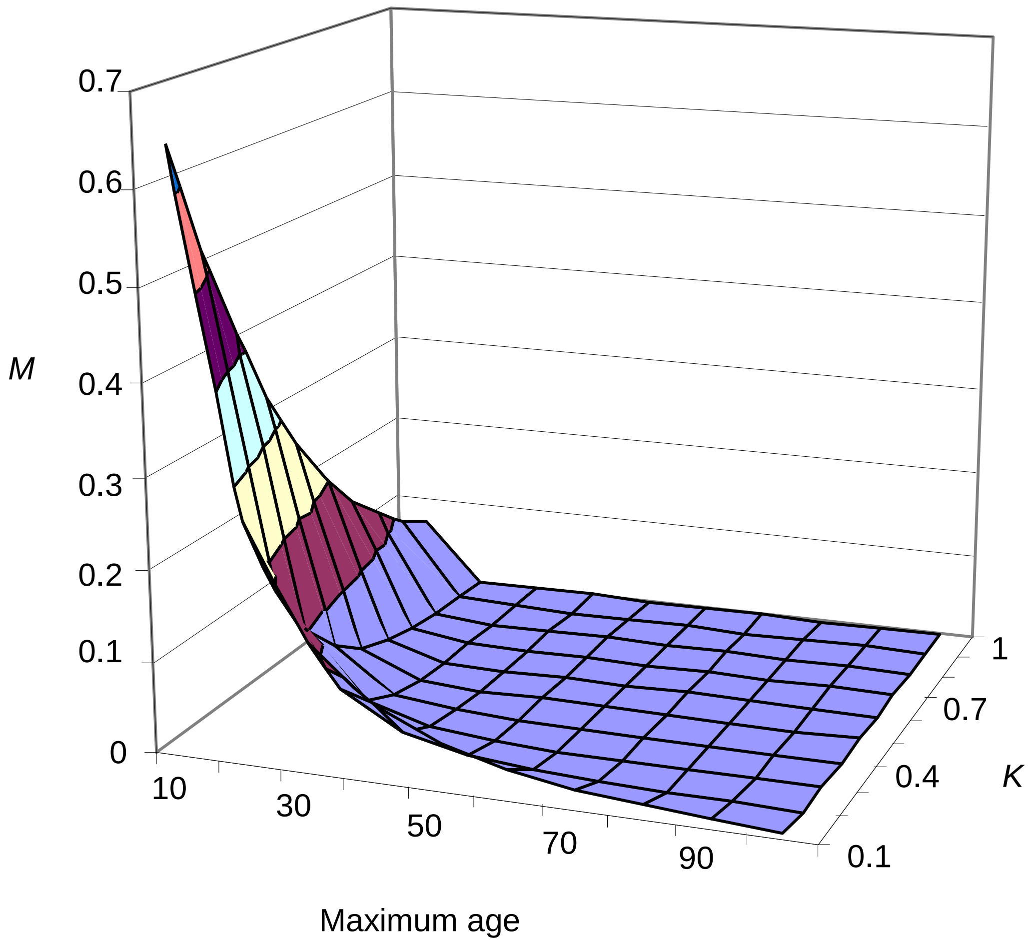
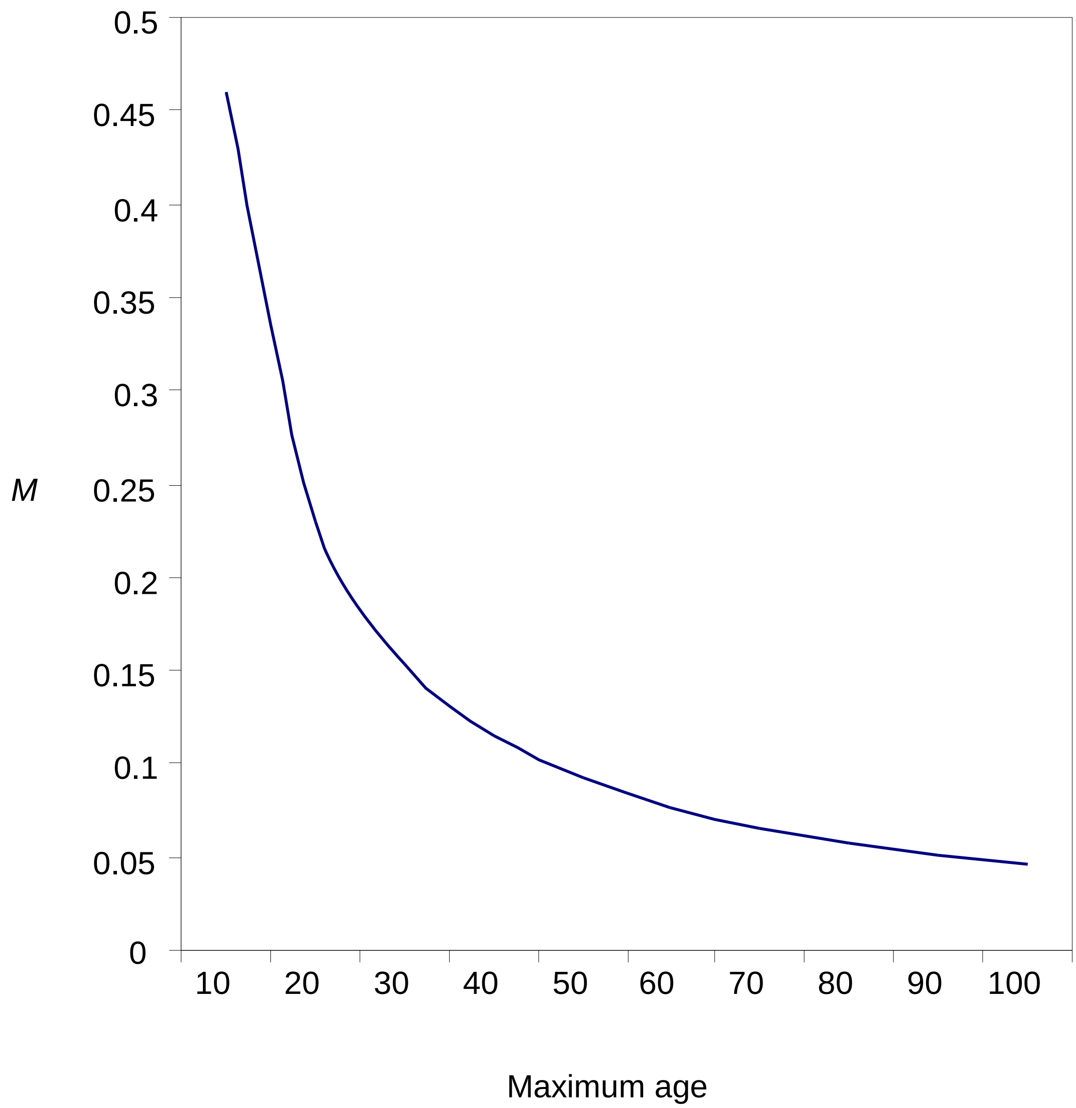


Figure 11.--Hoenig natural mortality estimates as a function of maximum age using 0.01 as the proportion that survives to $t_{m.}$



RECENT TECHNICAL MEMORANDUMS

Copies of this and other NOAA Technical Memorandums are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22167 (web site: *www.ntis.gov)*. Paper and microfiche copies vary in price.

AFSC-

171 HJELLVIK, V., and A. De ROBERTIS. 2007. Vessel comparison on the seabed echo: Influence of vessel attitude, 34 p. NTIS number pending.

170 RODGVELLER, C. J., J. H. MOSS, and A. M. FELDMANN. 2007. The influence of sampling location, timing, and hatching origin on the prediction of energy density in juvenile pink salmon, 27 p. NTIS number pending.

169 PELLA, J., and J. MASELKO. 2007. Probability sampling and estimation of the oil remaining in 2001 from the *Exxon Valdez* oil spill in Prince William Sound, 58 p. NTIS number pending.

168 ANGLISS, R. P., and R. B. OUTLAW. 2007. Alaska marine mammal stock assessments, 2006, 244 p. NTIS No. PB 2007-106476.

167 PEREZ, M. A. 2006. Analysis of marine mammal bycatch data from the trawl, longline, and pot groundfish fisheries of Alaska,1998-2004, defined by geographic area, gear type, and catch target groundfish species, 194 p. NTIS No. PB2007-106475.

166 WING, B. L, M. M. MASUDA, and S. G. TAYLOR. 2006. Time series analyses of physical environmental data records from Auke Bay, Alaska, 75 p. NTIS No. PB2007-101890.

165 EILER, J. H., T. R. SPENCER, J. J. PELLA, and M. M. MASUDA. 2006. Stock composition, run timing, and movement patterns of Chinook salmon returning to the Yukon River Basin in 2004, 107 p. NTIS No. PB2007-102224.

164 YANG, M-S., K. DODD, R. HIBPSHMAN, and A. WHITEHOUSE. 2006. Food habits of groundfishes in the Gulf of Alaska in 1999 and 2001, 199 p. NTIS number pending.

163 EILER, J. H., T. R. SPENCER, J. J. PELLA, and M. M. MASUDA. 2006. Stock composition, run timing, and movement patterns of chinook salmon returning to the Yukon River basin in 2003, 104 p.NTIS No. PB2006-108429.

162 IGNELL, S. E., B. L. WING, B. D. EBBERTS, and M. M. MASUDA. 2006. Abundance and spatial pattern of salps within the North Pacific Subarctic Frontal Zone, August 1991, 26 p. NTIS No. PB2006-108423.

161 ANGLISS, R. P., and R. OUTLAW. 2005. Alaska marine mammal stock assessments, 2005, 247 p. NTIS number pending.

160 SEPEZ, J. A., B. D. TILT, C. L. PACKAGE, H. M. LAZARUS, and I. VACCARO. 2005. Community profiles for North Pacific fisheries - Alaska, 552 p. NTIS No. PB2006-108282.

159 ETNIER, M. A., and C. W. FOWLER. 2005. Comparison of size selectivity between marine mammals and commercial fisheries with recommendations for restructuring management policies, 274 p. NTIS No. PB2006-102327.

158 LANG, G. M., P. A. LIVINGSTON, and K. A. DODD, 2005. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1997 through 2001, 222 p. NTIS number pending.

157 JOHNSON, S. W., A. DARCIE NEFF, and J. F. THEDINGA. 2005. An atlas on the distribution and habitat of common fishes in shallow nearshore waters of southeastern Alaska, 89 p. NTIS number pending.